AGENDA - Revised
Game, Fish and Parks Commission

September 2-3, 2020
Zoom and Conference Call
Livestream link https://www.sd.net/remote1/

Due to concerns regarding COVID-19, this meeting will be held via zoom/conference call and livestream. To listen to the entire meeting beginning at 1:00 p.m. CT on September 2nd livestream can be found at https://www.sd.net/.

The public hearing followed by the open forum will begin at 2:00 p.m. CT on September 2nd. The zoom and conference call number available for the public to call in starting at 2:00 p.m. CT to provide comments is you can dial in via conference call or join via zoom. The public is encouraged to participate remotely to limit our number of in person attendees and ensure social distancing.

Click on the link below to join Zoom Meeting. Depending on the application you use you may be required to enter the meeting ID and password. Remember to Mute your microphone. To help keep background noise to a minimum, make sure you mute your microphone when you are not speaking.

WEDNESDAY
Zoom Meeting Link https://state-sd.zoom.us/j/93430439993?pwd=ajZ2LzFoaldoeG56MmpqKzNIeXVDUT09
or join via conference call Dial 1 669 900 9128 Meeting ID: 934 3043 9993 Password: 210372

THURSDAY
Zoom Meeting Link https://state-sd.zoom.us/j/94420689581?pwd=MTZyTEVVRUVMRWxEQW9hMVNFKzZlUT09
or join via conference call Dial 1 669 900 9128 Meeting ID: 944 2068 9581 Password: 724615

Written comments can still be submitted at https://gfp.sd.gov/forms/positions/. To be included in the public record comments must include full name and city of residence and meet the submission deadline of seventy-two hours before the meeting (not including the day of the meeting)

Call to order 1:00 PM CT/ 12:00 PM MT

Division of Administration

Action Items:

1. Conflict of Interest Disclosure
2. Approve Minutes of the July 2020 Regular Meeting and Special Meeting
   https://gfp.sd.gov/commission/archives/
3. Additional Commissioner Salary Days
4. Commission 2021 Meeting Schedule

Information Items:

5. Volunteer Recognition
6. Shikar Award Presentation
7. Pheasant Hunting Marketing Update
8. Governance Meeting

Petitions

9. Sage Grouse Endangered Species Listing
10. Beaver Trapping
11. Lake Chub Endangered Species Listing

Proposals

12. State Park Modern Cabin Fees and Cancellation Policy

This agenda is subject to change without prior notice.

Due to the current public health concerns with COVID-19, this meeting is being conducted by electronic conference and individuals are encouraged to participate remotely. To conduct the public hearing and open forum as efficiently as possible we ask those wishing to testify to **register by 1:00 pm CT by email to** Rachel.comes@state.sd.us. **Testifiers should provide their full names, whom they are representing, city of residence, and which proposed topic they will be addressing.**

Public Hearing 2:00 PM CT/ 1:00 PM MT

Portion of the meeting designated for public comment on items pertaining to finalizations listed on the agenda *(Typically limited to 3 minutes per person.)*

Open Forum

Portion of the meeting designated for public comment on other items of interest. *(Typically limited to 3 minutes per person)*

Finalizations (all July proposals)

13. 3-Splash Waterfowl Hunting Package
14. Spring Turkey Hunting Season
15. Pheasant Hunting Season
16. Other Upland Bird Hunting Seasons
17. Private Shooting Preserve Bag Limits
18. Elk Raffle Drawing Date
19. Bobcat Hunting and Trapping Season
20. Fishing Regulations
21. Aeration Markings
22. AIS
23. Public Waters

Division of Parks and Recreation

Information Items:

24. Spring Creek and Roy Lake Resort Updates
25. Revenue, Camping and Visitation Report

Division of Wildlife

Action Items:

26. Elk Contingency License
27. River Otter Management Plan

Information Items:

28. Public Access Opportunities
29. DOT/GFP Mitigation Plan and MOA
30. AIS discussion and Law Enforcement Efforts
31. State Threatened and Endangered Species Status Review
32. Habitat Stamp Spending Approach
33. Mule Deer Harvest Information
34. License Sales Update

Solicitation of Agenda Items from Commissioners

Adjourn

Next meeting information: October 1-2, 2020

This agenda is subject to change without prior notice.

Donations can be made to honor former GFP Commissioner, Cathy Peterson, by visiting the SD Parks & Wildlife Foundation website at https://parkswildlifefoundation.org/donate.aspx. Select “Other” as the program you wish to contribute and note “Cathy Peterson” in the explanation box. The SD Parks & Wildlife Foundation and Cathy’s family will use the funds to honor her memory for future habitat projects.

Minutes of the Game, Fish, and Parks Commission
July 16-17, 2020

Chairman Gary Jensen called the meeting to order at 1:00 p.m. CT via conference call. Commissioners Gary Jensen, Travis Bies, Mary Anne Boyd, Jon Locken (day 1), Russell Olson, Doug Sharp, Charles Spring, Robert Whitmyre. Public and staff were able to listen via SDPB livestream and participate via conference call with approximately 180 total participants.

DIVISION OF ADMINISTRATION
Conflict of Interest Disclosure

Chair Jensen called for conflicts of interest to be disclosed. None were presented.

Approval of Minutes

Jensen called for any additions or corrections to the June 4, 2020 meeting minutes or a motion for approval.

Motion by Olson with second by Boyd TO APPROVE THE MINUTES OF THE June 4, 2020 MEETING WITH MINOR REVISIONS. Roll Call vote: Bies – yes; Boyd – yes; Locken – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 8 yes and 0 no votes.

Additional Commissioner Salary Days

No additional commissioner salary days were requested.

West River Right of Way Mowing

Tom Kirschenmann, wildlife director, presented information regarding South Dakota Department of Transportation proposed rules that would include Dewey, Jones, and Stanley Counties to the list of western SD counties where ditch mowing activity cannot begin before June 15 therefore providing nesting habitat.

Motioned by Olson, second by Sharp TO APPROVE RESOLUTION 20-13 SUPPORTING THE DOT COMMISSION IN HAVING DEWEY, JONES AND STANLEY COUNTIES NOT MOW DITCHES UNTIL JUNE 15. (see appendix A) Roll Call vote: Bies – yes; Boyd – yes; Locken – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 8 yes and 0 no votes.

Covid 19 Update

Kevin Robling, deputy secretary provided an update on Covid 19 as it relates to department operations. All office are open as of June 15th. Parks were open prior. Utilizing proper PPE, cleaning and symptom checking. Want to remind everyone the outdoors are open and note people have been taking advantage of the opportunity to use these resources showing an increase in license sales. Unfortunately, we have had some drownings recently and we remind recreational users to be safe and wear life jackets and kill switches. GFP will have more messaging on this in the future.

Jensen inquired about use of masks for users

Robling we ask people to take personal responsibility and social distance as much as possible, but we do not have the authority to require masks.

Flood Recovery Funding

Scott Simpson, Parks and Recreation regional supervisor, provided an update on financing we can use for recovering from last spring's flooding. At request of the Governor the legislature made available funds through public safety that we have qualified for to take care of flooding impacts.

Brood Count Survey

Travis Runia, senior wildlife biologist and Dr. Adam Janke, Iowa State provided detailed information on brood count surveys.

Pheasant Hunting Marketing Update

Emily Kiel, Mike Gussias and Kirk Hulstein provided an update on pheasant hunting marketing.

Hunt for Habitat

Secretary Kelly Hepler provided a brief update on hunt for habitat and noted the winners were announced via facebook live.

PROPOSALS

3-Splash Waterfowl Hunting Package

Chad Switzer, wildlife program administrator, presented the recommended changes to the duck hunting season to

1. Implementation of an experimental 2-tiered duck regulation in South Dakota with a 3-splash option.
2. Modify the special nonresident waterfowl hunting license by reducing the cost from $115 to $110 and by removing the inclusion of the migratory bird certification permit.

Motioned by Boyd, second by Olson TO APPROVE THE RECOMMENDED CHANGES TO THE DUCK HUNTING SEASON AS PRESENTED. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

Spring Turkey Hunting Season and Update

Switzer presented the recommended changes to the spring wild turkey hunting season as follows:

1. Offer residents 140 more one-tag "male turkey" licenses for the Prairie Units than 2020.
2. Add Clark County to Hamlin County unit.
3. Remove Douglas County from Charles Mix County unit.
4. Create Unit 10A that includes both Aurora and Douglas counties.
5. Add Buffalo County to Brule County unit.
6. Add Beadle and Hand counties to Jerauld County unit.
7. Increase the number of archer turkey access permits for Adams Homestead and Nature Preserve from 20 to 30.
8. Establish 20 mentored turkey access permits for Adams Homestead and Nature Preserve that would be limited to a bow or crossbow.
9. For Adams Homestead and Nature Preserve, allow for uncased bows and crossbows for a resident hunter who possesses a valid mentored spring turkey license and an access permit.

Motioned by Whitmyre, second by Spring TO APPROVE THE RECOMMENDED CHANGES TO THE SPRING TURKEY HUNTING SEASON.

Switzer informed the Commission there are no recommended changes to the Custer state park spring wild turkey hunting season.

Switzer presented the administrative action for spring turkey tag allocation by unit. (see appendix B)

Pheasant Hunting Season

Kirschenmann presented the recommended changes to the pheasant hunting season as follows:

1. Modify the shooting hours for the first week of the regular from Noon to 10:00 a.m. Central Time beginning with the 2020 hunting season.
2. Modify the season end date from the first Sunday in January to one of the following options beginning with the 2020 hunting season:
   a. Season end date of January 15, or
   b. Season end date of January 31
3. Increase the daily bag limit from 3 to 4 and modify the possession limit accordingly for rooster pheasants beginning December 1st beginning with the 2021 hunting season.

Motioned by Olson, second by Locken TO APPROVE THE RECOMMENDED CHANGES TO THE PHEASANT HUNTING SEASON WITH DELAYED IMPLEMENTATION OF 4 BIRDS AND JANUARY 31ST SEASON END DATE. Roll Call vote: Bies – yes; Boyd – yes; Locken – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 8 yes and 0 no votes.

Kirschenmann presented the recommended change to the pheasant hunting season to Modify the shooting hours from Noon to 10:00 a.m. Central Time beginning with the 2020 hunting season to provide additional hunting opportunity and take advantage of cooler temperatures.

Motioned by Boyd, second by Spring TO APPROVE THE RECOMMENDED CHANGES TO THE PHEASANT HUNTING SEASON AS PRESENTED. Roll Call vote: Bies – yes; Boyd – yes; Locken – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 8 yes and 0 no votes.

Other Upland Bird Hunting Seasons

Kirschenmann presented the recommended change to the grouse, partridge and quail hunting seasons to Modify the season end date from the first Sunday in January to one of the following options beginning with the 2020 hunting season: a. Season end date of January 15, or b. Season end date of January 31.

Motioned by Sharp, second by Olson TO APPROVE THE RECOMMENDED CHANGE TO THE GROUSE, PATRIDGE, AND QUAIL HUNTING SEASON AS PRESENTED. Roll Call vote: Bies – yes; Boyd – yes; Locken – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 8 yes and 0 no votes.

Private Shooting Preserve Bag Limits

Robling explained the Department has been in contact with private shooting preserve operators and other stakeholders to determine whether there is support for the opportunity for hunters to shoot an unrestricted bag limit on private shooting preserves. There was support among the groups so long as the additional cost was on the hunter and not the preserve operators. He then presented the recommended changes as follows:

1. Create two new small game permit types and establish fee:
a. Resident small game unrestricted permit (Unrestricted – Valid on private shooting preserves only).
b. Nonresident shooting preserve unrestricted permit (Unrestricted).
2. Amend bag limits on for individuals hunting private shooting preserves to reflect no bag limit when hunting with an unrestricted small game license or an unrestricted shooting preserve license.
3. Licenses would only be valid if used in conjunction with an already existing license that authorizes a hunter to hunt on PSP properties. For example: a nonresident would have to purchase either a nonresident small game license or 1 day, 5 day or annual PSP license first, and then could purchase an unrestricted nonresident shooting preserve license on top of their existing license and hunt unrestricted on PSPs that offer the option.
4. Amend language that would only allow an individual to exercise the unrestricted portion of their license in party hunting if all parties to the hunt have the same license.
5. Depending on method of sale, may have to amend reporting requirements by PSP operators to include tracking of unrestricted license sales.

Motioned by Bies, second by Sharp TO APPROVE THE RECOMMENDED CHANGE TO THE SHOOTING PRESERVE RULES AS PRESENTED. Roll Call vote: Bies – yes; Boyd – yes; Locken – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 8 yes and 0 no votes.

Motioned by Sharp, second by Whitmyre TO APPROVE THE RECOMMENDED CHANGE TO THE SHOOTING PRESERVE FEES AS PRESENTED. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

Elk Raffle Drawing Date

Switzer presented the recommended changes to the Custer state park elk hunting season to Modify the drawing time period for the elk license raffle from at least 120 days before the Custer State Park rifle elk season begins to no later than July 15. He explained the intent of the change being recommended is to allow an opportunity for unsuccessful applicants from the regular elk hunting season drawings to purchase raffle tickets for this elk license.

Motioned by Boyd, second by Locken TO APPROVE THE RECOMMENDED CHANGE TO THE ELK RAFFLE DRAWING AS PRESENTED. Roll Call vote: Bies – yes; Boyd – yes; Locken – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 8 yes and 0 no votes.

Bobcat Hunting and Trapping Season and Update

Keith Fisk, program administrator, presented the recommended changes to the bobcat hunting and trapping season as follows:

1. Modify the season dates in eastern South Dakota to align with western South Dakota. Proposed season dates would be December 15 to February 15, statewide.
2. Modify the open area in eastern South Dakota to include all counties. The proposed open area would be statewide.

Fisk explained bobcats occur in several areas of eastern South Dakota where the current bobcat season is not open. Some minimal harvest in those areas would not be detrimental to bobcat populations and are protected by the limit of one bobcat per hunter or trapper. This expansion would create additional opportunity and aligning the two seasons' dates (eastern South Dakota and western South Dakota) brings consistency and simplifies regulations.

Motioned by Boyd, second by Olson TO APPROVED THE RECOMMENDED CHANGES TO THE BOBCAT HUNTING AND TRAPPING SEASON. Roll Call vote: Bies – yes; Boyd – yes; Locken – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 8 yes and 0 no votes.

Fishing Regulations

Geno Adams, fisheries program administrator, presented the recommended changes to the spearing rules as follows:

1. Currently there is no gamefish spearfishing season on the Missouri River from the Nebraska - South Dakota border up to Ft. Randall dam. To standardize spearfishing regulations in this area with other Missouri River dam tailrace areas, a May 1 – March 31 is recommended.
2. This was requested by a spearer. According to surveyed spearers, as with rod and reel angling, the last hour of light is one of the best times to spearfish. Currently gamefish can be taken with legal spear, legal speargun, legal crossbow and bow and arrow, one-half hour before sunrise to sunset. Extending the hours to one-half hour after sunset will allow for additional opportunity for those spearers who choose to utilize it. Rough fish spearing is currently allowed 24 hours a day.

Motioned by Bies, second by Olson TO APPROVED THE RECOMMENDED CHANGES TO THE SPEARING RULES. Roll Call vote: Bies – yes; Boyd – yes; Locken – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 8 yes and 0 no votes.

Aeration and System Use Overview

John Lott, fisheries chief, presented the recommended changes to the aeration rules to require safety signage in association with operation of aeration systems during periods of ice cover on waters with open public access. He explained Aeration is used to prevent fish kills during the summer and winter and to prevent ice from forming that may damage permanent docks or other structures anchored in the lakebed. Operation of aeration systems during the winter can cause significant public safety issues, as systems create open water and weakened ice conditions. Often, the public is unaware of system operation until it is accidentally discovered, while on the ice. Establishing a requirement that an aeration system in operation during periods of ice cover, on waters to which the public has open access, be signed and marked, would reduce safety issues associated with winter operation of aeration systems. Signage requirements would include:

- Signs of highly visible size and design indicating "Danger Open Water", clearly showing the location of the open water created by the aeration system, posted at all boat ramps and public access points any time the aeration system is in operation.

- Conspicuous markers, sufficient to notify the public of the location of the aeration system, shall be placed around the open water area during periods of ice cover.
- Access area signs and on-lake markers must be removed by March 30 each year, or earlier, if weather conditions warrant.

Motioned by Sharp, second by Whitmyre TO MODIFY THE AERATION RULES TO REQUIRE SAFETY SIGNAGE AS RECOMMENDED. Roll Call vote: Bies – yes; Boyd – yes; Locken – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 8 yes and 0 no votes.

AIS

Lott presented the recommended changes to AIS rules as follows:

1. Remove the prohibition on possessing, transporting, selling, purchasing, or propagating AIS from administrative rule.
2. Create an additional exemption for possession of AIS to allow an owner or agent of the owner of a conveyance to transport the conveyance for decontamination using a department approved process.
3. Remove prohibitions in administrative rule on launching a boat or boat trailer into the waters of the state with AIS attached.
4. Repeal the rule allowing for the creation of local boat registries.
5. Remove the exemption to the decontamination requirement for boats in a local boat registry in association with repealing the rule allowing the creation of registries.
6. Create a new rule to define the department-approved decontamination protocol.
7. Update the list of containment waters to include Pickerel Lake and Waubay Lake.

Motioned by Sharp, second by Boyd TO APPROVE THE RECOMMENDED CHANGES TO THE AIS RULES. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

Public Waters

Geno Adams presented the recommended changes to public water zoning and fishing limits as follows:

1. Establish an electric-motors-only zone on Canyon Lake in Pennington County and Bismarck Lake in Custer County.
2. Change Nebraska – South Dakota border trout limit from 7 daily to 5 daily to match South Dakota inland waters.

Adams explained Canyon Lake and Bismarck Lake are utilized by canoers and kayakers. The City of Rapid City would like an electric motor only regulation on Canyon Lake. The United States Forest Service would like an electric motor only regulation on Bismarck Lake. And currently the trout daily limit of 7 on Nebraska – South Dakota border waters does not match the South Dakota inland waters daily limit (5) or the Nebraska border water daily limit (5) for trout. Changing the daily limit for trout on Nebraska – South Dakota border waters to 5 would align the daily limit with those for South Dakota inland waters and Nebraska border waters.

Motioned by Sharp, second by Whitmyre TO APPROVE THE RECOMMENDED CHANGES TO THE PUBLIC WATER ZONING AND FISH LIMITS RULES. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

PUBLIC HEARING

The Public Hearing began at 2:00 p.m. and concluded at 2:30 p.m. The minutes follow these Commission meeting minutes.

OPEN FORUM

Jensen opened the floor for discussion from those in attendance on matters of importance to them that may not be on the agenda.

Zack Hunke, Wildlife Federation President, Watertown, SD spoke regarding public water closure on Waubay Lake. This is a meandered body of water and meandered laws should be enforced. Believes in producer rights but does not want to see people completely restricted. Would like to see address the issues that would allow these bodies of water to remain open.

Jocelyn Nickerson, Humane Society, Omaha, NE spoke opposing bobcat hunting and trapping. This would allow an unlimited number of bobcats to be taken and it is extremely cruel. There are more wildlife watchers who enjoy watching them on film than those who trap them. They are helpful to farmers as they prey on other wildlife. Hound trapping is barbaric. Would like to see these small native carnivores be protected

Jamie Al-haj, Rapid City, SD Humans are an interesting animal that do what they desire and not what should be done. Asking when establishing trapping season that the time of year that they give birth and raise their young be taken into consideration. The public is watching.

Nancy Hilding, Black Hawk, SD, president of the Prairie Hills Audubon Society spoke, should require masks inside of buildings when the motorcycle rally is coming. Otter Management plan was distributed on May 8th and is listed for adoption tomorrow but have not seen changes made since then. Requested it and received it but doesn't see many changes although the public sent in recommendations. Does not want action to be taken until September and allow people to make additional comment because her comments were not integrated. Would like to see an introduction at the Little white, Belle Fourche and …. Rivers located West River.

Christine Sandvik, Rapid City, SD said only 1 percent of reports came from research and 40 were dead animals. 40 years of data was not broken down to provide current numbers. It's primarily east river and there should be an investment into observing these species if money can be spent on the nest predator bounty program. We need a strong population statewide before we open a trapping season

Tuffy Halls, Hot Springs, SD West River Fur Harvesters Association spoke regarding river otter season noting it is a good management tool. And support the river otter trapping season

Jasen Albrecht, Huron, SD spoke regarding concerns on a public road that in 1952 the public roadway has not been utilized on one end that services lake lots near their residence. If this road is utilized there would be a home and utilities that would need to be relocated 15-30 feet that would only allow for use of 1/5 acre of land. Spoke with county commissioner to correct or document how this could happen.

PUBLIC HEARING

The Public Hearing began at 2:00 p.m. and concluded at 2:30 p.m. The minutes follow these Commission meeting minutes.

FINALIZATIONS

Nonresident Landowner Owned Land License Application

Chad Switzer, wildlife program administrator, presented the recommended changes to modify 41:06:02:03 (16) from

Resident-landowner-on-own land deer or antelope license, one-half the fee of the deer or antelope license which has been applied for;

To

Landowner-on-own land deer or antelope license, one-half the fee of the deer or antelope license which has been applied for;

Switzer explained that during the 2020 South Dakota Legislative Session, House Bill 1184 provides for nonresident landowner licenses to qualifying landowners for the West River deer hunting season and firearm antelope hunting season. House Bill 1184 indicated the GFP Commission shall promulgate rules, in accordance with Chapter 1-26, to establish fees for licenses issued under this section.

Motioned by Bies, second by Olson TO FINALIZE THE NONRESIDENT LANDOWNER OWNED LAND LICENSE APPLICATION RULE 41:06:02:03 (16) AS RECOMMENDED. Roll Call vote: Bies – yes; Boyd – yes; Locken – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 8 yes and 0 no votes.

Use of Parks and Public Lands

Scott Simpson, parks and wildlife director, presented the recommended change to provide for an exemption to the requirement to purchase a park entrance license at North Point Recreation Area, Fort Randall South Shore Recreation Area, Randall Creek Recreation Area and Fort Randall Spillway Lakeside Use Area for enrolled members of the Yankton Sioux Tribe and their families. He explained this exemption would provide members of the Yankton Sioux Tribe and their immediate families greater access to local outdoor recreational opportunities. These four park units are located within proximity to the Yankton Sioux Tribe reservation area. This exemption does not apply to other fees such as camping, lodging, picnic shelter reservations, or equipment rentals.

Motioned by Boyd, second by Sharp TO FINALIZE THE PARK ENTRANCE LICENSE EXEMPTION RULE CHANGE 41:03:03 AS RECOMMENDED. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

River Otter Season

Switzer, presented the recommended changes to establish a conservative the river otter trapping season as follows:

1. Establish a trapping season that is open from sunrise on November 1 to sunset on December 31 in all counties of the state.
2. Limit of one river otter per trapper per season.
3. Statewide harvest limit of 15 river otters. Season will end prior to December 31 if the harvest limit is reached.
4. Trapping season open to residents only with a furbearer license.
5. A river otter shall be reported to the Department within 24 hours of harvest. At time of reporting, arrangements will be made to check-in carcass and detached pelt at a GFP office or designated location for registration and tagging of the pelt within 5 days of harvest. Additionally, once the season has closed (last day of season or harvest limit reached), a person has 24 hours to notify the Department of a harvested river.
6. The pelt shall be removed from the carcass and the carcass shall be surrendered to the Department. After the pelt has been tagged, it shall be returned to the trapper. Upon request, the carcass may be returned to the trapper after the carcass has been inspected and biological data collected.
7. Any river otter harvested after the 24-hour period following the close of the season, will be considered incidental take and shall be surrendered to the Department.
8. A person may only possess, purchase or sell raw river otter pelts that are tagged through the eyeholes with the tag provided by the Department or if the river otter was harvested on tribal or trust land of an Indian reservation or another state and is properly and securely tagged with a tag supplied by the governmental entity issuing the license.

And recommended change from proposal to Modify the open area from statewide to the following counties in eastern South Dakota: Aurora, Beadle, Bon Homme, Brookings, Brown, Charles Mix, Clark, Clay, Codington, Davison, Day, Deuel, Douglas, Grant, Hamlin, Hanson, Hutchinson, Jerauld, Kingsbury, Lake, Lincoln, Marshall, McCook, Miner, Minnehaha, Moody, Roberts, Sanborn, Spink, Turner, Union and Yankton

He explained River otter populations in South Dakota continue to grow and expand into available habitat. A statewide season will provide harvest information from across the state. It also provides the greatest opportunity to pursue trapping of river otter. Over the last five years (2015-2019) the Department has received an average of 16.6 incidentally trapped river otter/year. River otter are most frequently incidentally taken during the beaver trapping season given similarity of habitat and trapping methods. The majority (72%) of the 83 incidentally trapped river otter reported over the last five years were taken in November. Updates on river otter harvest will be available on the Department website and by calling a designated phone number. A press release and other information tools will be used when the harvest limit has been met, similar to the mountain lion harvest notification process.

Motion by Sharp, second by Olson TO AMEND THE RIVER OTTER TRAPPING SEASON AS RECOMMENDED. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

Motion by Olson, second by Sharp TO FINALIZE THE RIVER OTTER TRAPPING SEASON AS AMENDED. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

Fall Turkey

Chad Switzer, wildlife program administrator, presented the recommended changes to the Fall Turkey Hunting Season

1. Offer 125 less resident single tag licenses and 35 more resident double tag licenses for Prairie Units compared to 2019.
2. Close prairie units 12A (Gregory County), 50A (Mellette County), and 60A (Tripp County).
3. Establish and open prairie unit 12A (Bon Homme County).

And recommended change from proposal to Reduce the number of resident and nonresident single tag "any turkey" licenses for the Black Hills unit from 200 and 16 to 100 and 8, respectively.

Motion by Olson, second by Boyd TO AMEND THE FALL TURKEY HUNTING SEASON PROPOSAL AS RECOMMENDED. Motion by Boyd with second by Sharp. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 8 yes and 0 no votes.

Motion by Olson, second by Sharp TO FINALIZE CHANGES TO THE FALL TURKEY HUNTING SEASON 41:06:14 AS AMENDED. Motion by Boyd with second by Sharp. Roll Call vote: Bies – no; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 6 yes and 1 no votes.

Switzer presented the administrative action for turkey cense allocation by unit. (see appendix C)

Motioned by Boyd, second by Spring TO APPROVE THE RECOMMENDED CHANGES TO THE TURKEY HUNTING LICENSE ALLOCATIONS BY UNIT. Roll Call vote: Bies – yes; Boyd – yes; Locken – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

Lost License Replacement

Switzer presented the recommended change to remove the $20 administrative fee for lost or destroyed licenses, permits or game tags. The license agent's fee established by SDCL 41-6-66.1 would still be charged by license agents and the Department. He explained that after considering public comment and a review of this administrative fee for all license types, the Department recommends removing this administrative fee. Authorized license agents and the department as per SDCL 41-6-66.1 will charge a license agent's fee of $4 for resident and $8 for nonresident licenses.

Motioned by Boyd, second by Spring TO FINALIZE THE CHANGES TO THE REPLACEMENT OF LOST LICENSE RULES 41:06:02. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

Administrative Rules Review ARSD 41:08, 41:09, 41:10 and 41:13

Jon Kotilnek, senior staff attorney, explained that during the 2019 Legislative Session HB 1162 was introduced by Representative Gosch. The intent of the bill was to have the Department conduct a systematic review of our administrative rules. During the review the Department was to identify rules that are irrelevant, inconsistent, illogically arranged, or unclear in their intent and direction. After discussions with Representative Gosch, the Department agreed to conduct the systematic review without legislation and to report its findings and corrective changes back to the Executive Board of the Legislative Research Council. These formally proposed suggested changes are to correct inconsistencies, remove unnecessary barriers and arrange rules logically thus promoting an administrative code that benefits current, former and new users.

The Department recommends the following rule changes for the following administrative rules in an effort to reduce redundancy, increase transparency and improve consistency:

Chapter 41:08

Motion by Whitmyre, second by Spring TO AMEND RULES IN CHAPTER 41:08 TO REMOVE 41:08:03:01. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

Motion by Olson, second by Whitmyre TO APPROVE THE RECOMMENDED CHANGES AS RECOMMENDED TO RULES IN CHAPTER 41:08 AS AMENDED. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

Chapter 41:09

Motion by Whitmyre, second by Bies TO APPROVE THE RECOMMENDED CHANGES AS RECOMMENDED TO RULES IN CHAPTER 41:09. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

Chapter 41:10

Motion by Bies second by Boyd TO APPROVE THE RECOMMENDED CHANGES AS RECOMMENDED TO RULES IN CHAPTER 41:10. Roll Call vote: Bies – yes; Boyd – yes; Olson – yes; Sharp – yes; Spring – yes; Whitmyre – yes; Jensen – yes. Motion carried 7 yes and 0 no votes.

DIVISION OF PARKS AND RECREATION

Sylvan Lake Update

Pat Wyss provided an update on Sylvan Lake.

Roy Lake and Spring Creek Updates

Scott Simpson, Parks and Recreation Division Director, provided the Commission a brief update.

Visitation and Sales Report

Al Nedved, parks and recreation deputy director gave a report on revenue, camping and visitation through June.

DIVISION OF WILDLIFE

River Otter Management Plan (will be presented at the September meeting)

Mule Deer Harvest Information (will be presented at a future meeting)

State Threatened & Endangered Species Status Review (will be presented at a future meeting)

2020 Fishing Season Update

Geno Adams provide an update on the 2020 fishing season.

Licenses Sales Update

Heather Villa, wildlife administration chief, said license sales are still following an upward trend. For resident licenses we are up 35,800 licenses and $905,797 in revenue. Nonresident licenses are up 15,399 licenses and $603,649 in revenue. This puts us at a total gain of 51,199 licenses and $1,509,466 in revenue. July 1 the Habitat Stamp was enacted. This accounts for $235,395 in increased revenue. Habitat stamp funds can only be used for habitat and access improvements on public lands and waters.

Adjourn

Meeting adjourned at 12:18 p.m.

Respectfully Submitted,

Kelly R Hepler

Kelly R. Hepler, Department Secretary

Appendix A

Resolution 20-13

WHEREAS, current Administrative Rule prohibits ditch mowing before June 15 in Gregory, Lyman, and Tripp counties of western South Dakota and prohibits ditch mowing before July 10 for all counties east of the Missouri River on the state highway trunk system; and

WHEREAS, over time, additional counties west of the Missouri River have increased pheasant habitat resulting in steady increase in pheasant numbers; particularly in Dewey, Jones, and Stanley County; and

WHEREAS, these counties represent the primary western periphery of the pheasant range in western South Dakota; and

WHEREAS, in 2019 over 19,000 pheasants were harvested in these three counties; and

WHEREAS, roadside habitat can be locally important for pheasant nesting habitat; and

WHEREAS, the consideration in front of the DOT Commission falls in line with on-going discussions regarding efforts and actions to enhance habitat efforts, bolster pheasant numbers, and the promotion of pheasant hunting in South Dakota.

NOW, THEREFORE, BE IT RESOLVED, the Game, Fish and Parks Commission hereby expresses support to the South Dakota Transportation Commission for their consideration of adding Dewey, Jones, and Stanley Counties to the list of western SD counties where ditch mowing activity cannot begin before June 15.

Appendix B

2021 -2022 Spring Turkey

Unit #	Unit Name	Resident		Nonresident		License Totals							
		TomT 32	2 TomT 35	TomT 32	2 TomT 35	RES 1-tag	RES 2-tag	RES Licenses	RES Tags	NR 1-tag	NR 2-tag	NR Licenses	NR Tags
01A	Minnehaha	80	0	0	0	80	0	80	80	0	0	0	0
02A	Pennington	200	0	16	0	200	0	200	200	16	0	16	16
06A	Brookings	20	0	0	0	20	0	20	20	0	0	0	0
07A	Yankton	260	0	0	0	260	0	260	260	0	0	0	0
08A	Davison/Hanson	80	0	0	0	80	0	80	80	0	0	0	0
08B	Davison/Hanson	80	0	0	0	80	0	80	80	0	0	0	0
10A	Aurora/Douglas	30	0	0	0	30	0	30	30	0	0	0	0
11A	Bennett	30	0	3	0	30	0	30	30	3	0	3	3
12A	Bon Homme	250	0	0	0	250	0	250	250	0	0	0	0
13A	Brule/Buffalo	150	0	0	0	150	0	150	150	0	0	0	0
15A	Butte/Lawrence	350	0	28	0	350	0	350	350	28	0	28	28
16A	Campbell/Walworth	10	0	0	0	10	0	10	10	0	0	0	0
17A	Charles Mix	350	0	0	0	350	0	350	350	0	0	0	0
19A	Clay	120	0	0	0	120	0	120	120	0	0	0	0
19B	Clay	0	0	0	0	0	0	0	0	0	0	0	0
20A	Corson	50	0	4	0	50	0	50	50	4	0	4	4
21A	Custer	150	0	12	0	150	0	150	150	12	0	12	12
22A	Day/Codington	90	0	0	0	90	0	90	90	0	0	0	0
23A	Deuel	110	0	0	0	110	0	110	110	0	0	0	0
24A	Dewey/Ziebach	150	0	12	0	150	0	150	150	12	0	12	12
27A	Fall River	75	0	6	0	75	0	75	75	6	0	6	6
29A	Grant	260	0	0	0	260	0	260	260	0	0	0	0
30A	Gregory	700	0	56	0	700	0	700	700	56	0	56	56
31A	Haakon	0	200	0	16	0	200	200	400	0	16	16	32
32A	Hamlin/Clark	20	0	0	0	20	0	20	20	0	0	0	0
35A	Harding	100	0	8	0	100	0	100	100	8	0	8	8
36A	Hughes	30	0	0	0	30	0	30	30	0	0	0	0
37A	Hutchinson	60	0	0	0	60	0	60	60	0	0	0	0
39A	Jackson	150	0	12	0	150	0	150	150	12	0	12	12
40A	Jerauld/Beadle/Hand	20	0	0	0	20	0	20	20	0	0	0	0
41A	Jones	75	0	6	0	75	0	75	75	6	0	6	6
44A	Lincoln	50	0	0	0	50	0	50	50	0	0	0	0
44B	Lincoln	50	0	0	0	50	0	50	50	0	0	0	0
45A	Lyman	100	0	8	0	100	0	100	100	8	0	8	8
48A	Marshall/Roberts	440	0	0	0	440	0	440	440	0	0	0	0
49A	Meade	0	300	0	24	0	300	300	600	0	24	24	48
50A	Mellette	350	0	28	0	350	0	350	350	28	0	28	28
52A	Moody	60	0	0	0	60	0	60	60	0	0	0	0
53A	Perkins	0	100	0	8	0	100	100	200	0	8	8	16
56A	Sanborn	10	0	0	0	10	0	10	10	0	0	0	0
58A	Stanley	40	0	4	0	40	0	40	40	4	0	4	4
58B	Stanley	2	0	1	0	2	0	2	2	1	0	1	1
60A	Tripp	400	0	32	0	400	0	400	400	32	0	32	32
61A	Turner	20	0	0	0	20	0	20	20	0	0	0	0
62A	Union	120	0	0	0	120	0	120	120	0	0	0	0
62B	Union	0	0	0	0	0	0	0	0	0	0	0	0
65A	Oglala Lakota	40	0	4	0	40	0	40	40	4	0	4	4
67A	Todd	75	0	6	0	75	0	75	75	6	0	6	6
	TOTAL	5,807	600	246	48	5,807	600	6,407	7,007	246	48	294	342
	Unit	TomT 32	2 TomT 35	TomT 32	2 TomT 35	RES 1-tag	RES 2-tag	RES Licenses	RES Tags	NR 1-tag	NR 2-tag	NR Lic	NR Tags
				RES & NR:		**6,053**	**648**	**6,701**	**7,349**				

Appendix C

2020-2021 Fall Turkey

Unit #	Unit Name	Resident		Nonresident		License Totals							
		AnyT 31	2 AnyT 37	AnyT 31	2 AnyT 37	RES 1-Tag	RES 2-Tag	RES Licenses	RES Tags	NR 1-Tag	NR 2-Tag	NR License	NR Tags
07A	Yankton	150				150		150	150				
12A	Bon Homme	150		12		150		150	150	12		12	12
39A	Jackson		35		3		35	35	70		3	3	6
48A	Marshall/Roberts	100				100		100	100				
BH1	Black Hills	100		8		100		100	100	8		8	8
TOTAL		500	35	20	3	500	35	535	570	20	3	23	26
				RES & NR:		**520**	**38**	**558**	**596**				

Public Hearing Minutes of the Game, Fish and Parks Commission
July 16, 2020

The Commission Chair Gary Jensen began the public hearing at 2:00 p.m. CT via conference call. Commissioners Gary Jensen, Travis Bies, Mary Anne Boyd, Jon Locken, Russell Olson, Doug Sharp, Charles Spring, and Robert Whitmyre were present. Olson indicated written comments were provided to the Commissioners prior to this time and will be reflected in the Public Hearing Minutes. Olson then invited the public to come forward with oral testimony.

Nonresident Landowner Owned Land License Application

No verbal comments

Use of Parks and Public Lands

Jason Cooke, Vice Chair of Yankton Sioux Tribe, advocating for free access and swimming to the four sites for tribal members at North Point and South Shore. Good start to a working relationship with the state.

Derrick Marks, Wagner, SD said he wants to petition on behalf of their people for access as none of the tribal land has good access to the water. As ancestral people to the land there has been a lot of hope in this.

Nancy Hilding, Black Hawk, SD, president of the Prairie Hills Audubon Society supports giving the tribe what they want.

River Otter Season

Nancy Hilding, Black Hawk, SD, president of the Prairie Hills Audubon Society spoke regarding river otter and said people should have otter to look at and to trap, but there are few verified sightings so the trapping season should not extend across the state. Prefer it none exist at all as there is not data to support a 15 otter take. The incidental take happens for 6 months and the season would be 2 months and beaver for another 4 months. Sent prior messages that this is no valid as there was not adequate public notice should also have checked with each tribe and federal government and neighboring states. Want to see proof to this happening. You need otters on the land for reintroduction prior to trapping.

Christine Sandvik, Rapid City, SD failing to see the value of this animal as a live animal opposed to their value dead. They are great for recreation purposes and if they are hunted, they are only used once if it's for photography you can maintain the resources. Definitely against the trapping season and need a reintroduction to the Black Hills. Beaver trapping prevents dams which are good habitat, so we need to do things to encourage the river otter habitat.

Fall Turkey

No verbal comments

Lost License Replacement

No verbal comments

Administrative Rules Review ARSD 41:08, 41:09, and 41:10

Nancy Hilding, Black Hawk, SD, president of the Prairie Hills Audubon Society Complaint about how the fire protection district was divided. Complaints about consistence for beaver trapping in different areas of the state. Statute for mink says they can be killed with permission. Feels they should be consolidated, and beaver hunting should be ended at different time incase otter are accidently killed. Complaint about trap check time in trapping prohibitions rule about number of calendar days being unclear and silly. Would like it changed to hours to be clear. Complaint about public notice not being 20 days in advance and not following IRRC rules will bring it to their attention.

See attached written public comments submitted prior to the public hearing

The public Hearing concluded at 2:30 p.m.

Respectfully Submitted,

Kelly R Hepler

Kelly R. Hepler, Department Secretary

Public Comments

Administrative Rules Review

Jessica Necklace

Wagner SD

Position: other

Comment:

Our family utilize the Missouri River a lot on the Yankton Sioux Reservation. I feel that Native Americans within Boundaries of YST should not have to pay entrance fees because the land and waterways join tribal lands. This is one benefit the Native Americans could utilize their land without having the fee.

Fall Turkey

James Elsing

Lemmon SD

Position: other

Comment:

See attached letter.

John Janecke

Winner SD

Position: oppose

Comment:

This is an addendum to my previous email regarding the closing of Tripp County to fall turkey hunting. Even though I have attempted to find out the reason for NOT having a season, I have been unable to do so.

Yesterday, I was going fishing and saw at least two (2) HERDS (not flocks) of wild turkeys. Minimum of ten (10) each. I wish that I had a camera to send you photos...I use a flip phone, so any photos would have been realistically useless.

I am apposed to closing Tripp County to fall turkey hunting. The turkey population appears to me to be greatly adequate for residents to hunt.

Nonresident Landowner Owned Land License Application

Neil Hawthorne

Anchorage AK

Position: support

Comment:

I have hunted, as a resident for 20+ years and as a landowner nonresident for maybe 20 years for deer, turkey and antelope. I pay your taxes on 400 (now 900) acres in Custer county and feel that my license should not be much more than twice what I used to pay for a deer license. This would be, of course, on my own land. Thank you

---

Adam Golay

Sioux Falls SD

Position: oppose

Comment:

If non resident landowners want to hunt deer west river they already have a process for them to get tags. That's why there is a west river special buck non resident app that they can apply for. They won't draw every year but the privilege of hunting deer in South Dakota every year should only be for residents. If someone wants to hunt deer every year & buy land in another state that they don't live in then they should consider buying land in a state that has a lot more deer in it than South Dakota. There needs to be incentives to stay in South Dakota & hunting privileges are one of them. Plus more non residents hunting our big game takes away an opportunity for a resident to hunt big game in the state he or she lives in.

Jim Gruber

Estelline SD

Position: other

Comment:

look, if you are going to do this for west river landowners.. then do the same for east river non resident owners also... why just west river?

Casey Foster

Sparks, Ne 69220 NE

Position: support

Comment:

I am one of the non-resident landowners that will be eligible for one of these permits. I pay about $8000 a year in SD taxes. So, I would like to see the fee lower but believe $140 is a fair price.

Hale Kreycik

Douglas WY

Position: support

Comment:

I am of the opinion that this proposal is a wise one. As a non-resident landowner, I see value and especially fairness since I am paying several thousand dollars in real estate taxes to S. D. each year. Any incentive encouraging visitors to the State can only result in additional income for small business, generate sales tax revenues, and be of an overall benefit.

In addition, I suggest you consider a procedure for the landowner to be able to have the license issued to an immediate family member as well, especially youngsters under a certain age. Anything that can be done to encourage and recruit a new hunting population would be a positive for all concerned, including wildlife. Thank you for the opportunity to comment!!

Eric Gonzale

Glen Burnie MD

Position: support

Comment:

As a non-resident landowner of 160 acres in Fall River, I completely support this action. Many states have similar rules - for example, in NY non-resident land owners are allowed to hunt their land provided they own a minimal 50 acres. I believe WY has a similar rule, as does MO, ME, OH and many others...

Other

Raymond Martinmaas

Orient SD

Position: other

Comment:

Disabled hunter access

Pamela Scouten

Pierre SD

Position: oppose

Comment:

I cannot believe we are approving such a large budget going towards promoting the increase in license sales to bring in more out of state hunters. The reason why those brood report numbers deterred people is because THERE ARE NO BIRDS left to hunt. I have always been an avid bird hunter and not from lack of trying, but I did not take a single pheasant last year. Unless you own land or you pay a game farm $100+ PER BIRD, you cannot pheasant hunt in this state. That money should have been spent to improve public hunting so people actually had a chance to hunt. Another disappointing decision for SD hunting.

Greg Fecho

Mpls MN

Position: support

Comment:

Hello, in regards to marketing plan and elimination of brood count.

Eliminating the BCS will come back and bite you, non resident hunters like myself have relied on that info to plan our hunts, I have hunted Chamberlain west to Presho, up for a number of years by Ipswich , and the last number of yers byMiller, Highmore.
You have to give us some guage to plan our destination, for the cost of a 3 day trip for NR, 120.00 license, lodging, food, fuel, pay farmer , etc can easily hit 600- 1000.00 per hunter, that is a lot of money to drive 6 hours and not see a bird (which has happened the last couple of years)help us, don't hide facts.

2) youth hunting, google " Greg Fecho hunting" story down by Mpls Outdoor writer on getting kids involved. When I go to a steak house, bar, gas station in SD during hunting season, u never see a group of NR with kids , never, the reason , COST, very few people can bring their 2 sons along for 3 days and spend 2000-2500 all in , it is outrageous. Come up with a NR family license, a cost that helps bring down the cost.

3) give a option for 3 , 3 day hunts, the 5 day is worthless , most people can't hunt 5 days for reasons of work, family, etc. if you offered that license (or something similar) you would I bet get some of those hunters to come out 3 times vs 2.

Don't get me wrong, I love SD, I rented a camper last year and drove west to Pollack, SD , met a rancher and spend 3 days on back of a horse driving cattle , went from there to Gregory helped cook at a archery deer camp, from their to Wagner where I met up and hunted with friends from MN and Wagner folks, 23 days I was gone, going again this year.

Feel free to call, love to give u input on NR hunters opinion.

Thanks gf

Alex Petrik

Lake Andes SD

Position: oppose

Comment:

I believe this should not be passed as the money from the passes should be used to manage, maintain, and operate our parks.

Gregory Nowak

Armour SD

Position: oppose

Comment:

The decision to end the South Dakota Pheasant Brood Survey is extremely disappointing to me. It is sad to see my state making decisions based on some "marketing" scheme and discontinuing a 70 years old South Dakota tradition. The state takes in $218 Million from Pheasant hunters, can spend $700,000 during the first year of it's marketing plan but can't spend $80,000 to $90,000 to complete the survey. Give me 15 mins worth of training, a route in south central SD, the time you want it surveyed and I will do it for free!

Sharon Blais

Sioux Falls SD

Position: oppose

Comment:

Quit killing all of our wildlife. All animals play an important role in our ecosystem.

Curt Rich

Rapid City SD

Position: oppose

Comment:

Doing away with the pheasant road survey is a grave mistake.This data is a valuable tool to measure the effectiveness of management programs . ..and to do away it is irresponsible and short sighted . ...if this is the new philosophy of the GF&P then may there need to be an evaluation of those responsible for this policy . ....

Paul Lepisto

Pierre SD

Position: other

Comment:

Please see the attached comments from the SD Division of the Izaak Walton League of America urging reconsideration of decision to stop conducting annual pheasant brood survey.

Bruce Knowlan

Webster SD

Position: other

Comment:

Is it true that Sd pheasant hunting isn’t now a business not a sport ?

River Otter Season

Steven Peterson

Ramona SD

Position: support

Comment:

The river otter is a valuable resource to the trappers of South Dakota. I am 100% in favor of our South Dakota outdoor enthusiasts being able to tag and keep the otter they catch.

Jerry Herbst

Pukwana SD

Position: support

Comment:

If their numbers support the a season then go for it. Conservation efforts have supported and expanded wildlife greatly over the years. One thing you can bet on is the antis did nothing to help really, just a thorn in the side of success.

Anne Fuehrer

Sioux Falls SD

Position: oppose

Comment:

We have worked to bring these creatures back and now you are opening them up so hunters have something else to make money on. You have given no fact based reasoning to remove protections for otters. Aren't these otters sacred to the Lakota? You continue to cater to the trump administrations need to remove protections for wildlife. All to the detriment of our ecosystems.

Randy Ristesund

Sioux Falls SD

Position: oppose

Comment:

Not for killing for fun

Kim Benning

Redfield SD

Position: oppose

Comment:

Trapping is inhumane and should be outlawed. How can anyone with any humanity in their body think trapping is good. Those poor animals suffer and die a horrific death. Save the otters!

Sharon Rose

Rapid City SD

Position: oppose

Comment:

Inhumane, let's work on getting SD back on track since COVID and leave indigenious wildlife alone.

Peggy Mann

Aberdeen SD

Position: oppose

Comment:

Leave the River otter alone. Stop killing.

Jeanie Dumire

Hot Springs SD

Position: oppose

Comment:

Please stop killing these animals

Theresa Giannavola

Aberdeen SD

Position: oppose

Comment:

I do not agree with trapping this animal or any animal for that matter, nor removing it from protected status. Most states have banned trapping in this century. We just got them back in our state and they pose no threat to farmers. Leave them alone and let nature be wild.

Rochelle Von Eye

Plankinton SD

Position: oppose

Comment:

Must we kill every living creature? I live on a farm and appreciate nature. I do not think it is necessary to kill for the sake of killing. ????????????

Nancy Smidt

Sturgis SD

Position: oppose

Comment:

It is so rare to see an otter in SD, I have actually only seen 1 in the last 20 years I have paddled our creeks and rivers. It was such a mind blowing honor to have seen him. Please do not trap these beautiful, fun loving creatures. They are a true delight to see.

Darlene Finberg

Redfield SD

Position: oppose

Comment:

PLEASE leave them alone

Kathy Mills

Custer SD

Position: oppose

Comment:

Due we really need to trap, hunt, everything in this state. Can’t be an environment first state? Next we will be paying 10 bucks a paw for otters! I understand, having come from a hunting family but we refuse to provide better habitats..just bounty and shoot.

Tammy Jungen

Waterown SD

Position: oppose

Comment:

The relatively rare population of river otter in SD must be protected. I strongly oppose the opening of a trapping season. The native population of them is not known. Also, with clean water needs, the population is unlikely grow due the deplorable conditions of SD waterways.

It is unconscionable to even consider a trapping season at this time with so little know of the current population and health of this reintroduced native species.

If this comes from a financial aspect, you would draw more tourism business by watching them, not trapping them.

Please do not support this plan.

Klara Parks

Piedmont SD

Position: oppose

Comment:

Exactly what is wrong with this state??? I very much.oppose what appears to be a plan to get rid of River otters once again. It seems the wonton and unnecessary killing of wildlife in this state is just business as usual. We have to endure a second year of the horrible and cruel Nest Preditor program and now this. I am a life long resident of this state and have never been ashamed of that until now. What a sad sorry state.

Tammie Mohr

Brookings SD

Position: oppose

Comment:

I do not support the killing of these rare and precious River Otters. There are plenty of other opportunities for "families to get outside" and there are more conservation-focused ways and more economical ways to generate income; such as through education tours and encounter experiences. Fund preservation for once.

Tasha Redday

Brookings SD

Position: oppose

Comment:

This is wrong. You just spent so much time trying to bring these guys back! Now you are going to allow trappers to bring their numbers to an all time low again. Stop this insanity!

David Goronja

Howard SD

Position: oppose

Comment:

Save the otters

Kim Duke

Sioux Falls SD

Position: oppose

Comment:

Please leave the river otters alone. They are so helpful to the environment. They are listed as a protected species for a reason. If this happens you will just be killing harmless but yet very important animals. Trapping of any kind is so cruel. PLEASE do not delist the river otters!!

Dana Zoelle

Brookings SD

Position: oppose

Comment:

Save the Otters!!

Cristin Holm

Rapid City SD

Position: oppose

Comment:

Please continue to protect the river otter!

Dianna Torson

Brookings SD

Position: oppose

Comment:

Families should go outside to bike, hike, horseback ride and other non-lethal activities. Killing these beautiful creatures is immoral!

Suzanne Hodges

Rancho Cordova CA

Position: oppose

Comment:

Historically, river otters were, and still are, a sacred species for us as Lakota people, as well as for many indigenous nations in North America. In the annals of Societies of the Plains Indians, the river otter is shown to be held in the highest esteem, with more than 40 references found throughout the documentation,”Historically, river otters were, and still are, a sacred species for us as Lakota people, as well as for many indigenous nations in North America. In the annals of Societies of the Plains Indians, the river otter is shown to be held in the highest esteem.

Juie Berry

Vermillsion SD

Position: oppose

Comment:

The river otter is a very important animal for healthy wetlands, (and other habitats). It took a lot of work to get these river otters here, and it is important for the beauty of this state that they stay here.

Dana Loseke

Sioux Falls SD

Position: oppose

Comment:

No comment text provided.

Shaun Grassel

Reliance SD

Position: oppose

Comment:

I would hope that the GFP would only allow harvest in areas where otters are abundant, such as the James River and Big Sioux River watersheds. I do not oppose otter trapping in eastern SD but I do have concerns about the impacts of harvesting otters from small, disjunct populations that might occur along or west of the Missouri River. I am not in favor of a statewide season. Please leave the counties along the Missouri River and all other west river counties closed.

Julie Hagen

Britton SD

Position: oppose

Comment:

I oppose having a river otter season. This mammal would be a pleasure to see and I can't imagine why they would need a hunting season. If you don't even have an accurate account why would you feel you could kill any. I strongly disagree with your over ruling of public comment.

Kenifer Meadows

Rapid Ciry SD

Position: oppose

Comment:

Otters are essential to the ecosystem balance and keeping the rivers healthy and clean. Besides the obvious moral benefit of healthy waterways, there are financial benefits as well.

South Dakota's tourism relies on natural attractions. Covid is driving people outdoors because it is one of the only safe places to play. This means that SD's outdoor adventures will only increase in the next few years.

Decaying the waterways will decrease the value to the majority of ricer goers for the limited benefit of the few.

Christina Yates

Jackson OH

Position: oppose

Comment:

I oppose trapping river otter. They are a protected species and should remain so.

Ray Starling

Wilmington NC

Position: oppose

Comment:

These are an endangered species. Their population and cultural value is more important than pelts.

Michael Kurtz

Lower Brule SD

Position: oppose

Comment:

Protect the otter, save the ones that are free. Otters are sacred to the Lakota, let them live freely. At this time the population needs to continue to increase. No trapping.

Gavin Lammers

Hartington NE

Position: support

Comment:

I would suggest moving the season start date to make sure that threat from the river otter is prime

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Paul Lepisto

Pierre SD

Position: oppose

Comment:

Please see the attached comments from the South Dakota Division of the Izaak Walton League of America.

Susan Braunstein

Rapid City SD

Position: oppose

Comment:

I don't believe there is significant scientific data to support the river otter season. Please just leave the otters to thrive in their recovery. It is not humane or necessary on any level.

Gena Parkhurst

Rapid City SD

Position: oppose

Comment:

Please do not create a river otter hunting season. After being wiped out by European immigrants, the otters were re-introduced by the Santee Sioux Tribe's initiative. It is far too early for a hunting season. These creatures are just beginning to re-populate South Dakota's waterways.

Expand otter habitat to the Black Hills and other areas.

Incidental take in beaver kills is unacceptable and should not be legitimized by a hunting season. Create a contest for inventors to figure out how to keep otters out of beaver traps.

Thank you for considering these comments.

Use of Parks and Public lands

James Van Loan

Rapid City SD

Position: oppose

Comment:

After reserving a Big Sioux campsite for $55 I cancelled it 18 days before the reservation and was charged $27.50. If you think this is a way to attract visitors by charging 50% cancellation fee it is nothing a private campground could do. It is excessive!!!!

Dan Kotab

Dante SD

Position: oppose

Comment:

No comment text provided.

Robert Bennett

Lake Andes SD

Position: oppose

Comment:

Commenting regarding YST fee exemption

I do not support this. Why not allow free entrance for everyone to have greater outdoor recreation and more education opportunities that the park provides? Why only the YST? Why not everyone like it used to be?

Corey Irwin

Lake Andes SD

Position: oppose

Comment:

They are a "sovereign nation" if they want to be involved in state functions then they should pay for their park entrance just like the rest of us. If they want to be involved in any of the joys of the river and its activities then they should pay what we pay or they should find an area that is on "their lands" aka a true reservation. The area that is called the yankton reservation is not an actual reservation. Every member should be required to pay for their entrance because they are part of this STATE.

Ryan Frederick

Lake Andes SD

Position: oppose

Comment:

I am writing in regards to the state giving the tribes free passes into the state parks. Why as tax paying individuals do we need to pick up the extra money that they get for free. We pay to enter and to use these areas, so should everyone else, including the natives. This is not a right, this is a privilege we pay for!! Please keep it fair to everyone, not just a few!!

Karen Soulek

Lake Andes SD

Position: oppose

Comment:

Regarding no-fee access provided to Yankton Sioux Tribal members, we feel that the South Dakota STATE Parks should be equally accessible to all residents regardless of who you are. The fees are already reasonable and provide access for an entire year to ALL state parks, so we do not feel that there should be an extra exemption to Tribal members - especially since the GFP already grants an exemption for religious purposes. Every entrance fee obtained is necessary to pay for the costs of upkeep and yearly maintenance of the State Parks.

Marsha Johnson

Lake Andes SD

Position: oppose

Comment:

Ridiculous!!! I work hard for my income and pay my taxes!!! Why would you ever think this is even right!! Tired of giving giving and giving!!!! Not even an option! Why would I have to pay to use state facilities and someone else doesn’t!!! Because they are native! No thought we were all equal, then treat them that way!!

Greg Hubbard

Lake Andes SD

Position: oppose

Comment:

Yankton Sioux Tribe members free park usage around Pickstown. NO WAY!! I live along the river in that area and regularly have to pick up bags & bags of trash left by Tribal members. Many do not respect the environment and should be given benefits other residents won’t have. Your park employees will be picking up dirty diapers, liquor bottles, food wrappers, etc.

John Kokesh

Wagner SD

Position: oppose

Comment:

I’m not Native American and I live in the bounds of the Yankton Sioux Reservation so based on my heritage my family’s is being discriminated against. The SDGFP must not be concerned about creating “greater access” for my family and is basing that discriminating decision off our race/religion and that is exactly what we are allowing to divide our country at this present time. Do not pass this if you truly believe in equality for all American, native or otherwise.

Jmaes Stone

Lake Andes SD

Position: support

Comment:

I am in support of the proposed park entrance fee exemption for Yankton Sioux Tribal members. I suggest adding the White Swan Use Area.

Jonelle Drapeau

Wagner SD

Position: support

Comment:

Greetings, I would like to encourage the committee to vote full access for the Yankton Sioux Tribe and it's members. This would be a huge step forward in mending relationships between the state and the tribes. I can see this action of solidarity gaining full support by all parties and gaining national headlines as they see a move to acknowledging the importance of water to the Native American culture and peoples. My hats off to all of you that are involved in such proposal and the consideration of the proposal. Thank you.

Jonelle Meyer

Wagner SD

Position: support

Comment:

As a non-enrolled member of any tribe, I think that Tribal members should be able to access the parks at no cost. They take pride in the care and love for water and see it as something very sacred. I feel that this kind of actions would benefit the relationship between state and tribal government.

Alexis Rouse

Marty SD

Position: support

Comment:

No comment text provided.

Helen Fischer

Lake Andes SD

Position: support

Comment:

No comment text provided.

Trinia Lerew

Sioux Falls SD

Position: support

Comment:

I support giving all Yankton Sioux Ihanktowan members free park passes into and around the Pickstown recreation areas. My family and I have been swimming, fishing, picnicking in and around these places our whole lives. I grew up on the river, going to the river and would appreciate having the right to do so without having to pay a fee or a fine. Thank you for your time and consideration.

Etraya Olson

Vermillion SD

Position: support

Comment:

No comment text provided.

Garrett Cournoyer

Vermilion SD

Position: support

Comment:

No comment text provided.

Chereas Houseman

Lake Andes SD

Position: support

Comment:

I am a member of the Yankton Sioux Tribe and I fully support and encourage the free full access to the Ft. Randall Dam beached & recreational areas for all Yankton Sioux tribal members. I personally grew up in the area and know the joy the river brings to many Native American families. It is very much beloved by the YST people. Our ancestors have utilized the river long before GFP ever became established and think it’s a great idea for both the YST and GFP to move in a positive direction of honoring the aboriginal people of the land. I believe it would improve the lively hood and happiness of all tribal members.
-Chereas Houseman

Derrick Marks

Wagner SD

Position: support

Comment:

This is a great step to state tribal relations and acknowledgment of the native people to the region.

Nancy Denney

Lake Andes SD

Position: support

Comment:

What about fishing licenses... due to all the floodings last year..went once. There's about 15 in my family that get one every year.?.

Terri Garvey

Lake Andes SD

Position: support

Comment:

This would be a HUGE step forward in mending state/tribal relations. I support passing the motion to allow tribal members access without requiring a payment.

Shawn Perkinas

Wagner SD

Position: support

Comment:

I fully support allowing the Yankton Sioux members free access. (non-enrolled member)

Ramona Drapeau

Lake Andes SD

Position: support

Comment:

My family and I enjoy fishing and some times it's difficult for every family member to purchase a pass so we end up not being able to fish. I vote to allow free passes for tribal members.

Colton Drapeau

Wagner SD

Position: support

Comment:

I would like to see the tribe be allowed free river access.

SOUTH DAKOTA
DIVISION

The Izaak Walton
League of America

DEFENDERS OF SOIL, AIR, WOODS, WATERS, AND WILDLIFE

June 18, 2020

South Dakota Game, Fish and Parks Department
523 East Capitol Avenue
Pierre, SD 57501

Re: Annual Pheasant Brood Survey

Secretary Hepler, Commissioners Jensen, Bies, Boyd, Locken, Olson, Sharp, Spring and Whitmyre,

The South Dakota Division of the Izaak Walton League of America (Division) wishes to express our anguish and extreme disappointment in your recent decision to discontinue the annual pheasant brood survey. The League and its members firmly believe in science-based, common sense decisions. We're asking you to reconsider the decision to end this annual scientific survey conducted every year since 1949.

We respectfully request you reinstate the survey and conduct it this summer and every year in the future.

The Game, Fish and Parks Department (GFP) historically has based nearly everything it does on the best available science. It conducts activities that are in the best interest of landowners, hunters and anglers - resident and nonresident - who fund most of the operations of the GFP."

The Division is also very troubled that the decision to stop conducting the survey, which costs about $90,000 per year, was reached without accepting any public comment. We do not see that as serving the needs of your "customers".

If the decision to eliminate the pheasant brood survey was based on budgetary reasons, we would ask that the nest predator bounty program, which has no scientific support, be cancelled instead. A portion of the $250,000 earmarked for predator tails could be re-appropriated to conduct the pheasant survey. Years of research show that any program failing to reduce predator levels below their annual mortality rate has no scientific merit. As currently implemented, the nest predator bounty program does not include a youth trapping education component. Without that, we feel it is not a good use of valuable sportsmen's dollars.

Recent results from the summer brood survey have revealed very troubling numbers. While South Dakota can still claim to be "the pheasant capital of the world" and always has the best pheasant hunting opportunities, recent surveys have shown significantly lower populations. We believe the low numbers directly reflect the ongoing loss of critical nesting and wintering habitat across the state.

The Division believes the brood survey is an invaluable tool needed to track population trends as well as changes in the condition of year-round habitats required by pheasants. The survey determines what areas have lower numbers and where quality habitat development, on both public and private land, must occur.

The summer brood survey is also valuable as it provides a real sense for the status of other wildlife species and the condition of crops in the county for the year. The data collected over the long history of this survey is important. The loss of this annual data cannot be recovered once time passes. The GFP would be left just guessing on population numbers without any concrete data. If the brood survey is not conducted it could take years for GFP to get back on track with pheasant population estimates and trends.

The South Dakota Division of the Izaak Walton League of America asks you to reconsider your decision to end the annual summer pheasant brood survey. Please reinstate it as an annual scientific research activity, and don’t take the science out of South Dakota pheasant management. The pheasant means too much to this state, the people who hunt it and those who depend on it for their livelihood.

Thank you for your time and consideration. Stay safe and well.

Sincerely,
Kelly J Kistner
Kelly Kistner
National IWLA President and President of the South Dakota Division of the IWLA
603 Lakeshore Drive
McCook Lake, SD 57049
605-232-2030 (H) – 712-490-1726 (C)
iwlasdpresident@outlook.com

June 8, 2020

Kelly Hepler, Secretary and Game, Fish & Parks Commission
South Dakota Game, Fish and Parks Department
523 E. Capitol Avenue
Pierre, South Dakota 57501

Secretary Hepler and Commissioners:

Re: *Friends of the Big Sioux River* Comments on the River Otter Management Plan and de-listing the otter from its "threatened" status

Friends of the Big Sioux River is an organization working to improve water quality and clean up the Big Sioux River and other waterways in the Big Sioux watershed. We also work to increase people's interest in the outdoors. The enhancement of wildlife habitat in the watershed is another objective. Our members and friends have removed barb wire fences, cleaned out trash dumps, planted countless trees, and pulled invasive species from buckthorn to garlic mustard to help improve the flora and fauna of South Dakota's state parks.

This past weekend we organized a clean-up with the Big Sioux Recreation Area Park Managers, John Dummer and Luke Dreckman, to start the removal of tons of trash from a popular trail system in that recreation area that was damaged by two years of flooding. We are squeezing this clean-up in between the water quality monitoring we are doing in the Split Rock Creek watershed to help identify pollution sources which contaminate the creek as it flows through Palisades State Park. We have been doing water testing for several years at another fifteen sites, including state park access areas such as the Big Sioux Recreation Area and Newton Hills, as well as Lake Alvin and Lake Lakota.

We have tremendous respect for the work done by the South Dakota GF&P. We realize that without the state park system many residents in eastern South Dakota would have few places to enjoy nature. We also know that much of this work is accomplished on thin budgets, and that revenues are shrinking as fewer people are involved in hunting. It is important that GF&P recognizes a shift in people's uses of the outdoors from harvesting wildlife to simply enjoying the experience of observing wild birds and animals. As our outdoor spaces shrink, and as our human footprint expands, more people are embracing wild animals as creatures that add beauty and fascination to their outdoor experiences and to their lives. We believe that the enjoyment of seeing living creatures is something future generations deserve to enjoy, as well.

There is no greater representation of the fascination and joy in observing wildlife than watching a river otter! The otter is an iconic symbol of river wildlife, and it also represents a species that is playful and communal and fun to watch. Unfortunately, it is difficult to observe them in South Dakota because there are not very many of them here. As you know, hunting, trapping and the degradation of waterways and wetlands obliterated our state's otter population. By 1977, it was postulated that this species might be extinct in our state. Through the next several decades things did not improve, as sighting were extremely rare. Fortunately, the Flandreau Santee Sioux tribe introduced 38 otters on the Big Sioux River in Moody County in 1998 and 1999. Scientists have identified the Big Sioux River as possessing the best potential for otter habitat in the entire state.

We now know that from this group of otters introduced on the Big Sioux River have spread out and are now residing on three waterways in eastern South Dakota: The lower James River, the Vermillion River, and the Big Sioux River. By 2004, otter sightings in the entire state of South Dakota climbed to 22. By 2012, sightings rose to 46. This increase can be traced to the re-introduction efforts by the Flandreau Sioux tribe.

We note that a "sighting" might be simply observing scat or tracks or an otter slide in the snow, in addition to an actual animal sighting or finding an incidental catch by a trapper or an animal killed by a vehicle.

Two years ago, verified reports sightings of river otters in our state totaled 38. Last year that total reached 40. These are small numbers, to be sure. Considering how a "sighting" is defined, does this sound like a species that is comfortably rebounding in our state? Is this the level of population resurgence that warrants a de-listing of this species? We suggest that de-listing is not a reasonable step in the recovery of this species currently.

Your agency is making the claim that otters have reached a harvestable point. A spokesperson for your agency stated that improved conditions on waterways and wetlands make de-listing possible. We would strongly argue the opposite. Wetland destruction continues, and water quality issues in waterways such as the Big Sioux River are worrisome. How successful is the state's riparian buffer program? Habitat remains problematic. Otters continue to face major challenges caused by human beings. This de-listing adds to their challenges.

Your agency explained that for this species to be de-listed there should be confirmed reports of reproduction in three of the five watersheds within the species recovery area. Another factor, according to your agency, is that you need reports indicating satisfactory distribution. We note that over the past five years average sightings are only about 40 per year. We find this inadequate evidence that this species is prospering and no longer deserves to be protected under "threatened" designation.

Your agency's new recommended management plan calls for an annual harvest of 15 otters per year. Already, 16 incidental otters are trapped each year. There may an increase in otter numbers in our state, but it is happening at a terribly slow pace. Consider the statistics in the following chart.

State	Square Miles	Estimated Otter Population	Annual Harvest	Otters per Square Mile
Minnesota	87,000	12,000	2,000	**.14**
Iowa	56,000	7,000	692 (5 yr. Avg.)	**.125**
Nebraska	77,000	5,000	2020 Start	**.065**
North Dakota	71,000	No actual data is available	20	**???**
South Dakota	77,000	No actual data is available	15	**???**

Minnesota, Iowa, and Nebraska have sizeable otter populations and a harvest is allowed, however, Nebraska with an estimated 5,000 otters will just start its harvest this year. Based on the surrounding states' knowledge of their otter populations , South Dakota is hardly ready for a harvest.

The research done by your agency does not support a harvest and this move is premature. The question is why have a harvest season at all? Please consider the facts that:

- Otters do not destroy crops or harm any type of livestock.
- Otters do not create burrows. They mostly use other animal dens or burrows or downed trees for homes.
- They do not cut down and damage trees nor cause any flooding of property.
- Otters do not eat upland game bird eggs, so they do not hurt pheasant populations.
- There is no real economic reason for trapping otters.

Each year our organization teaches classes at water festivals for school kids, and we also teach classes at local schools. We lead off our presentation with a video of a river otter family frolicking as they live their lives. The children are fascinated and curious where they can see an otter. Our answer is: "There may be some around the Flandreau area , but despite all the time our members spend on the Big Sioux River and other rivers and streams in eastern South Dakota we have never seen one." We also tell students that we could have more otters in our state if our state agencies would enforce and prioritize the implementation of clean water practices that would help otters thrive. Clean water is critical for otters, and our state has fallen short until recently in monitoring water quality and enforcing water standards. That unfortunate situation has been well-documented, with admissions by state leaders that funding to pursue clean water projects is scarce.

Friends of the Big Sioux River renamed its printed newsletter *The Otter*. We re-designed our logo to include an image of an otter. We did this because otters represent healthy rivers and waterways. We did it because it is an aspirational goal for our organization – we recognize that healthier waterways mean more otters. But only if otters are given a chance to thrive.

Rather than open otters to harvest and reduce protections for this important animal, we suggest your agency take steps to accomplish this following:

1. Restore clean water to our streams and lakes.
2. Require all landowners to implement riparian buffers on all lakes and streams.
3. Develop an otter monitoring program that accurately determines population thresholds in various watersheds.
4. Set up an otter monitoring team of stakeholders for each of the three main watersheds in eastern South Dakota with verified sightings reported to a GF & P web site with date and location. This can be followed up with verification by a GF & P wildlife specialist.
5. Set a goal of reaching .075 otter per square mile before an eastern watershed is open to a harvest. This is at the low end of otters per square mile compared to other states. Based on the relative size of the watersheds here are our recommendations:

Watershed	Sq. Miles	Goal per Sq. Mile	**Needed Otter Population**
James	14,700	.075	**1,100**
Big Sioux	5,400	.075	**400**
Vermillion	2,700	.075	**200**
Remaining Area	54,000	.005	**270**
Total	77,000		**2,000**

We believe GF&P should recognize the advantage of drawing people to the outdoors by protecting the otter from any harvest. There are far more people and children who admire and appreciate the remarkable otter than there are who want to trap this animal.

We suggest that the public disapproves your agency permitting the trapping of otters and de-listing them considering current numbers. We advise you to work on behalf of all the people in South Dakota who appreciate wildlife. They far outnumber those who wish to trap. We believe it is premature to de-list the otter from its threatened status. Forty sightings through the entire state is hardly a reason to celebrate. It is, however, a reason to focus more attention on doing what it takes to restore otters to our landscape. Doing this sort of work is how an agency earns its keep. It is what you should be doing. We urge you to reverse this decision.

Sincerely,

Travis Entenman
Director
Friends of the Big Sioux River

SOUTH DAKOTA
DIVISION

The Izaak Walton League of America

DEFENDERS OF SOIL, AIR, WOODS, WATERS, AND WILDLIFE

June 18, 2020

South Dakota Game, Fish and Parks Commission
523 East Capitol Avenue
Pierre, SD 57501

Dear Commissioners,

The South Dakota Division of the Izaak Walton League of America (Division) appreciates this opportunity to comment on the proposed river otter trapping season. This proposal would establish a state-wide river otter trapping season in November and December or until 15 otters are trapped and reported to the Game, Fish and Parks Department (GFP).

While the Division supports responsible trapping and the sustainable harvest of furbearers, we strongly oppose this proposal. We ask the commission to reject it as we believe this goes too far, too fast for this specie.

The commission took two steps during your May meeting. First, voting to delist the river otter then, approving the development of this proposal. The Division believes this marked the first time in history that a governing game and fish body voted to delist, and then approved development of a harvest season on that specie during the same meeting. Again, we believe, this is going too far, too fast.

The state's river otter management plan is currently undergoing revision. The existing plan states otters are difficult to monitor thus making development of a suitable monitoring program challenging. The Division agrees with the GFP's stance that a healthy, growing population of river otters would be welcomed in watersheds across our state.

South Dakota's current population of river otters emanated from a reintroduction effort. The reintroduction was conducted by the Flandreau Santee Sioux Tribe in Moody County along the Big Sioux River in 1998 and 1999.

Current research and reports show much of the suitable otter habitat and most of the documented sighting are in watersheds in extreme eastern and northeastern South Dakota. We believe this makes opening even a very limited state-wide season extremely premature.

Data shows the population of river otter in the western two thirds of the state is either very low or non-existent. The Division is concerned the current relatively small population of otters could not withstand even a "limited" harvest without suffering a major setback. This at the same time the GFP wants to see this specie expand its range across the state.

The reason given by GFP for the establishing the proposed limited trapping season is the department has been getting about 15 or 16 incidentally taken otters in each of the last five years. These animals were mostly taken in the beaver trapping season.

The Division is very concerned the same level of incidental take that has occurred will continue. That incidental take, coupled with this proposed state-wide trapping season, could possibly double the actual annual harvest of river otters in the state. This added harvest could occur before GFP could get information out to trappers announcing the season is over when the proposed 15 river otters allowed in this proposal are harvested. The potential higher harvest would result in lowering, not expanding, the state’s river otter population.

The existing management plan states otters require high water quality and access to year-round open water to survive and successfully reproduce. The Division is concerned that increased surface and tile drainage and grassland conversion is contributing to a decline in water quality in many of the state’s watersheds. This, combined with the ongoing riparian habitat loss and the fluctuating water levels due to our highly varied climate, makes accurately predicting long-term otter population growth extremely difficult.

Before a season for river otters is considered in South Dakota the Division asks the GFP to fully address the following:

- Research possible impacts of agricultural run-off on otters
- Develop a peer reviewed otter monitoring program
- Establish peer reviewed otter survey methods to accurately determine population
- Develop peer reviewed otter population goals and objectives and metrics on how they can be achieved
- Methodology to track otter reproduction and population movements
- Coordination of all future otter management with agencies, tribes and other stakeholders
- An outreach plan to inform trappers on ways to avoid incidental otter catches
- A public outreach program to educate the public about river otters

Until these steps are implemented, the South Dakota Division of the Izaak Walton League of America respectfully requests that the South Dakota Game, Fish and Parks Commission reject this and all other otter trapping proposals.

Thank you for your time and consideration and for this opportunity to comment.

Sincerely,

Kelly J Kistner

Kelly Kistner
National IWLA President and President of the South Dakota Division of the IWLA
603 Lakeshore Drive
McCook Lake, SD 57049
605-232-2030 (H) – 712-490-1726 (C)
iwlasdpresident@outlook.com

Public Comments

Other

Jim Shurts

Madision WI

Position: other

Comment:

Thank you for sharing the Tourism/GFP marketing plan; the proposed marketing plan looks good. Increasing hunter numbers is very important for many reasons and is a problem nation-wide. I am one of those traditionalists, though it seems I’ve aged out of the listed age group. :-) I am concerned, however, with the decision to discontinue the annual brood count. It may not be used to manage pheasant populations or to set the season structure and bag limits, but it does provide important information to out-of-state hunters like me. Poor brood counts factor in to whether or not my hunting partner (who lives in Massachusetts) and I will make the trip. He and I have certainly long reached the point in our hunting lives where the number of birds bagged is low on the list defining success. But that being said we do want to know that putting in our efforts of walking/hunting the land with the dogs will have a good chance of putting up birds. Brood counts is one of the pieces of information we use to determine that. Obviously weather and the price of ethanol corn are major factors in pheasant populations, and those don’t need brood counts to be ascertained. But we still like our brood counts.

Thanks for listening and stay well.

Greg Compson

Sioux Falls SD

Position: other

Comment:

In response to the news story that pheasant numbers will no longer be released, one has to wonder why. I know why. I have been hunting and fishing in South Dakota since the late 60's. The last 10 or more years have been dismal for your average pheasant hunter in South Dakota. As well as waterfowling . Habitat is mostly gone. Commercial hunting is now the norm. Average folks cannot afford booked hunting trips. Permission to access private land is hard to come by. Land owners are looking to maximise their incomes from guided hunts. I can't blame them for that. However, public lands are vast in some cases prohibiting reasonable access unless you are young and fit for major trekking. Others are so small that there is no point putting in an effort. Young people have little or no interest in hunting. Political correctness, lack of parental enthusiasm, cost, are surely the demise of this great sport. How sad. The experiences my dad and I had, along with those times I enjoyed with my sons and family are distant memories. Times are changing I guess. Ditches are mowed down, land is tilled and planted from fenceline to fenceline. Rural folks give you the stink eye or confront you when trying to hunt right of ways. Who needs it? It's pretty much a big hassle hunting anymore. It's done for the average guy in my opinion.

William Miller

Brandon SD

Position: oppose

Comment:

I would like to write in opposition to the ban on the use of high power rifles to hunt spring, west river turkey on private land. Since the last fatal incident was in 1999 in the black hills and not on the wide open prairie it would seem you're trying to fix something that isn't broken. As a senior citizen I have appreciated the commission's efforts to make hunting more pleasurable for us. Two rulings come to mind. Allowing lighted sight pins on bows and lowering the poundage to hunt big game to 30lbs. Reinstating the use of high power rifles would be another way to increase success when hunting west river turkeys on private land. A sentence in red on the license application reminding hunters to be sure of their target would go a long way toward promoting safety. Please reconsider your ban on the use of high power rifles to hunt west river turkey on private land.

Randy Thaler

Lake Andes SD

Position: other

Comment:

I would like my free access permit to the Missouri River also. As a resident of Charles Mix County which Yankton Sioux Tribal Members are residents of also, I to do not have access to the Missouri River and should not have to purchase a permit to use the boat ramps. Actually the Tribe has more access than I as they own land that borders the river and could put in their own boat ramp.

Jennifer Swanson

Sioux Falls SD

Position: oppose

Comment:

I am very opposed to the nest predator bounty program. What is going to control the pests that these animals naturally control, i.e. wood ticks..?

Ethel Cournoyer

Wagner SD

Position: support

Comment:

I support the approval to waive the required pass for members of the Yankton Sioux Tribe around the area of the Fort Randall Dam. The river is necessary to Indigenous culture and wellbeing in all areas.

Gregg Yonkovich

Aberdeen SD

Position: oppose

Comment:

Extremely disappointed to learn GF&P is discontinuing brood survey's. We've consistently had this data for nearly 100 years, and now we've decided to stop? I'd understand if it were a budgetary issue, but we're stopping because we don't want people to know if bird numbers are down? Instead we're intending to hope folks come to our State with no information, and hope they aren't pissed if they don't find birds? Also, how will we know if habitat and other programs are making a difference? If you're relying on hunter surveys, you're making a huge mistake. Please consider reinstituting the brood survey, and figure out a better way to disseminate the information.

Use of Parks and Public lands

Irene Provost

Wagner SD

Position: support

Comment:

I think this will be a great opportunity for everyone.

Michael Holly

Belden NE

Position: oppose

Comment:

You need to open the area below Gavins Point dam to non resident archery paddlefish i.e. the same are all others get to use. The few non resident tags that you do give out surely are not going to be detrimental to the fishery. I will no longer apply for an archery tag in SD, because during "normal" summer flow your area open to archers is almost void of paddlefish. I would like to hear the reasoning behind you closing this area.

Valerie Habben

Lake Andes SD

Position: support

Comment:

Yankton Sioux tribal members should b waived fees and fort Randall dam rec areas in my opinion. Thank you

---

Dawn Hope

Sioux Falls SD

Position: support

Comment:

Yankton Sioux Tribal member

Gayle Hayward

Wagner SD

Position: support

Comment:

I’m in full support of members of the Yankton Sioux Tribe being able to access the parks without paying admission.

Kip Spotted Eagle

Wagner SD

Position: support

Comment:

My name is Kip Spotted Eagle and I am in support of the State of South Dakota adhering to the 1851 and 1858 treaties between the Yankton Sioux and the United States Government. Our people never gave up their treaty rights to the use of the River. I believe other tribes exercise There usufructuary fishing and hunting rights as well as uninhibited access to the rivers. Please understand the Tribes are nations that do not need you to recognize their rights to the river but to adhere to the treaty rights we are promised.

Greg Hayward

Wagner SD

Position: support

Comment:

I support the proposal for YST members to have free access to the river through the parks.

Jason Dion

Lake Andes SD

Position: support

Comment:

I think we as a sovereign nation should have free camping

Spiritdreamer French

Wagner SD

Position: support

Comment:

No comment text provided.

Public Comments

Administrative Rules Review

Georgine Young

Huron SD

Position: support

Comment:

I would like to see where we are given the opportunity of free fishing,camping and hunting. I believe we had free fishing before but tht was taken away.

Nancy Hilding

Black Hawk SD

Position: other

Comment:

Nancy Hilding
President
Prairie Hills Audubon Society

This is a comment on changes to beaver trapping seasons, being proposed to make beaver seasons more consistent. We think you are trying to make all beaver trapping start on November 1st. We think this leaves other season inconsistencies. The East River beaver season is 6 months, the Black Hills Beaver season is 3 months and the West River beaver season is 365 days. River otters are incidentally trapped in beaver traps. 365 days of beaver trapping is given as a reason it would be difficult to re-introduce otters West River.
The reason for this longer West River season is alleged to be, that West River ranchers complain more about "conflict" beavers. Why not require them to apply for permit to take a "conflict" beaver, as provided in SDCL 41-8-23, rather than have year long trapping?
Why not make the East-West River seasons match and make both of them 6 months. Why not make trapping on all public lands three months later in the winter, like the Black Hills National Forest. Beavers provide for habitat for many other species and federal and state public lands are often supposed to be managed at least in part for wildlife and water quality/quantity.

Fall Turkey

Pat Malcomb

Sioux Falls SD

Position: oppose

Comment:

I oppose shutting down Tripp County for fall turkey hunting there are plenty of birds to support giving some tags out. If you think its an issue make them male turkey tags.

James Elsing

Lemmon SD

Position: other

Comment:

No comment text provided.

Wolfgang & Kathleen Schmidt

Nemo SD

Position: oppose

Comment:

In the many years we have lived in the Black Hills, we have usually seen some turkeys in our area. This year, we have seen NONE. There are NO HENS, NO BABIES, absolutely NOTHING. We are AGAINST ANY FALL TURKEY SEASON. The numbers indicate that there is a less than 35% "success" rate. Why are you allowing a turkey hunting season when there are so few out there anymore? Does the research not tell you this should be put on hold until they increase in numbers?

Other

Paul St.Pierre

Brookings SD

Position: other

Comment:

YST MEMBERS SHOULD GET FREE ACCESS TO THE PISCKTOWN SWIMMING AREAS.

Lynn Bruguier

Lake Andes SD

Position: support

Comment:

No comment text provided.

Sandra Knudsen

Wagner SD

Position: support

Comment:

Support YST and access, use of river.

Markayla Yellow Horse

Marty SD

Position: support

Comment:

No comment text provided.

Andrea Archambeau

Wagner SD

Position: support

Comment:

As a tribally enrolled member we are the original owners of this land, we should be given unlimited free access for eternity. This is our home. Visitors should have to pay if they want access and have no right to comment on whether we gain free access or not.

Randy Schmiesing

Chokio MN

Position: other

Comment:

canceling road side survey for pheasants is wrong step I wont hunt pheasants in SD with it gone

Dear Managers

Hiding your pheasants numbers will discourage new out of state hunters from coming to state. Most people want to know if they are wasting their time in going to an area that has no Pheasants. I was talking to person who only has limted amount of vacation time for hunting and said he isnt blindly going to south dakota picking a spot to hunt and waste his time.

I am a conservationist who believes how do you fix a problem . know the facts and change your habitat problem.

Not Bury your heads in the sand.

Are you going to get rid of the water fowl numbers next. I wont hunt that season if you do that also.

Your money will dry up no out of state hunters

Arnold Veen

Milbank SD

Position: other

Comment:

Hello, Just want to air out a problem with your West river archery deer CF196 access permitting system.
The issue is as follows: I hunt the Slim Butt area of the Custer National Forest in which I need a CF196 access permit.
It requires that I buy a West River Archery Deer license before applying which I did.
I then applied for the CF196 access permit and now I received a unsuccessful draw result on my application for CF196.
I now have a West River Archery tag that I can not use for my hunting area of the Slim Butts. Money spent!!
This is backwards It should allow hunters to apply for the Access Unit CF196 before buying a tag to keep from spending the money on the Achery Tags that will not allow you to hunt your chosen area in this case Custer National Forest Land (35L).
I assume there is no refunds at this point?
It probably not your problem but I will send this to your dept as well as the GFP commission also.
Thanks for listening.
ArnoldVeen, 14789 482 ave., Milbank, South Dakota, 57252

Dustin Dierks

Sioux Falls SD

Position: other

Comment:

Dear SDGFP,

I think that the Hunt for Habitat raffle is a great idea and opportunity. As a resident of SD, I am hoping to someday have the opportunity to hunt elk in my home state. I have several years of preference points, now which I pay for.

I have a father who passed away last year who had one opportunity in his lifetime to hunt elk in South Dakota, his life-long state of residence. And unfortunately, he drew during the Atlas blizzard year in the Black Hills which significantly altered his plans and life long dream.

However, he never did get the chance to hunt archery elk as he never drew a tag. Hence, I do have concerns with the opportunity you afford non residents in this raffle. For those of us who have tried many years to draw a tag, and who have observed family members do the same over a lifetime, it is difficult to comprehend the opportunity a non resident has to hunt SD elk for a $20.00 raffle ticket.

I understand the economics involved; however, I do recommend and suggest you reevaluate. In my opinion, the difference of $10.00 between a resident and non resident raffle opportunity for a cherished South Dakota elk tag is offensive.

Thank you

Dustin Dierks
Sioux Falls SD

Tyra Honomichl

Wagner SD

Position: support

Comment:

It was brought to my attention that native americans should have free access to the river. I was talking to a tribal member and they have valid opinions and feelings. As you know most of the native population dont have a lot of financial resources, so to be able to help them in this way would be good for everyone. It will help build a bridge between cultural difference and build new connections with each other. With everything that is happening today with BLM movement, you would be able to support the movement. Which will also help you bring new visitors to this beautiful area which in turn gives you more business and revenue. I admit I dont know a lot about business but I know if more people visit the more money you yet. This is a win-win situation. Thank you for your time and hope to hear from you soon.

Matthew Provost

Seattle WA

Position: support

Comment:

"As long as the water flows and the grass grows".. We know where our Motherland is.

Would you pay money to visit your birthplace?

Jessi Jo

Lake Andes SD

Position: support

Comment:

No comment text provided.

Stefanie Morales

Wichita KS

Position: support

Comment:

No comment text provided.

Tasheena Zephier

Marty SD

Position: support

Comment:

No comment text provided.

Brenda Zephier

Marty SD

Position: support

Comment:

No comment text provided.

River Otter Season

John Hopple

Black Hawk SD

Position: support

Comment:

Hello Secretary Hepler, Chairman Jesen an Commissioners.
as President of the South Dakota Trappers Association I speak for our members in supporting the river otter season proposed by GFP. In addition I would like to add the following comments.

This was not asked for by us or proposed by us. I have read the public comments and wanted to address some attacks we have taken. This was a proposal by GFP based on science and experts in wildlife biology. There was no emotion, just facts and figures. GFP has the right to decide seasons and harvest for ALL creatures that fall under its purview. As such this is much the same as setting the west river deer season or antelope season dates and number of tags. Research, facts and figures are used to come to those decisions. It is not made by the hunters but by the experts at GFP who are funded by sportsman's tax dollars. We trust these folks to provide this information on all other species why the backlash for this one animal? Just as some seasons/harvest limits for certain species are changed every year so may the river otter be in future seasons. It is the right of GFP to manage the wildlife and should be so unabated. So in conclusion, Yes the SDTA strongly supports the GFP's decision to establish an otter season based on the information presented by its experts who do these studies and analyzing of facts/figures emotion free every day.
Thank You
John Hopple
SDTA President

Alan Lekness

Sisseton SD

Position: other

Comment:

No comment text provided.

Cybele Knowles

Tucson AZ

Position: oppose

Comment:

Attached please find 282 comments from supporters of the Center for Biological Diversity urging you to withdraw plans for trapping of South Dakota's tiny river otter population. Thank you for your attention.

Steven Peterson

Ramona SD

Position: support

Comment:

Having an otter season for the outdoorsmen of South Dakota is a great step forward. The otter population in the state has grown significantly and steadily since their first release. I have been trapping in South Dakota for 47 years. The opportunity to catch my first otter in the state would be a unforgettable experience.

Vince Logue

Oelrichs SD

Position: support

Comment:

I am the president of the WSDFHA and our
membership is between 175 and 200 members. I am supporting this proposal for the season on river otter. I believe it is vital as a viable control plan to manage the increase in the river otter population in South Dakota.

Kelsey Vig

Opal SD

Position: support

Comment:

I am in support of a river otter season as a plan ready in place to help manage a balanced habitat for fish populations. Wildlife management is crucial for the health of all species.

Jacob Helms

Reva SD

Position: support

Comment:

I think trapping the River otters would be beneficial not only for the state but also the public. We have to control the numbers or the population will get way out of hand and once it’s out of hand it’s hard to come back from that.

Katie Helms

Reva SD

Position: support

Comment:

I am a firm believer in keeping animals at a controllable level.

Kathleen Schmidt

Nemo SD

Position: oppose

Comment:

There are so few otters in the Black Hills that there they should be protected for the future. There should be no trapping season on these wonderful little creatures. Please let them live so that they may increase in numbers so we do not lose this endangered species.

Brian Gundvaldson

Egan SD

Position: support

Comment:

I am in full support of season. I believe we have the otters and would be nice if trappers could keep the incidentals that are already being caught, and use the resource to it’s full potential.

Vickie Hauge

Deadwood SD

Position: oppose

Comment:

I am writing to question why there is a trapping season for the River Otter in the West of the Missouri River? We have not seen the otter here since 2018. I do also question The GFP management reasoning when their estimate of possibly 40 Otters in the whole state of South Dakota. 40 is a very small number & when they are trapped out, so you introduce them back so that 10 years later, they get trapped again? Our Otters are being killed accidentally in traps that are set out for other animals all ready. The methods used to count these endangered animals is in my view, leaves much to be desired. Really not knowing if there are even 40 out there, it would be prudent for you to stop this trapping season all together. The trappers in South Dakota are given what ever they want & the non trappers who are amazed by these beautiful creatures in our state, have to live with it. Do you represent all South Dakotans? I think not!
Please reconsider this & show is that we are all being represented by you.

Thank you.

Vickie Hauge
Deadwood

Nancy Hilding

Black Hawk, SD

Position: oppose

Comment:

Nancy Hilding
President
Prairie Hills Audubon Society
Black Hawk, SD

Dear GFP Commission

We are attaching our first letter in opposition to the northern river otter trapping season. Our first letter discusses how the otter delisting was done illegally, due to violation of public notice requirements. You would be tiering a trapping season to an illegal delisting rule and we advise against doing that.
We are also attaching 5 documents to our letter - These attachment's will include
1. Native Sun News Article on River Otters
2. 2006 Public Notice of December's GFP Commission Meeting
3. 2020 Public Notice of May's GFP Commission Meeting
4. List of Statutes for Chapter 1-26
5. List of Statutes for Chapter 34A-8

However your portal only allows one attachment per comment, thus I must use 5 postings to attach 5 attachments.

Nancy Hilding

Black Hawk, SD

Position: oppose

Comment:

I am submitting an attachment to our first letter

Nancy Hilding

Black Hawk, SD

Position: oppose

Comment:

Nancy Hilding
President
Prairie Hills Audubon Society

I am submitting an attachment to our previous letter

Nancy Hilding

Black Hawk, SD

Position: oppose

Comment:

Nancy Hilding
Prairie Hills Audubon Society

I am submitting attachments to our first letter.
One at a time

Nancy Hilding

Black Hawk, SD

Position: oppose

Comment:

Nancy Hilding
Prairie Hills Audubon Society

I am submitting attachments to our first letter

Nancy Hilding

Black Hawk SD

Position: oppose

Comment:

Nancy Hilding
President
Prairie Hills Audubon Society

We are submitting our first comment letter on the river otter trapping season. I thought I had sent it already, but I have not yet gotten a receipt for it, thus for safety I send it again.

This is a comment letter discussing how the delisting of the river otter was done illegally, as you did not provide the required 30 days public notice. We think it improper to tier a trapping season to an illegal delisting rule. This letter has 5 attachments. We already sent 4 of them and got receipts for those. We could not successfully send a 5th attachment, so we e-mailed it to Rachel Comes. The attachments are about

1. Native Sun News Article on River Otters
2. 2006 Public Notice of December's GFP Commission Meeting
3. 2020 Public Notice of May's GFP Commission Meeting
4. List of Statutes for Chapter 1-26
5. List of Statutes for Chapter 34A-8

Wendy Luedke

Lead SD

Position: oppose

Comment:

I am against otter delisting & the delisting was not done procedurally (inadequate public notice)
2. I would like otter season to be postponed until we have a higher number of otters in SD & otters are recovered in both east & west river.
3. I would like the trapping area be limited to a smaller area and not apply to west river and not apply along the Missouri River.
4 There should be West River otter reintroduction project(s), especially to La Creek NWR before any West River trapping.
5. Otters are killed accidentally in beaver, raccoon and mink traps. As a result the beaver trapping season in West River should be shortened.. The current West River season - except Black Hills - is 365 days, East River season is 6 months. The Black Hills Season is 3 months. The reason for this longer west river season is alleged that West River ranchers complain more about "conflict" beavers. Why not require them to apply for permit to take a "conflict" beaver, as provided in SDCL 41-8-23, rather than have year long trapping?
6. All beaver traps that are not set during an otter season, should have the trip wire off to the side, rendering them less likely to incidentally take otter.
7. Any otter taken by humans..incidental trapping, vehicle kills, be counted against the next season's "harvest limit".
8. The 2020 SD Otter Management Plan...has inadequate information in it.
9. The wildlife watchers, photographers & hikers make up a much larger sector of the population and their wildlife enjoyment should be considered and given respect by SD GFP. And enough otters should be kept to expand to West River . Please recognize that viewing otters provides the benefits to quality of life for residents and reasons to visit for tourists.
10. I would like an actual otter monitoring plan in place before beginning otter trapping, this has not been done yet.
11. In doing so, you should ask for consultation with SD Tribes and USFWS.

Julie Anderson

Rapid City SD

Position: oppose

Comment:

To: SDGF&P regarding 2020-2029 River Otter Management Plan

I object to this plan because of the reason for its inception, which is to pay trappers for the pelts of the otters inadvertently killed in beaver traps. The population does not warrant delisting, nor are the population numbers given reliable. GF&P admits monitoring otters is difficult, and a better system will eventually be developed. A reliable monitoring system should be established before any thought is given to delisting. There should also be efforts made to prevent otters from falling victim to beaver traps by moving the trap trigger. This would alleviate the need for delisting in the first place. To subject otters to excruciating pain and suffering and risk the extinction of the species in this state to put money into the pockets of a few is cruel, foolhardy and unnecessary.

The time and opportunity has come for this agency to address the majority of people who want to see wildlife in their natural habitat.   SDGF&P should scrap the current plan in favor of creating and establishing a river otter tour.   This is a much more profitable endeavor, as people love to watch otters, and current tours in other states charge from $100 to $150 per person. This would also open up opportunities for professional photography tours as well, which could bring in additional revenue.   This would also provide a chance to study the river otter and its population numbers in depth, and at the same time become a reliable source of income. River Otter tours would also spur growth in the state's tourism industry by providing new jobs.

Please take this opportunity to move this agency into a new direction that will provide economic sustainability and find a whole new group of people wanting to experience South Dakota's rich wildlife heritage.

Thank You,

Julie Anderson
845 Virginia Lane
Rapid City, SD
57701

Nancy Hilding

Rapid City SD

Position: oppose

Comment:

Nancy Hilding
President
Prairie Hills Audubon Society

I am attaching our second letter on the proposed river otter trapping season

Use of Parks and Public lands

Lisa Arrow

Wagner SD

Position: support

Comment:

No comment text provided.

Agnes Nelson

Lake Andes SD

Position: support

Comment:

Should have free access to the River and Fishing.

Shavonne Flying Hawk

Lake Andes SD

Position: support

Comment:

I am in support of the Yankton Sioux being able to utilize the Parks on the reservation. If it wasn't for the Pick Sloan Act, we would still be living by the water. Allowing our people access to lands that have been given by treaty, is vital to our nation. We already have "free" access to the Pipestone Quarry. We just show our tribal ID. I think we should only have to show tribal ID to access these areas.

Amelia Parry

Wagner SD

Position: support

Comment:

No comment text provided.

Elliott Rainbow

Lake Andes SD

Position: support

Comment:

I support this option

Merna Hare

Wagner SD

Position: support

Comment:

I’m in favor of waving fees to Yankton Sioux Tribal members.

Sasheen Thin Elk

Lake Andes SD

Position: support

Comment:

I am in Support of the fee waiver, because we never gave up our treaty rights. I am in support of Yankton Sioux Tribe members having the fees waived. For our tribal members, Land is more than just ground beneath our feet. We try and protect our land and water, not for us but for future generations. We have strong ties to our land and have remained resilient even when our own lands were taken from us. Conflicts over the use and ownership of Native lands are not new. Land has been at the center of virtually every significant interaction between Natives and non-Natives since the earliest days of European contact with the indigenous peoples of North America. By the 19th century, federal Indian land policies divided communal lands among individual tribal members in a proposed attempt to make them into farmers. The result instead was that struggling tribes were further dispossessed of their land. In recent decades, tribes, corporations, and the federal government have fought over control of Native land and resources in contentious protests and legal actions, This would be a good step forward for all people’s involved.

George Cournoyer Jr

Wagner SD

Position: support

Comment:

We never gave up our treaty rights to the river

Lois Weddell

Wagner SD

Position: support

Comment:

I support the waiver of fees for members of the Yankton Sioux Tribe in our local state parks at Pickstown, SD due to the fact that they were built on our tribal lands, our people were displaced due to the construction of that dam and we have never wavered in declaring our right to fish and hunt on our part of the river.

Patti Mattus

Wsgner SD

Position: other

Comment:

No comment text provided.

Misty Bruguier

Lake Andes SD

Position: support

Comment:

I am in support of having entrance fees waived for YST members. It feels good that this idea would even be considered & like with anything nowadays there will either be supportive opinions or rotten ones. I will be more than appreciative or thankful if this passes.

Charles Hopkins

Lake Andes SD

Position: support

Comment:

No comment text provided.

Summer Zephier

Wagner SD

Position: support

Comment:

No comment text provided.

Etraya Olson

Vermillion SD

Position: support

Comment:

No comment text provided.

Ronald Knudsen Jr

Lake Andes SD

Position: other

Comment:

Let us have our water rights free fishing swimming anything to do with the water

---

Elizabeth Hughes

Wagner SD

Position: support

Comment:

No comment text provided.

Jenna Leibel

Wagner SD

Position: oppose

Comment:

No comment text provided.

Julie Weddell

Wagner SD

Position: support

Comment:

As a member of the Yankton Sioux tribe, it has always been important to take my kids to the river and teach them its importance in our culture. Having full, open access would allow all tribal members more of an opportunity to teach our kids and to strengthen our connection with the river.

Sandra Anderson

Wagner SD

Position: support

Comment:

The treaties should be honored.

Ryan Knudsen

Wagner SD

Position: support

Comment:

No comment text provided.

Mike Marshall

Mission SD

Position: support

Comment:

In support of Yankton Sioux tribe members having fees waived

Jaymie Phillips

Rapid City SD

Position: support

Comment:

Yankton Sioux Tribal members fee waived for parks.

Celeste Reynolds

Marty SD

Position: support

Comment:

No comment text provided.

Maria Rivas

Marty SD

Position: support

Comment:

In support of having the fees waived for Yankton sioux members. This is native land we're in support of. We should have never been charged a fee!

Lindsey Morrow

Flandreau SD

Position: support

Comment:

I support having fees waved for all tribal members.

Donis Drappeau

Vermillion SD

Position: support

Comment:

I definitely support waiving fees for Yankton Sioux tribal members, of which I am an enrolled member.

Destiny Holiday

Dante SD

Position: support

Comment:

No comment text provided.

Ernest Neault Lll

Ravinia SD

Position: support

Comment:

I lived in this area all my life and i feel and believe it is only fair for you to let our yankton sioux tribal members use our river with cost out of our pockets .. Do to the fact that we have fought and lost many battles over land and jurisdiction with the government and. Because of that many people lost their land and homes, this river is like a piece of our home our living our way of food and enjoyment .. Why would you make us pay for what was already in our lives before this border war of our land and rivers . just to put my coin in the pocket of the gov.

Nichola Leroy

Wagner SD

Position: support

Comment:

Support Yankton Sioux Tribe having the fee

Bethann Standing Cloud

Marty SD

Position: support

Comment:

My family enjoys going to the river, we always pick up trash after ourselves and other trash that was left. We love fishing and swimming.

Becky Monnens

Hermosa SD

Position: support

Comment:

Support YST members having fees waived. Uphold their treaty rights to the river.

Mary Kurniawan

Rapid City SD

Position: support

Comment:

Support Yankton Sioux Tribal members use of public lands without need of a licence.

Paula Packard

Rapid City SD

Position: support

Comment:

Allowing Yankton Sioux Tribe free access to parks n recreational areas

Andrew Wood

Lake Andes SD

Position: support

Comment:

The free access of the SD Parks and Recreation, would give the Yankton Sioux people, great advantages of recreation, physical, mental enjoyment to share with their children.

Donald Necklace

Wagner SD

Position: other

Comment:

I am a Yankton Sioux member and I feel members should be able to have full access to the parks and recreation at anytime. We should have the fee waived because we never gave up the Treaty Rights to our river. Should include fishing and camping.

Aiyana Jack

Wagner SD

Position: support

Comment:

I am in support of Yankton Sioux Tribe members having the fees waived for fishing and hunting.

Gordena Hare

Lake Andes SD

Position: support

Comment:

In favor of.. thank you.

Cecily Engelhart

Rapid City SD

Position: support

Comment:

In support of Yankton Sioux tribal members having fees waived, as we have never surrendered our treaty rights to access the river. Thank you very much for your consideration!

Lonnie Provost

Wagner SD

Position: support

Comment:

this land was taken from my people to built the dam. The excess land was originally suppose to go back to my people. But of course that didn't happen & now we are required to pay for access to the river. I fully support that tribal members get free access to the river to fish or other recreational activities. Honor our rights. Honor the treaties.

Debbie White

Lake Andes SD

Position: support

Comment:

I feel it would be beneficial to have a lifeguard on duty at specific beaches, such as St. Francis beach, to assist or provide comfort for those less educated on water safety. I also think boats should not be allowed to Shore dock a boat within designated swim areas.

Chelaine Knudsen

Lake Andes SD

Position: support

Comment:

I am strongly in favor of Tribal members gaining free access to the Missouri river to exercise freely the inherent rights such as fishing & swimming as they were/are the original inhabitants of these lands. These lands were forcefully taken from them. Tribal members were removed of their family plots, their ancestral hunting & fishing grounds, and relocated for the use of the Fort Randall Dam and parks. At minimum, Tribal members should be allowed to utilize them for free. At the very minimum they should be allowed to fish & swim in the same river that their ancestors once relied on for survival. At the very minimum, we should give them the access to that connection, free of charge.

Chauncey Clark

Sioux Falls SD

Position: support

Comment:

No comment text provided.

Jason Smith

Lake Andes SD

Position: oppose

Comment:

No comment text provided.

Melissa Sanchez

Wagner SD

Position: support

Comment:

No comment text provided.

Candace Dvorak

Lake Andes SD

Position: support

Comment:

I am in support of Yankton Sioux tribal members gaining free access to the SD state parks and such.

Jessica Little

Marty SD

Position: support

Comment:

I strongly support the use of water rights as they were Ihanktonwan lands before parks were even here. We as Indigenous people have the right to swim, fish and camp on our lands for free.

Tara St Pierre

Wagner SD

Position: support

Comment:

Our lands were taken away from us and we were forced to be on a specified location. If we cannot utilize our own land that was our originally to begin with we shoaled at least get free access to it. Our ancestors, our land and our rights are things that got stripped away from us, allow us to at least not have to pay to access our own land.

Sara Williamson

Wagner SD

Position: support

Comment:

No comment text provided.

Marissa Cournoyer

Brookings SD

Position: support

Comment:

No comment text provided.

Blaine Bruguier

Wagner SD

Position: support

Comment:

No comment text provided.

Ray Diaz

Wagner SD

Position: support

Comment:

It is our land and we should not have to pay for fishing,camping,swimming,boating ,etc.

Justina Zephier

Marty SD

Position: support

Comment:

Its on tribal land why arent we allowed to fish for free or or any recreational activity. Some of us depend on that meat because its expensive in stores.

Olivia Good Cane Milk

Springfield SD

Position: support

Comment:

No comment text provided.

Vikki Eagle Bear

Norris SD

Position: support

Comment:

I strongly support free access to the Missouri River for all state residents.

Ronald Sully

Lake Andes SD

Position: support

Comment:

Please WAIVE the fee for tribal members...

Alexis Rouse

Marty SD

Position: support

Comment:

No comment text provided.

Jewel Shears

Marty SD

Position: support

Comment:

No comment text provided.

Kathleen Bernie

Lawrence KS

Position: support

Comment:

No comment text provided.

Victoria Holiday

Brookings SD

Position: support

Comment:

Being Native American I feel this should be ine of our rights.

Leah Antelope

Lake Andes SD

Position: support

Comment:

No comment text provided.

Victoria Johnson

Carthage SD

Position: support

Comment:

No comment text provided.

Susan Doren

Lake Andes SD

Position: support

Comment:

We should be able to access our own land without fees I remember growing up we didnt have to pay

---

Sherry Hare

Wagner SD

Position: support

Comment:

I love going to the parks in pickstown, I support the free entry for Yankton Sioux tribal members

---

Micki Gallegos

Lake Andes SD

Position: support

Comment:

No comment text provided.

Wayne Frederick

Winner SD

Position: support

Comment:

I support that all Tribally enrolled members have free access to parks areas as is we never relinquished that right and to be charged for it is absurd.

Deonne Tibbetts

Marty SD

Position: support

Comment:

No comment text provided.

Summer Lunderman

White River SD

Position: support

Comment:

Enrolled Tribal Members should be allowed to have free access to all state parks and public lands.

Michael Williams

Piedmont SD

Position: support

Comment:

No comment text provided.

Dustie Arpan

Rapid City SD

Position: support

Comment:

No comment text provided.

Fawn Fields

Wagner SD

Position: support

Comment:

I am in support of Yankton Sioux tribal members having waived fees for use of parks.

Natalie Johner

Winner SD

Position: support

Comment:

With our treaty rights we should have free use and access to Parks and Public Lands.

Eileen Lafferty

Mission SD

Position: other

Comment:

Native Americans be allowed access with no fee at any time.

Brian Tibbetts

Marty SD

Position: support

Comment:

No comment text provided.

Carmelita Means

Mission SD

Position: support

Comment:

No comment text provided.

Whitney Jones

Mission SD

Position: support

Comment:

As An Enrolled Tribal member of the Rosebud Sioux Tribe I say we should not have to pay to utilize these facilities

---

Tanya Haskell

Okreek SD

Position: support

Comment:

I support Native Americans having free access to all state parks and state land.

Michelle Aungie

Wagner SD

Position: support

Comment:

Native Americans should be able to access the rivers and parks. There are willows growing for inipis (sweats) and many medicines for health and wellness, not to mention fishing. Thank you

---

Valene Hawk

Mission SD

Position: support

Comment:

No comment text provided.

Brian Tibbetts

Marty SD

Position: support

Comment:

No comment text provided.

Deonne Tibbetts

Marty SD

Position: support

Comment:

In favor of Tribal members gaining free access to the Missouri river.

Brian Tibbetts

Marty SD

Position: support

Comment:

In favor of Tribal members gaining free access to the Missouri river.

Santana Gravatt

Wagner SD

Position: support

Comment:

I am strongly in favor of tribal members gaining free access to the Missouri River as they are original inhabitants of these lands.

Hillary Hare

Wagner SD

Position: support

Comment:

No comment text provided.

Dave Cournoyer

Wagner SD

Position: support

Comment:

No comment text provided.

Marianne Decora

Mission SD

Position: support

Comment:

No comment text provided.

Lilyann Bechen

Rapid City SD

Position: support

Comment:

I believe native Americans enrolled in any Tribal afiliation should have free access into the parks.

Marisa Joseph

Wagner SD

Position: support

Comment:

As a lifelong resident, and member of the Yankton Sioux Tribe, I feel that free access is highly beneficial for all. We utilize the river in not only recreational/ entertainment ways, but also in conducting ceremonies, etc there. We have a bloodline connection to the river. There is a deep and sad history our previous generations lived through, as the dam was built. We remember the sacredness and connection to our relatives. It's a step forward to acknowledge the history of the area, and to understand the river is not just for fun and enjoyment, it's also a place where we pray.

Shirley Lacourse Jaramillo

Albuquerque NM

Position: support

Comment:

I support free park access for enrolled Tribal members.

Darrell Gunhammer

Wagner SD

Position: support

Comment:

No comment text provided.

Latasha Hrdlicka

Delmont SD

Position: support

Comment:

No comment text provided.

Lionel Rich

Lawrence KS

Position: support

Comment:

No comment text provided.

Maria Gravatt

Mitchell SD

Position: support

Comment:

No comment text provided.

Hehaka Akichita Elk Soldier

Lake Andes SD

Position: support

Comment:

No comment text provided.

Sarah W. Zephier

Marty SD

Position: support

Comment:

I am in favor of Tribal members being able to utilize the Missouri River as they are among the original inhabitants of these specific lands. It is absurd that they should have to pay for something that is their inherent right.

Jonita Zephier

Marty SD

Position: support

Comment:

No comment text provided.

Adrienne Zephier

Marty SD

Position: support

Comment:

Native Americans should be able to access the river for free

Seanne King-Mosley

Canistota SD

Position: support

Comment:

I support the free and unrestricted use of all public parks, camping, fishing, and hunting lands by Native American members in accordance with our treaty rights. There are several Supreme Court cases that already back up these rights. Honor them.

Gregory Drapeau

Marty SD

Position: support

Comment:

No comment text provided.

Tessa St. Pierre

Sioux Falls SD

Position: support

Comment:

No comment text provided.

Allison Renville

Sisseton SD

Position: support

Comment:

This is indian land, we shouldn’t be required to pay to use it.

Lacy Lapointe

Mission SD

Position: support

Comment:

Native Americans should have free access to parks and public lands

---

Jade Arrow

Lake Andes SD

Position: support

Comment:

I feel the natives should get in free to the rivers

Bethany Siers

Wagner SD

Position: support

Comment:

I am a tribal member and the use of these parks and lands were originally here for everyone to use for free. It is only right for tribes to enjoy the parks and land for no cost after the Indigenous lands were taken over and claimed by foreigners.

Geneva Kazena

Pickstown SD

Position: support

Comment:

No comment text provided.

Chris Snow

Omaha NE

Position: support

Comment:

No comment text provided.

Misty Mcbride

Wagner SD

Position: support

Comment:

Please uphold treaty rights and let us have free access to the river.

Teri St. Pierre

Sioux Falls SD

Position: support

Comment:

Although I am Native American, I still oay for my permits because they are not that expensive at all and the second vehicle is at a discount price. I dont mind help funding whatever the money goes to. You guys rock!!

Larry Archambeau

Chamberlain SD

Position: support

Comment:

I strongly support the proposed rule change allowing Yankton Sioux Tribal members use of there land, without fee or licensing, taken for the creation of the Ft. Randall Dam and reservoir.

Jaime Young

Rapid City SD

Position: support

Comment:

No comment text provided.

Lyla Dion

Greenwood SD

Position: support

Comment:

No comment text provided.

Darius Honomichl

Chamberlain SD

Position: support

Comment:

No comment text provided.

Heather Miller

Mitchell SD

Position: support

Comment:

No comment text provided.

Darci Bultje

Lake Andes SD

Position: other

Comment:

.

Isabel Bernie

Lake Andes SD

Position: support

Comment:

No comment text provided.

Jalen Bernie

Wagner SD

Position: other

Comment:

I think the Yankton Sioux tribal members should have free access to the river for recreational and fishing/hunting purposes. The river was not only a route for travel but also ceremonial purposes and food.

Tara Roaneagle

Lakeandes SD

Position: support

Comment:

No comment text provided.

Mara Spitzer

Spokane WA

Position: oppose

Comment:

I support parks being open and free and oppose shutting parks to public

---

Bryan Joseph

Wagner SD

Position: support

Comment:

No comment text provided.

Jennifer Noteboom

Pickstown SD

Position: support

Comment:

I support the waiving of usage fees for Yankton Sioux Tribal Members.

Marisa Cummings

Sioux City IA

Position: support

Comment:

Tribal members have the right to harvest and practice ceremonies on their historical and treaty lands. The state of South Dakota exists as a result of treaties. Therefore, you must honor them.

Patty Blagburn

Sacramento CA

Position: support

Comment:

Support so me and my family are able to use without any cost to them or me. Please consider opening the parks and land for all to use. Should be a right without a cost. Please consider and support.

Jennifer Veilleux

Lake Andes SD

Position: support

Comment:

I am writing in support of free Tribal Enrolled Access to all State Parks - and you should consider reparations. Charging any enrolled member a fee to enter their homelands protected by treaty is a violation of Federal Law.

Gail Hubbeling

Greenwood SD

Position: support

Comment:

Because of violations of Treaties with the Yankton Sioux/Ihanktonwan Dakota and continued violations of these treaties, this is one step of ratifying what the United States really owes our People, we were promised free electricity for our People while they were being flooded out of their homes, and to this day we have never received free electricity, the US goverenment, i.e. the U.S. Corps. of Engineers has never honored our Treaties, once the lands at Pickstown were done in creating the dam, it was to be given back to the Ihanktonwan Nation/Yankton Sioux Tribe but, instead of honoring the treaty, the courts decided to give the lands to the so called city/town of Pickstown. Our People's remains were found along the shores of White Swan, and were desecrated. Imagine, the government said, we're going to take your home and there isn't anything you can do about it, even though there is a treaty/legal document saying this is your home, oh and by the way, if you don't comply with this order, we are going to take your children and if you don't give your children up, we are going to withhold the funds and annuities we promised you in a legal document called a "TREAT"

Savannah Fischer

Mitchell SD

Position: support

Comment:

No comment text provided.

Richard Bruguier

Marty SD

Position: support

Comment:

No comment text provided.

Tammy Valdez

Rapid City SD

Position: support

Comment:

Tribal members should have free access to parks. We still retain all rights to useage of waterways and hunting and fishing. GFP should adhere to our right of useage.

Denise Brooks

Lake Andes SD

Position: support

Comment:

I support Tribal members getting park admission free. When the Corp of Engineers built the dam. Many tribal people we’re displaced. The burial mounds and cemeteries we’re supposed to be moved we all know that didn’t work out so well. Let the Non Indian people that were living there in also.

Marcella Uribe

Wagner SD

Position: support

Comment:

No comment text provided.

Becca Redlightning

Marty SD

Position: support

Comment:

My sisters and I pick up the trash whenever we go swimming or fishing. We respect the land.

Patricia Stricker

Marty SD

Position: support

Comment:

Clean place...

Candace Jeanotte

Wahpeton ND

Position: support

Comment:

I support the efforts of free access to the Missouri river for native communities sharing the boundaries, because the Picksloane Project did not consider native communities to begin with, as they flooded the native communities to benefit others.

Jay Maynard

Lake Andes SD

Position: support

Comment:

I support the measure to give Yankton Sioux Tribal members free access to the local park land. I rarely use my passes but each year I purchase at least 2 if not more passes to access the river for those times my children wish to go to the river, or when relatives who are visiting want to go.
Although I would propose a slight raise in Out of State passes for the privilege of using the land , I would be willing to pay even a little more for my own passes to give YST members the right to access land that was historically under their stewardship to begin with.

Sandra Patterson

Wagner SD

Position: support

Comment:

No comment text provided.

Sarah Benton

Lake Andes SD

Position: other

Comment:

Natives Americans have every right.

Kymmm Gresset

Grangeville ID

Position: support

Comment:

I am a former resident of the Lake Andes community and a 6th generation South Dakotan. I would like to offer my support for the finalization of the proposal to exempt enrolled Yankton Sioux Tribal members and their families from the purchase of park entrance licenses at North Point Recreation Area, Fort Randall South Shore Recreation Area, Randall Creek Recreation Area and Fort Randall Spillway Lakeside Use Area. This exemption provides access to traditional use areas by the YST and provides increased outdoor recreation opportunities that were previously free in the area. I would like to thank the commission for unanimously supporting this proposal.

Although not part of this proposal, I would also urge the commission to consider a different fee structure for South Dakota residents for the annual park pass such as that in Idaho where it is $10 a year for every registered vehicle. Further, consideration to residents of local communities for fee free access days (or fee free passes) would ensure that residents of local communities have reasonable access to public lands that is not an economic burden within their community. Access to these lands were previously fee free for everyone's enjoyment. I realize that fees help support maintenance and upkeep of these lands, but fees should not be an impediment in the community for simple enjoyment such as swimming, picnicking with your family and other outdoor recreation opportunities.

Mark Soukup

Wagner SD

Position: other

Comment:

No comment text provided.

Charon Asetoyer

Lake Andes SD

Position: support

Comment:

I support the free use/access to the Missouri River for the Yankton Sioux Tribal members. The lands were part of the original Treaty and the Government should honor those agreements. Treaties are the highest law of the land and should be followed not violated. As just seen in the Supreme Court ruling "reaffirming" sovereignty, Justice Neil Gorsuch said, "we hold the government to its word". So should the government in this case as well.

Sarah Benton

Lake Andes SD

Position: other

Comment:

No comment text provided.

Kari Simpson

Rapid City SD

Position: other

Comment:

No comment text provided.

Raven Tiger

Sioux Falls SD

Position: support

Comment:

No comment text provided.

Amy Arrow

Ravinia SD

Position: support

Comment:

No comment text provided.

Jodi Zephier

Wagner SD

Position: support

Comment:

I am in Full Support of Yankton Sioux Tribal members to have access to parks without paying fees and feel it is within our original treaty rights to do.

Loren Lyles

Lawrence KS

Position: support

Comment:

I support waiving the fee for Yankton Sioux Tribal members to have full access to the Missouri River for recreational use and fishing.

Christopher French

Wagner SD

Position: support

Comment:

No comment text provided.

Deshayla Heth

Pickstown SD

Position: support

Comment:

As a member of the Yankton Sioux Tribe, I strongly stand with allowing tribal members to freely enter the parks and beaches located on our reservation. The beaches are where we like to enjoy our children's birthday parties. A lot of our tribal members go fishing to provide meals for their families. Some are restricted of doing so because they can't afford to pay the fee each time they want to cast a line into the river. Please give us all an opportunity to enjoy the river, and to fish on our very own Ihanktowan lands. Thank you.

Clement Zephier

Marty SD

Position: other

Comment:

It is my position that we as Dakota (native) people should have free use of public parks in America. This position is based upon treaty law and historical land use.

Simone Cournoyer

Wagner SD

Position: support

Comment:

No comment text provided.

Pamela Aungie

Marty SD

Position: support

Comment:

It would be nice to take grand kids down to fish and to just listen to the water and trees when the wind blows.
#STAYINGCONNECTED

Victoria Flying Hawk

Mission SD

Position: support

Comment:

No comment text provided.

Solana Fischer

Wagner SD

Position: support

Comment:

We have every right...

Florence Hare

Lake Andes SD

Position: support

Comment:

No comment text provided.

Amelia Knife

Delmont SD

Position: support

Comment:

No comment text provided.

Isabelle Knife

Delmont SD

Position: support

Comment:

No comment text provided.

Vanessa Hopkins

Marty SD

Position: support

Comment:

Natives really preparing to take all our lands back. Just trying to keep peace

---

Wanbdi Fischer

Mitchell SD

Position: support

Comment:

No comment text provided.

Lashawn Medicine Horn

Lake Andes SD

Position: support

Comment:

No comment text provided.

Cleo Rouse

Mitchell SD

Position: oppose

Comment:

Save our water and wildlife!

Rachel Fischer

Mitchell SD

Position: support

Comment:

No comment text provided.

Lisa Miller

Wagner SD

Position: support

Comment:

I believe the parks and areas along the river in question are within the reservation boundries and any tribal member should be allowed free access. Also, it should not be required for anyone with a tribal ID to have a fishing license as it is an inherent right to provide food and sustenance in order to survive. I know similar areas along the Lower Brule and Crow Creek Sioux tribes, indigenous persons are not required to pay a fee to use river access areas and are not required to have a license to fish. I support indigenous peoples free access and use based on sovereign and inherent rights.

Kenneth St. Pierre

Wagner SD

Position: support

Comment:

No comment text provided.

Tina Marks

Wagner SD

Position: support

Comment:

I think it’s a great idea. Thank you GFP for the consideration!

Anna Perez Selwyn

Sioux Falls SD

Position: support

Comment:

Yankton Sioux tribe land

Pearl Smith

Lake Andes SD

Position: support

Comment:

No comment text provided.

Jimmy Samchez

Wagner SD

Position: support

Comment:

Support.

Theodore Kranig

Yankton SD

Position: support

Comment:

No comment text provided.

Michele Costello

Wagner SD

Position: support

Comment:

I agree that we should get free acess to the river.

Marcy Joseph

Marty SD

Position: support

Comment:

No comment text provided.

Daniel Archambeau

Lake Andes SD

Position: support

Comment:

No comment text provided.

Kim F Hawk

Lake Andes SD

Position: support

Comment:

The land and Missouri River belong to our people, so it's our right to visit the river as needed. We will prosper!!!

Narcisse Shields

Marty SD

Position: support

Comment:

Considering the fact that the native people have been since the beginning. Why would we not have access to the lands we hunted, the river we drank, bathed and fished from for generations upon generations ago.

Carly Neal

Kenneth MN

Position: support

Comment:

Respect

Synona Drapeaux

Rapid City SD

Position: support

Comment:

YST RIVER ACCESS

Jamie Archambeau

Kenneth MN

Position: support

Comment:

Respect

William Turner

Wagner SD

Position: support

Comment:

Respect

Heather Rouse

Wagner SD

Position: support

Comment:

We as people of the Ihanktonwan are entitled to free use of OUR MNI SOSE!! We are the people of the Missouri River! Wasicus took everything the least they can do is give us this back! Water is life Mni Wiconi as a Ihanktonwan I'm in full support of getting free PASSES!!!

Karl Archambeau

Sioux Falls SD

Position: support

Comment:

Rights

Roseanne Cooke

Sioux Falls SD

Position: support

Comment:

Rights

Deaja Tilley

Lake Andes SD

Position: other

Comment:

Native people should swim for free for it is our land

Gail Holiday

Wagner SD

Position: support

Comment:

Don’t kno if u can vote twice but if u can’t don’t remember if I did

---

Shylah Medicine Horn

Brookings SD

Position: support

Comment:

As the Rivers and Lakes are a part of our Natural habitats, I believe it is only right to let us as Native Americans have free access to our waters. This is something that should never have been taken away from us in the first place. It is bad enough that our Ancestors grave cites were disrespected and there are now park buildings built over them.

Cheyanne Quinn

Sisseton SD

Position: support

Comment:

Tribal Members should be able to have free access to all state parks and state lands to fish-hunt-swim.

Cora Janis

Pine Ridge SD

Position: support

Comment:

No comment text provided.

Cleo Rouse

Mitchell SD

Position: support

Comment:

I'm for free swimming and camping!

Sharon Drapeau

Lake Andes SD

Position: support

Comment:

I believe that native Americans should have full free access to the river and it's park's to use for ceremonies, prayers, offerings, celebrations as well as hunting/fishing which are essential to our way of life.

Andrew Fobb

Marty SD

Position: support

Comment:

No comment text provided.

Kimberlee Selwyn

Wagner SD

Position: support

Comment:

Be nice to be an enrolled member and be able to access parks free of fees.

Andrea Fischer

Wagner SD

Position: support

Comment:

YST tribal members should have free access to the river. They've been here since the beginning.

Dayla Picotte

Lake Andes SD

Position: support

Comment:

I support the request for free swimming access for the Yankton Sioux Tribe. It is a way of life and ceremony that we have been doing since the beginning of time. It isn't just a place to swim. It is a healing place, not only for our tribe but everyone. Water is life and we have always respected that connection and relationship.

Pidamiya
Thank you

Dawn King

Pickstown SD

Position: support

Comment:

No comment text provided.

Wade Nelson

Brookings SD

Position: support

Comment:

No comment text provided.

Laurel Long

Sioux Falls SC

Position: support

Comment:

No comment text provided.

Pamela Redlightning

Wagner SD

Position: support

Comment:

I support the YST endeavor for free access swimming

Savannah Valdez

Vermillion SD

Position: support

Comment:

I support the Yankton Sioux Tribes endeavors for free access to the rivers and parks. It is their way of life and they rely on the land and rivers and take care of the land and rivers.

Angele Blaine

Vermillion SD

Position: support

Comment:

Please waive the fees for the Yankton Sioux Tribe.

Kenneth Honomichl

Wagner SD

Position: support

Comment:

I don't believe the State of South Dakota owners the Taken areas on the Yankton Sioux Reservation. I would like the State recognize that this area is saturated with burials and some ancient mounds that were not demolish like the ones in the Picktown town site were. I hope that the State has the moral conviction to right a wrong. You local governments and business people will eventually put a monetary value on these areas and as always destroy the natural beauty of what remains. I would at least request the State to return the Whit Swan area and the Area between St Francis Bay and the Prarie Dog Bay Area. I would like a nature preserve established with on limited cularal activity and primitively camping allowed. Everyone can still access the current areas.

Georgia Holiday

Lake Andes SD

Position: support

Comment:

No comment text provided.

Byron Standing Could Sr

Marty SD

Position: support

Comment:

We signed treaties for land and mineral rights and still don’t have our treaty land rights to fish swim that’s the least you could do if your not going to honor all our rights

---

Holly Song Hawk

Sioux Falls SD

Position: support

Comment:

No comment text provided.

Tregan Rouse

Lake Andes SD

Position: support

Comment:

I believe these are our inherent rights as American Indians to go to these public lands and parks because a lot of them are considered sacred sites and we conduct ceremonies there. The 1851 treaty of fort Laramie defines our boundaries and most of these lads are within the said boundaries. In my opinion everyone should be allowed to access these public lands for free and find a different way to pay for the expenses needed to maintain and operate the parks

---

Eliza Weddell

Wagner SD

Position: support

Comment:

No comment text provided.

Tila Anderson

Wagner SD

Position: support

Comment:

I think it is a great idea to give the Tribal members free access to something that was once theirs to begin with. It shouldn't even be a question.

Hannah Arrow

Ravinia SD

Position: support

Comment:

No comment text provided.

Arlette Rodriguez

Huron SD

Position: support

Comment:

I'm an enrolled member and must have free access to these areas for my tribal members and our families. Your understanding is very much appreciated.

Monica Weddell

Wagner SD

Position: support

Comment:

No comment text provided.

Hayli Gray

Lake Andes SD

Position: support

Comment:

No comment text provided.

Ward Zephier

Wagner SD

Position: support

Comment:

No comment text provided.

Justin Songhawk

Marty SD

Position: support

Comment:

No comment text provided.

Franki Espinoza

Marty SD

Position: support

Comment:

I'm thankful that this issue is bringing some folks' true colors & ugly natures out into the light for everyone to see. We see you!

Morissia Holiday

Marty SD

Position: support

Comment:

First off there was a treaty and in it was the agreement that tribal members would always have access to hunting ,fishing,ect. Second the land along parts of the river that is now fort Randal was tribal land but was taken when the damn was built. Without an agreement is my understanding.

Calvin Wright

Wagner SD

Position: support

Comment:

No comment text provided.

Terry Bruguier Sr.

Lake Andes SD

Position: support

Comment:

No comment text provided.

Giselle Weddell

Wagner SD

Position: support

Comment:

No comment text provided.

David Tolliver

Wagner SD

Position: oppose

Comment:

No comment text provided.

Evaline Arrow

Fort Pierre SD

Position: support

Comment:

No comment text provided.

Marquel Holiday

Wagner SD

Position: support

Comment:

Free access for Native Americans to use the parks and rec. areas for free will be good for natives, as we have always used these areas before there was fees.

Paul Gravatt

Lake SD

Position: support

Comment:

I strongly support yankton Sioux tribal members having free access any and all parks

---

Mandi Knudsen

Lake Andes SD

Position: support

Comment:

Free access is just a BABY step in the right direction!

Stephanie Cournoyer

Marty SD

Position: support

Comment:

No comment text provided.

Monica Drapeau

South Sioux City NE

Position: support

Comment:

No comment text provided.

Shannon O’Connor

Sioux Falls SD

Position: support

Comment:

As a member of the Yankton Sioux Tribe I believe we should have a right to use it. We should have never been charged a fee because Of our treaty rights.

Marie Picotte

Wagner SD

Position: support

Comment:

No comment text provided.

Brent Cooke Jr

Wagner SD

Position: support

Comment:

No comment text provided.

Allishia Abdo

Lake Andes SD

Position: support

Comment:

No comment text provided.

Larry Abdo Iii

Wagner SD

Position: support

Comment:

No comment text provided.

Alexander Zephier Iii

Wagner SD

Position: support

Comment:

No comment text provided.

Arabella Zephier

Wagner SD

Position: support

Comment:

No comment text provided.

Will Bennett

Lake Andes SD

Position: support

Comment:

I believe that there should be access to all state parks by tribal members without fees. In our area those were their traditional homes and areas, not to mention the treaties signed that granted use rights to the peoples as long as they flow. Furthermore I believe that the county you hold residency you should have free access to the state parks of that county. We provide support and aid to those areas while getting little in return. The parks should be free to the people and I am happy they are starting with the tribe and hope the program expands to all parks and all residents.

Wileen Rouse

Wagner SD

Position: support

Comment:

No comment text provided.

Janell Garcia

Lake Andes SD

Position: support

Comment:

I fully support the proposal to waive park access fees for Ihanktonwan Tribal members. It's ludicrous to me that Tribal members gave to pay to access their own land and river, especially since these are already rights guaranteed through treaties!

Kandi World Turner

Lake Andes SD

Position: support

Comment:

Supporting the ability of Yankton Sioux Tribe members and their families to access the areas of their own river and lands without paying the State to do so.

Minutes of the Game, Fish, and Parks Commission
July 29, 2020

Chairman Gary Jensen called the meeting to order at 11:00 a.m. CT at via teleconference. Commissioners Gary Jensen, Jon Locken, Russell Olson, Douglas Sharp, Charles Spring, and Robert Whitmyre were present when the roll was called. It was noted that a quorum was present. Secretary Kelly Hepler was present along with 34 staff and public.

Conflict of Interest Disclosure

Chair Jensen called for conflicts of interest to be disclosed. None were presented.

Jon Kotilnek, senior staff attorney, explained the reason for the special meeting and the requirements.

Finalize Emergency Amendment to Containment Water Rules to Include Pickerel, Waubay, North Rush, South Rush, and Minnewasta Lakes

Tom Kirschenmann, wildlife division director, presented the emergency rule change that would allow Game, Fish and Parks to designate Pickerel, Waubay, North Rush, South Rush, and Minnewasta Lakes as containment waters thus requiring boaters to follow decontamination rules as laid out in ARSD 41:10:04:08.

Rosie Smith, South Dakota Glacial Lakes and Prairies, executive director, expressed wanting to help in any way to support partner agencies.

Dan Loveland, Pickerel Lake Conservancy, vice president, spoke to express support to add pickerel lake as a containment water. Continue to protect these resources and work with GFP and other parties to protect Pickerel Lake and other lakes in the region.

Whitmyre asked about violations and noted it is more prevalent for fisherman to be cognizant of the water in their live wells. Previously the issue was recreators who were not fisherman. Is this still the case?

Kirschenmann explained primary customers like anglers who are in our licensing system are more connected with GFP and receive messaging while we continue to reach out to other recreators and continue to educate all recreators.

Kevin Robling, deputy secretary, said staff have inspected over 6,000 watercraft to date with 145 tickets written.

Locken said lake Lamour in ND recently found zebra mussel and asked if that is something, we will need to be aware as it is on the James River drainage

John Lott, fisheries chief, explained that because the James has a low rate of flow it would spread more slowly than it would in other rivers. He also stated it doesn’t flow into the glacial lakes fisheries.

Locken asked how many live mussels have been found during inspections?

Lott responded he is not aware of any adults found during inspections.

Jensen asked the purpose of inspections, what are the types of citations and what are the costs?

Blake Swanson, conservation officer, provided a summary of how inspections are going and that the majority of violations deal with plugs in boats and a few instances where people do not stop at the inspection stations. The need exists to continue to inform and educate recreators of the AIS rules.

Olson inquired how long a lake would remain on the list.

Kirschenmann explained it would remain on the list until the Commission took action to remove it due to the status of the body of water.

Motion by Locken, second by Whitmyre TO APPROVE THE AMENDMENT OF AQUATIC INVASIVE SPECIES RULES 41:10:04:06 TO INCLUDE PICKEREL, WAUBAY, NORTH RUSH, SOUTH RUSH, AND MINNEWASTA LAKES IN THE CONTAINMENT WATERS. Roll call vote: Locken – yes; Olson- yes; Whitmyre - yes; Sharp- yes; Spring – yes; Jensen-yes. Motion passes with 6 yes votes and 0 no vote.

Adjourn

The meeting adjourned at 11:30 a.m.

Respectfully Submitted,

Kelly R Hepler

Kelly R. Hepler, Department Secretary

PETITION TO LIST THE GREATER SAGE-GROUSE
Centrocercus urophasianus
UNDER THE SOUTH DAKOTA ENDANGERED SPECIES ACT

Presented by

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PETITION FOR RULEMAKING

This petition for rulemaking is submitted pursuant to SDCL 1-26-13.

Western Watersheds Project, Prairie Hills Audubon Society of western South Dakota, Erik Molvar, and Nancy Hilding submit this petition. Nancy Hilding is a resident of Meade County, South Dakota. Erik Molvar is a resident of Laramie, Wyoming. Prairie Hills Audubon Society is a non-profit corporation registered in South Dakota. Western Watersheds Project is a nonprofit corporation registered in Hailey, Idaho. As such, both organizations are persons by South Dakota law and Federal Supreme Court decisions.

We request that the South Dakota Game, Fish and Parks Commission amend South Dakota administrative rule 41:10:02:02 to add the greater sage grouse to South Dakota's list of threatened bird species. Below find the rule with the proposed amendment inserted as item number (4):

41:10:02:02. List of threatened birds. Birds classified as threatened in the state are as follows:

(1) Osprey, ***Pandion haliaetus***;

(2) Piping plover, ***Charadrius melodus***;

(3) American dipper, ***Cinclus mexicanus.***

(4) Greater Sage Grouse, ***Centrocercus urophasianus***

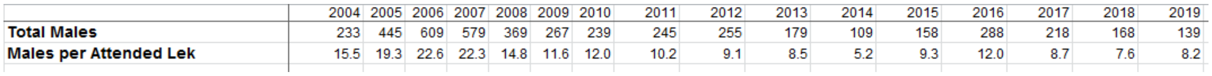
STATEMENT OF REASONS

Western Watersheds Project and Prairie Hills Audubon Society hereby petition the South Dakota Game, Fish, and Parks Commission to list the greater sage-grouse (*Centrocercus urophasianus*) as an endangered species under the South Dakota Endangered Species Law. (Chapter 34A-8 of South Dakota codified laws). SDCL 34A-8-4 gives the authority to list species to the Commission.

The greater sage-grouse has been declining in numbers for many years and is in imminent danger of extirpation across its entire range in South Dakota. Sage-grouse may be already extirpated in southwestern South Dakota, although there is reason to believe that birds may still occur in this part of the state. Current conservation measures currently in place are failing to address the causes of the decline or to compensate for habitat degradation by habitat improvement elsewhere, as evidenced by the continued decline of the species.

POPULATION STATUS

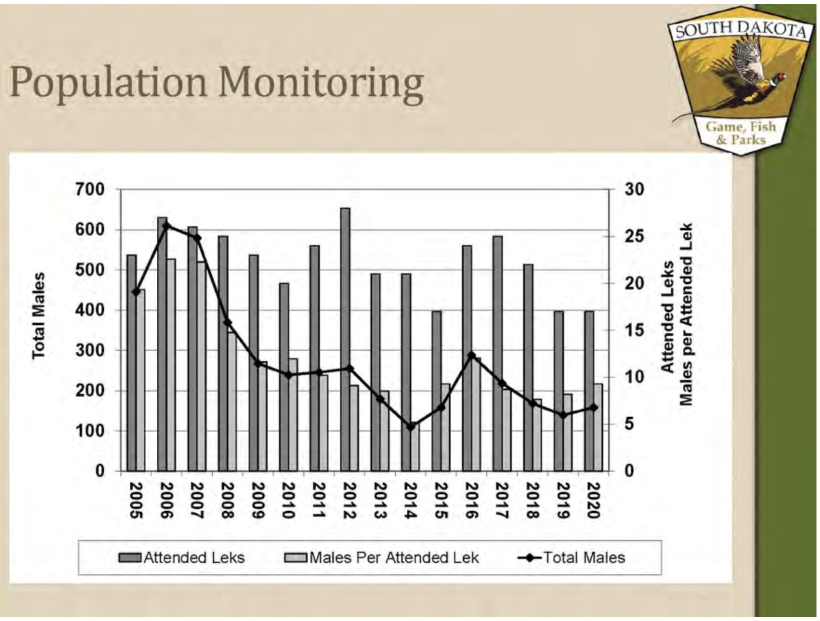
South Dakota’s statewide cumulative count of sage-grouse descended to a historic low in 2019, down to 139 strutting males. This represents a 77.2% decline from the male count at the last major peak, in 2006. In 2020, the cumulative number of strutting males stood at 158. Lek count trends, based on South Dakota Fish, Wildlife, and Parks data, follow:



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total Males	233	445	609	579	369	267	239	245	255	179	109	158	288	218	168	139
Males per Attended Lek	15.5	19.3	22.6	22.3	14.8	11.6	12.0	10.2	9.1	8.5	5.2	9.3	12.0	8.7	7.6	8.2

Conservatively assuming a sex ratio of two females per male (*sensu* Braun et al. 2015), and a conservative census success rate for strutting males of 75 percent (as demonstrated by Fremgen et al. 2016 and Coates et al. 2019, high male counts represent between 77% and 93% of males in each population) to yield the largest scientifically defensible figure, 158 strutting males can be extrapolated to a total population size of 632 birds.

The minimum viable population threshold for species generally is 5,000 individuals (Traill et al. 2010), and the 5,000-bird minimum viable population threshold has been established for sage-grouse in particular (Aldridge and Brigham 2003). Because the sage-grouse is a lekking species, in which one or two males typically do all of the breeding at a given lek, the genetic contributions of the sexes are skewed. Between the low total population, its danger of isolation from sage-grouse populations in other states, and this skewed ratio of breeding birds, the current total sage-grouse population in South Dakota is too small to prevent inbreeding and the genetic problems (birth defects, inbreeding depression reducing the number of viable offspring) that go with it.



Population Monitoring

Garton (2015) performed the most current population viability analysis for the Dakotas population (encompassing North and South Dakota and small portions of Montana and Wyoming), and found a 72.5% probability that the overall multi-state population would decline below 50 strutting males for this population in 100 years, and a 21.5% chance of declining below

20 males by 2045. In effect, the South Dakota sage-grouse population may already be trapped within an extinction vortex.

According to the 2014 South Dakota Sage Grouse Plan (SDGFP 2014), greater sage-grouse habitat is currently found predominantly on private lands:

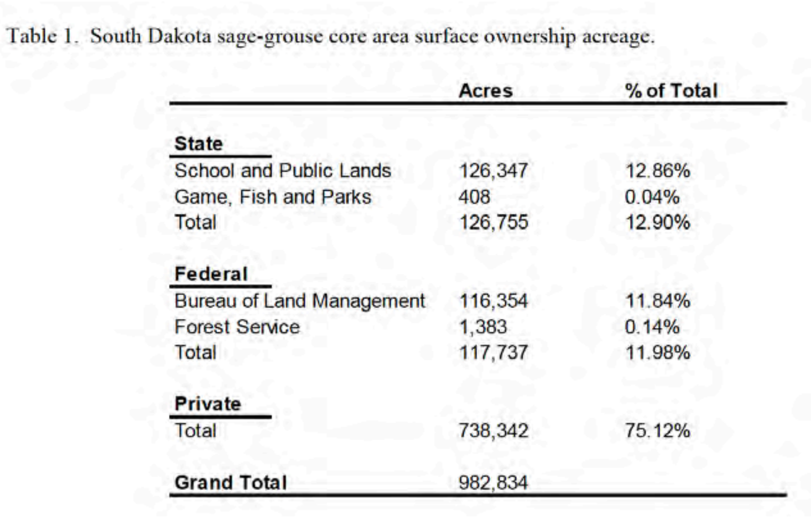
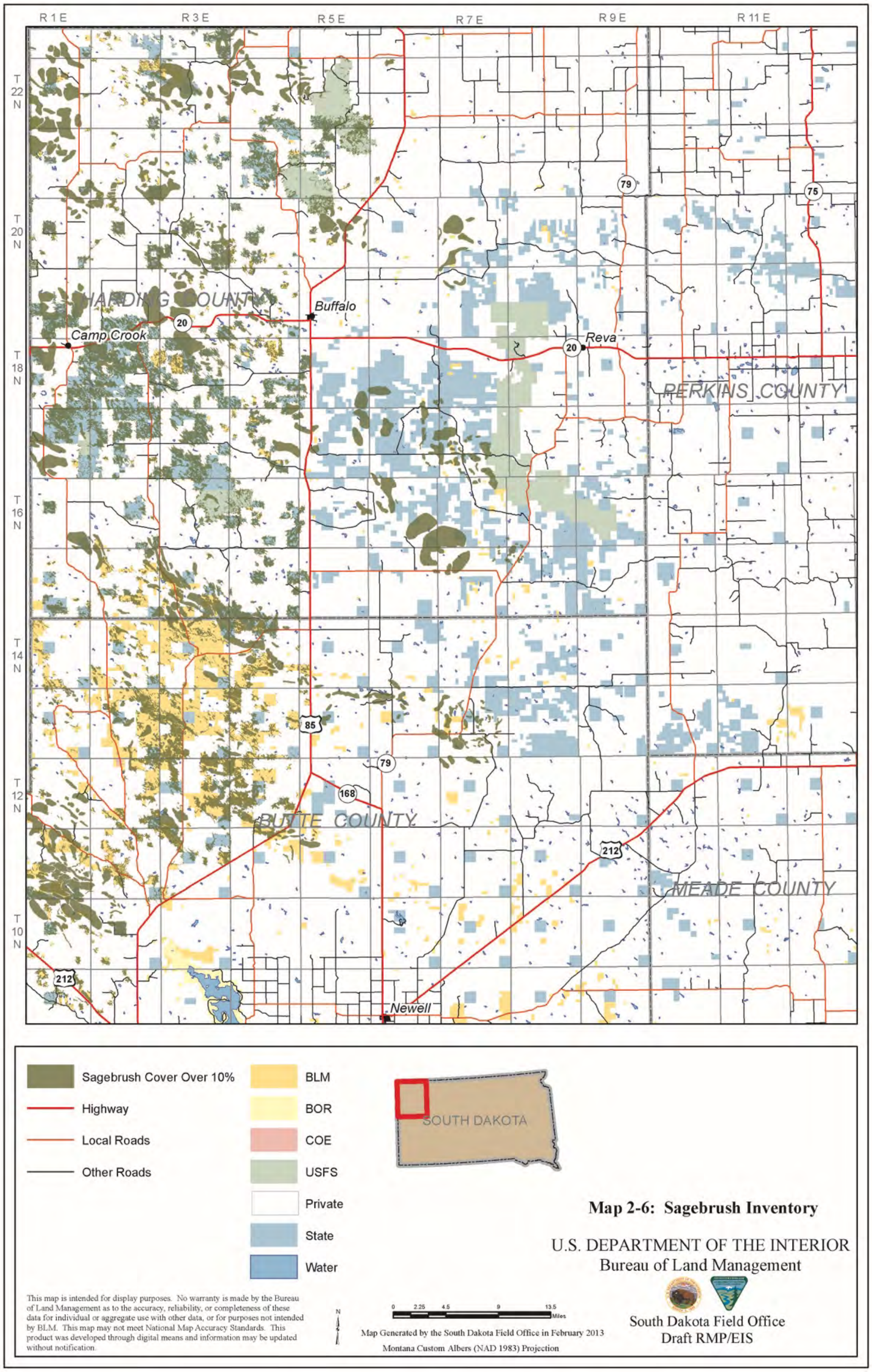


Table 1. South Dakota sage-grouse core area surface ownership acreage.

	Acres	% of Total
State		
School and Public Lands	126,347	12.86%
Game, Fish and Parks	408	0.04%
Total	126,755	12.90%
Federal		
Bureau of Land Management	116,354	11.84%
Forest Service	1,383	0.14%
Total	117,737	11.98%
Private		
Total	738,342	75.12%
Grand Total	982,834	

The Bureau of Land Management mapped sage-grouse habitats in northwestern South Dakota only, in the following map from their 2013 Greater Sage-grouse Resource Management Plan Amendment Draft EIS.



Map 2-6: Sagebrush Inventory

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Land Management

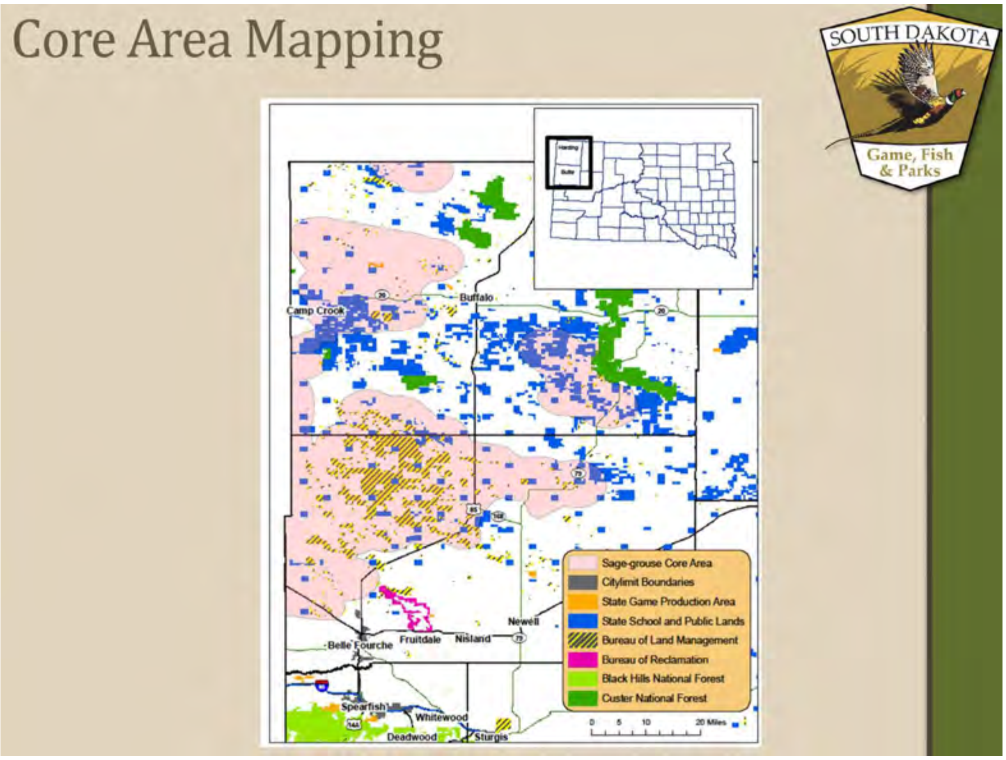
South Dakota Field Office
Draft RMP/EIS

Map Generated by the South Dakota Field Office in February 2013
Montana Custom Albers (NAD 1983) Projection

This map is intended for display purposes. No warranty is made by the Bureau of Land Management as to the accuracy, reliability, or completeness of these data for individual or aggregate use with other data, or for purposes not intended by BLM. This map may not meet National Map Accuracy Standards. This product was developed through digital means and information may be updated without notification.

THREATS TO THE SURVIVAL OF THE SPECIES

South Dakota's surviving sage-grouse population in South Dakota occupies the northwestern corner of the state, a sparsely populated area with limited industrial and residential development. Nonetheless, human activity has rendered habitat changes sufficient to initiate unnatural declines of sage-grouse in South Dakota which continue to the present day. The following is a brief summary of known causes of sage-grouse habitat degradation that have been linked to population declines based on the best available scientific information.


Core Area Mapping

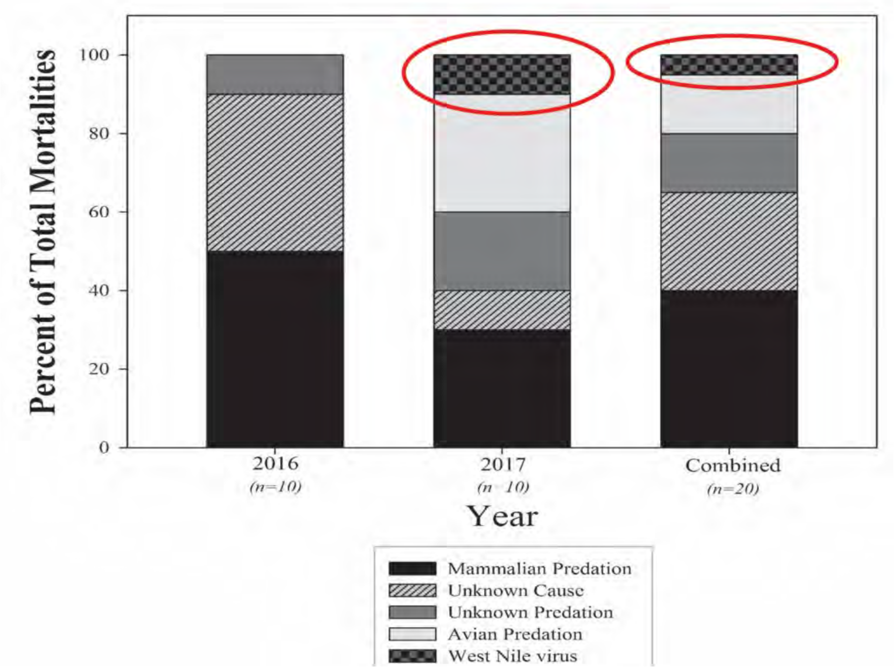
Sagebrush buds and leaves are the dominant proportion of their diets, and they use sagebrush shrubs as cover to site their nests. Crop farming (including operations producing hay and alfalfa for livestock) directly converts the sagebrush/grassland habitats that sage-grouse require to survive and reproduce into sagebrush-free non-habitat. In addition, the common pesticides commonly aerially sprayed on cropfields can directly poison sage-grouse directly (Blus et al. 1989).

Livestock grazing is the most widespread, and likely most significant, threat to sage-grouse survival in South Dakota. The best available science has established that at least 7 inches (18 cm) of residual stubble height needs to be provided in nesting and brood-rearing habitats throughout their season of use. According to Gregg et al. (1994: 165), "Land management practices that decrease tall grass and medium height shrub cover at potential nest sites may be detrimental to sage-grouse populations because of increased nest predation.... Grazing of tall grasses to <18 cm [7 inches] would decrease their value for nest concealment.... Management activities should allow for maintenance of tall, residual grasses or, where necessary, restoration of grass cover within these stands." Hagen et al. (2007) analyzed all extant scientific datasets up to that time and concluded that the 7-inch threshold was the threshold below which significant impacts to sage-grouse occurred (*see also* Herman-Brunson et al. 2009). The exception to this 7-inch rule is found in the mixed-grass prairies of the Dakotas, where sparser cover from sagebrush and greater potential for tall grass have led to a recognition that a 26-cm (10.2-inch) stubble height standard is warranted (Kaczor 2008, Kaczor et al. 2011). Foster et al. (2014) found that livestock grazing could be compatible with maintaining sage-grouse populations, but notably stubble heights they observed averaged more than 18 cm (7 inches) during all three years of their study, and averaged more than 10.2 inches in two of the three years of the study.

Doherty et al. (2014) found a similar relationship between grass height and nest success in northeast Wyoming and south-central Montana but did not prescribe a recommended grass height. While there are those who have attempted to cast doubt on the necessity of maintaining grass heights to provide sage-grouse hiding cover, based on timing differences in grass height measurements between failed nests and successful nests, these concerns have been refuted for Wyoming. The significance of the Doherty et al. (2014) study was explicitly tested by Smith et al. (2018a), who confirmed that grass height **continued to have a significant effect** on nest success for this Wyoming study after correction factors were applied to the data. Smith et al. (2018b) found little effect of livestock grazing on sage-grouse nest success in Montana, but the grass heights in grazed pastures differed little from ungrazed controls in this study, indicating an unusually light level of livestock grazing in sage-grouse habitat. This outcome supports management for very light livestock grazing. As yet, there has been no mechanism in South Dakota to require that at least 10.2 inches of residual grass behind to provide adequate hiding cover for sage-grouse, and this lack is likely the primary reason that these birds have been declining, and continue to decline.

Barbed-wire fencing presents multiple serious impacts for sage-grouse. Stevens et al. (2013) found that fence collisions are a significant cause of grouse mortality, with fences on flat areas near leks posing a particularly high risk for causing sage-grouse fatalities (*see also* Van Lanen et al. 2017). Christiansen (2009) documented 146 sage-grouse fence collisions and mortalities along a 4.7-mile length of barbed-wire fence in western Wyoming over a 2½-year period, and found that marking fences reduced collisions by only 61%, such that 39% of the collision rate on unmarked fences continues to occur on marked fence sections. All three of these studies documented that fence markers could reduce collision mortality, but marked fences were still the cause of major amounts of collision mortality under all three studies. Unused fences should be removed, and their rights-of-way (as applicable) withdrawn. Removal of this existing fencing would decrease potential raptor perching and subsequently the indirect impacts of raptors preying on grouse as and other prey species. The removal of fencing could also eliminate any direct mortality due to grouse colliding with problem fences. However, there is currently an absence of regulations that require or even incentivize the removal of the fences that are collision hazards for grouse.

Stock watering reservoirs and coalbed methane retention ponds provide breeding habitat for mosquitoes that carry West Nile virus. West Nile virus mortalities have been confirmed in South Dakota (Kaczor 2008), as recently as 2017 (T. Runia, SDFWP, pers. comm.). Documented West Nile deaths in South Dakota are as follows:



Source: Travis Runia presentation, August 20, 2020.[1] West Nile has been implicated in major sage-grouse population declines in the Powder River Basin (Doherty 2007, Walker et al. 2007a, Walker and Naugle 2011), and presents an ongoing threat to sage-grouse (Taylor et al. 2012), which have demonstrated little to no ability to develop a natural immunity to this non-native disease (Walker et al. 2007b). Accordingly, new stock watering and fluid mineral production reservoirs should be prohibited in Core Areas (BLM Priority Habitat Management Areas), and existing manmade reservoirs should be breached and eliminated to the extent possible.

There is a limited history of past oil and gas development in northwest South Dakota, although there currently are few active oil and gas wells in this area.[2] Holloran (2005) conducted the seminal study (funded by the oil and gas industry), and it found significant negative impacts from both access roads (even when shielded from the lek by intervening topography) and individual producing (post-drilling) oil and gas wells within 1.9 miles from active leks (Holloran 2005). Measurable impacts on sage-grouse from coalbed methane development in northeast Wyoming were found to extend out to 4 miles (Walker 2008), and subsequent research has recorded effects as far away as 12.4 miles from leks (Taylor et al. 2012). Holloran et al. (2007) found that yearling sage-grouse avoided otherwise suitable nesting habitat within 930m (almost 0.6 mile) of oil and gas-related infrastructure. This means that individual wellsites, and their access roads and other related facilities, will be surrounded by a 0.6-mile band of habitat that has substantially lost its habitat capability for use by nesting grouse. The consequences of industrial development in the context of inadequate lek buffers are reductions in population size and persistence. State researchers, using lek buffers of 0.25 mile, 0.5 mile, 0.6 mile, 1.0 mile, and 2.0

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[1] Online at https://gfp.sd.gov/management-plans/

[2] See map, https://denr.sd.gov/des/og/maps/New%20Maps%2001.22.2020/State_wide_oil_gas_wells.pdf

mile, estimated lek persistence of 4, 5, 6, 10, and 28 percent, respectively (Apa et al. 2008). Standard energy development within 2 miles of a lek is projected to reduce the probability of lek persistence from 87% to 5% (Walker et al. 2007a). Manier et al. (2014) placed the range of appropriate lek buffer distances for industrial projects at 3.1 to 5 miles.

Advances in science make it increasingly clear that noise from roads or industrial facilities is having a major negative effect on sage-grouse and their ability to make use of otherwise suitable habitats. Noise can mask the breeding vocalizations of sage-grouse (Blickley and Patricelli 2012), displaces grouse from leks (Blickley et al. 2012a), and causes stress to the birds that remain (Blickley et al. 2012b). According to Blickley et al. (2010), “The cumulative impacts of noise on individuals can manifest at the population level in various ways <u>that can potentially range from population declines up to regional extinction</u>. If species already threatened or endangered due to habitat loss avoid noisy areas and abandon otherwise suitable habitat because of a particular sensitivity to noise, their status becomes even more critical.” Noise must be limited to a maximum of 10 A-weighted decibels (dBA) above the ambient natural noise level after the recommendations of Patricelli et al. (2012); the ambient noise level in central Wyoming was found to be 22 dBA (Patricelli et al. 2012) and in western Wyoming it was found to be 15 dBA (Ambrose and Florian 2014, 2015; Ambrose et al. 2015). Sage-grouse lek population declines once noise levels exceed the 25 dBA level. With this in mind, ambient noise levels should be defined as 15 dBA and cumulative noise should be limited to 25 dBA in occupied breeding, nesting, brood-rearing, and wintering habitats, which equates to 10 dBA above the scientifically-derived ambient threshold.

Federal sage-grouse plans have applied a 3% limit on surface disturbance (per Knick et al. 2013), and a site density standard limiting sites to one per square mile. However, these densities are calculated across a project analysis area, which can exceed 225 square miles based on the real-world example of BLM analysis of the Lost Creek uranium project in the Red Desert of Wyoming. Knick et al. (2013) measured disturbance across an area <u>much smaller</u> (a 3-mile buffer around leks) than a project analysis area. Therefore, 3% surface disturbance as measured across a project area is an even higher percentage of surface disturbance when calculated using the Knick et al. (2013) protocol. According to the BLM’s expert team (National Technical Team 2011) both site density and disturbance percentage should be calculated per square-mile section of land.

Currently, important sage-grouse wintering habitats have not been spatially identified in South Dakota, and even if they were, there is an absence of measurable, enforceable standards to prevent degradation of wintering habitats at the federal, state, and local levels, across all land ownerships. Doherty et al. (2008) demonstrated that Greater Sage-Grouse in the Powder River Basin avoided otherwise suitable wintering habitats once they have been developed for energy production, even after timing and lek buffer stipulations had been applied. In addition, Carpenter et al. (2010) found that wintering sage-grouse avoided otherwise suitable habitats within a 1.2-mile radius of wellsites. Dzialek et al. (2012: 12) confirmed these relationships for wintering sage-grouse in Wyoming, and concluded:

> First, we can say with increasing confidence that the winter pattern of occurrence among sage-grouse shows consistency throughout disparate portions of its

> distribution. Second, avoidance of human activity appears to be a general feature of winter occurrence among sage-grouse.

Holloran et al. (2015) determined that increasing wellpad density had a negative impact on sage-grouse winter habitat use regardless of whether liquid gathering systems were used to reduce human activity levels or not, and also found a negative impact of distance to wellsites (within 2.8 km or 1.75 miles) and distance to roads. To the extent that new road construction, mineral development, and transmission and utility lines continue to occur, they should be excluded from important wintering areas, which exclusion should also be applied to a buffer of 2 miles around any such habitats.

Transmission lines are known to negatively affect sage-grouse, due in part to the propensity of raptors and corvids to perch on them and/or concentrate their hunting activity nearby. Wisdom et al. (2011) found that lands within 3.1 miles of transmission lines and highways had an elevated rate of lek abandonment. Nonne et al. (2011) found that raven abundance increased along the Falcon-Gondor powerline corridor in Nevada both during the construction period, and long-term after powerline construction activities had ceased. Braun et al. (2002) reported that 40 leks with a power line within 0.25 mile of the lek site had significantly slower population growth rates than unaffected leks, which was attributed to increased raptor predation. Dinkins (2013) documented sage-grouse avoidance of powerlines not just during the nesting period but also during early and late brood-rearing. LeBeau et al. (2014) found that sage-grouse avoided habitats within 2.9 miles of transmission lines during the brood-rearing period. The National Technical Team (NTT 2011) recommended that Priority Habitats be exclusion areas for overhead powerlines, and that General Habitats should be avoidance areas for overheads lines. Regulations blocking transmission lines from being built across key sage-grouse habitats, and requiring existing overhead lines to be buried, do not exist at any governmental level in South Dakota.

The National Technical Team (2011) reviewed the best available science on wind energy facilities, noting the sage-grouse's avoidance of tall structures, and recommended that priority habitats be "exclusion areas" for these facilities. LeBeau (2012) found that sage-grouse experienced significant declines in nest and brood survival in proximity to wind turbines. Yet no moratorium is presently in place to prevent wind farm development in key sage-grouse habitats. Federal sage-grouse plans offer mere avoidance, which is discretionary, rather than exclusion.

Wisdom et al. (2011) found that extirpated range of sage-grouse was closer to highways (mean = 3.1 miles) than occupied range for sage-grouse, and Holloran (2005) found that "main haul roads" — gravel roads accessing 5 or more natural gas wells — had a significant negative effect up to 1.9 miles from the road on sage-grouse lek attendance compared to unaffected leks (regardless of whether the road was visible from the lek or not), and that increased traffic led to increased impact. At minimum, all roads need to be sited at least 0.8 miles from lekking and nesting habitat, and main haul roads should be sited at least 2 miles away. At minimum, all roads need to be sited at least 0.8 miles from lekking and nesting habitat. Patricelli et al. (2012) tested the impact or road and drilling noise on sage-grouse, and reached the following conclusions:

> "…we recommend that interim management strategies focus not on limiting traffic noise levels, but rather on the siting of roads or the limitation of traffic volumes during crucial

> times of the day (6 pm to 9 am) and/or season (i.e. breeding season). We estimate that noise levels will typically drop to 30 dBA at 1.3 km (0.8 mi) and to 32 dBA at 1.1 km (0.7 mi) from the road (these levels represent 10 dB over ambient using 20 or 22 dBA ambient respectively). Therefore to avoid disruptive activity in areas crucial to mating, nesting and brood-rearing activities, we recommend that roads should be sited (or traffic should be seasonally limited) within 0.7-0.8 miles from the edge of these areas. We emphasize that we are not recommending the siting of roads 0.7-0.8 miles from the edge of the lek perimeter, but rather 0.7-0.8 miles from the edge of crucial lekking, nesting and early brood-rearing areas."

There is presently no regulation blocking road construction in nesting habitats (within 5.3 miles of leks), or within two miles of leks to prevent disturbance to breeding birds, nor is there any program in place to close or re-route existing roads that presently occur within these sensitive areas.

There has been a great deal of interest in uranium mining in southwest South Dakota, and rare-earth minerals have also been the subject of mining speculation in the local region. In addition, bentonite mining is a significant problem in northwestern South Dakota, and indeed sage grouse habitat protections have been excluded in bentonite mining areas in the past. Braun (1986) also found a significant negative effect of mining haul roads on sage-grouse leks within 1.9 miles of the road. Yet there is nothing to prevent mining within sage-grouse habitats in South Dakota.

CONCLUSIONS

It is necessary to list the greater sage-grouse under the South Dakota Endangered Species Law because of the ongoing decline of sage-grouse populations in South Dakota, and the absence of required regulatory actions to prevent new habitat impacts or to restore previously impacted sage-grouse habitats. The current state plan includes only voluntary or discretionary measures, with an absence of measurable, enforceable, and mandatory standard to protect sage-grouse and their habitats.

Listing will have the effect of preventing hunting of this species, which is of limited effect given the very few grouse taken each year. It is in the long-term best interest of hunters to increase the sage grouse population to the point where it becomes huntable once again, and listing offers the best path to achieve this result. While hunting is typically not considered a principle cause of sage-grouse population declines, when populations get as small as South Dakota's, the taking of even a few could make the difference between survival and extirpation of an individual lek population.

Various federal, state or local agencies may require environmental impact reviews prior to permitting or approving various development activities. The greater sage grouse is rated as a species of greatest conservation need in the South Dakota Wildlife Action Plan. As such, it may be reviewed in some environmental impact statements. However, some may just require review of federal species and some just federal and state species. Being listed as a state listed species may improve the quality of environmental review allocated to it and potentially result in protection by agencies of government during permitting and approval processes.

We appreciate your diligence and consideration of applying science-based state-level protections to this bird.

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Review of Greens Hollow Sound Study by Tetra Tech (2008)

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Summary of Findings

The Tetra Tech "Green Hollow Sound Study" has several deficiencies, including:

1. Tetra Tech sound level meters measured down to about 27 dBA, but actual sound levels in the area are often less than 15 dBA.
2. Tetra Tech measured sound levels in July; grouse typically display in late March to early May when sound levels are generally lower.
3. Tetra Tech measured from mid-morning to mid-afternoon. Grouse typically display between 1800-0800, which is generally a quieter time of day.
4. Tetra Tech did not follow protocols developed by the American National Standards Institute (ANSI) for outdoor sound level measurements.
5. Tetra Tech did not use acoustic metrics recommended by ANSI for reporting sound level information (L_{90} for background ambient and L_{50} for existing ambient). Tetra Tech used a metric (L_{eq}) that would suggest higher sound levels at leks than actually present.

The Tetra Tech Greens Hollow Sound Study (2008) concluded that average "background" sound levels in the lek areas was ±34.7 dBA. However, sound level measurements by Sandhill Company between March 29-31, 2015, found that background sound levels (L_{90}) were 16.3 dBA for all hours of the day, and 15.1 dBA for hours important to lekking activity (1800-0800). Using the same (incorrect) metric as Tetra Tech to establish background (L_{eq}), Sandhill Company reported L_{eq} = 24.5 dBA, while Tetra Tech reported L_{eq} = 34.7 dBA.

The existing vent fan is 4350 m from the Wildcat Knolls lek and clearly audible. The proposed vent fan would be 2680 m from the Wildcat Knolls lek, resulting in higher sound levels at the lek. Anthropogenic sounds >25 dBA have the potential to negatively impact greater sage-grouse.

For these reasons, the report by Tetra Tech and subsequent analysis of potential impacts in the DEIS and SEIS are inaccurate and misleading, and could result in harmful impacts to greater sage-grouse.

Introduction

The purpose of this paper is to provide a review of the Greens Hollow Sound Study in 2008, conducted by Tetra Tech, Salt Lake City, UT. The purpose of the Tetra Tech study was to measure sound levels at sensitive resource locations, such as leks of greater sage-grouse (*Centrocercus urophasianus*), and determine potential acoustic impacts of a proposed coal mine vent fan on sensitive resources. Anthropogenic sounds have the potential to negatively impact greater sage-grouse (Blickley et al. 2011; Blickley and Patricelli 2012; Patricelli et al. 2013). Accurate background sound level data are essential for assessment of potential negative impacts.

Specific Issues in the Tetra Tech Study

Equipment

The sound level meter used in this study was a Quest Technologies Model 2200. The manufacturer states that this model is capable of measuring sound levels between 30-140 dBA (this is the range the manufacturer guarantees, most sound level meters will measure slightly better than guaranteed, 27.5 dBA in the Tetra Tech study). The minimum sound levels reported by Tetra Tech are at or near the minimum level that can be measured by this model sound level meter. *This means that actual sound levels are lower than reported.*

Use of inappropriate equipment most often leads to false and deceptive results. Consider a study attempting to determine the average height of all individuals in Utah, and using a 36” stick as a measuring device. The results would show the average height of a person in Utah to be about 35.9” which of course is not true. The average height is about 59 inches, considering babies to adults, but if the measuring device only goes to 36” an accurate study is not possible.

Sound level meters used in any measurement should be capable of measuring the full range of sound levels at the study site. Other acoustic studies in sage habitats relative to greater sage-grouse have shown sound levels are often <10 dBA during April during early morning hours (Ambrose et al. 2014). The use of a sound level meter that measures down to only 27 dBA cannot provide accurate results if actual sound levels are lower. If background sound levels are reported as high, a new noise source would be less likely to have any influence, whereas if background sound levels are low, the potential for impacts due to a new noise source is greater.

Metric Used to Establish “Background Sound Level”

The Tetra Tech study used the L_{eq} metric to establish the background sound level. L_{eq} is an energy average (or logarithmic average), and, as such, a very short but very loud sound will greatly influence (increase) the average sound level. The American National Standards Institute (ANSI) recommends that the L_{90} metric be used to establish background sound level (ANSI 1994). L_{90} levels are always lower than L_{eq} levels. The background sound levels reported by Tetra Tech are much higher than typical sound levels in the study area.

Dates and Time of Day

Greater sage-grouse typically display between about 0500-0800, or starting just before sunrise and ending 3-4 hours later. This is usually the quietest time of day, and this is why birds with audio displays are most active at this time; their songs and display sounds carry a great distance because few other sounds are present.

The Tetra Tech study measured sound levels in late July between the hours 0823 and 1433. Grouse typically display in April and May, and typically do not display after about 0800. The time of season and time of day when Tetra Tech measured are not appropriate for measuring sound levels at leks used by greater sage-grouse. One would expect sound levels to be higher in July due to the presence of more birds and insects in July as compared to April, and one would expect sound levels to be higher after 0800 due to increasing winds (which produces sound due to wind through vegetation). Further, meteorological conditions in July are substantially different from April, and as a result, sound attenuation rates would be different. One would expect sound to attenuation more in July than in April due to warmer temperatures.

Sound levels in April during the primary lekking hours (0500-0800) would almost certainly be lower than reported by Tetra Tech, and thus the potential for impacts would be greater than determined in the DEIS and SEIS.

Measurement Duration
Tetra Tech made 2-minute sound level measurements at several locations. A 2-minute sample may or may not be representative of actual conditions. Measurement periods need to be long enough to ensure all variability in sound levels are measured, and this usually requires several days at each measurement location.

Microphone Height
The Tetra Tech study placed microphones at approximately 1 meter off the ground. Grouse ear height is 0.3 m (12”), thus data collected at 1 m may not represent what the target species, greater sage-grouse in this case, experience.

Discussion
The current mine vent fan is 4350 m from the Wildcat Knolls lek and is clearly audible at the lek. The proposed mine vent fan is 2680 m from the Wildcat Knolls lek. One would expect the proposed vent fan to be audible and also result in higher sound levels at the lek than the current vent fan.

Analysis of anthropogenic sound levels at greater sage-grouse leks in the Pinedale Anticline Project Area sound of Pinedale, WY, relative to trends of counts of male greater sage-grouse at those leks, demonstrate that sound levels <25 dBA are not significantly associated with trends of counts, while sound levels >30 dBA are strongly and significantly associated with declining trends (7 of 9 leks with sound levels >30 dBA no longer have grouse present). These data suggest that when anthropogenic sound levels approach 25-30 dBA, negative impacts to greater sage-grouse will start to occur (S. Ambrose, unpublished data).

Summary
The Tetra Tech study (1) used inappropriate equipment (not sensitive enough), (2) measured at inappropriate times of year and times of day (not when greater sage-grouse are displaying), and (3) did not follow protocols developed by the American National Standards Institute (ANSI) for outdoor sound level measurements. Further, Tetra Tech did not use acoustic metrics recommended by ANSI for reporting sound level information, and metrics used by Tetra Tech

suggested higher sound levels at leks than probably occurred there during the lekking period. For these reasons, the report by Tetra Tech and subsequent analysis of potential impacts in the DEIS and SEIS are inaccurate and misleading.

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Summary of Sound Level Measurements at Wildcat Knolls Lek, March 29-31, 2015

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Introduction and Methods

Between March 29, 2014, 1400 hours, and March 31, 2015, 1430, we collected continuous 1-second dBA and 1/3 octave band data (12.5-20,000 Hz) at the Wildcat Knolls greater sage-grouse lek. The sound level meter was placed on the north side of the lek, within the boundary of the lek, at 12" above ground height (average grouse ear height). One-third octave band data are useful in determining the potential for masking sounds important to wildlife. For example, most sounds produced by greater sage-grouse during lekking activity are low frequency, typically <500 Hz. Sounds of the current mine vent fan are highest in the 250 Hz range, suggesting the potential for masking grouse sounds is high.

Results

The "existing ambient" (L_{50}) sound level at Wildcat Knolls was 19.4 dBA for all hours (0000-2400) and 17.1 dBA for greater sage-grouse lekking hours (1800-0800) (Table 1). The "background ambient" sound level (L_{90}) was 16.3 dBA for all hours and 15.1 dBA for lekking hours. Daily L_{50} dBA patterns are shown in Figure 1, showing lower sound levels during evening and early morning, with elevated levels during daylight hours when winds are higher.

The current vent fan was audible during all hours of the day, and was clearly noticeable at 250 Hz (Figure 2). This fan sound likely has some influence on both the L_{50} and L_{90} levels.

The Tetra Tech sound study (2008) reported "average" (L_{eq}) sound levels at the Wildcat Knolls lek between 31.0-39.2 dBA. We found L_{eq} = 24.5 dBA, median for all hours of the day, and 21.2 dBA for hours important to lekking greater sage-grouse.

Discussion

Sound level measurements from March 29-31, 2015, found that sound levels were much lower than reported by Tetra Tech. These differences were likely due to several factors, including:

- Tetra Tech used sound levels meters that were not capable of measuring as low as actual sound levels are in the area.
- Tetra Tech measured during daytime hours in July, times and months when greater sage-grouse are not displaying (and which would result in higher readings).
- Tetra Tech used inappropriate metrics to determine existing and background sound levels. Tetra Tech used the L_{eq} metric, an energy average that almost always results in higher levels. ANSI recommends using the L_{50} metric to determine existing ambient and the L_{90} metric to determine background ambient.
- Tetra Tech collected sound levels for 2 minutes at each location, and such a short measurement can either over-estimate or under-estimate actual sound levels.

Table 1. Hourly metrics for Wildcat Knoll Greater Sage-grouse lek, March 29-31, 2015.

Hour	NHours	LMin	LMax	Leq	L10	L50	L90
0	2	13.6	44.2	20.9	19.7	16.1	14.5
1	2	13.8	49.0	23.2	23.2	18.0	15.6
2	2	14.6	31.4	19.8	22.2	18.9	16.4
3	2	14.5	47.2	23.3	22.4	18.7	16.2
4	2	13.9	27.6	18.1	20.2	17.4	15.6
5	2	13.9	28.9	17.7	20.0	16.7	14.9
6	2	14.2	47.5	25.6	27.0	20.0	15.9
7	2	15.4	51.7	30.3	31.3	24.1	19.8
8	2	14.4	57.0	29.5	25.0	19.3	16.6
9	2	14.4	58.6	23.4	25.8	19.6	17.2
10	2	15.2	43.2	25.7	28.5	21.1	17.3
11	2	15.3	45.6	26.5	30.4	22.1	18.3
12	2	15.5	46.9	29.5	33.2	25.2	20.0
13	2	15.8	49.3	31.2	35.1	26.2	20.1
14	2	16.0	48.9	29.9	33.9	25.6	20.1
15	2	14.7	45.1	27.1	29.9	21.0	16.6
16	2	15.1	51.0	29.2	30.3	22.1	17.2
17	2	14.6	44.8	26.9	30.1	21.0	17.3
18	2	14.3	37.3	21.5	24.5	19.5	15.3
19	2	13.9	50.4	27.3	23.4	15.3	14.2
20	2	13.7	45.7	23.0	22.7	15.0	14.1
21	2	13.6	40.5	18.7	17.9	14.4	13.9
22	2	13.5	26.2	15.4	16.9	14.7	14.0
23	2	13.6	27.7	17.6	19.9	16.7	14.7
GRHO001	0000-2400	13.5	58.6	24.5	24.8	19.4	16.3
	0800-1800	14.4	58.6	28.2	30.2	21.6	17.3
	1800-0800	13.5	51.7	21.2	22.3	17.1	15.1

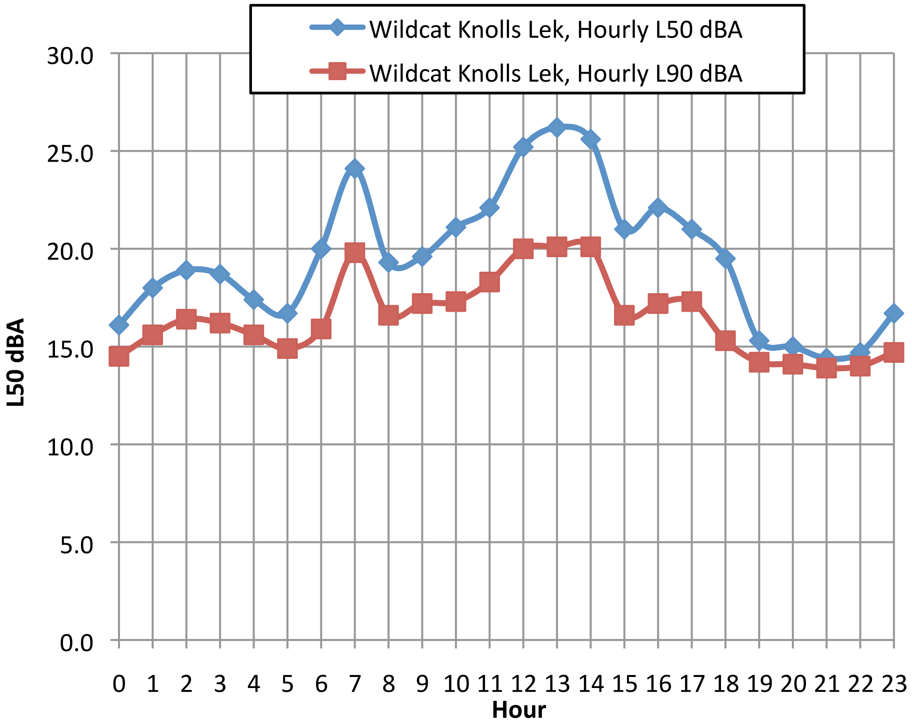


Figure 1. L50 dBA and L90 dBA, Wildcat Knolls lek, March 29-31, 2015.

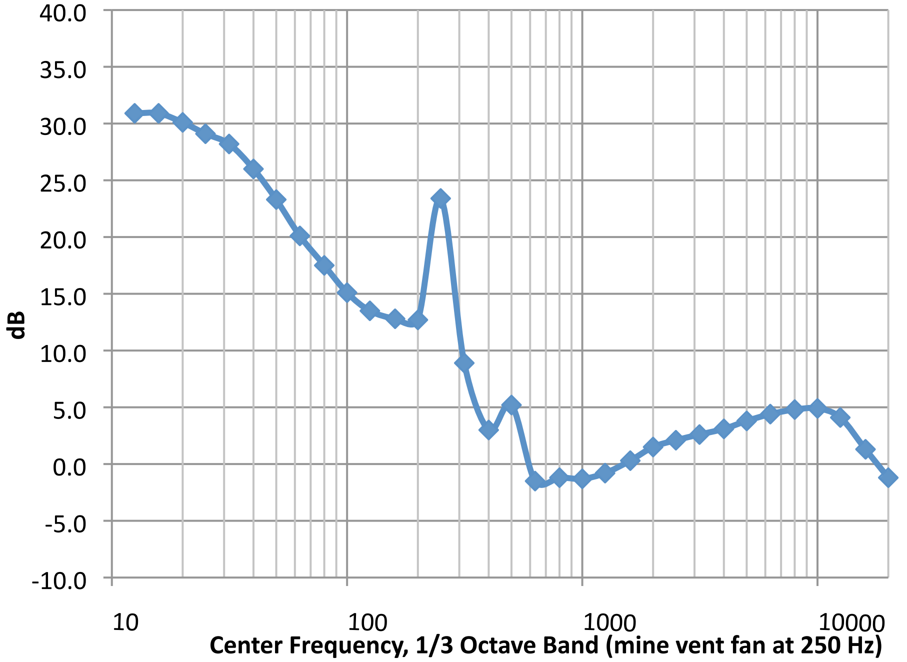


Figure 2. One-third octave band levels, Wildcat Knoll Greater Sage-grouse lek, March 29-31, 2015. Note higher levels at 250 Hz; this is noise from the mine vent fan, 4350 m from the lek.

Review of Wildlife Section, Technical Report, Greens Hollow Coal Lease Tract

Section 3.2.5.1.2.1 TES Birds. P. 92

> "As the drilling activities would occur year-round, breeding birds would either become habituated to the noise and disturbance or move to another location for that breeding period or permanently."

Comment: This statement implies that grouse have the option of simply moving to an alternate location. This is rarely the case for wildlife species. They are where they are for a reason.

Section 3.2.5.1.2.1 TES Birds. P. 92

> "If vent shaft construction occurred during sage-grouse lekking season, noise from the construction measured at the edge of the lek would not be allowed to exceed 10 dB above ambient sound level at sunrise."

Comment: For this assessment, it is essential to know the actual ambient sound level at sunrise. The Tetra Tech does not provide such information.

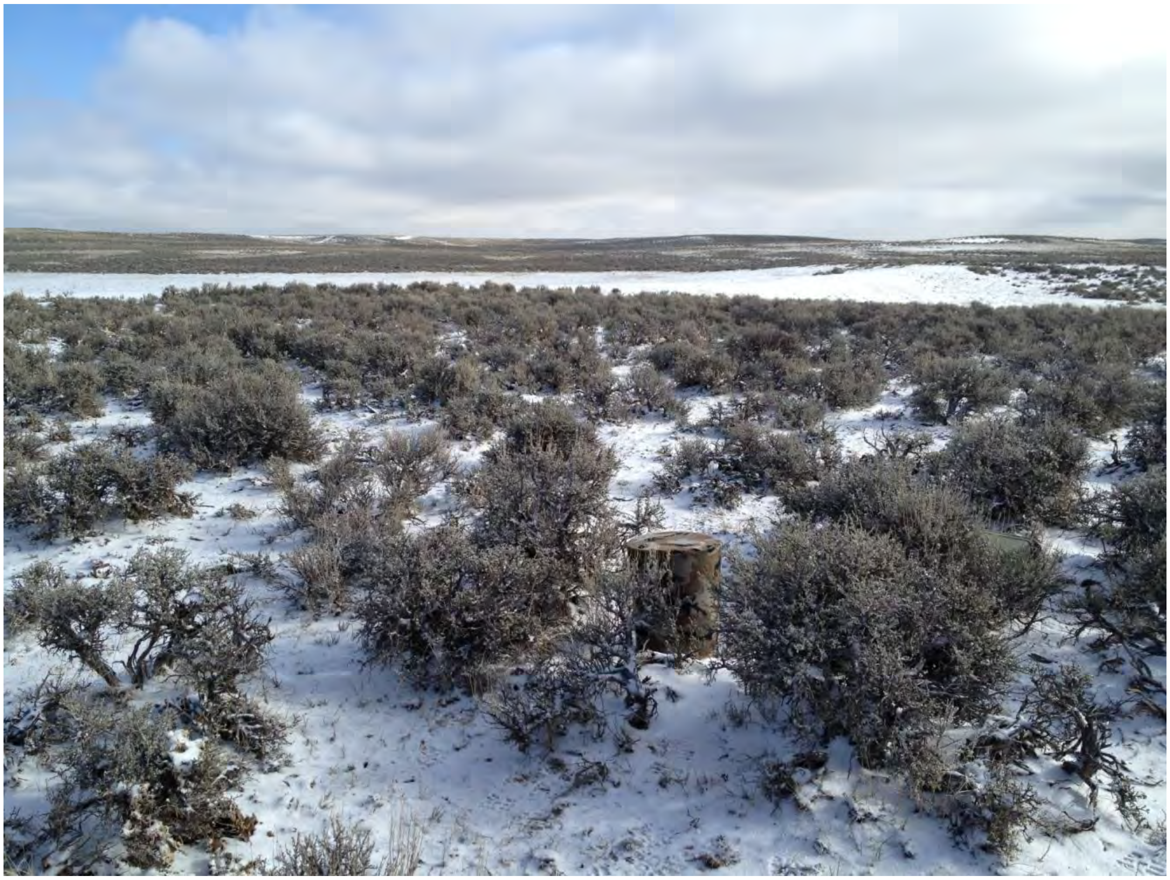
Section 3.2.5.2.4 Constant Background Sound. P. 99

> "Sampling in the study area determined that background sound levels for the analysis area averaged 34.0 dBA. This level was recorded within the vicinity of the analysis area where the currently-operating SUFCO fan was not audible to human researchers sampling noise levels. These readings were taken at various locations throughout the analysis area to get an average baseline across the area without noise interference from passing vehicles, overhead airplanes, during calm wind conditions, quiet researchers, and as stated above, where the SUFCO mine was inaudible to researchers. This is considered to be the background noise levels for the analysis area in mid-summer (Tetra Tech 2008).
>
> "Current guidelines for limiting noise impacts on sage-grouse suggest a maximum of 10 dB above ambient measured at the edge of the lek (Morales et al 2011). Noise levels above this threshold have been shown to reduce peak male attendance at affected leks. This same study also showed intermittent noise to be more detrimental than constant noise of the same decibel level (Blickley et al 2012)."

Comment: For this assessment, it is essential to know the actual ambient sound level at sunrise during the time of grouse lekking in order to assess the 10 dBA over ambient threshold. The SEIS points out some of the shortcomings in the Tetra Tech sound study (time of year of sound study not during lekking, different meteorological conditions in April versus July), but regardless used the findings of that study to establish a "background noise" level for impact analysis.

As pointed out earlier, the Tetra Tech analysis did not use appropriate equipment or appropriate metrics to establish background ambient sound level. Tetra Tech used sound level meters that would not capable of measuring as low as actual conditions, and also used L_{eq} establish "background ambient sound level" while ANSI recommends L_{90}.

Sound Levels at Greater Sage-grouse Leks, Pinedale Anticline Project Area, Wyoming, April 2013



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Sound Levels at Greater Sage-grouse Leks, Pinedale Anticline Project Area, Wyoming, April 2013

Executive Summary

Greater sage-grouse (*Centrocercus urophasianus*) use elaborate acoustic and visual display behaviors to attract and select mates, and depend on vocal communication between females and nestlings during brood rearing. A potential threat to greater sage-grouse is anthropogenic noise associated with human activity, including noise from oil and gas development and production. Several greater sage-grouse leks occur in and around the Pinedale Anticline Project Area (PAPA).

The objectives of this project were to:

- Monitor sound levels at 19 leks in PAPA;
- Monitor sound levels of common gas field activities near leks in PAPA; and
- Determine baseline ambient sound levels in sage land cover at reference areas outside PAPA (3 leks without influence of gas field sounds).

Acoustic data were collected at 39 locations in or near the PAPA in April 2013: 3 reference leks, 19 treatment leks, and 17 gas field sound sources near leks in PAPA. The reference leks were in the Speedway and Ryegrass complexes, and the treatment leks were in the Mesa, Duke's Triangle, and Yellowpoint complexes.

At the three reference leks, the baseline ambient sound level (L_{90}) was 15.8 dBA, and the existing ambient sound level (L_{50}) was 19.4 dBA (all hours, 0000-2400). At two of these leks, L_{50} metrics (and to a lesser extent L_{90} metrics) were influenced by grouse display sounds. For the time period 0000-0500, a time with few grouse display sounds yet with the same general metrological conditions (wind and temperature) as the primary display hours (0500-0900), the L_{50} was 14.6 dBA and the L_{90} was 14.2 dBA for the three reference leks.

The noise floor of sound level meters used at these reference leks were between 13-14 dBA (this is also described as instrument self-noise, the lowest measurement limit of the instrument). Whenever reported sound levels are near the noise floor of the instrument, there is some influence of instrument self-noise on dB data (the closer to the noise floor, the greater the influence). In such situations, actual sound levels are less than recorded by the sound level meter. In other words, actual sound levels at the three reference leks in this study were less than reported above. Results of this 2013 study suggest that future measurements in remote (pre-developed) locations should use instruments that measure down to approximately 5 dBA.

At the 19 treatment leks, the existing ambient sound level (L_{50}) was 26.6 dBA (all hours, 0000-2400). The L_{50} sound level at treatment leks varied according to distance from and type of gas field sound source.

Of the common activities in the gas field, the sound level (L_{50}, 0000-2400 hours) of an active drill rig in the Duke's Triangle complex was the loudest (62 dBA @ 100 m), followed by the injection well complex (56 dBA @ 100 m) in the northern part of the Yellowpoint complex. Other gas field sound sources with L_{50} >50 dBA @ 100 m were a second drill rig being disassembled the Duke's Triangle complex (54 dBA); Jonah compressor station (54 dBA); central gathering facility in the Mesa Complex with generator (52 dBA); and a well pad with 21 well heads and generator (50 dBA).

Equipment type and methods used for sound level measurements relative to greater sage-grouse in Wyoming have varied considerably. Both Type 1 and Type 2 sound level meters have been used, with noise floors ranging from less than 14 dBA to greater than 25 dBA. Microphone height has ranged from 12 inches to 96 inches. Measurement periods have ranged from one hour to more than 14 days. Such inconsistencies can produce significantly difference results. Instruments that measure down to only 25 dBA cannot describe acoustic conditions less than that. Wind pressure influence on dB data varies considerably due to microphone height. Short measurement periods can over- or under-estimate typical acoustic conditions. Collecting acoustic data with such a variety of equipment types and protocols can generate unusable and potentially misleading results. A standardized protocol for sound level measurement is needed to ensure acoustic data are accurate, useful for greater sage-grouse management, and comparable with data from other acoustic studies.

We recommend future acoustic studies follow guidelines prepared by Blickley and Patricelli (2012) "Noise monitoring recommendations for greater sage-grouse habitat in Wyoming" with slight modifications. We suggest these changes based on our experience measuring sound levels at over 150 remote locations in the western United States.

Equipment must be capable of measuring the entire the acoustic environment experienced by greater sage-grouse, and measurement periods must be long enough that natural variations in the acoustic environment are captured. The following basic standards are recommended for data collection:

- Microphone height should be 0.3 m (12") to ensure that measurements capture acoustic conditions experienced by greater sage-grouse.
- Sound level meters should be capable of capturing the full range of sounds (12.5-20,000 Hz) and sound levels (<10 dBA to >80 dBA) experienced by greater sage-grouse.
- Measurement periods should be long enough to capture normal acoustic variation due to seasonal and metrological conditions (estimated 14 days but needs further study).
- Continuous recordings should be collected during the entire measurement period to allow for source identification of all sounds.

The purpose of this study was to monitor sound levels at leks in the PAPA and to determine baseline ambient sound levels near leks outside the PAPA gas field. This study did not attempt to assess impacts of gas field sounds on greater sage-grouse, or at what levels such sounds negatively impact greater sage-grouse.

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Introduction

Greater sage-grouse (*Centrocercus urophasianus*) use elaborate audio and visual display behaviors to attract and select mates, and depend on audio communication between females and nestlings during brood rearing. A potential threat to greater sage-grouse is anthropogenic noise associated with human activity, including noise from oil and gas development and production (BLM 2008, Patricelli et al. 2013).

Objective

The primary objectives of this project were to:

- Monitor sound levels at 19 leks in PAPA;
- Monitor sound levels of common gas field activities near leks in PAPA; and
- Determine baseline ambient sound levels in sage land cover at reference areas outside PAPA (3 leks without influence of gas field sounds).

Study Area

The study area for this project was south and west of Pinedale, WY, primarily in the Pinedale Anticline Project Area (Figure 1). The 6 lek complexes studied were East Fork, Ryegrass, Speedway, Mesa, Duke's Triangle, and Yellowpoint.

Methods

Definitions

The following are definitions of acoustic terms used in this report (NPS 2005). A brief introduction to acoustics is presented in Appendix F.

Audibility: Audibility is the ability of animals with normal hearing, including humans, to hear a given sound. Audibility is affected by the hearing ability of the animal, other simultaneous interfering sounds or stimuli, and by the frequency content and amplitude of the sound.

A-Weighting (dBA): A-weighting is used to account for differences in human hearing sensitivity as a function of frequency. A-weighting de-emphasizes the high (6.3 kHz and above) and low (below 1 kHz) frequencies, and emphasizes the frequencies between 1 kHz and 6.3 kHz, in an effort to simulate the relative response of human hearing.

Decibel (dB): A logarithmic measure commonly used in the measurement of sound. The decibel provides the possibility of representing a large span of signal levels in a simple manner as opposed to using the basic pressure unit Pascal. The difference between the sound pressure of silence versus a loud sound is a factor of 1,000,000:1 or more, therefore it is less cumbersome to use a small range of equivalent values: 0 to 130 decibels.

Frequency: The number of times per second that the sine wave of sound repeats itself. It can be expressed in cycles per second, or Hertz (Hz). Frequency equals Speed of Sound / Wavelength.

*L_{eq} (*Equivalent Sound Level): The logarithmic average (i.e., on an energy basis) of sound pressure levels over a specific time period. "Energy averaged" sound levels are logarithmic values, and as such are generally much higher than arithmetic averages. L_{eq} values are typically calculated for a specific time period (1-hour and 12-hour time periods are often used). L_{eq} values are computed from

all of the 1-second L_{eq} values for the specific time period. L_{eq} must be used carefully in quantifying natural ambient sound levels because occasional loud sound levels may heavily influence (increase) the L_{eq} value, even though sound levels for that period of time are typically lower.

L_{max}: The maximum sound pressure level for a given period.

L_{min}: The minimum sound pressure level for a given period.

L_x (Exceedance Percentile): This metric is the sound pressure level (L), in decibels, exceeded *x* percent of the time for the specified measurement period. L_{50} is the sound pressure level exceeded 50 percent of the time (L_{50} is the same as the median).

Noise Floor: The lower measurement limit of a sound level meter, also referred to as self-noise or electrical noise of all components of a sound level meter (meter, microphone, and preamplifier).

Sound Level: Generally, *sound level* refers to the *weighted* sound pressure level obtained by frequency weighting, usually A- or C-weighted.

Sound Level, Baseline Ambient: The sound level in a given location including all sounds of nature but absent most human-caused sounds. L_{90} is the sound pressure level exceeded 90 percent of the time, and is commonly used to establish the baseline ambient sound level.

Sound Level, Existing Ambient: The sound level of all sounds in a given area, including all natural sounds as well as all mechanical, electrical and other human-caused sounds. The existing ambient sound level is generally characterized by the L_{50} exceedance level (i.e., the median).

Sound Pressure: Sound pressure is the instantaneous difference between the actual pressure produced by a sound wave and the average barometric pressure at a given point in space. Not all pressure fluctuations detected by a microphone are sound (e.g., wind over the microphone). Sound pressure is measured in Pascals (Pa), Newtons per square meter, which is the metric equivalent of pounds per square inch.

Sound Pressure Level (SPL): The logarithmic form of sound pressure. Generally, sound pressure level refers to unweighted sound pressure levels of one-third octave bands.

Time Weighting: The response speed of a sound level meter. Fast and slow time response were developed primarily to slow needle movement in analog meters so investigators could read and record sound levels. This is not needed with modern digital sound level meters. Both fast and slow time response add a decay factor. Decay factors can induce some error, although over time there is little difference in fast, slow, or actual sound levels.

Measurement Protocol

The Wyoming Game and Fish Department’s Request for Proposals (RFP) for this project included acoustic measurement protocols developed for the Pinedale Anticline Project Office by Blickley and Patricelli (2012), “Noise monitoring recommendations for Greater Sage Grouse habitat in Wyoming.” Methodology for this project followed the requirements and recommendations provided in the RFP and those of Blickley and Patricelli (2013), and expanded those protocols in a few situations.

In brief, Blickley and Patricelli (2013) recommended the following:

- Measurements should be made with a high quality, calibrated Type I (noise floor < 25 dB) sound level meter (SLM) with a microphone windscreen and environmental housing.
- Measurements should be collected during times when noise exposure is most likely to affect greater sage-grouse— nights and mornings (i.e. 6 pm – 9 am) and should be taken for >1 hour at each site, ideally over multiple days with suitable climactic conditions. To capture typical variability in noise level at the site of interest, deployment of SLM units for multiple days is preferred. If measurements are made on or near a lek, measurements made while birds are present on the lek period (for approximately four hours after sunrise) should be excluded from ambient or noise level calculations.
- Measurements should be made at multiple locations between each noise source and the edge of the protected area. On-lek measurements should exclude time periods when birds are lekking. If measurements are made off-lek to avoid measuring the sound produced by grouse, they should be at an equivalent location with similar topography and relative distance to noise sources in the area.
- Metrics collected should include L_{10} L_{50}, L_{90}, L_{eq}, and L_{max}. All measurements should be collected in A-weighted decibels (dBA) and, if possible, also collected in unweighted (dBF) and C-weighted (dBC) decibels. SLM should log 1/3-octave band levels throughout the measurement period.
- To determine baseline ambient levels, the use of A-weighted L_{90} metric is recommended. As a measure of median noise exposure, the use of A-weighted L_{50} metric is recommended.
- Collect acoustic data with microphone height matching the height of a greater sage-grouse ear, approximately 0.3 m (12 in).

In addition to the protocols above recommended by Blickley and Patricelli (2013), we considered protocols used in other studies in remote areas. In 2000, the National Parks Air Tour Management Act was enacted. This Act required the National Park Service (NPS) and Federal Aviation Administration (FAA) to cooperatively develop air tour management plans for all parks that had commercial air tours (over 100 parks). This process required field measurements to establish baseline ambient sound levels in these parks which were used to assess potential impacts of noise from air tour aircraft via modeling. The NPS and FAA jointly developed protocols for measuring sound levels in remote areas such as national parks. These protocols are discussed in NPS 2005 and 2013, Lee et al. 2006, Lynch et al. 2011, Hari 2005, and Rapoza et al. 2008.

The NPS/FAA protocols are similar to those of Blickley and Patricelli (2013) but differ in a few areas, primarily microphone height, measurement duration, and collection of digital recordings. The NPS/FAA protocol calls for a microphone height of 1.5 m which is generally used for assessing noise impacts to people, while Blickley and Patricelli (2013) recommend a microphone height of 0.3 m, the height of a greater sage-grouse ear. We placed our microphones at 0.3 m.

Blickley and Patricelli (2013) recommended that measurements be for >1 hour at each site, ideally over multiple days. The NPS/FAA protocol calls for baseline ambient sound level measurements of 25 days/season (summer/winter) to ensure that dB data are no more than ±3 dB from actual levels, or 14 days to ensure ±5 dB of actual levels. The NPS/FAA recommendations were based on a statistical review of several long-term (>12 months) data sets (Hari 2005). This review found that sound levels in nature vary considerably, both seasonally and daily. This variation is due to several factors, including seasonal sound differences (birds, insects) and meteorological differences, primarily wind. Short measurement periods of only a few hours could significantly over- or under-estimate real levels. While the sounds of nature vary considerably, some human-caused sounds and patterns do not. In this study, several gas field sounds were remarkably consistent. For some sources, such as injection wells, drill rigs, and compressor stations, primary metrics such as L_{eq}, L_{10}, L_{50}, and L_{90}, were all within 2 dBA of each other. With such consistency, very short measurement periods, 24 hours or less, may be adequate. In consideration of both Blickley and Patricelli (2013) and NPS/FAA experience, we measured more than14 days at reference leks (where human-caused sounds were infrequent and sounds of nature dominated), and more than 24 hours at treatment leks and gas field sources (where human-caused sounds dominated).

NPS/FAA protocol calls for collecting continuous digital recordings with all measurements. This allows researchers to review and identify all sound sources, as well as review any unusual sound level data. Additionally, recordings allow researchers to determine the most common sources of sounds in a study area and to determine the percent of time that each is audible. When assessing potential impacts of noise on wildlife, it is important to know the duration that noise was audible as well as the amplitude of the noise. We collected continuous digital recordings at all measurement locations.

Baseline Ambient and Existing Ambient

The objectives of this study were to determine baseline ambient sound levels in sage land cover similar to that in the PAPA (but without gas field sounds), and to determine existing ambient sound levels at leks in the PAPA area. An explanation of the use of the L_{90} and L_{50} metrics follow.

The L_{90} sound level is the sound level exceeded 90 percent of the time. In computing the L_{90}, most common human-caused sounds such as vehicles, aircraft, and other mechanical and electrical sounds are generally excluded. Such events may have high sound levels but many are relatively short in duration. In computing the L_{90} sound level, these loud but short events are excluded and allow an estimate of the “baseline” sound level without such intrusions. Federal, state, and local governments generally use the L_{90} metric to establish baseline ambient sound levels for use in environmental reviews and for assessing acoustic impacts of proposed projects or activities (EPA 1971). Blickley and Patricelli (2013) recommend the use of L_{90} to establish baseline ambient sound levels. The L_{50} sound level is the sound level exceeded 50% of the time, or the median, half of the levels are above this level and half are below. The L_{50} metric is used to determine existing ambient sound levels, and includes all sounds in a given area (natural and non-natural) (EPA 1971).

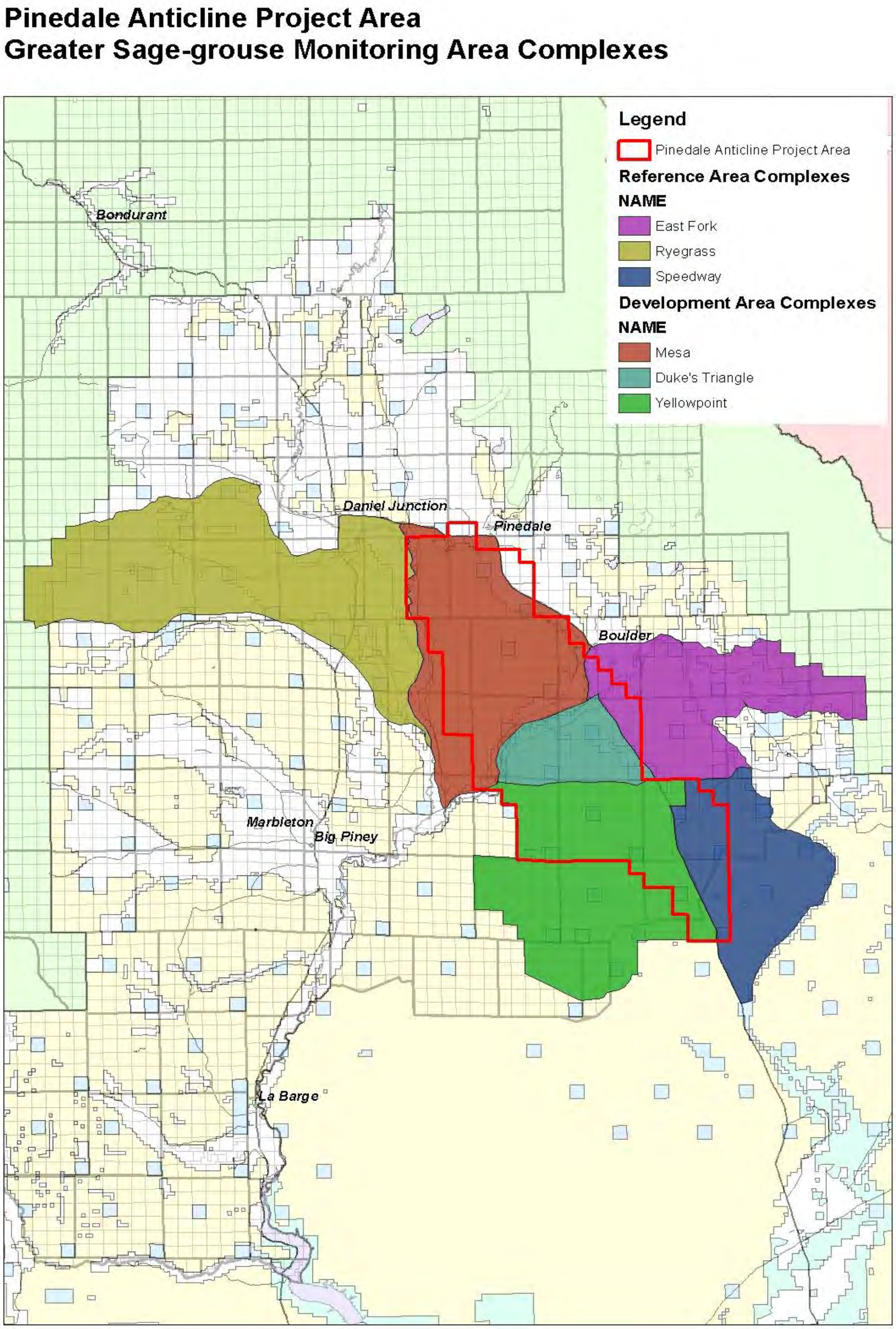

Figure 1. PAPA greater sage-grouse noise monitoring project area and lek complexes.

Sound Level Meters

Acoustic equipment used for data collection (sound level meters, microphones, and preamplifiers) met or exceeded ANSI S1.4-1983 Type 1 standards. One-third octave band analyzers and dBA analyzers met ANSI S1.11-2004 and ANSI S1.42-2001, respectively. All acoustic equipment and field calibrators were calibrated to meet ANSI S1.40-2006 (typically by manufacturer, Larson-Davis or B&K) prior to deployment. All systems and calibrators were factory calibrated as recommended by the manufacturer (Appendix G), and all systems were field calibrated at the beginning and end of each measurement period at each location using a field calibrator that met ANSI S1.40-1984 standards. We also collected continuous digital recordings at all measurement locations. Figure 2 shows a typical deployment (PAPA019, Bloom Reservoir Satellite lek) showing equipment case, microphone with fleece cage cover, and anemometer.

We used nine acoustic systems, each with the following components:

- Sound level meter: Larson-Davis LD831
- Microphone: PCB 377B20 or PCB377B02
- Preamplifier: Larson-Davis PRM831
- Environmental Shroud: Larson-Davis EPS2106 (case, 90 mm foam windscreen)
- Fleece windscreen over 90 mm foam (cylindrical, 0.4 m high and 0.3 m wide)
- Roland R05 digital recorder (to make continuous digital recordings)

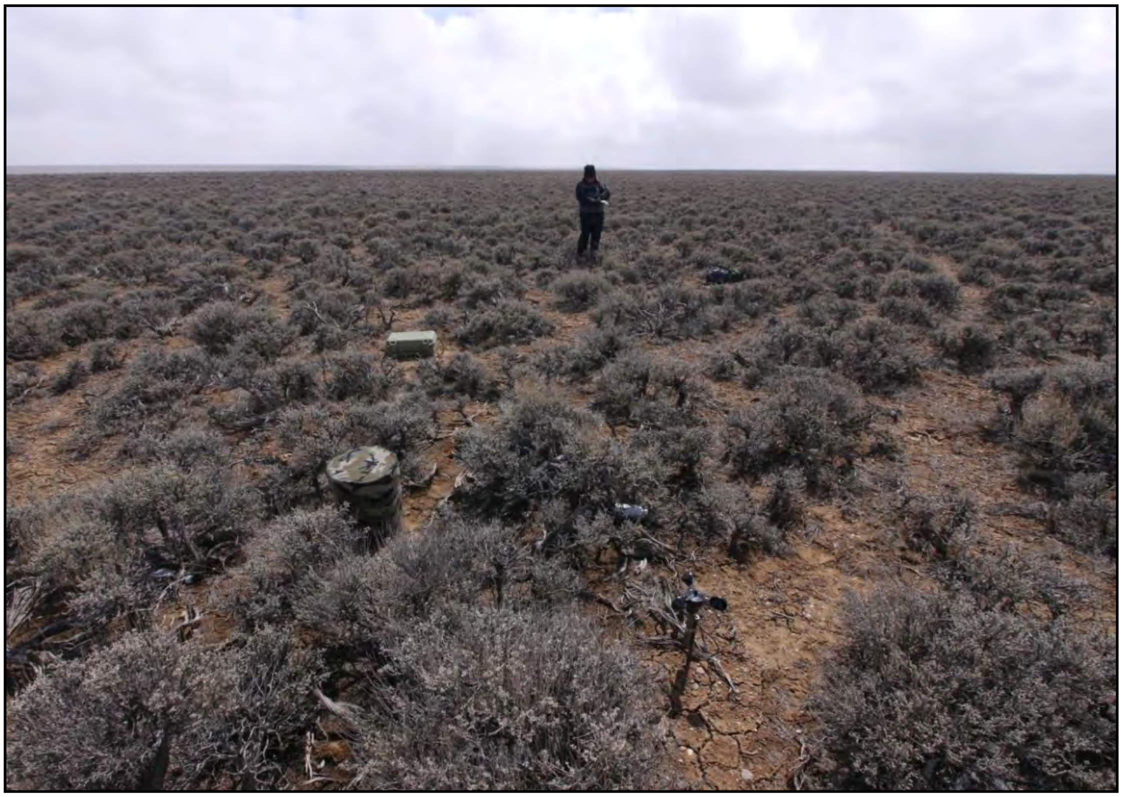

Figure 2. Typical acoustic equipment deployment.

All system components (SLM, digital recorder, and anemometer) were synchronized with GPS time, and differences at the end of the measurement period noted. We used a Bruel and Kjaer (B&K) Acoustic Calibrator Type 4231 for field calibration. In this calibrator, the reference microphone response is independent and does not change with barometric pressure. As a result, there is no need to correct calibration for the effect of elevation above sea level.

The sound level meters used in this study could measure down to approximately 13-14 dBA. This lower measurement limit is referred as the “noise floor” or "instrument self noise." The noise floor of any instrument is essentially the electrical noise of the instrument. Most ANSI Type 1 sound level meters, microphones, and preamplifiers have a noise floor, or instrument self noise, of less than 20 dBA. Manufacturers such as Larson-Davis provide general noise floor data for each of their sound level meter models and components. Although such data are provided for each model, actual noise floor levels can vary by 1-2 dBA per individual instrument. Very sensitive, low-noise microphones and preamplifiers have much lower self noise, and some can measure down to 0 dBA.

Data Collection

All acoustic data were collected continuously at 1-second intervals. Sound level meters were set to collect 1-second dBA, dBF, and dBC, as well as unweighted one-third octave band data, 12.5-20,000 Hz. Because we expected sound levels at some locations to be very low (<20 dBA), sound level meters were set to "low-range" with a gain of +20 dB. These settings ensured meters would collect data at the lowest measurement limit for these systems. Time response was set to “fast.”

Data Processing

Acoustic metrics required by the Request for Proposals and recommended by Blickley and Patricelli (2013) were computed for each measurement location, including dBA L_{10}, L_{50}, L_{90}, L_{eq}, L_{min}, and L_{max}. One-third octave data, 20-20,000 Hz, unweighted, were collected at each measurement location. L_{min} and L_{max} values are just that, minimum and maximum values; exceedance metrics, L_{10}, L_{50}, and L_{90}, are the percent time sound levels exceeded 10%, 50%, and 90% of the time; and L_{eq} metrics are energy-averaged from 1-second L_{eq} data. As recommended by Blickley and Patricelli (2012), the L_{90} metric at reference lek locations was considered the “baseline ambient” sound level for native sage land cover in the PAPA. Times during which investigators were present were not included in analysis. Hours with <2700 seconds (75% of an hour) were not included. This ensured that any hour with only a few samples did not bias the analysis

In acoustic studies, it is common to report results in hourly statistics, L_{eq}, L_{10}, L_{50}, L_{90}, etc., over one-hour periods. Two different methods have generally been used to compute acoustic metrics. The first is referred to as the “unpooled” approach, and the second as the “pooled” approach. Both approaches report hourly statistics, but the computational methods differ. The “unpooled” approach computes hourly metrics (L_{eq}, L_{10}, L_{50}, L_{90}, etc.) for each individual hour. For long-term measurements over many days, medians, variances, etc., are computed from hourly data sets. For a 30-day data set, for example, summary hourly metrics for each hour of the day are computed from 30 data points.

Metrics are reported as a function of time of day, for each hour. The "pooled" approach combines all 1-second data from each hour or all hourly data into a single data set, and averages, medians, variances, etc., are computed from the pooled data. As with the "unpooled" approach, metrics are reported as a function of time of day.

Although prior studies (Plotkin 2002) have shown that results for pooled analyses are generally more conservative (i.e., lower) than results for an hourly analysis, analyzing ambient data by hour helps to ensure hour-to-hour and day-to-day variation is addressed. Additionally, many management decisions are based on hour of day. In the case of greater sage-grouse, for example, "lekking" hours may receive special consideration. For these reasons, analysis in this report used "unpooled" data.

We were not able to collect acoustic data for common sources in the gas field at the same distance due to different situations at each source (other nearby sound sources, terrain, land cover, security, etc.). However, it is possible to estimate sound levels at specific distances based on inverse square law and using sound levels measured at known distances. This computation assumes a loss of 6 dB per doubling of distance. Although loss of 6 dB per doubling of distance is commonly used to estimate sound attenuation, several factors influence this rate of loss, including frequency content of the sound, terrain, meteorological conditions, and others. It is important to keep in mind that these calculations are estimates, and we present the results for comparative purposes only. We used 100 meters as a common distance to present the relative (estimated) sound level of common sound sources in the gas field.

Meteorological Data

Meteorological data (wind speed, wind direction, temperature, and humidity) can improve the utility of acoustic data. Previous acoustic studies have established a strong correlation between land cover, wind speed, and ambient sound levels (Lee et al. 2006). Sound levels also attenuate differently in cold or hot temperatures. In general, ambient sound levels tend to increase with increasing wind speeds. Depending primarily upon the vegetative characteristics of the measurement site, a substantial change in sound level can occur as wind speeds increase. For example, ambient sound level data measured at a site containing dense foliage will be influenced by wind, primarily due to the wind interacting with leaves.

Jakobsen and Andersen (1983) described three types of wind sounds: natural wind sounds (sounds of turbulence in the air); vegetation wind sounds (sounds of vegetation being blown by wind): and microphone sounds (sounds of air flow turbulence against windscreen foam or over the microphone, generally considered "distorted" or "contaminated" sound). The first two types of wind sounds listed above are considered natural; the third type of wind sound is considered non-natural.

We used two types of anemometers during measurements. At two of the reference leks, we used Davis anemometers (Model 07911) that input data to the Larson-Davis 831 every second. At three locations in the PAPA gas field area, we use Onset HOBO anemometers (Model S-WSA-M003) that logged 1-second wind speed data to a data logger independent of the Larson-Davis 831. All anemometers were placed 1.5-2.0 m from the microphone at that site. Anemometers were placed at 0.3 m height to match the height of the microphones.

Microphone Windscreen

In the PAPA area, high winds, animals, and human activity are common. In order to minimize the influence of wind on the decibel data and to protect the equipment, we used a second windscreen in addition to the standard 90 mm foam windscreen. The additional windscreen was made of thin fleece material placed over a 0.4 m (15 in) high and 0.3 m (12 in) wide wire cylindrical cage (Appendix D; Figures 7-8). This approach is similar to the dual-stage windscreen used in noise measurement systems in remote and windy areas of national parks (Miller et al. 1997, Lee et al. 2006). In order to test the influence of the fleece windscreen on decibel data, we collected data simultaneously using two LD 831 sound level meters at the Big John lek from April 7-10, 2013. One system had the standard 90 mm foam windscreen only and the other system had the 90 mm foam windscreen plus the fleece and wire cage windscreen. We tested the influence of the additional windscreen on dBA and one-third octave band decibel data, both daily and for all days, and found the influence to be minimal, generally less than the measurement precision of the instruments. Details on the windscreen test are presented in Appendix D. During the course of this study and data analysis, we determined that we did not have wind, security, or animal issues with our microphones or systems. Therefore, we believe the addition of the fleece windscreen is not required.

Microphone and Anemometer Height

Microphones and anemometers were placed 0.3 m (12 in) above the ground. This placement matched the approximate height of a greater sage-grouse ear and thus provided sound levels experienced by greater sage-grouse (Pater et al. 2009, Blickley and Patricelli 2012).

In order to test the influence of microphone height on decibel data, we collected data simultaneously using two LD 831 sound level meters. One system had the microphone at 1.5 m and the other system had the microphone at 0.3 m. We compared the L_{eq}, L_{10}, L_{50}, L_{90}, L_{min} and L_{max} dBA metrics for 1 hour on March 13, 2013 (prior to deployment in Wyoming). All metrics of the 1.5 m microphone were slightly greater than the 0.3 m microphone, but the differences were small (<1.5 dBA for L_{10}, L_{50}, and L_{90}). Test results are presented in Appendix E.

Measurement Locations

We collected acoustic data at 39 different locations in the PAPA in April 2013 (Table 1). We collected data at three reference leks, 19 treatment leks, and 17 gas field sound sources. The reference leks were in the Speedway and Ryegrass complexes, and the treatment leks were in the Mesa, Duke's Triangle, and Yellowpoint complexes. Exact measurement locations for reference and treatment leks are not provided due to security concerns. Most of the measurement locations for gas field sound sources were near leks, and exact locations are not provided due to security concerns. We collected data at the

Jonah compressor station because the compressor station near the South Rocks and Rocks leks was not operational during April 2013.

We placed sound level meters 100-200 meters from the edge of the leks to minimize the potential of grouse display sounds contaminating measurements data. This proved to be a subjective judgment as lekking grouse used a large area in and around the lek area, and grouse sounds were audible at some measurement locations.

We followed recommendations of Blickley and Patricelli (2013), citing Mueller (2002), for placement of sound level meters relative to gas field sound sources near leks. These recommendations included placing sound level meters two source widths away from the source. In most cases, gas field sound sources had several different sound sources within that activity, and these different individual sources were spread throughout the area of the source. For example, a drill rig might be on a pad 150 m across, with drilling, generators, vehicles, and other activities occurring simultaneously on the pad. In this situation, we placed the sound level meter 300 m from the drill pad (150 m x 2 = 300 m). This was not always possible due to interference from other near-by sound sources in the gas field. We placed multiple sound level meters at different distances from gas field sources, and, whenever possible, we doubled the distance between source and each meter. We used a Leica LRF 1200 laser rangefinder to determine distance from sound source to sound level meter.

Measurement Schedule and Duration

All acoustic data were collected during April 2013. At reference leks, data were collected more than14 days, while at treatment leks and gas field sound sources, data were collected for at least 24 hours at most locations.

Results

Acoustic data were collected at 39 different locations (3 reference leks, 19 treatment leks, and 17 gas field sound sources). 2,549 hours of data were collected, 1,001 hours at reference leks, 999 hours at treatment leks, and 549 hours at gas field sound sources (Table 1). Complete dBA and one-third octave band metrics are presented in Appendix A (reference leks); Appendix B (treatment leks); and Appendix C (gas field sound sources).

Reference Leks

At the three reference leks, the L_{90} levels for all hours (0000-2400) ranged from 14.5 dBA to 17.0 dBA, and the L_{50} levels ranged from 16.8 dBA to 20.4 dBA (Table 2). At reference lek PAPA101, distance highway sounds influenced decibel data, while at reference lek PAPA104, grouse display sounds influenced decibel data. Reference lek PAPA103 was least influenced by vehicle sounds or grouse display sounds (L_{90} = 14.5 dBA; L_{50} = 16.8 dBA). L_{eq}, L_{10}, L_{50}, and L_{90} dBA levels for reference leks are shown in Table 3. Hourly dBA metrics and one-third octave band metrics for all reference leks are shown in Appendix A.

Treatment Leks

At the 19 treatment leks, the median sound level (L_{50}) (0000-2400) for all 999 hours was 26.6 dBA. L_{eq}, L_{10}, L_{50}, and L_{90} dBA levels for all treatment leks are shown in Table 4. The Duke's Triangle Complex had the highest sound levels for all metrics of the three complexes, and the Mesa Complex had the lowest (Table 5). Sounds levels at leks were correlated with the type and distance to gas field activities. The Big Fred lek in Duke's Triangle was close to an active drill rig (1055 m) and had the highest sound levels (35.9 dBA), while the Cat lek was far from current gas field activity and had a median sound level of 17.5 dBA.. Hourly dBA metrics and one-third octave band metrics for all treatment leks are shown in Appendix B.

Gas Field Sound Sources

Sound levels of common PAPA gas field activities are shown in Table 6. Of the common activities in the gas field, the median sound level (L_{50}) of active drill rig in the Duke's Triangle complex was the loudest (est. 62 dBA @ 100 m), followed by the injection well complex (56 dBA @ 100 m) in the northern part of the Yellowpoint complex. Other gas field sound sources with L_{50} >50 dBA @ 100 m were a second drill rig being disassembled in the Duke's Triangle complex (54 dBA); Jonah compressor station (54 dBA); central gathering facility in the Mesa Complex with generator (52 dBA); and a well pad with 21 well heads and generator (50 dBA). Hourly dBA metrics and one-third octave band metrics for gas field sound sources are shown in Appendix C.

Table 1. Number, complex, name, date-time start, date-time end, and number of hours of acoustic data collection sites, PAPA, April 2013.

Site Num.	Complex	Lek Name	Date_Time Start	Date_Time End	Hours
Reference Leks					
PAPA101	Speedway	Big John	20130406_1045	20120421_0850	346
PAPA103	Rye Grass	Jewett Red Flat Res.	20130411_1320	20130425_0738	329
PAPA104	Rye Grass	Onion Springs 2	20130411_1445	20130425_0650	326
Treatment Leks					
PAPA001	Duke's Triangle	Big Fred	20130405_1450	20130407_1520	47
PAPA002	Duke's Triangle	Little Fred	20130405_1150	20130407_1235	47
PAPA003	Duke's Triangle	Lower Sand Springs Draw	20130405_1305	20130407_1645	50
PAPA004	Mesa	Two Buttes	20130418_0910	20120421_1345	75
PAPA005	Mesa	Mesa Spring	20130418_0950	20130421_1410	75
PAPA006	Mesa	Lovatt Draw Res.	20130418_1025	20130421_1433	59
PAPA007	Yellowpoint	Shelter Cabin Res.	20130410_0855	20130412_1145	49
PAPA008	Yellowpoint	The Rocks	20130410_1015	20130412_1330	50
PAPA009	Yellowpoint	South Rocks	20130410_1115	20130412_1404	50
PAPA010	Yellowpoint	Stud Horse Butte	20130410_1200	20130412_1434	49
PAPA011	Yellowpoint	Little Saddle	20130412_0910	20130414_0910	47
PAPA012	Yellowpoint	Alkali Draw	20130412_1100	20130414_1020	46
PAPA013	Yellowpoint	Sand Draw	20130412_1245	20130414_1135	46
PAPA014	Mesa	Lovatt West	20130418_1105	20130421_1456	75
PAPA015	Mesa	Cat	20130421_1100	20130423_1300	49
PAPA016	Mesa	Tyler Draw North	20130415_1000	20130417_0920	46
PAPA017	Mesa	Oil Fork Road	20130415_1100	20130417_1005	46
PAPA018	Mesa	Mesa Road 3	20130415_1145	20130417_1115	47
PAPA019	Mesa	Bloom Res. Sat.	20130415_1230	20130417_1134	46
PAPA Sound Sources					
PAPA201	Yellowpoint	Injection well 100 m	20130414_0810	20130415_1355	28
PAPA202	Yellowpoint	Injection well 200 m	20130414_0810	20130415_1355	28
PAPA203	Yellowpoint	Well (3) pad 50 m	20130415_1520	20130416_1420	22
PAPA204	Yellowpoint	Well (3) pad 100 m	20130415_1520	20130416_1420	22
PAPA205	Mesa	CGF (with gen.) 555 m	20130416_1640	20130417_1035	17
PAPA206	Mesa	CGF (with gen.) 255 m	20130416_1715	20130417_1045	16
PAPA207	Duke's Triangle	Drill rig (pad 9-24) 2300 m	20130405_1600	20130407_1605	47
PAPA208	Duke's Triangle	Drill rig (pad 9-24) 300 m	20130405_1730	20130407_1440	44
PAPA209	Speedway	Hwy 191 100 m	20130417_1325	20130418_1335	23
PAPA210	Speedway	Hwy 191 200 m	20130417_1335	20130418_1338	23
PAPA211	Mesa	Well pad ICI 100 m	20130418_1440	20130421_1510	72
PAPA212	Mesa	Well pad ICI-30 200 m	20130415_1455	20130421_1510	65
PAPA213	Mesa	Gobbler's Knob, North, 150 m	20130422_0820	20130424_0925	48
PAPA214	Mesa	N. Anticline Road, 50 m	20130422_0850	20130423_0905	24
PAPA215	Mesa	Well heads, 21 (pad 3-27), 200 m	20130423_0840	20130424_0910	24
PAPA216	Duke's Triangle	Drill rig (pad 5-19), 435 m	20130423_1020	20130424_1020	23
PAPA217	Jonah	Jonah Compressor Sta., 140 m	20130423_1128	20130424_1105	23

Table 2. Hourly existing ambient and baseline ambient sound levels at three reference leks near PAPA, April 2013.

	L50			L90		
Hour	PAPA101	PAPA103	PAPA104	PAPA101	PAPA103	PAPA104
0	16.6	13.7	15.5	15.7	13.5	14.2
1	17.6	13.7	14.8	15.8	13.5	14.2
2	16.4	13.7	14.4	15.5	13.5	14.1
3	16.6	13.6	14.5	15.7	13.4	14.1
4	16.3	13.6	14.6	15.5	13.5	14.3
5	21.5	16.6	34.2	16.8	13.6	16.8
6	23.3	17.0	28.8	18.6	15.3	16.9
7	19.4	16.2	18.0	17.1	14.4	15.0
8	18.0	15.6	16.5	16.3	14.8	14.8
9	19.4	19.6	19.1	16.6	14.5	15.5
10	20.6	20.4	19.0	18.1	15.9	15.3
11	18.5	22.5	20.8	17.2	15.4	17.0
12	21.3	24.0	23.8	17.8	18.4	18.1
13	23.2	24.3	25.7	18.0	18.0	18.2
14	24.2	26.6	26.5	19.1	20.0	20.3
15	24.2	25.1	24.3	19.0	17.6	19.0
16	25.7	26.1	24.6	19.3	18.6	18.7
17	26.6	24.3	22.5	20.6	17.2	15.8
18	25.0	21.4	21.3	19.6	16.4	16.5
19	23.5	17.2	17.2	16.7	14.0	14.4
20	21.4	15.1	19.6	17.6	13.7	14.5
21	20.2	15.4	23.5	16.8	13.7	15.3
22	16.7	14.3	16.1	15.7	13.5	14.3
23	16.8	13.7	15.6	15.6	13.5	14.1

	L50			L90		
Time Period	PAPA101	PAPA103	PAPA104	PAPA101	PAPA103	PAPA104
0000-2400	20.4	16.8	19.4	17.0	14.5	15.3
1800-0900	18.0	15.1	16.5	16.3	13.6	14.4
0500-0900	20.5	16.4	23.4	17.0	14.6	15.9
0000-0500	16.6	13.7	14.6	15.7	13.5	14.2

Time Period	L50 All Sites	L90 All Sites
0000-2400	19.4	15.8
1800-0900	16.6	14.8
0500-0900	18.0	15.8
0000-0500	14.6	14.2

Table 3. L_{eq}, L_{10}, L_{50}, and L_{90} dBA metrics at three reference leks, 0000-2400.

	Lek Name	Hours	Leq	L10	L50	L90
PAPA101	Big John	346	31.0	25.1	20.4	17.0
PAPA103	Jewett Red Flat Res.	329	28.7	24.2	16.8	14.5
PAPA104	Onion Springs 2	326	30.2	29.4	19.4	15.3

Table 4. L_{eq}, L_{10}, L_{50}, and L_{90} dBA metrics at 19 treatment leks, 0000-2400.

Site Number	Complex	Lek Name	Hours	Leq	L10	L50	L90
PAPA001	Duke's Triangle	Big Fred	47	39.8	40.3	36.9	34.8
PAPA002	Duke's Triangle	Little Fred	47	34.7	33.1	28.4	25.2
PAPA003	Duke's Triangle	Lower Sand Springs Draw	50	33.3	32.9	28.4	24.9
PAPA004	Mesa	Two Buttes	75	32.6	30.6	26.4	22.7
PAPA005	Mesa	Mesa Spring	75	36.2	34.6	30.0	26.7
PAPA006	Mesa	Lovatt Draw Res.	59	36.7	35.2	32.0	29.7
PAPA007	Yellowpoint	Shelter Cabin Res.	49	32.7	29.6	26.0	24.1
PAPA008	Yellowpoint	The Rocks	50	32.0	29.5	26.2	24.0
PAPA009	Yellowpoint	South Rocks	50	31.2	30.0	26.2	24.0
PAPA010	Yellowpoint	Stud Horse Butte	49	32.2	31.6	27.3	25.4
PAPA011	Yellowpoint	Little Saddle	47	30.2	29.3	22.3	18.8
PAPA012	Yellowpoint	Alkali Draw	46	31.4	28.7	23.3	20.4
PAPA013	Yellowpoint	Sand Draw	46	36.1	32.0	27.3	23.1
PAPA014	Mesa	Lovatt West	75	33.5	33.7	29.6	27.0
PAPA015	Mesa	Cat	49	28.5	24.8	17.5	16.0
PAPA016	Mesa	Tyler Draw North	46	27.7	26.5	21.8	18.5
PAPA017	Mesa	Oil Road Fork	46	29.2	28.6	24.9	22.2
PAPA018	Mesa	Mesa Road 3	47	30.2	29.3	24.1	20.1
PAPA019	Mesa	Bloom Res. Satellite	46	28.6	26.6	22.0	18.3

Table 5. L_{eq}, L_{10}, L_{50}, and L_{90} dBA metrics for all hours in three complexes.

Complex	Hours	Leq	L10	L50	L90
Duke's Triangle	144	34.7	33.1	28.4	25.2
Mesa	518	30.2	29.3	24.9	22.2
Yellowpoint	337	32.0	29.6	26.2	24.0

Table 6. L_{eq}, L_{10}, L_{50}, and L_{90} dBA metrics for PAPA gas field sound sources, 0000-2400.

Site Number	Complex	Lek Name and Distance	Hours	Leq	L10	L50	L90
PAPA201	Yellowpoint	Injection well 100 m	28	55.6	56.5	55.8	54.9
PAPA202	Yellowpoint	Injection well 200 m	28	48.2	49.5	48.5	47.7
PAPA203	Yellowpoint	Well (3) pad 50 m	22	38.4	39.8	37.5	35.4
PAPA204	Yellowpoint	Well (3) pad 100 m	22	34.8	35.4	31.3	29.3
PAPA205	Mesa	CGF (with gen.) 555 m	17	36.6	37.8	35.7	34.2
PAPA206	Mesa	CGF (with gen.) 255 m	47	39.1	39.5	37.4	35.9
PAPA207	Duke's Triangle	Drill rig (pad 9-24), 2300 m	47	34.9	34.8	30.4	27.2
PAPA208	Duke's Triangle	Drill rig (pad 9-24), 300 m	44	53.7	54.2	52.5	51.0
PAPA209	Speedway	Hwy 191 100 m	23	40.7	34.9	25.8	21.0
PAPA210	Speedway	Hwy 191 200 m	23	36.1	32.6	24.9	21.0
PAPA211	Mesa	Well pad ICI 100 m	72	46.9	46.7	45.5	44.3
PAPA212	Mesa	Well pad ICI-30 200 m	65	40.2	41.4	38.6	37.0
PAPA213	Mesa	Gobbler's Knob, North, 150 m	48	46.0	46.9	43.8	40.3
PAPA214	Mesa	N. Anticline Road, 50 m	24	43.6	39.9	26.9	24.1
PAPA215	Mesa	Pad 3-27 (21 wells), 200 m	24	45.4	47.3	44.4	40.4
PAPA216	Duke's Triangle	Drill rig (pad 5-19), 435 m	23	42.2	42.5	41.2	38.8
PAPA217	Jonah	Jonah Compressor Sta., 140 m	23	51.9	51.8	50.9	50.1

Wind Speed

Wind speed data were collected at five locations in 2013. Wind speed at 0.3 m height rarely exceeded 5 m/s (11 mph) (average 0.022% of the time at five locations) (Table 7). This was due to surrounding sage plants being higher than the anemometers and thus acting as an effective windscreen. As a result, metrics with and without wind >5 m/s did not differ and metrics reported in this report include all 1-second data.

Table 7. Wind speed data at five locations in 2013, three near PAPA leks and two near reference leks.

Wind Speed (m/s)	PAPA011	PAPA019	PAPA207	PAPA101	PAPA103
Mean	0.5	0.4	0.3	0.7	0.2
Min	0.0	0.0	0.0	0.0	0.0
Max	5.7	5.0	6.1	7.2	6.4
Percent >5.0 m/s	0.004%	0.000%	0.003%	0.045%	0.060%

Discussion

Reference Leks

Sound levels at the three reference leks were similar (75% of L_{50} and L_{90} levels <20 dBA). Both PAPA103 (Jewett Red Flat Reservoir) and PAPA104 (Onion Springs 2) were slightly quieter, on average, than PAPA101 (Big John lek), probably due to distant highway noise at PAPA101 (Highway 191 was 7.8 km or 4.5 mi from PAPA101). One-third octave band data were also similar, with higher levels in lower frequencies at Big John lek probably due to distance highway sounds (Figure 3).

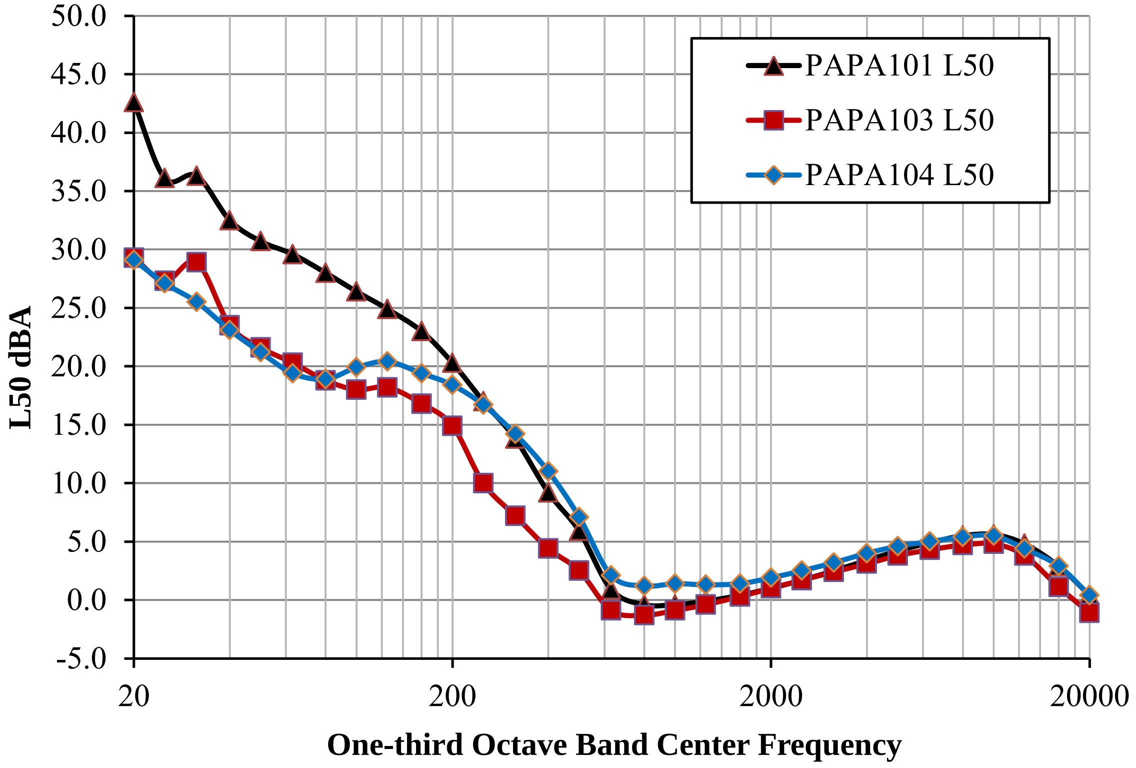

Figure 3. One-third octave band L_{50} levels for all hours at three reference leks, Big John lek, Jewett Flat Red Flat Reservoir lek, and Onion Springs 2 lek, April 2013.

Measurements at Reference Leks and Influence of Greater Sage-Grouse Display Sounds

Sound level meters at the three reference leks were placed 100-200 m from the edge of the lek in an effort to minimize the influence of greater sage-grouse display sounds on the dB data. We assumed this distance would be adequate to minimize such influence but this was not always the case. Both the L_{50} metric, and to a less degree the L_{90} metric, were influenced by grouse sounds (apparent in dB data and verified by playback of recordings). In Figures 4 and 5, it is clear that grouse sounds influenced L_{50} and L_{90} levels during the primary lekking hours, 0500-0900. This was most evident at PAPA104, and to a lesser degree at PAPA101 and PAPA103. Decibel levels from 0000 to 0500 were very low, as was the 0900 hour after lekking activity ended for the day. Review of decibel data and recordings suggest that sound levels during the hours 0500-0900 would be similar to levels during 0000-0500 if grouse were not present. General daily acoustic patterns were evident at the three reference leks and can be seen in Figures 4 and 5. From 0000-0500, sound levels were generally low with few natural or non-natural sounds. From about 0500-0800, grouse sounds were common, declining between the 0800-0900 hours. After the 0900 hour, sound levels began to increase due to common daily sounds sources, including wind through vegetation and increased human activity (vehicle and aircraft sounds).

Use of L_{90} or L_{50} to Establish Baseline Ambient Sound Level

The appropriateness of using either the L_{90} or the L_{50} to establish baseline ambient sound level depends on the duration (or percent time audible) of human-caused sounds. If no human-caused sounds were present, the L_{50} metric would represent the ambient sound level. However, in most locations, there is usually a great deal of human-caused sounds, often more than 50% and L_{90} is the appropriate metric for establishing baseline ambient sound levels. In situations where human-caused sounds are uncommon, the L_{90} metric can underestimates baseline ambient sound level, and the L_{50} is a more appropriate metric for establishing baseline ambient sound levels. The appropriateness of using the L_{90} or L_{50} for establishing baseline ambient sound levels depends on the amount of time that anthropogenic sounds are audible.

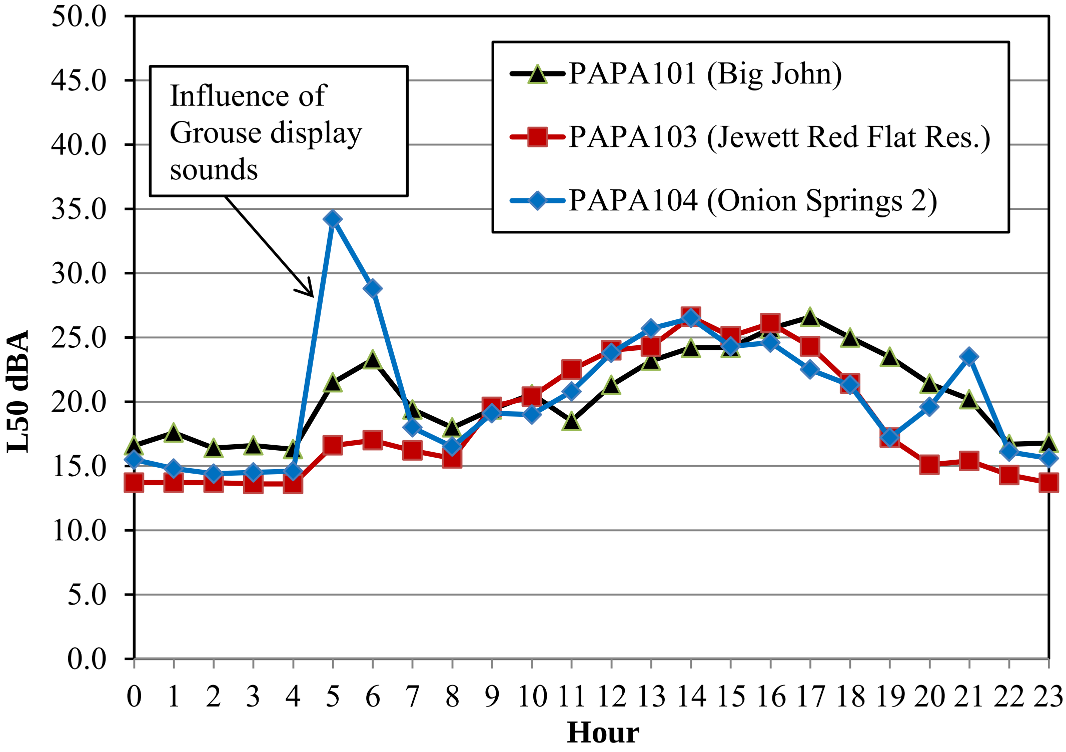

Figure 4. L_{50} dBA at three reference leks, PAPA101, PAPA103, and PAPA104.

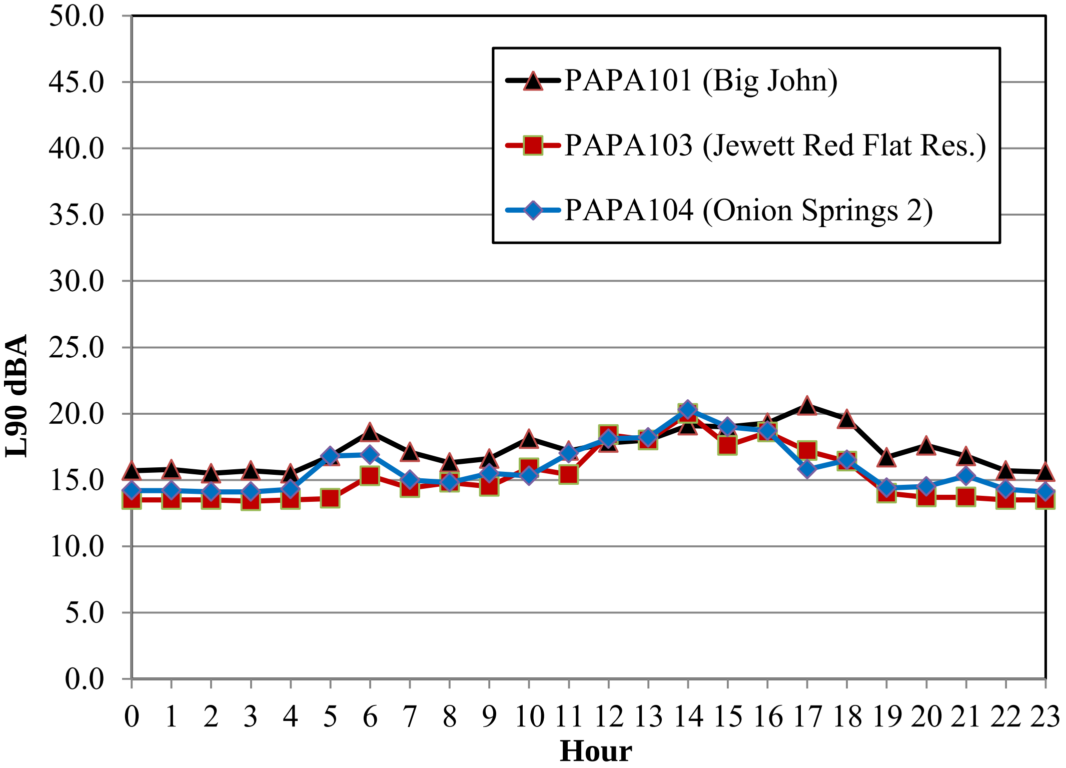

Figure 5. L_{90} dBA at three reference leks, PAPA101, PAPA103, and PAPA104.

Treatment Leks

Sound levels at treatment leks varied a great deal. The lek with the highest median sound level (L_{50}) was the Big Fred lek at 36.9 dBA. This lek was 1050 m from an operating drill rig at pad 9-24 (this drill rig had the highest L_{50} sound level in the gas field, estimated 62 dBA @ 100 m). The treatment lek with the lowest median sound level (L_{50}) was the Cat lek at 17.5 dBA, and the closest gas field activity was 2.6 km. Differences in sound levels at treatment leks were due primarily to distance from and type of gas field activity.

Hours Exceeding Baseline Ambient + 10 dBA

The Record of Decision (ROD) (BLM 2008) specified noise thresholds above baseline levels that should not be exceeded by industry. Specific changes requiring mitigation are described as follows: "Decibel levels at the lek more than 10 dBA above baseline measured from the edge of the lek" (BLM 2008)." The ROD also specifies concurrent declines in grouse numbers, but that aspect was not part of this project. The ROD used 39 dBA as a baseline ambient based on an EPA 1973 study that measured sound levels in a farming area in Ohio. Of the 999 hours measured at the treatment leks, no hours exceeded 49 dBA (39 + 10 = 49 dBA), and 565 (57%) exceeded 26 dBA (10 dBA over baseline ambient, 16+10 = 26 dBA). This study did not attempt to evaluate the appropriateness of either 10 dBA above an ambient of 39 dBA or 10 dBA above an ambient of 16 dBA as a trigger for mitigation. Results of this study show that 16 dBA is a more accurate baseline ambient sound level in the PAPA area, and we concur with the KC Harvey (2009) conclusion that "development of the 39 dBA background level did not include collection or analysis of any noise data from the project area. Therefore, the relevance of the 39 dBA value should be evaluated with respect to noise data from the project area"

Sound Levels in 2013 and 2013 Counts of Greater Sage-grouse at Leks

One should use caution in comparing 2013 sound levels at treatment leks and 2013 counts of greater sage-grouse at these leks. The 2013 count numbers may have been influenced by sound levels in 2013; however, the 2013 counts were also probably influenced by activities and sounds of gas field operations in previous years, among other factors. Sound levels in the gas field change often, depending on the activity and the duration of that activity. For example, an operational drill rig near a lek in some years before 2013 might have produced sound levels sufficient to influence grouse numbers at that lek, but in 2013, that drill rig might have been replaced by well heads only, a much quieter type of activity. The potential influence of gas field sounds on counts of greater sage-grouse, and how long those influences last, are not well understood, and any single year of data should be used with caution.

Gas Field Sound Sources

We measured gas field sound sources at 100 m whenever possible; however, this could not be done for all sources. When we could not measure at 100 m, we estimated sound levels at 100 m by re-computing sound levels measured at known distances (assuming a loss of 6 dBA per doubling of distance). We then used 100 m as the common distance to compared sound levels of different sources in the gas field. The drill rig (pad 9-24) in the Duke's Triangle complex was the loudest sound source (est. 62 dBA @ 100 m) followed by the injection well complex (est. 56 dBA @ 100 m) in the northern part of the

Yellowpoint complex. Other gas field sound sources with L_{50} >50 dBA (est.) @ 100 m were a drill rig (pad 3-21) (54 dBA); Jonah compressor station (54 dBA); central gathering facility in the Mesa Complex, with generator (52 dBA); and a well pad with 21 well heads and generator (50 dBA). Other gas field sound sources measured had L_{50} levels <50 dBA @100 m. Sound levels of gas field activities are shown in Table 8 with the estimated dBA level at 100 m. As discussed earlier, wind speed did not significantly influence sound levels in this study due to the microphones being 0.3 m high and lower than surrounding vegetation. However, sound levels measured long distances from sources can be influenced by wind speed and direction (downwind levels are higher and upwind levels are lower). We did not measure wind direction when collecting data at gas field sound sources, but the levels reported could have some directional wind influence.

At both road measurement sites (Highway 191 and North Anticline Road), median (L_{50}) sound levels for all hours were relatively low, 31 dBA and 21 dBA respectively. Vehicle sounds levels were highest during normal work hours, between about 0500-1900, and some maximum levels were higher than 70 dBA. At both locations, the L_{50} and L_{90} sound levels for all hours were generally close, while the L_{10} and L_{eq} levels were much higher, suggesting the vehicle events, while often at high sound levels, occurred <50% of the time at these locations.

Table 8. Estimated dBA @ 100 m of common gas field activities, PAPA, April 2013.

Site Number	Complex	Gas Field Sound Source	Measured Dist. (m)	L50 @ Meas. Dist.	L50 (est.) @ 100 m
PAPA208	Duke's Triangle	Drill rig, pad 9-24	300	52.5	62.0
PAPA207	Duke's Triangle	Drill rig, pad 9-24	2300	30.4	57.6
PAPA001	Duke's Triangle	Drill rig, pad 9-24	1055	36.9	57.4
PAPA201	Yellowpoint	Injection well	100	55.8	55.8
PAPA202	Yellowpoint	Injection well	200	48.5	54.5
PAPA216	Duke's Triangle	Drill rig, pad 5-19	435	41.2	54.0
PAPA217	Jonah	Jonah Compressor Station	140	50.9	53.8
PAPA206	Mesa	CGF (with generator)	255	37.4	52.3
PAPA215	Mesa	Pad 3-27 (21 wells)	200	44.4	50.4
PAPA213	Mesa	Gobbler's Knob, North	150	43.8	47.3
PAPA211	Mesa	Well pad ICI-30	100	45.5	45.5
PAPA212	Mesa	Well pad ICI-30	200	38.6	44.6
PAPA205	Mesa	CGF (with generator)	555	35.7	43.8
PAPA203	Yellowpoint	Well (3) pad	50	37.5	31.5
PAPA204	Yellowpoint	Well (3) pad	100	31.3	31.3
PAPA210	Speedway	Hwy 191	200	24.9	30.9
PAPA209	Speedway	Hwy 191	100	25.8	25.8
PAPA214	Mesa	North Anticline Road	50	26.9	20.9

Human-caused mechanical sounds tend to have more energy in the lower frequencies (<1,000 Hz), and common sound sources in the gas field followed this trend. Some gas field sound sources had levels higher than ambient at higher frequencies, up to 8,000 Hz. Figure 6 shows the L_{eq} levels for frequency data, 12.5-20,000 Hz, for three measurement locations: PAPA103 (Jewett Red Flat Reservoir reference lek); PAPA208 (drill rig, pad 9-24 in Duke's Triangle complex); and PAPA201 (Yellowpoint injection well complex). Note that Figure 3 is a plot of L_{50} values, whereas this figure is a plot of L_{eq} values

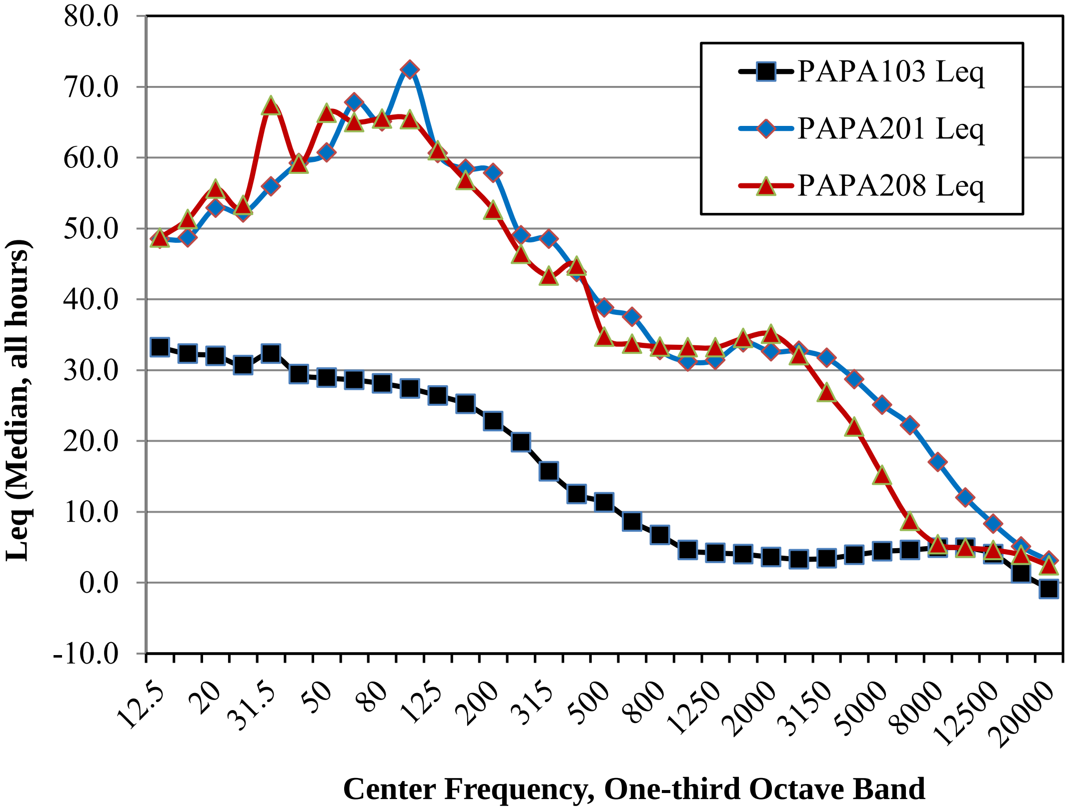

Figure 6. L_{eq} (median, all hours) one-third octave band frequency levels for three measurement sites: PAPA103 (Jewett Red Flat Reservoir reference lek); PAPA201 (Yellowpoint injection wells); and PAPA208 (Drill rig at pad 9-24).

Sound Levels at Treatment Leks Relative to Gas Field Activities

Acoustic measurements at the treatment leks were generally made 100-200 m from the lek (in an effort to minimize lekking sounds influence on dB data). Most of these treatment leks were relatively close to some type of gas field activity (average distance 1690 m, range 375-5800 m). In Table 9, the distance to the nearest gas field activity and the 24-hour L_{50} dBA are presented. As one would expect, the farther the lek was from the sound source, the lower the L_{50} value. However, some gas field activities were much louder than others, especially the active drill rigs, and had a greater influence on sound levels at leks.

Table 9. Sound levels (L_{50} dBA, 0000-2400) of gas field activities as measured at treatment leks, distance from lek to activity, and type of closest activity.

Treatment Lek Name	Treatment Lek	Distance to Activity (m)	L_{50} dBA (24-hr)	Type of Activity
Big Fred	PAPA001	1050	36.9	Drill rig, active
Little Fred	PAPA002	1250	29.3	Pump pad, small, no generator
Lower Sand Springs Draw	PAPA003	1723	29.0	Drill rig, active
Two Buttes	PAPA004	1931	26.4	Pump pad, large (out of view)
Mesa Spring	PAPA005	913	29.9	Pump pad, large (out of view)
Lovatt Draw Res.	PAPA006	710	32.1	Drill rig, maintenance
Shelter Cabin Res.	PAPA007	780	26.6	Pump pad, small, no generator
The Rocks	PAPA008	1590	26.3	Road, inactive compressor
South Rocks	PAPA009	1670	26.2	Pump pad, small
Stud Horse Butte	PAPA010	580	27.4	Pump pad, small, no generator
Little Saddle	PAPA011	5800	22.4	Injection facility, large (out of view)
Alkali Draw	PAPA012	520	22.6	Pump pad, small
Sand Draw	PAPA013	810	27.3	Drill rig
Lovatt West	PAPA014	375	29.6	Pump pad with injection well, generator
Cat	PAPA015	2600	19.0	Pump pad, small (out of view)
Tyler Draw North	PAPA016	810	21.5	Pump pad, small (out of view)
Oil Fork Road	PAPA017	2060	24.8	Central Gathering Fac., generator.
Mesa Road 3	PAPA018	2300	24.1	Pump pad, small
Bloom Res. Sat.	PAPA019	4700	22.0	Pump pad, small

Sound Levels near the Instrument Self Noise (Noise Floor)

When sound levels are very low (near the lower measurement limit of the sound level meter, or "noise floor"), self noise of the instrument can influence decibel readings. When this occurs, actual environmental sound levels are lower than the value reported by the meter. It is important to acknowledge that very low readings reflect some influence by instrument self-noise and actual levels are lower than reported.

All sound level meters have some inherent electrical noise (self noise) in the system components, such as that introduced by the microphone, preamplifier, and power supply. All system components contribute some degree to the inherent noise of the sound level meter system. Highly sensitive, low-noise components have less inherent noise and thus can measure lower sound levels.

The sound pressure level displayed by the sound level meter is actually the addition of instrument self noise and the actual ambient sound level. Two sound levels of equal value, when added together, produce a level 3 dB greater than the sound level from one of these sources because of logarithmic addition [$10*\log_{10}(2)=3$]. For example, if the self noise of the sound level meter was 15.0 dBA, and the actual ambient sound level was 15.0

dBA, the reading on the meter would read 18.0 dBA (15 dBA + 15 dBA = 18 dBA). When two SPLs that are 10 dB different from each other are added together, there is little added influence from the lower value. For example, 15.0 dB + 25.0 dB = 25.5 dB. Thus, the influence of instrument self noise is greatest when actual sound levels are near instrument self-noise, and this influence decreases as environmental sound levels increase. When environmental sound levels are greater than10 dB above instrument self-noise, there is very little influence.

The most important aspect of this issue is that when reported sound levels are near the self noise of the instrument, actual sound levels are lower. The actual sound levels can be estimated using the log additive function. For example, at PAPA103 (reference lek near Jewett Red Flat Reservoir), the reported L_{90} was 14.5 dBA (0000-2400), and the minimum reported level was 13.1 dBA. Assuming a noise floor of approximately this level, the reported L_{90} of 14.5 dBA would represent an estimated L_{90} of 8.9 dBA (13.1 dBA + 8.9 dBA = 14.5 dBA). Similarly, the reported L_{50} of 16.8 dBA would represent an estimated L_{50} of 14.4 dBA. Because these estimated L_{90} and L_{50} values are just estimates, they are generally not reported. Regardless, in such situations, one can be sure that actual values are lower than reported.

Wind Speed

For the five locations where wind speed data were collected, winds rarely exceeded 5 m/s (<0.022% on average). This was due to the sage vegetation being higher than the anemometer and thus providing a "natural" windscreen. The same benefit likely shields greater sage-grouse from experiencing high winds when they are in sage vegetation. Based on these wind speed data collected in 2013, it may not be necessary to collect wind speed relative to decibel data; however, wind speed and wind direction data may be important for other needs, such as modeling sound levels at specific locations upwind or downwind from a sound source.

Audibility and Common Sound Sources

At one location, reference lek PAPA103, Jewett Red Flat Reservoir, we used the digital recordings to determine the percent time that common sound sources were audible for one day, April 19, 2013. We sampled the continuous recording by listening to a 10-second recording every 4 minutes of that day, and logging all sounds heard on those samples. The most common natural sounds were wind (43.9%) and birds (28.9%). The most common non-natural sounds were jet aircraft (16.1%) and vehicles/motors (6.7%). In Table 10, percent time audible of common sound sources, natural and non-natural, are presented for three time periods of the day, all day (0000-2400), day time (0700-1900), and night time (1900-0700).

Table 10. Percent time common sound sources were audible at PAPA103, Jewett Flat Red Reservoir, April 19, 2013, for three time periods of the day.

Sound Source	0000-2400	0700-1900	1900-0700
No Sound Audible	22.2	2.8	41.7
Wind	43.9	80.0	7.8
Bird	28.9	18.9	38.9
Jet	16.1	20.0	12.2
Prop	2.5	2.8	2.2
Helicopter	0.0	0.0	0.0
Road Vehicles	2.8	5.0	0.6
Motor Sounds	3.9	2.8	5.0

Total Non-natural	25.0	30.0	20.0
Total Natural	69.7	92.8	46.7

Recommendations

Establish Protocol for Measuring Sound Levels Relative to Greater Sage-grouse

In previous acoustic studies regarding greater sage-grouse and gas exploration and production activities, several different measurement approaches and instrument types have been used. Noise floors of instruments used in those studies have ranged from less than15 dBA (this study) to 25 dBA (McGregor 2008). Microphone height has ranged from 0.3 m (this study) to 2.4 m (BLM 2012). Measure periods have ranged from less than 1 hour to more than 14 days. A standard protocol for measuring sound levels is necessary to ensure all data are useful for greater sage-grouse management. The measurement protocol below is proposed for acoustic studies regarding greater sage-grouse and anthropogenic noise. This proposed protocol follows recommendations by Blickley and Patricelli (2013) as well as those by the FAA and NPS (NPS 2005 and 2013, Lee et al. 2006, Lynch et al. 2011, Hari 2005, Rapoza et al. 2008), and based on our experience in and near the PAPA in 2013. We recommend that this draft protocol be reviewed by all parties involved in acoustic studies relative to greater sage-grouse, including federal, state, and industry officials, and a common protocol be developed and agreed upon for future acoustic studies.

Sound level measurements must be representative of the sound levels experienced by the target species (Grubb et al. 1998, Delaney et al. 1999, Pater et al. 2009, Blickley and Patricelli 2013). This includes both microphone height as well as equipment sensitivity. For greater sage-grouse, average ear height is about 0.3 m and this species is a ground nester, hence microphones should be 0.3 m high. Although ANSI standards recommend placing microphones at 1.5 m, these standards were written specifically for assessing impacts to human, and use the typical height of a human ear, 1.5 m.

Sound levels vary greater due to seasonal and meteorological conditions, and the appropriate measurement duration for the breeding season of greater sage-grouse is not well understood. This period lasts from approximately mid-March to July. Long-term NPS studies demonstrated that summer and winter seasons vary considerable, and a 25-day measurement period would generally ensure measurement accuracy to ±3 dBA for either season (Hari 2005). Given that the breeding season of greater sage-grouse is typically four to five months, and wind speeds are considerably less at 0.3 m, we recommend a minimum 14-day measurement period until more is known about sound level variability during the March-July period.

Recommended Protocol for Measuring Sound Levels relative to Greater Sage-grouse.

- Sound level meters should meet ANSI Type 1 standards.
- Sound level meters should be capable of measuring <15 dBA.
- Data collected should include dBA, dBC, and dBF, and unweighted one-third octave band frequency data, 12.5-20,000 Hz.
- Decibel data should be collected continuously, at 1-second intervals.
- Data analysis: At a minimum, report hourly dBA, dBC, and dBF, and unweighted one-third octave band metrics, including L_{eq}, L_{10}, L_{50}, L_{90}, L_{min}, and L_{max}.
- Microphone height should be 0.3 m, approximate ear height of greater sage-grouse.
- Measurement duration should be a minimum of 14 days at each location.
- Continuous digital recordings should be collected at all measurement locations. This will ensure all unusual sound sources and sound levels can be reviewed, and will allow the opportunity to determine the percent time that different sound sources are audible. Recording quality should be at a minimum MP3, 16-bit, 128 kbps; uncompressed .wav, 16-bit, 44,100 kHz preferred.
- In most acoustic studies, wind speed data are needed to assess influence of wind pressure on dB data. However, when microphones are placed at 0.3 m and good windscreens are used, and measurements are made in sage habitat that is higher than 0.3 meters, it is unlikely that wind pressure over microphone will influence dB data. Therefore, wind speed data are not required if the microphone height of 0.3 meters is used. If meteorological data are needed for modeling efforts, such should be collected during the measurement period.
- Instruments should be placed >500 m from any lek to ensure grouse display sounds do not significantly influence dB data.
- For determining baseline ambient sound levels, the L_{90} metric should be used if human-caused sounds are audible >25% of the time. If human-caused sounds are audible <25% of the time, the L_{50} metric should be used. Audibility of human-caused sounds should be determined by logging sound sources from a sample of continuous digital recordings (7 days minimum and a sampling rate of 10 seconds every 4 minutes minimum). It is important that all hours of the day be considered when determining baseline ambient sound levels. While lekking hours are important to grouse, females with nestlings rely on relatively low-level calls to maintain contact with each other and to warn of potential predators. Therefore, all hours should be measured and reported.

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Appendix A. dBA and One-third Octave Metrics for PAPA Reference Leks.

Table 11. PAPA101 (Big John lek) hourly dBA metrics, April 6-21, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/6/2013	4/21/2013	0	14	13.7	49.7	23.4	19.3	16.6	15.7
4/6/2013	4/21/2013	1	14	13.8	49.0	22.4	20.0	17.6	15.8
4/6/2013	4/21/2013	2	14	13.7	47.1	21.1	18.4	16.4	15.5
4/6/2013	4/21/2013	3	14	13.7	46.3	21.6	17.8	16.6	15.7
4/6/2013	4/21/2013	4	14	13.7	48.1	22.3	20.2	16.3	15.5
4/6/2013	4/21/2013	5	14	13.8	50.2	24.4	27.0	21.5	16.8
4/6/2013	4/21/2013	6	14	13.8	49.3	25.5	28.0	23.3	18.6
4/6/2013	4/21/2013	7	14	13.8	68.9	33.0	24.3	19.4	17.1
4/6/2013	4/21/2013	8	13	13.9	54.7	26.4	25.6	18.0	16.3
4/6/2013	4/21/2013	9	13	14.0	51.7	26.3	24.8	19.4	16.6
4/6/2013	4/21/2013	10	14	14.2	53.2	30.3	24.7	20.6	18.1
4/6/2013	4/21/2013	11	14	14.4	55.0	31.9	24.4	18.5	17.2
4/6/2013	4/21/2013	12	15	14.4	67.6	34.1	28.5	21.3	17.8
4/6/2013	4/21/2013	13	15	14.9	56.4	33.1	32.3	23.2	18.0
4/6/2013	4/21/2013	14	15	14.5	56.9	33.8	31.1	24.2	19.1
4/6/2013	4/21/2013	15	15	14.4	57.0	34.0	31.4	24.2	19.0
4/6/2013	4/21/2013	16	15	14.2	53.8	32.3	33.6	25.7	19.3
4/6/2013	4/21/2013	17	15	14.3	54.8	31.8	34.5	26.6	20.6
4/6/2013	4/21/2013	18	15	14.0	56.6	32.8	31.2	25.0	19.6
4/6/2013	4/21/2013	19	15	14.1	57.4	32.7	30.2	23.5	16.7
4/6/2013	4/21/2013	20	15	14.0	60.2	30.7	25.4	21.4	17.6
4/6/2013	4/21/2013	21	15	13.8	60.4	31.2	23.8	20.2	16.8
4/6/2013	4/21/2013	22	15	13.8	60.7	32.8	22.2	16.7	15.7
4/6/2013	4/21/2013	23	15	13.7	54.7	24.0	20.9	16.8	15.6

Appendix A. dBA and One-third Octave Metrics for PAPA Reference Leks (cont.).

Table 12. PAPA101 (Big John lek) dBA and one-third octave band metrics, April 6-12, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/6/13	4/21/13	dBA	346	13.7	68.9	30.8	25.8	20.1	17.1
4/6/13	4/21/13	12.5	346	14.2	78.7	54.2	46.0	39.2	34.0
4/6/13	4/21/13	16	346	16.2	76.3	51.7	45.7	39.3	34.7
4/6/13	4/21/13	20	346	17.2	75.3	50.1	48.0	42.6	37.6
4/6/13	4/21/13	25	346	17.2	74.5	46.5	41.5	36.1	32.1
4/6/13	4/21/13	31.5	346	15.5	71.4	44.3	41.7	36.3	31.7
4/6/13	4/21/13	40	346	13.2	70.7	41.4	36.8	32.5	29.1
4/6/13	4/21/13	50	346	11.1	74.7	38.9	35.5	30.7	27.3
4/6/13	4/21/13	63	346	8.8	81.6	37.3	34.7	29.6	26.1
4/6/13	4/21/13	80	346	4.7	82.2	36.3	33.5	28.0	24.4
4/6/13	4/21/13	100	346	2.7	86.2	35.4	32.0	26.4	22.6
4/6/13	4/21/13	125	346	0.5	74.4	33.0	30.7	24.9	20.8
4/6/13	4/21/13	160	346	-2.5	69.3	30.3	29.7	23.0	18.1
4/6/13	4/21/13	200	346	-3.1	71.6	28.5	27.2	20.3	14.9
4/6/13	4/21/13	250	346	-3.9	64.7	26.6	24.7	17.0	11.2
4/6/13	4/21/13	315	346	-5.0	62.6	24.2	21.9	13.8	7.0
4/6/13	4/21/13	400	346	-4.8	57.7	21.5	17.2	9.2	2.4
4/6/13	4/21/13	500	346	-4.7	53.7	19.7	14.9	5.9	-0.1
4/6/13	4/21/13	630	346	-4.5	50.0	17.3	7.2	0.9	-1.9
4/6/13	4/21/13	800	346	-4.0	47.6	15.8	5.6	-0.4	-2.0
4/6/13	4/21/13	1000	346	-3.3	45.5	15.5	5.5	-0.4	-1.7
4/6/13	4/21/13	1250	346	-2.6	44.8	15.1	5.0	-0.1	-1.1
4/6/13	4/21/13	1600	346	-1.8	42.5	14.8	4.9	0.4	-0.5
4/6/13	4/21/13	2000	346	-0.8	45.7	14.7	4.7	1.0	0.4
4/6/13	4/21/13	2500	346	0.1	56.8	14.4	4.3	1.7	1.2
4/6/13	4/21/13	3150	346	0.3	65.1	16.2	3.8	2.5	2.1
4/6/13	4/21/13	4000	346	-0.2	64.3	14.4	4.2	3.4	3.1
4/6/13	4/21/13	5000	346	-0.4	51.0	8.9	4.8	4.2	3.9
4/6/13	4/21/13	6300	346	-0.7	45.7	8.3	5.4	4.9	4.7
4/6/13	4/21/13	8000	346	-0.9	46.0	8.5	5.8	5.5	5.3
4/6/13	4/21/13	10000	346	-0.7	45.6	8.4	5.9	5.6	5.4
4/6/13	4/21/13	12500	346	-0.9	44.7	7.4	5.3	4.8	4.6
4/6/13	4/21/13	16000	346	-1.2	44.8	5.6	3.5	2.9	2.6
4/6/13	4/21/13	20000	346	-1.0	41.3	2.8	1.4	0.4	0.0

Appendix A. dBA and One-third Octave Metrics for PAPA Reference Leks (cont.).

Table 13. PAPA102 (Big John lek) hourly dBA metrics, April 6-10, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/6/2013	4/10/2013	0	4	14.8	48.1	25.4	24.6	21.0	18.8
4/6/2013	4/10/2013	1	4	15.0	48.1	23.7	23.0	19.2	17.0
4/6/2013	4/10/2013	2	4	15.4	42.5	22.7	22.5	19.8	16.9
4/6/2013	4/10/2013	3	4	15.4	39.4	23.9	24.4	20.9	18.1
4/6/2013	4/10/2013	4	4	15.6	48.4	24.9	21.8	19.2	17.5
4/6/2013	4/10/2013	5	4	15.8	41.8	21.9	24.4	20.5	17.3
4/6/2013	4/10/2013	6	4	15.4	44.8	25.3	28.2	24.7	19.6
4/6/2013	4/10/2013	7	4	14.6	46.8	22.5	24.2	19.9	17.9
4/6/2013	4/10/2013	8	4	14.6	49.4	24.6	23.9	18.0	16.4
4/6/2013	4/10/2013	9	4	14.9	49.2	24.1	23.9	18.6	17.1
4/6/2013	4/10/2013	10	4	15.4	49.5	23.1	23.2	18.4	17.3
4/6/2013	4/10/2013	11	4	15.9	45.6	22.8	22.7	18.2	16.7
4/6/2013	4/10/2013	12	5	15.6	68.5	33.5	24.9	20.3	17.8
4/6/2013	4/10/2013	13	5	15.5	48.1	27.9	29.8	22.6	18.5
4/6/2013	4/10/2013	14	5	15.3	51.1	28.8	28.4	21.2	19.3
4/6/2013	4/10/2013	15	5	15.2	47.5	29.5	28.3	23.5	19.9
4/6/2013	4/10/2013	16	5	15.1	48.9	28.0	27.8	24.1	18.4
4/6/2013	4/10/2013	17	5	15.2	52.3	30.2	27.3	23.0	17.7
4/6/2013	4/10/2013	18	5	14.7	52.5	31.1	30.6	21.6	19.8
4/6/2013	4/10/2013	19	5	14.9	51.1	33.7	29.2	23.2	20.6
4/6/2013	4/10/2013	20	5	15.0	60.3	32.2	27.2	22.4	20.7
4/6/2013	4/10/2013	21	4	14.8	52.4	32.1	26.5	22.5	19.9
4/6/2013	4/10/2013	22	4	14.7	53.8	34.7	26.3	21.5	17.9
4/6/2013	4/10/2013	23	4	15.0	47.2	24.8	25.6	22.0	18.9

Appendix A. dBA and One-third Octave Metrics for PAPA Reference Leks (cont.).

Table 14. PAPA102 (Big John lek) dBA and one-third octave band metrics, April 6-10, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/6/13	4/10/13	dBA	105	14.6	68.5	29.3	25.5	20.9	17.8
4/6/13	4/10/13	12.5	105	15.8	79.2	54.1	45.0	39.2	34.5
4/6/13	4/10/13	16	105	18.2	76.2	51.7	46.1	40.5	35.5
4/6/13	4/10/13	20	105	16.9	74.7	49.2	48.8	43.1	38.9
4/6/13	4/10/13	25	105	17.5	70.5	44.3	41.5	37.2	33.3
4/6/13	4/10/13	31.5	105	16.4	67.5	42.7	41.8	37.3	33.2
4/6/13	4/10/13	40	105	14.1	65.9	39.4	37.2	33.4	30.1
4/6/13	4/10/13	50	105	11.3	75.1	37.3	35.2	31.5	28.6
4/6/13	4/10/13	63	105	9.3	80.8	37.3	34.7	30.5	27.4
4/6/13	4/10/13	80	105	8.7	84.1	37.3	34.0	28.9	25.2
4/6/13	4/10/13	100	105	5.4	84.5	37.7	32.5	27.7	24.4
4/6/13	4/10/13	125	105	3.3	72.7	33.2	31.0	26.4	22.3
4/6/13	4/10/13	160	105	1.1	69.5	30.5	30.4	24.0	19.8
4/6/13	4/10/13	200	105	-0.8	69.4	28.0	27.3	21.2	16.5
4/6/13	4/10/13	250	105	-2.8	66.8	25.2	23.3	17.6	12.5
4/6/13	4/10/13	315	105	-3.4	58.2	23.0	21.2	14.5	9.0
4/6/13	4/10/13	400	105	-4.2	58.5	20.9	16.7	10.1	4.6
4/6/13	4/10/13	500	105	-4.1	51.2	18.9	14.6	6.3	0.3
4/6/13	4/10/13	630	105	-3.7	48.4	16.3	8.5	1.3	-1.3
4/6/13	4/10/13	800	105	-3.0	47.2	14.2	6.2	0.3	-1.1
4/6/13	4/10/13	1000	105	-2.3	43.3	14.0	5.9	0.5	-0.6
4/6/13	4/10/13	1250	105	-1.3	40.3	14.1	5.7	1.0	0.1
4/6/13	4/10/13	1600	105	-0.4	37.8	14.7	5.6	1.7	0.9
4/6/13	4/10/13	2000	105	0.6	38.5	13.7	4.8	2.4	1.8
4/6/13	4/10/13	2500	105	1.5	39.6	12.4	4.7	3.1	2.6
4/6/13	4/10/13	3150	105	2.6	40.4	10.4	4.9	3.8	3.4
4/6/13	4/10/13	4000	105	0.6	42.4	9.0	5.2	4.5	4.2
4/6/13	4/10/13	5000	105	0.0	48.7	8.7	5.6	5.0	4.8
4/6/13	4/10/13	6300	105	0.0	42.6	8.2	5.7	5.3	5.1
4/6/13	4/10/13	8000	105	-0.3	39.2	7.8	5.7	5.4	5.1
4/6/13	4/10/13	10000	105	-0.5	38.4	7.2	5.5	5.2	4.9
4/6/13	4/10/13	12500	105	-0.7	36.9	6.4	5.1	4.7	4.4
4/6/13	4/10/13	16000	105	-0.5	34.1	5.5	4.5	3.9	3.6
4/6/13	4/10/13	20000	105	-0.2	30.9	4.2	3.7	2.8	2.6

Appendix A. dBA and One-third Octave Metrics for PAPA Reference Leks (cont.).

Table 15. PAPA103 (Jewett Red Flat Reservoir lek) hourly dBA metrics, April 11-25, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/11/2013	4/25/2013	0	14	13.2	55.1	23.6	15.1	13.7	13.5
4/11/2013	4/25/2013	1	14	13.2	49.4	20.8	15.5	13.7	13.5
4/11/2013	4/25/2013	2	14	13.1	42.7	16.7	14.4	13.7	13.5
4/11/2013	4/25/2013	3	14	13.1	45.4	16.4	14.0	13.6	13.4
4/11/2013	4/25/2013	4	14	13.1	50.8	21.8	15.5	13.6	13.5
4/11/2013	4/25/2013	5	14	13.1	46.5	20.0	19.9	16.6	13.6
4/11/2013	4/25/2013	6	14	13.1	47.2	19.7	20.9	17.0	15.3
4/11/2013	4/25/2013	7	13	13.1	47.5	19.6	18.7	16.2	14.4
4/11/2013	4/25/2013	8	13	13.3	49.8	25.3	21.9	15.6	14.8
4/11/2013	4/25/2013	9	13	13.6	57.4	28.9	26.5	19.6	14.5
4/11/2013	4/25/2013	10	13	13.7	50.5	28.3	29.7	20.4	15.9
4/11/2013	4/25/2013	11	13	13.7	56.2	28.4	29.9	22.5	15.4
4/11/2013	4/25/2013	12	13	13.9	55.0	33.0	32.2	24.0	18.4
4/11/2013	4/25/2013	13	13	13.9	84.3	42.2	33.8	24.3	18.0
4/11/2013	4/25/2013	14	14	13.9	53.9	31.9	33.4	26.6	20.0
4/11/2013	4/25/2013	15	14	13.8	55.0	31.5	33.0	25.1	17.6
4/11/2013	4/25/2013	16	14	13.6	53.4	32.6	33.2	26.1	18.6
4/11/2013	4/25/2013	17	14	13.5	56.5	31.7	31.7	24.3	17.2
4/11/2013	4/25/2013	18	14	13.4	59.2	33.5	29.8	21.4	16.4
4/11/2013	4/25/2013	19	14	13.4	60.1	35.4	26.7	17.2	14.0
4/11/2013	4/25/2013	20	14	13.3	53.6	29.6	23.3	15.1	13.7
4/11/2013	4/25/2013	21	14	13.2	64.3	32.4	24.4	15.4	13.7
4/11/2013	4/25/2013	22	14	13.2	57.5	32.5	24.0	14.3	13.5
4/11/2013	4/25/2013	23	14	13.2	51.7	23.9	20.1	13.7	13.5

Appendix A. dBA and One-third Octave Metrics for PAPA Reference Leks (cont.).

Table 16. PAPA103 (Jewett Red Flat Reservoir lek) dBA and one-third octave band metrics, April 11-25, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/11/13	4/25/13	dBA	329	13.1	84.3	32.0	24.1	16.4	14.2
4/11/13	4/25/13	12.5	329	8.8	77.0	46.2	34.9	30.1	26.1
4/11/13	4/25/13	16	329	9.9	74.2	43.6	34.0	29.5	25.9
4/11/13	4/25/13	20	329	10.8	73.2	41.6	34.0	29.3	25.6
4/11/13	4/25/13	25	329	9.7	69.6	37.9	32.8	27.3	23.7
4/11/13	4/25/13	31.5	329	9.3	68.1	36.9	34.8	28.9	24.6
4/11/13	4/25/13	40	329	4.2	64.1	34.0	31.8	23.5	20.2
4/11/13	4/25/13	50	329	1.8	66.3	32.5	31.4	21.6	18.3
4/11/13	4/25/13	63	329	-0.4	77.8	32.1	30.8	20.3	16.3
4/11/13	4/25/13	80	329	-1.1	77.5	31.8	30.0	18.8	14.1
4/11/13	4/25/13	100	329	-2.2	77.6	33.5	29.3	18.0	12.9
4/11/13	4/25/13	125	329	-4.2	86.8	36.2	27.9	18.2	11.2
4/11/13	4/25/13	160	329	-4.6	77.2	29.5	26.4	16.8	8.3
4/11/13	4/25/13	200	329	-4.8	68.5	27.2	24.5	14.9	6.1
4/11/13	4/25/13	250	329	-5.2	75.4	26.5	20.4	10.0	2.7
4/11/13	4/25/13	315	329	-5.2	69.6	22.8	16.7	7.2	0.1
4/11/13	4/25/13	400	329	-5.3	72.7	21.0	12.9	4.4	-1.6
4/11/13	4/25/13	500	329	-5.0	68.8	19.0	11.4	2.5	-2.4
4/11/13	4/25/13	630	329	-4.7	65.3	16.8	7.8	-0.9	-2.5
4/11/13	4/25/13	800	329	-4.3	67.7	16.8	6.7	-1.3	-2.3
4/11/13	4/25/13	1000	329	-3.5	70.4	18.4	5.4	-0.9	-1.8
4/11/13	4/25/13	1250	329	-2.8	71.8	19.5	4.6	-0.4	-1.2
4/11/13	4/25/13	1600	329	-1.9	69.8	19.3	4.7	0.3	-0.5
4/11/13	4/25/13	2000	329	-1.0	65.6	18.2	4.4	1.0	0.3
4/11/13	4/25/13	2500	329	-0.1	67.0	15.8	3.7	1.7	1.1
4/11/13	4/25/13	3150	329	1.0	65.6	13.9	3.7	2.4	2.0
4/11/13	4/25/13	4000	329	2.0	63.4	11.3	3.9	3.1	2.8
4/11/13	4/25/13	5000	329	1.5	61.3	10.2	4.2	3.8	3.6
4/11/13	4/25/13	6300	329	1.4	60.1	9.4	4.6	4.3	4.2
4/11/13	4/25/13	8000	329	1.6	56.5	8.7	5.0	4.7	4.6
4/11/13	4/25/13	10000	329	1.3	55.4	8.6	5.1	4.8	4.6
4/11/13	4/25/13	12500	329	0.8	54.6	7.6	4.2	3.8	3.6
4/11/13	4/25/13	16000	329	-0.4	49.4	4.8	1.7	1.1	0.9
4/11/13	4/25/13	20000	329	-1.9	43.8	1.1	-0.6	-1.1	-1.3

Appendix A. dBA and One-third Octave Metrics for PAPA Reference Leks (cont.).

Table 17. PAPA104 (Onion Springs 2 lek) hourly dBA metrics, April 11-25, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/11/2013	4/25/2013	0	14	13.8	52.2	25.3	21.9	15.5	14.2
4/11/2013	4/25/2013	1	14	13.8	53.4	27.2	28.5	14.8	14.2
4/11/2013	4/25/2013	2	14	13.8	42.2	27.2	22.8	14.4	14.1
4/11/2013	4/25/2013	3	14	13.8	58.6	26.2	20.4	14.5	14.1
4/11/2013	4/25/2013	4	14	13.7	55.7	28.6	24.1	14.6	14.3
4/11/2013	4/25/2013	5	14	13.7	52.6	34.3	38.2	34.2	16.8
4/11/2013	4/25/2013	6	13	13.7	51.9	34.1	36.2	28.8	16.9
4/11/2013	4/25/2013	7	13	13.7	51.4	28.9	28.0	18.0	15.0
4/11/2013	4/25/2013	8	13	14.0	61.4	28.8	26.5	16.5	14.8
4/11/2013	4/25/2013	9	13	14.3	62.8	28.6	28.0	19.1	15.5
4/11/2013	4/25/2013	10	13	14.3	65.5	29.6	30.9	19.0	15.3
4/11/2013	4/25/2013	11	13	14.3	56.6	30.3	28.2	20.8	17.0
4/11/2013	4/25/2013	12	13	14.5	78.1	39.6	31.7	23.8	18.1
4/11/2013	4/25/2013	13	13	14.5	64.3	33.4	34.5	25.7	18.2
4/11/2013	4/25/2013	14	13	14.5	49.3	30.1	33.3	26.5	20.3
4/11/2013	4/25/2013	15	13	14.5	55.8	31.4	32.6	24.3	19.0
4/11/2013	4/25/2013	16	14	14.4	52.2	30.5	31.9	24.6	18.7
4/11/2013	4/25/2013	17	14	14.1	54.2	30.4	31.2	22.5	15.8
4/11/2013	4/25/2013	18	14	14.1	55.1	31.8	30.0	21.3	16.5
4/11/2013	4/25/2013	19	14	14.0	57.1	33.5	28.0	17.2	14.4
4/11/2013	4/25/2013	20	14	14.0	60.7	30.9	33.1	19.6	14.5
4/11/2013	4/25/2013	21	14	13.9	64.7	33.0	32.3	23.5	15.3
4/11/2013	4/25/2013	22	14	13.9	53.4	29.5	28.8	16.1	14.3
4/11/2013	4/25/2013	23	14	13.9	49.8	25.2	27.4	15.6	14.1

Appendix A. dBA and One-third Octave Metrics for PAPA Reference Leks (cont.).

Table 18. PAPA104 (Onion Springs 2 lek) dBA and one-third octave band metrics, April 11-25, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/11/13	4/25/13	dBA	326	13.7	78.1	31.7	30.0	19.7	15.2
4/11/13	4/25/13	12.5	326	9.6	78.4	41.8	33.9	29.7	25.9
4/11/13	4/25/13	16	326	11.4	69.7	38.6	34.0	29.4	26.0
4/11/13	4/25/13	20	326	11.9	67.2	37.2	33.8	29.1	25.7
4/11/13	4/25/13	25	326	10.6	67.7	34.6	33.0	27.1	23.9
4/11/13	4/25/13	31.5	326	9.3	67.8	33.8	33.0	25.5	22.3
4/11/13	4/25/13	40	326	6.0	66.6	32.4	32.2	23.1	20.1
4/11/13	4/25/13	50	326	2.8	69.1	31.9	31.5	21.2	17.8
4/11/13	4/25/13	63	326	-0.1	76.7	32.0	30.5	19.4	15.6
4/11/13	4/25/13	80	326	-2.1	76.4	32.4	30.1	18.9	14.6
4/11/13	4/25/13	100	326	-2.4	83.5	34.3	29.6	19.9	13.9
4/11/13	4/25/13	125	326	-3.9	83.7	36.2	30.6	20.4	12.5
4/11/13	4/25/13	160	326	-4.1	77.4	30.9	30.2	19.4	10.6
4/11/13	4/25/13	200	326	-4.2	69.6	29.3	29.2	18.4	8.7
4/11/13	4/25/13	250	326	-4.7	74.1	28.9	27.2	16.7	6.3
4/11/13	4/25/13	315	326	-4.6	61.9	29.7	24.9	14.2	3.6
4/11/13	4/25/13	400	326	-4.4	69.2	25.6	21.6	11.0	1.0
4/11/13	4/25/13	500	326	-4.1	72.7	23.8	19.0	7.1	-1.0
4/11/13	4/25/13	630	326	-3.9	74.2	21.1	10.7	2.1	-1.5
4/11/13	4/25/13	800	326	-3.5	69.3	19.0	9.8	1.2	-1.2
4/11/13	4/25/13	1000	326	-2.9	63.1	17.8	9.6	1.4	-0.7
4/11/13	4/25/13	1250	326	-2.2	67.5	19.0	9.2	1.3	-0.2
4/11/13	4/25/13	1600	326	-1.2	63.2	18.0	7.8	1.4	0.4
4/11/13	4/25/13	2000	326	-0.3	62.5	16.8	7.4	1.9	1.1
4/11/13	4/25/13	2500	326	0.6	59.7	14.3	5.9	2.5	1.9
4/11/13	4/25/13	3150	326	1.6	55.3	11.6	5.2	3.2	2.7
4/11/13	4/25/13	4000	326	2.6	56.6	10.1	5.4	4.0	3.6
4/11/13	4/25/13	5000	326	2.3	59.7	11.0	5.5	4.6	4.2
4/11/13	4/25/13	6300	326	1.4	62.5	10.6	5.6	5.0	4.7
4/11/13	4/25/13	8000	326	0.8	64.4	9.9	5.7	5.4	5.2
4/11/13	4/25/13	10000	326	0.9	40.4	8.1	5.8	5.5	5.3
4/11/13	4/25/13	12500	326	-0.7	39.9	7.1	4.8	4.4	4.2
4/11/13	4/25/13	16000	326	-0.8	45.3	5.7	3.3	2.9	2.7
4/11/13	4/25/13	20000	326	-1.5	35.2	2.6	0.9	0.4	0.3

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks.

Table 19. PAPA001 (Big Fred lek) hourly dBA metrics, April 5-7, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/5/2013	4/7/2013	0	2	33.0	67.1	43.6	44.0	41.2	36.6
4/5/2013	4/7/2013	1	2	31.6	60.6	42.4	44.0	39.7	37.2
4/5/2013	4/7/2013	2	2	31.7	60.7	41.1	43.6	38.2	35.8
4/5/2013	4/7/2013	3	2	30.8	63.2	38.9	39.3	37.1	34.8
4/5/2013	4/7/2013	4	2	34.6	60.4	41.8	44.4	40.2	37.1
4/5/2013	4/7/2013	5	2	32.6	60.4	41.3	44.3	39.2	37.3
4/5/2013	4/7/2013	6	2	32.7	56.0	40.4	42.0	39.1	36.2
4/5/2013	4/7/2013	7	2	27.1	45.1	33.9	36.5	32.6	29.4
4/5/2013	4/7/2013	8	2	28.5	48.6	33.4	34.9	32.5	31.0
4/5/2013	4/7/2013	9	2	26.2	45.4	33.2	34.6	32.6	30.8
4/5/2013	4/7/2013	10	2	22.1	45.9	33.1	34.2	31.2	28.6
4/5/2013	4/7/2013	11	2	23.1	53.7	34.1	35.4	30.9	27.9
4/5/2013	4/7/2013	12	2	26.1	45.9	33.4	35.5	32.3	29.3
4/5/2013	4/7/2013	13	2	28.4	49.2	35.6	37.6	34.2	31.7
4/5/2013	4/7/2013	14	2	25.8	55.2	36.1	37.8	33.3	29.3
4/6/2013	4/6/2013	15	1	29.4	48.6	34.8	36.1	33.9	32.0
4/5/2013	4/7/2013	16	2	26.2	53.0	39.8	40.9	36.7	33.8
4/5/2013	4/7/2013	17	2	28.6	51.4	37.6	38.8	36.0	33.7
4/5/2013	4/7/2013	18	2	30.6	62.1	38.8	39.2	36.4	34.4
4/5/2013	4/7/2013	19	2	30.4	61.8	39.5	40.9	37.4	34.7
4/5/2013	4/7/2013	20	2	34.7	65.7	41.3	41.9	38.9	37.1
4/5/2013	4/7/2013	21	2	33.0	60.7	41.2	41.8	39.4	37.3
4/5/2013	4/7/2013	22	2	34.8	59.6	42.3	43.6	41.0	39.3
4/5/2013	4/7/2013	23	2	33.8	58.2	44.1	45.3	41.8	38.7

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 20. PAPA001 (Big Fred lek) dBA and one-third octave band metrics, April 5-7, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/5/13	4/7/13	dBA	47	22.1	67.1	39.8	40.3	36.9	34.8
4/5/13	4/7/13	12.5	47	22.0	73.0	47.5	48.2	43.3	38.7
4/5/13	4/7/13	16	47	27.0	70.5	48.3	49.6	46.0	42.2
4/5/13	4/7/13	20	47	34.6	74.0	53.9	56.0	52.2	48.1
4/5/13	4/7/13	25	47	34.9	67.2	51.6	53.2	49.0	45.7
4/5/13	4/7/13	31.5	47	40.2	75.0	63.8	66.4	61.5	56.1
4/5/13	4/7/13	40	47	32.8	66.1	51.7	52.5	49.8	47.3
4/5/13	4/7/13	50	47	35.5	68.7	53.5	55.5	52.9	50.1
4/5/13	4/7/13	63	47	34.9	69.5	52.9	54.8	52.0	49.6
4/5/13	4/7/13	80	47	29.0	71.7	50.2	51.4	48.3	45.9
4/5/13	4/7/13	100	47	28.8	66.5	49.2	49.4	45.9	43.0
4/5/13	4/7/13	125	47	23.7	67.1	45.8	44.6	40.4	37.6
4/5/13	4/7/13	160	47	19.5	67.1	42.6	41.3	36.7	32.2
4/5/13	4/7/13	200	47	17.7	66.6	39.7	39.8	35.4	30.1
4/5/13	4/7/13	250	47	13.7	61.5	37.7	38.3	33.2	28.5
4/5/13	4/7/13	315	47	10.8	57.2	35.2	36.3	31.6	26.1
4/5/13	4/7/13	400	47	8.0	55.6	32.9	35.0	30.4	24.8
4/5/13	4/7/13	500	47	3.5	53.2	26.5	27.6	22.7	16.5
4/5/13	4/7/13	630	47	1.8	50.8	22.9	23.0	18.5	13.5
4/5/13	4/7/13	800	47	2.1	49.8	23.7	24.5	19.8	14.7
4/5/13	4/7/13	1000	47	2.4	48.3	24.9	26.0	21.0	15.8
4/5/13	4/7/13	1250	47	2.2	46.8	25.3	26.3	20.7	14.9
4/5/13	4/7/13	1600	47	1.6	44.8	23.8	24.5	19.4	13.1
4/5/13	4/7/13	2000	47	1.8	58.6	22.4	21.8	17.3	12.6
4/5/13	4/7/13	2500	47	2.3	63.1	19.8	15.2	10.2	6.3
4/5/13	4/7/13	3150	47	3.0	57.3	14.5	9.7	5.2	4.1
4/5/13	4/7/13	4000	47	3.7	47.8	12.4	5.2	4.5	4.2
4/5/13	4/7/13	5000	47	4.3	47.3	11.9	5.3	5.0	4.8
4/5/13	4/7/13	6300	47	4.2	44.6	11.9	5.5	5.3	5.2
4/5/13	4/7/13	8000	47	3.4	43.8	11.9	5.5	5.3	5.2
4/5/13	4/7/13	10000	47	2.3	41.6	10.4	5.1	5.0	4.8
4/5/13	4/7/13	12500	47	1.6	39.8	9.2	4.3	4.2	4.1
4/5/13	4/7/13	16000	47	0.6	37.4	7.6	3.3	3.2	3.1
4/5/13	4/7/13	20000	47	1.3	33.4	4.8	1.9	1.8	1.7

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 21. PAPA002 (Little Fred lek) hourly dBA metrics, April 5-7, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/5/2013	4/7/2013	0	2	20.6	47.7	31.3	31.4	27.6	25.1
4/5/2013	4/7/2013	1	2	22.4	49.3	29.4	31.0	26.9	24.9
4/5/2013	4/7/2013	2	2	23.9	52.1	32.1	34.5	30.5	26.0
4/5/2013	4/7/2013	3	2	24.3	55.9	31.3	31.0	28.8	27.2
4/5/2013	4/7/2013	4	2	25.6	48.4	31.5	33.2	29.8	27.4
4/5/2013	4/7/2013	5	2	25.9	50.3	34.7	35.6	32.6	29.6
4/5/2013	4/7/2013	6	2	26.0	46.3	32.5	34.1	31.1	29.1
4/5/2013	4/7/2013	7	2	24.8	49.4	33.8	36.0	32.3	28.9
4/5/2013	4/7/2013	8	2	24.6	55.7	34.7	36.8	32.4	29.2
4/5/2013	4/7/2013	9	2	24.3	57.0	34.4	35.1	31.5	28.7
4/5/2013	4/7/2013	10	2	21.2	46.6	30.5	32.9	27.8	25.0
4/5/2013	4/7/2013	11	2	19.5	52.9	29.2	28.4	25.1	23.4
4/6/2013	4/6/2013	12	1	20.1	39.6	25.7	27.4	23.5	21.7
4/5/2013	4/7/2013	13	2	20.1	48.6	32.7	35.9	27.0	23.2
4/5/2013	4/7/2013	14	2	21.9	49.2	32.0	34.6	29.7	25.8
4/5/2013	4/7/2013	15	2	20.6	56.8	38.6	39.5	31.1	23.9
4/5/2013	4/7/2013	16	2	19.5	60.2	42.1	39.1	33.8	29.1
4/5/2013	4/7/2013	17	2	19.6	56.9	38.5	38.1	31.5	26.9
4/5/2013	4/7/2013	18	2	19.1	55.6	39.2	37.8	32.5	26.4
4/5/2013	4/7/2013	19	2	18.8	51.3	33.6	36.8	28.5	22.2
4/5/2013	4/7/2013	20	2	20.9	51.4	28.6	29.7	25.8	23.6
4/5/2013	4/7/2013	21	2	19.0	46.4	25.6	26.9	24.0	21.4
4/5/2013	4/7/2013	22	2	19.2	41.7	26.1	28.1	24.1	21.9
4/5/2013	4/7/2013	23	2	20.5	47.4	30.4	32.2	26.8	23.8

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 22. PAPA002 (Little Fred lek) dBA and one-third octave band metrics, April 5-7, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/5/13	4/7/13	dBA	47	18.8	60.2	34.7	33.1	28.4	25.2
4/5/13	4/7/13	12.5	47	23.9	78.7	55.6	54.5	47.3	41.0
4/5/13	4/7/13	16	47	29.8	75.3	53.3	51.9	48.1	44.3
4/5/13	4/7/13	20	47	36.9	77.4	57.5	58.2	54.8	50.6
4/5/13	4/7/13	25	47	30.4	74.0	53.4	55.7	46.5	42.7
4/5/13	4/7/13	31.5	47	31.2	72.5	50.8	52.2	47.1	43.0
4/5/13	4/7/13	40	47	29.4	70.4	46.4	46.5	43.5	40.8
4/5/13	4/7/13	50	47	30.6	67.4	45.2	46.2	43.3	40.8
4/5/13	4/7/13	63	47	27.7	65.6	42.8	44.2	40.2	37.0
4/5/13	4/7/13	80	47	23.3	71.6	41.0	42.5	37.2	34.0
4/5/13	4/7/13	100	47	21.6	70.5	39.4	39.9	35.6	32.2
4/5/13	4/7/13	125	47	18.9	62.4	36.7	37.2	32.9	30.0
4/5/13	4/7/13	160	47	16.7	62.1	36.7	36.5	31.5	27.4
4/5/13	4/7/13	200	47	13.6	59.3	32.9	32.5	28.8	25.4
4/5/13	4/7/13	250	47	12.2	55.4	30.4	31.4	25.9	22.2
4/5/13	4/7/13	315	47	10.3	55.0	29.2	29.0	24.5	20.8
4/5/13	4/7/13	400	47	5.0	54.0	25.8	25.8	20.9	16.4
4/5/13	4/7/13	500	47	1.0	51.5	23.8	21.5	16.7	12.2
4/5/13	4/7/13	630	47	-0.7	46.9	22.4	19.9	13.4	9.0
4/5/13	4/7/13	800	47	-1.5	42.0	21.4	18.0	9.9	5.5
4/5/13	4/7/13	1000	47	-1.3	42.5	21.2	15.2	7.1	2.8
4/5/13	4/7/13	1250	47	-0.9	40.5	21.1	10.6	4.0	1.5
4/5/13	4/7/13	1600	47	-0.2	41.8	21.1	8.1	2.5	1.5
4/5/13	4/7/13	2000	47	0.6	42.4	19.5	4.5	2.5	1.8
4/5/13	4/7/13	2500	47	1.5	44.2	17.7	4.4	2.9	2.5
4/5/13	4/7/13	3150	47	2.3	41.9	14.9	4.1	3.4	3.1
4/5/13	4/7/13	4000	47	3.1	43.5	12.3	4.8	4.0	3.7
4/5/13	4/7/13	5000	47	3.7	53.6	12.9	5.1	4.4	4.2
4/5/13	4/7/13	6300	47	2.7	53.7	10.9	4.9	4.6	4.4
4/5/13	4/7/13	8000	47	2.1	38.2	8.3	4.7	4.5	4.4
4/5/13	4/7/13	10000	47	1.8	36.1	7.3	4.4	4.3	4.1
4/5/13	4/7/13	12500	47	0.4	35.8	6.7	3.9	3.8	3.6
4/5/13	4/7/13	16000	47	0.3	34.9	6.1	3.1	3.0	2.9
4/5/13	4/7/13	20000	47	1.1	34.8	4.6	1.8	1.8	1.7

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 23. PAPA003 (Lower Sand Springs Draw) hourly dBA metrics, April 5-7, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/5/2013	4/7/2013	0	2	21.5	49.0	34.5	35.0	29.6	26.5
4/5/2013	4/7/2013	1	2	21.9	51.3	30.5	31.5	29.0	25.7
4/5/2013	4/7/2013	2	2	22.5	47.8	32.7	35.1	30.8	26.8
4/5/2013	4/7/2013	3	2	23.8	52.2	30.4	31.0	28.1	26.1
4/5/2013	4/7/2013	4	2	25.0	49.6	33.4	34.4	31.6	27.5
4/5/2013	4/7/2013	5	2	24.9	51.7	37.3	36.3	33.3	30.8
4/5/2013	4/7/2013	6	2	26.9	50.5	33.8	34.7	32.3	30.9
4/5/2013	4/7/2013	7	2	26.5	54.3	35.7	37.8	34.1	30.3
4/5/2013	4/7/2013	8	2	28.1	59.1	37.0	38.3	34.5	31.9
4/5/2013	4/7/2013	9	2	22.2	53.0	35.2	37.8	33.6	27.4
4/5/2013	4/7/2013	10	2	18.6	50.5	28.3	29.3	26.2	22.7
4/5/2013	4/7/2013	11	2	19.4	47.8	29.6	29.7	25.6	23.4
4/5/2013	4/7/2013	12	2	19.9	48.7	29.2	31.5	24.8	22.1
4/5/2013	4/7/2013	13	2	19.2	49.4	29.0	30.5	25.1	22.1
4/5/2013	4/7/2013	14	3	19.2	48.6	30.5	32.9	28.9	24.9
4/5/2013	4/7/2013	15	3	20.3	52.2	33.9	36.6	26.8	23.9
4/5/2013	4/7/2013	16	2	19.4	52.7	35.5	35.6	30.5	26.2
4/5/2013	4/7/2013	17	2	18.8	51.9	34.9	35.5	29.6	25.7
4/5/2013	4/7/2013	18	2	19.4	53.5	35.2	35.9	30.5	25.6
4/5/2013	4/7/2013	19	2	18.5	54.5	32.5	34.6	28.3	22.8
4/5/2013	4/7/2013	20	2	22.7	51.4	30.5	31.6	28.1	25.7
4/5/2013	4/7/2013	21	2	20.0	46.9	27.2	28.0	25.1	23.1
4/5/2013	4/7/2013	22	2	17.4	43.3	27.2	28.7	25.5	22.1
4/5/2013	4/7/2013	23	2	20.3	52.3	32.3	32.7	28.3	25.1

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 24. PAPA003 (Lower Sand Springs Draw) dBA and one-third octave band metrics, April 5-7, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/5/13	4/7/13	dBA	50	17.4	59.1	33.3	32.9	28.4	24.9
4/5/13	4/7/13	12.5	50	21.8	81.6	59.0	51.4	44.9	39.1
4/5/13	4/7/13	16	50	29.0	77.8	55.7	51.3	46.5	42.0
4/5/13	4/7/13	20	50	34.9	74.4	55.8	56.2	51.3	47.0
4/5/13	4/7/13	25	50	31.3	73.2	51.8	51.9	46.2	42.3
4/5/13	4/7/13	31.5	50	33.3	68.2	53.5	56.1	51.5	46.3
4/5/13	4/7/13	40	50	27.5	66.4	46.8	47.8	44.1	40.0
4/5/13	4/7/13	50	50	26.9	64.8	44.8	45.8	42.1	37.7
4/5/13	4/7/13	63	50	24.8	67.1	44.3	45.4	41.1	37.2
4/5/13	4/7/13	80	50	14.5	69.1	42.5	43.4	39.0	34.1
4/5/13	4/7/13	100	50	16.9	70.5	40.6	40.8	36.4	32.3
4/5/13	4/7/13	125	50	16.4	63.0	38.5	38.0	33.9	30.5
4/5/13	4/7/13	160	50	16.0	65.3	36.8	36.0	31.5	27.8
4/5/13	4/7/13	200	50	13.7	60.1	34.3	33.1	29.1	25.3
4/5/13	4/7/13	250	50	8.7	56.4	31.3	31.2	25.9	22.7
4/5/13	4/7/13	315	50	7.3	53.8	30.4	29.1	24.5	20.3
4/5/13	4/7/13	400	50	2.9	50.7	26.2	26.4	21.0	17.0
4/5/13	4/7/13	500	50	-0.1	50.8	23.8	22.8	16.8	12.4
4/5/13	4/7/13	630	50	-1.4	47.6	21.5	20.2	13.9	8.6
4/5/13	4/7/13	800	50	-2.0	41.6	18.4	17.7	10.7	5.3
4/5/13	4/7/13	1000	50	-1.5	39.4	17.0	15.2	8.5	3.5
4/5/13	4/7/13	1250	50	-1.0	39.4	15.2	12.2	5.1	1.8
4/5/13	4/7/13	1600	50	-0.2	36.4	13.7	9.3	2.8	1.5
4/5/13	4/7/13	2000	50	0.5	39.4	12.6	7.1	2.4	1.8
4/5/13	4/7/13	2500	50	1.5	39.6	11.5	4.8	3.0	2.5
4/5/13	4/7/13	3150	50	2.3	38.6	10.5	4.4	3.5	3.2
4/5/13	4/7/13	4000	50	3.3	50.8	11.3	5.0	4.2	4.0
4/5/13	4/7/13	5000	50	3.6	57.9	14.4	5.4	4.8	4.6
4/5/13	4/7/13	6300	50	3.5	48.8	11.0	5.4	5.1	4.9
4/5/13	4/7/13	8000	50	1.7	41.3	10.7	5.3	5.1	5.0
4/5/13	4/7/13	10000	50	1.4	38.4	9.2	5.0	4.8	4.7
4/5/13	4/7/13	12500	50	1.1	37.8	8.1	4.3	4.2	4.1
4/5/13	4/7/13	16000	50	0.4	35.7	6.7	3.4	3.3	3.2
4/5/13	4/7/13	20000	50	0.9	31.8	4.7	2.1	1.9	1.8

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 25. PAPA004 (Two Buttes lek) hourly dBA metrics, April 18-21, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/18/2013	4/21/2013	0	3	18.0	41.1	28.2	30.6	24.9	23.7
4/18/2013	4/21/2013	1	3	16.5	48.5	29.3	26.2	23.8	21.2
4/18/2013	4/21/2013	2	3	16.1	39.8	27.1	30.3	26.8	24.5
4/18/2013	4/21/2013	3	3	14.8	49.6	29.3	29.3	26.7	23.1
4/18/2013	4/21/2013	4	3	15.0	43.6	27.3	29.4	25.5	22.2
4/18/2013	4/21/2013	5	3	18.3	57.1	29.9	30.0	26.0	23.0
4/18/2013	4/21/2013	6	3	17.0	43.1	30.2	29.7	27.2	23.5
4/18/2013	4/21/2013	7	3	20.0	44.0	28.1	29.9	26.1	23.0
4/18/2013	4/21/2013	8	3	16.8	52.4	29.1	28.5	22.6	19.8
4/18/2013	4/21/2013	9	3	17.3	43.6	25.4	26.8	22.7	19.6
4/18/2013	4/21/2013	10	4	17.2	52.1	26.8	24.5	21.2	19.6
4/18/2013	4/21/2013	11	4	16.3	51.2	30.0	29.7	23.5	20.4
4/18/2013	4/21/2013	12	4	19.8	49.2	31.5	33.8	27.2	23.0
4/18/2013	4/21/2013	13	3	19.2	51.3	32.6	35.9	29.0	23.1
4/18/2013	4/21/2013	14	3	19.7	54.9	33.8	38.0	31.4	25.4
4/18/2013	4/21/2013	15	3	19.0	52.7	36.1	40.6	33.5	27.7
4/18/2013	4/21/2013	16	3	19.1	52.8	36.5	39.5	32.7	26.3
4/18/2013	4/21/2013	17	3	18.5	58.7	38.6	41.2	34.5	28.4
4/18/2013	4/21/2013	18	3	16.6	52.8	36.5	41.0	33.5	27.7
4/18/2013	4/21/2013	19	3	16.4	55.4	36.7	35.1	28.8	25.2
4/18/2013	4/21/2013	20	3	16.4	61.5	35.9	30.5	28.1	26.1
4/18/2013	4/21/2013	21	3	15.3	43.7	27.0	31.3	24.7	22.3
4/18/2013	4/21/2013	22	3	14.6	50.7	27.2	29.6	24.2	21.1
4/18/2013	4/21/2013	23	3	15.1	44.4	28.7	28.7	24.7	21.9

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 26. PAPA004 (Two Buttes lek) dBA and one-third octave band metrics, April 18-21, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/18/13	4/21/13	dBA	75	14.6	61.5	32.6	30.6	26.4	22.7
4/18/13	4/21/13	12.5	75	15.8	81.6	61.7	47.7	41.6	37.4
4/18/13	4/21/13	16	75	24.7	78.0	57.3	47.0	42.3	38.9
4/18/13	4/21/13	20	75	31.2	75.9	56.4	58.6	52.9	46.8
4/18/13	4/21/13	25	75	24.2	72.8	50.8	44.9	40.4	36.4
4/18/13	4/21/13	31.5	75	22.3	70.6	49.9	50.5	42.5	36.4
4/18/13	4/21/13	40	75	21.9	69.3	46.5	43.8	38.6	34.2
4/18/13	4/21/13	50	75	18.8	67.9	44.0	42.4	36.8	32.8
4/18/13	4/21/13	63	75	15.4	66.3	41.5	40.8	35.4	31.7
4/18/13	4/21/13	80	75	11.8	69.1	39.1	38.5	33.6	30.2
4/18/13	4/21/13	100	75	10.8	69.4	37.7	38.7	33.2	29.0
4/18/13	4/21/13	125	75	9.0	65.8	35.6	37.0	31.4	27.6
4/18/13	4/21/13	160	75	5.0	61.9	32.6	33.3	28.5	24.7
4/18/13	4/21/13	200	75	4.5	62.8	31.2	32.5	27.1	23.2
4/18/13	4/21/13	250	75	2.0	58.9	28.5	29.1	24.4	20.6
4/18/13	4/21/13	315	75	0.7	53.3	26.8	27.1	22.3	18.0
4/18/13	4/21/13	400	75	-1.0	50.3	24.9	24.7	19.8	15.5
4/18/13	4/21/13	500	75	-3.0	47.4	22.5	21.5	15.9	12.2
4/18/13	4/21/13	630	75	-3.5	44.3	20.4	18.3	11.2	7.6
4/18/13	4/21/13	800	75	-3.2	47.1	18.6	14.8	8.5	5.1
4/18/13	4/21/13	1000	75	-2.6	51.1	18.7	12.8	5.7	2.4
4/18/13	4/21/13	1250	75	-1.5	50.7	19.7	10.5	4.7	1.2
4/18/13	4/21/13	1600	75	-0.6	52.2	19.4	7.2	2.2	1.1
4/18/13	4/21/13	2000	75	0.3	53.5	17.8	5.8	2.2	1.7
4/18/13	4/21/13	2500	75	1.2	43.2	16.1	5.8	2.9	2.5
4/18/13	4/21/13	3150	75	2.1	39.7	13.1	5.1	3.5	3.2
4/18/13	4/21/13	4000	75	1.2	37.2	10.0	4.8	4.1	3.8
4/18/13	4/21/13	5000	75	0.3	35.5	7.5	4.8	4.5	4.3
4/18/13	4/21/13	6300	75	-0.1	33.7	6.1	4.9	4.7	4.5
4/18/13	4/21/13	8000	75	-0.6	36.3	5.4	4.7	4.6	4.4
4/18/13	4/21/13	10000	75	-0.4	29.5	4.6	4.3	4.2	4.0
4/18/13	4/21/13	12500	75	-0.5	27.8	3.8	3.7	3.5	3.4
4/18/13	4/21/13	16000	75	-1.1	25.9	2.9	2.7	2.5	2.4
4/18/13	4/21/13	20000	75	-0.8	20.2	1.5	1.1	0.8	0.7

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 27. PAPA005 (Mesa Spring lek) hourly dBA metrics, April 18-21, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/18/2013	4/21/2013	0	3	22.2	53.6	37.5	34.4	31.8	30.0
4/18/2013	4/21/2013	1	3	21.7	50.5	34.2	30.9	27.6	24.1
4/18/2013	4/21/2013	2	3	21.4	45.3	33.2	34.4	29.3	26.7
4/18/2013	4/21/2013	3	3	19.7	47.1	34.2	32.5	29.2	26.8
4/18/2013	4/21/2013	4	3	18.3	46.4	32.0	33.2	29.8	27.5
4/18/2013	4/21/2013	5	3	22.9	45.7	31.1	32.4	29.3	27.2
4/18/2013	4/21/2013	6	3	21.8	45.5	33.6	32.8	29.3	25.0
4/18/2013	4/21/2013	7	3	21.1	44.0	32.7	32.8	28.3	24.3
4/18/2013	4/21/2013	8	3	20.4	50.9	31.9	33.9	29.2	26.5
4/18/2013	4/21/2013	9	3	20.1	45.7	29.4	33.6	27.7	23.7
4/18/2013	4/21/2013	10	3	20.5	51.9	29.9	30.8	27.5	24.7
4/18/2013	4/21/2013	11	4	17.2	51.6	31.6	30.1	26.2	23.8
4/18/2013	4/21/2013	12	4	20.1	62.2	34.8	35.7	29.9	26.7
4/18/2013	4/21/2013	13	4	21.4	56.8	35.4	38.6	31.4	27.0
4/18/2013	4/21/2013	14	3	22.8	63.6	37.9	41.0	34.5	28.4
4/18/2013	4/21/2013	15	3	22.3	66.6	40.9	42.5	35.6	28.9
4/18/2013	4/21/2013	16	3	23.6	57.1	39.7	42.8	36.9	31.6
4/18/2013	4/21/2013	17	3	21.6	60.2	42.0	45.4	39.4	33.7
4/18/2013	4/21/2013	18	3	21.2	54.5	40.0	44.5	37.9	32.9
4/18/2013	4/21/2013	19	3	22.5	52.5	37.5	38.9	32.8	29.4
4/18/2013	4/21/2013	20	3	22.9	51.0	35.8	39.7	34.7	28.6
4/18/2013	4/21/2013	21	3	18.3	43.8	31.8	33.0	30.3	28.6
4/18/2013	4/21/2013	22	3	18.1	50.3	31.7	32.1	29.9	28.4
4/18/2013	4/21/2013	23	3	17.4	53.7	36.0	32.4	30.6	28.8

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 28. PAPA005 (Mesa Spring lek) dBA and one-third octave band metrics, April 18-21, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/18/13	4/21/13	dBA	75	17.2	66.6	36.2	34.6	30.0	26.7
4/18/13	4/21/13	12.5	75	23.5	78.5	58.0	45.8	41.8	37.8
4/18/13	4/21/13	16	75	29.2	78.0	55.8	50.2	46.3	42.5
4/18/13	4/21/13	20	75	36.4	73.6	59.2	62.9	57.0	51.6
4/18/13	4/21/13	25	75	29.7	71.2	49.1	48.0	44.0	40.5
4/18/13	4/21/13	31.5	75	29.3	67.9	49.4	51.2	45.3	41.1
4/18/13	4/21/13	40	75	29.1	66.7	45.9	47.1	43.1	40.3
4/18/13	4/21/13	50	75	24.8	63.8	46.5	48.4	45.2	41.3
4/18/13	4/21/13	63	75	22.5	68.5	43.5	45.2	41.0	37.2
4/18/13	4/21/13	80	75	18.6	77.5	41.9	42.8	37.9	33.3
4/18/13	4/21/13	100	75	16.2	73.8	41.1	42.0	36.7	33.1
4/18/13	4/21/13	125	75	15.7	72.4	38.1	38.4	34.6	31.0
4/18/13	4/21/13	160	75	9.6	64.1	35.5	36.2	31.3	27.6
4/18/13	4/21/13	200	75	7.1	60.0	34.2	35.2	30.7	26.8
4/18/13	4/21/13	250	75	4.3	62.9	32.9	31.8	27.7	24.3
4/18/13	4/21/13	315	75	1.4	56.3	31.0	30.1	25.6	21.6
4/18/13	4/21/13	400	75	-0.4	53.0	28.0	28.0	22.5	18.3
4/18/13	4/21/13	500	75	-1.9	56.4	25.1	25.5	19.5	13.2
4/18/13	4/21/13	630	75	-2.4	53.7	23.4	23.5	16.5	10.2
4/18/13	4/21/13	800	75	-2.4	45.3	23.9	23.5	15.6	8.5
4/18/13	4/21/13	1000	75	-1.4	44.7	24.0	22.9	14.1	7.5
4/18/13	4/21/13	1250	75	-0.9	43.0	23.0	20.4	12.0	5.6
4/18/13	4/21/13	1600	75	-0.2	44.7	22.3	16.8	8.6	3.2
4/18/13	4/21/13	2000	75	0.9	44.1	20.5	9.3	4.1	2.7
4/18/13	4/21/13	2500	75	1.9	43.0	18.6	6.3	3.4	3.0
4/18/13	4/21/13	3150	75	2.8	42.2	15.8	5.7	4.1	3.7
4/18/13	4/21/13	4000	75	3.7	40.7	12.8	5.5	4.7	4.4
4/18/13	4/21/13	5000	75	4.4	62.1	16.4	5.8	5.2	5.0
4/18/13	4/21/13	6300	75	3.3	66.6	23.7	5.8	5.5	5.4
4/18/13	4/21/13	8000	75	3.1	45.7	7.7	5.8	5.6	5.4
4/18/13	4/21/13	10000	75	2.5	41.9	6.6	5.5	5.3	5.2
4/18/13	4/21/13	12500	75	2.0	50.9	10.7	4.9	4.8	4.7
4/18/13	4/21/13	16000	75	1.6	31.7	4.9	4.1	4.0	3.9
4/18/13	4/21/13	20000	75	1.9	31.8	3.7	3.0	2.8	2.7

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 29. PAPA006 (Lovatt Draw Reservoir lek) hourly dBA metrics, April 18-21, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/18/2013	4/20/2013	0	2	22.0	49.8	31.8	33.2	30.3	27.6
4/18/2013	4/20/2013	1	2	25.7	45.1	32.0	33.8	31.2	29.0
4/18/2013	4/20/2013	2	2	27.9	47.1	33.8	35.7	32.9	31.2
4/18/2013	4/20/2013	3	2	27.0	41.4	33.9	35.6	32.9	30.6
4/18/2013	4/20/2013	4	2	29.5	42.0	34.1	35.8	33.4	31.7
4/18/2013	4/20/2013	5	2	28.7	52.6	33.5	34.8	32.7	30.9
4/18/2013	4/20/2013	6	2	31.4	60.4	47.5	52.9	37.3	33.4
4/18/2013	4/20/2013	7	2	28.4	54.4	35.7	37.0	34.4	32.5
4/18/2013	4/20/2013	8	2	26.8	53.0	33.7	35.2	31.1	28.8
4/18/2013	4/20/2013	9	2	25.4	47.7	30.7	32.6	29.4	27.7
4/18/2013	4/20/2013	10	2	24.8	46.6	31.2	32.6	29.8	28.0
4/18/2013	4/20/2013	11	3	23.2	50.9	32.6	34.0	30.2	28.2
4/18/2013	4/20/2013	12	3	23.8	60.6	33.8	35.2	31.0	28.1
4/18/2013	4/20/2013	13	3	25.1	58.0	34.6	36.1	31.2	28.6
4/18/2013	4/20/2013	14	3	25.1	50.7	34.4	37.3	33.0	29.8
4/18/2013	4/20/2013	15	3	24.8	55.5	36.7	41.1	33.9	29.9
4/18/2013	4/20/2013	16	3	23.7	55.4	36.6	38.7	34.1	31.4
4/18/2013	4/20/2013	17	3	23.2	54.9	38.0	39.5	34.8	30.7
4/18/2013	4/20/2013	18	3	22.6	52.9	35.7	39.4	35.0	31.5
4/18/2013	4/20/2013	19	3	22.4	54.2	36.8	33.7	29.8	27.1
4/18/2013	4/20/2013	20	3	25.0	51.3	34.1	33.8	31.5	26.9
4/18/2013	4/20/2013	21	3	24.6	47.0	33.7	35.6	33.2	31.4
4/18/2013	4/20/2013	22	2	23.7	45.9	32.4	33.6	30.1	28.1
4/18/2013	4/20/2013	23	2	21.4	51.6	31.2	32.9	28.7	26.1

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 30. PAPA006 (Lovatt Draw Reservoir lek) dBA and one-third octave band metrics, April 18-21, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/18/13	4/20/13	dBA	59	21.4	60.6	36.7	35.2	32.0	29.7
4/18/13	4/20/13	12.5	59	27.7	74.8	51.1	48.5	44.5	40.3
4/18/13	4/20/13	16	59	33.9	74.2	51.4	52.3	48.4	45.1
4/18/13	4/20/13	20	59	42.2	75.8	60.6	63.4	58.5	54.6
4/18/13	4/20/13	25	59	35.8	70.1	50.6	52.5	49.0	46.1
4/18/13	4/20/13	31.5	59	36.2	71.1	56.5	59.0	55.1	48.4
4/18/13	4/20/13	40	59	33.2	75.1	51.3	52.7	49.0	46.0
4/18/13	4/20/13	50	59	29.5	73.6	49.7	50.4	46.1	43.0
4/18/13	4/20/13	63	59	28.5	69.4	48.0	49.4	45.7	42.3
4/18/13	4/20/13	80	59	22.9	75.3	43.1	43.7	39.7	36.7
4/18/13	4/20/13	100	59	23.6	72.5	40.8	41.9	38.1	35.3
4/18/13	4/20/13	125	59	22.4	72.2	38.6	39.4	35.9	32.0
4/18/13	4/20/13	160	59	14.2	66.4	35.8	36.7	33.7	30.8
4/18/13	4/20/13	200	59	11.1	66.5	35.9	35.8	32.2	28.7
4/18/13	4/20/13	250	59	8.0	60.7	31.7	32.5	29.2	26.4
4/18/13	4/20/13	315	59	6.3	56.6	29.4	29.3	26.1	23.4
4/18/13	4/20/13	400	59	3.8	52.1	27.2	27.3	23.5	20.4
4/18/13	4/20/13	500	59	0.4	52.9	24.8	23.6	19.5	16.1
4/18/13	4/20/13	630	59	-0.9	50.3	23.2	21.4	16.4	12.6
4/18/13	4/20/13	800	59	-0.6	53.4	25.4	21.1	15.8	11.8
4/18/13	4/20/13	1000	59	-0.4	52.0	26.5	22.3	15.3	11.1
4/18/13	4/20/13	1250	59	0.1	54.8	27.6	20.4	12.9	8.3
4/18/13	4/20/13	1600	59	0.5	53.9	25.1	17.5	10.7	6.0
4/18/13	4/20/13	2000	59	0.9	54.6	23.4	14.9	7.5	4.3
4/18/13	4/20/13	2500	59	1.6	51.3	20.1	11.1	5.5	3.7
4/18/13	4/20/13	3150	59	2.4	51.2	15.1	7.3	4.4	3.8
4/18/13	4/20/13	4000	59	3.4	47.0	10.2	6.0	4.6	4.3
4/18/13	4/20/13	5000	59	3.5	41.7	7.5	5.3	5.0	4.9
4/18/13	4/20/13	6300	59	3.5	38.3	6.8	5.6	5.4	5.2
4/18/13	4/20/13	8000	59	2.9	40.8	6.4	5.6	5.4	5.3
4/18/13	4/20/13	10000	59	1.5	39.6	5.9	5.3	5.2	5.0
4/18/13	4/20/13	12500	59	1.2	40.0	5.2	4.7	4.6	4.4
4/18/13	4/20/13	16000	59	0.5	37.1	4.3	3.9	3.7	3.5
4/18/13	4/20/13	20000	59	1.0	34.8	3.1	2.6	2.4	2.2

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 31. PAPA007 (Shelter Cabin Reservoir lek) hourly dBA metrics, April 10-12, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/10/2013	4/12/2013	0	2	18.1	38.6	23.1	24.4	21.8	20.1
4/10/2013	4/12/2013	1	2	18.0	32.8	23.0	24.9	22.6	20.3
4/10/2013	4/12/2013	2	2	17.1	40.5	24.1	25.2	22.0	20.6
4/10/2013	4/12/2013	3	2	18.3	39.2	23.2	24.9	22.7	20.7
4/10/2013	4/12/2013	4	2	17.9	39.1	23.5	25.4	22.6	20.9
4/10/2013	4/12/2013	5	2	19.4	44.0	25.8	27.6	24.3	22.1
4/10/2013	4/12/2013	6	2	21.8	38.5	27.7	29.6	26.9	24.7
4/10/2013	4/12/2013	7	2	22.3	46.2	27.3	28.8	26.1	24.3
4/10/2013	4/12/2013	8	2	19.5	49.3	28.2	30.2	26.3	23.4
4/10/2013	4/12/2013	9	2	18.6	48.9	30.6	33.1	25.5	22.4
4/10/2013	4/12/2013	10	3	19.7	52.0	33.3	35.8	29.7	24.5
4/10/2013	4/12/2013	11	2	22.1	52.8	34.3	34.8	29.9	26.0
4/10/2013	4/12/2013	12	2	21.7	73.2	40.8	34.0	29.4	25.8
4/10/2013	4/12/2013	13	2	21.4	50.8	32.7	33.6	28.5	24.6
4/10/2013	4/12/2013	14	2	20.9	47.7	31.8	33.8	28.5	24.7
4/10/2013	4/12/2013	15	2	21.4	50.8	33.0	34.6	29.0	25.5
4/10/2013	4/12/2013	16	2	19.6	50.0	34.8	38.4	30.7	25.3
4/10/2013	4/12/2013	17	2	20.4	49.1	34.8	38.3	31.6	26.3
4/10/2013	4/12/2013	18	2	23.1	54.3	37.8	41.1	34.8	29.8
4/10/2013	4/12/2013	19	2	19.5	50.0	34.9	37.6	31.5	26.7
4/10/2013	4/12/2013	20	2	20.8	49.6	32.8	34.0	28.8	25.6
4/10/2013	4/12/2013	21	2	20.0	44.1	27.7	29.6	25.8	23.6
4/10/2013	4/12/2013	22	2	20.2	45.0	26.6	28.7	24.0	22.1
4/10/2013	4/12/2013	23	2	20.4	36.7	24.0	25.9	23.2	21.9

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 32. PAPA007 (Shelter Cabin Reservoir lek) dBA and one-third octave band metrics, April 10-12, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/10/13	4/12/13	dBA	49	17.1	73.2	32.7	29.6	26.0	24.1
4/10/13	4/12/13	12.5	49	24.4	78.3	58.4	53.8	47.2	41.8
4/10/13	4/12/13	16	49	29.0	76.0	56.3	50.9	45.4	41.2
4/10/13	4/12/13	20	49	36.8	73.9	56.3	58.3	54.8	50.5
4/10/13	4/12/13	25	49	33.9	70.6	50.3	50.6	46.6	43.1
4/10/13	4/12/13	31.5	49	30.4	69.3	47.3	49.3	43.2	39.2
4/10/13	4/12/13	40	49	27.8	68.6	44.5	44.5	40.6	37.3
4/10/13	4/12/13	50	49	26.5	75.7	42.3	42.5	38.1	35.2
4/10/13	4/12/13	63	49	23.9	80.7	42.4	41.8	36.9	34.2
4/10/13	4/12/13	80	49	22.1	85.3	42.4	39.6	34.6	31.5
4/10/13	4/12/13	100	49	20.7	83.3	39.8	37.5	33.3	30.2
4/10/13	4/12/13	125	49	20.8	73.3	36.0	36.7	32.6	29.4
4/10/13	4/12/13	160	49	14.5	73.6	33.4	33.0	29.3	26.3
4/10/13	4/12/13	200	49	11.9	78.8	32.5	30.4	26.6	24.1
4/10/13	4/12/13	250	49	10.3	63.6	27.5	27.3	23.5	21.0
4/10/13	4/12/13	315	49	7.1	65.9	25.4	25.1	20.5	17.6
4/10/13	4/12/13	400	49	1.2	68.6	24.1	20.6	15.8	12.7
4/10/13	4/12/13	500	49	-1.5	65.3	21.5	19.2	12.7	8.8
4/10/13	4/12/13	630	49	-2.4	56.9	19.2	17.7	10.0	5.4
4/10/13	4/12/13	800	49	-2.4	53.8	18.7	17.3	9.0	3.9
4/10/13	4/12/13	1000	49	-1.9	49.6	18.9	14.9	7.0	2.2
4/10/13	4/12/13	1250	49	-1.2	48.6	18.8	11.6	4.6	1.1
4/10/13	4/12/13	1600	49	-0.2	43.8	18.8	10.4	4.3	1.8
4/10/13	4/12/13	2000	49	0.5	41.5	17.3	9.7	3.5	2.1
4/10/13	4/12/13	2500	49	1.3	38.4	15.0	8.2	3.7	2.8
4/10/13	4/12/13	3150	49	2.3	46.6	12.9	7.7	3.8	3.4
4/10/13	4/12/13	4000	49	2.0	46.8	10.3	6.3	4.3	4.0
4/10/13	4/12/13	5000	49	1.3	41.7	7.3	5.2	4.6	4.4
4/10/13	4/12/13	6300	49	0.2	34.4	5.7	5.0	4.7	4.5
4/10/13	4/12/13	8000	49	0.1	25.5	5.0	4.9	4.6	4.4
4/10/13	4/12/13	10000	49	-0.6	23.5	4.5	4.5	4.3	4.0
4/10/13	4/12/13	12500	49	-1.3	21.9	3.8	4.0	3.7	3.4
4/10/13	4/12/13	16000	49	-1.3	21.1	3.0	3.2	2.8	2.5
4/10/13	4/12/13	20000	49	-1.2	25.8	1.8	2.0	1.2	0.9

Table 33. PAPA008 (The Rocks lek) hourly dBA metrics, April 10-12, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/10/2013	4/12/2013	0	2	19.7	36.5	23.7	25.0	22.5	21.1
4/10/2013	4/12/2013	1	2	20.4	34.5	24.3	25.9	23.6	21.9
4/10/2013	4/12/2013	2	2	19.5	46.0	26.0	26.6	23.9	22.4
4/10/2013	4/12/2013	3	2	19.5	36.2	24.8	25.8	24.0	22.4
4/10/2013	4/12/2013	4	2	18.8	34.7	23.7	25.7	22.8	21.1
4/10/2013	4/12/2013	5	2	20.2	36.7	24.5	26.2	23.8	22.0
4/10/2013	4/12/2013	6	2	21.3	51.5	26.9	28.4	25.2	23.3
4/10/2013	4/12/2013	7	2	21.2	43.8	27.3	29.3	26.1	24.1
4/10/2013	4/12/2013	8	2	19.2	53.6	29.2	30.2	25.6	23.5
4/10/2013	4/12/2013	9	2	18.9	50.9	30.5	31.7	26.5	23.5
4/10/2013	4/12/2013	10	2	20.9	47.1	33.6	36.0	30.8	26.2
4/10/2013	4/12/2013	11	3	19.2	49.5	33.1	32.3	26.5	25.1
4/10/2013	4/12/2013	12	3	18.0	64.5	35.8	31.3	26.5	25.0
4/10/2013	4/12/2013	13	2	22.4	49.8	33.6	34.4	29.9	25.8
4/10/2013	4/12/2013	14	2	20.5	52.6	32.7	34.2	30.0	26.4
4/10/2013	4/12/2013	15	2	21.5	47.6	32.2	34.2	29.1	25.5
4/10/2013	4/12/2013	16	2	22.3	49.0	34.1	36.9	30.7	26.4
4/10/2013	4/12/2013	17	2	22.9	47.6	35.2	38.2	32.7	27.8
4/10/2013	4/12/2013	18	2	21.2	49.6	36.6	39.5	33.8	27.9
4/10/2013	4/12/2013	19	2	22.4	51.7	35.9	38.5	33.1	28.1
4/10/2013	4/12/2013	20	2	21.5	49.9	34.3	35.8	30.3	26.3
4/10/2013	4/12/2013	21	2	20.9	42.9	25.9	28.2	24.8	22.8
4/10/2013	4/12/2013	22	2	21.2	38.6	26.2	28.6	24.7	23.1
4/10/2013	4/12/2013	23	2	20.3	35.2	24.2	25.8	23.5	22.3

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 34. PAPA008 (The Rocks lek) dBA and one-third octave band metrics, April 10-12, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/10/13	4/12/13	dBA	50	18.0	64.5	32.0	29.5	26.2	24.0
4/10/13	4/12/13	12.5	50	26.7	78.6	54.6	53.5	47.5	41.7
4/10/13	4/12/13	16	50	24.1	75.8	52.7	52.2	46.2	41.0
4/10/13	4/12/13	20	50	32.2	73.6	53.5	55.5	51.2	47.3
4/10/13	4/12/13	25	50	28.7	71.0	48.3	50.7	45.0	41.4
4/10/13	4/12/13	31.5	50	28.9	69.1	46.3	48.1	44.1	41.0
4/10/13	4/12/13	40	50	29.7	66.8	43.8	45.7	42.0	38.8
4/10/13	4/12/13	50	50	26.1	66.7	40.4	41.2	37.5	34.9
4/10/13	4/12/13	63	50	24.3	85.0	42.0	41.9	37.6	34.6
4/10/13	4/12/13	80	50	22.7	84.1	41.3	38.4	34.1	31.0
4/10/13	4/12/13	100	50	21.1	79.3	38.1	37.1	33.2	30.2
4/10/13	4/12/13	125	50	20.0	66.9	34.3	35.5	31.7	29.0
4/10/13	4/12/13	160	50	16.9	70.4	31.7	32.4	28.4	25.6
4/10/13	4/12/13	200	50	14.9	65.3	30.1	31.2	27.1	24.0
4/10/13	4/12/13	250	50	13.0	53.3	27.6	28.3	24.0	21.3
4/10/13	4/12/13	315	50	9.8	46.0	25.7	25.0	21.2	18.2
4/10/13	4/12/13	400	50	4.9	47.5	23.2	21.3	16.5	12.9
4/10/13	4/12/13	500	50	1.6	52.4	21.4	19.1	14.3	10.4
4/10/13	4/12/13	630	50	-1.9	48.6	19.2	17.4	11.2	6.5
4/10/13	4/12/13	800	50	-1.7	43.5	18.0	16.7	9.5	4.4
4/10/13	4/12/13	1000	50	-1.0	46.5	18.0	16.0	7.9	3.3
4/10/13	4/12/13	1250	50	-0.9	48.7	18.5	14.8	5.5	1.5
4/10/13	4/12/13	1600	50	-0.2	36.1	19.4	12.6	4.1	1.6
4/10/13	4/12/13	2000	50	0.5	36.7	18.7	9.7	3.3	2.2
4/10/13	4/12/13	2500	50	1.5	35.9	16.4	8.1	3.4	3.0
4/10/13	4/12/13	3150	50	2.4	34.8	13.0	7.2	4.1	3.7
4/10/13	4/12/13	4000	50	2.2	49.3	10.0	5.9	4.7	4.4
4/10/13	4/12/13	5000	50	2.3	52.5	10.7	6.4	5.2	4.8
4/10/13	4/12/13	6300	50	2.6	38.1	6.7	5.9	5.4	5.1
4/10/13	4/12/13	8000	50	2.2	26.1	6.2	5.9	5.4	5.2
4/10/13	4/12/13	10000	50	0.7	28.8	5.8	5.6	5.2	4.9
4/10/13	4/12/13	12500	50	0.4	23.9	5.1	5.1	4.7	4.4
4/10/13	4/12/13	16000	50	-0.3	22.7	4.3	4.4	3.9	3.5
4/10/13	4/12/13	20000	50	0.5	22.3	3.2	3.4	2.7	2.3

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 35. PAPA009 (South Rocks lek) hourly dBA metrics, April 10-12, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/10/2013	4/12/2013	0	2	18.6	34.8	24.2	26.6	23.1	21.0
4/10/2013	4/12/2013	1	2	17.2	40.1	27.2	27.6	23.8	22.1
4/10/2013	4/12/2013	2	2	17.6	49.2	29.9	27.8	25.2	23.4
4/10/2013	4/12/2013	3	2	18.1	38.8	27.6	29.0	24.9	22.2
4/10/2013	4/12/2013	4	2	19.4	33.6	25.0	27.1	24.3	22.1
4/10/2013	4/12/2013	5	2	21.6	32.9	25.9	28.0	25.3	23.3
4/10/2013	4/12/2013	6	2	21.5	39.8	25.4	26.9	25.1	23.5
4/10/2013	4/12/2013	7	2	21.8	44.6	27.1	28.6	26.3	24.4
4/10/2013	4/12/2013	8	2	18.7	46.2	28.9	30.5	26.2	23.0
4/10/2013	4/12/2013	9	2	18.8	47.6	31.3	32.3	26.6	23.9
4/10/2013	4/12/2013	10	2	19.9	47.6	33.3	35.1	29.8	25.6
4/10/2013	4/12/2013	11	2	19.6	50.4	32.9	34.6	28.7	24.6
4/10/2013	4/12/2013	12	3	18.2	59.0	33.4	30.0	23.5	22.1
4/10/2013	4/12/2013	13	3	18.4	54.2	32.0	32.9	26.2	23.3
4/10/2013	4/12/2013	14	2	22.1	47.3	32.0	33.6	29.5	26.1
4/10/2013	4/12/2013	15	2	21.5	47.7	32.4	33.9	29.4	25.9
4/10/2013	4/12/2013	16	2	23.5	49.6	33.9	35.6	30.0	26.1
4/10/2013	4/12/2013	17	2	22.9	48.3	34.1	37.1	31.5	27.3
4/10/2013	4/12/2013	18	2	22.3	48.7	35.5	38.2	33.1	28.2
4/10/2013	4/12/2013	19	2	22.1	52.1	33.6	36.2	31.1	27.1
4/10/2013	4/12/2013	20	2	21.6	45.0	32.8	34.3	29.8	27.0
4/10/2013	4/12/2013	21	2	20.8	38.7	26.1	28.3	25.0	23.1
4/10/2013	4/12/2013	22	2	21.6	37.0	26.3	28.3	25.5	23.6
4/10/2013	4/12/2013	23	2	20.0	39.8	26.7	28.6	25.7	23.7

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 36. PAPA009 (South Rocks lek) dBA and one-third octave band metrics, April 10-12, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/10/13	4/12/13	dBA	50	17.2	59.0	31.2	30.0	26.2	24.0
4/10/13	4/12/13	12.5	50	26.6	77.2	58.6	56.9	50.5	45.6
4/10/13	4/12/13	16	50	30.2	73.1	55.4	55.3	50.6	45.7
4/10/13	4/12/13	20	50	33.0	71.5	54.0	55.4	50.8	46.6
4/10/13	4/12/13	25	50	30.5	68.1	50.6	51.5	47.2	43.4
4/10/13	4/12/13	31.5	50	30.7	66.9	49.0	50.7	45.8	41.4
4/10/13	4/12/13	40	50	28.8	64.0	45.6	45.5	41.8	38.2
4/10/13	4/12/13	50	50	24.0	73.6	42.5	42.7	38.0	33.6
4/10/13	4/12/13	63	50	24.6	75.9	41.3	42.5	37.9	34.1
4/10/13	4/12/13	80	50	21.6	75.3	39.3	40.1	35.5	31.7
4/10/13	4/12/13	100	50	20.5	73.8	37.8	38.0	34.2	31.2
4/10/13	4/12/13	125	50	19.6	66.0	35.7	37.7	32.6	29.7
4/10/13	4/12/13	160	50	16.0	68.3	32.6	33.7	30.1	27.8
4/10/13	4/12/13	200	50	13.8	66.1	30.9	31.7	27.5	24.9
4/10/13	4/12/13	250	50	11.6	56.4	28.0	28.3	24.6	21.6
4/10/13	4/12/13	315	50	5.9	45.9	25.1	25.0	20.8	16.8
4/10/13	4/12/13	400	50	2.2	43.4	23.0	22.6	17.5	13.4
4/10/13	4/12/13	500	50	-0.2	49.1	20.8	19.8	14.0	9.7
4/10/13	4/12/13	630	50	-1.9	45.4	17.9	15.5	9.7	5.5
4/10/13	4/12/13	800	50	-2.3	40.7	16.2	14.0	7.0	3.3
4/10/13	4/12/13	1000	50	-1.6	37.3	16.0	13.1	5.7	1.9
4/10/13	4/12/13	1250	50	-1.1	40.3	16.3	12.4	3.4	1.5
4/10/13	4/12/13	1600	50	-0.2	40.0	16.0	11.1	2.4	1.7
4/10/13	4/12/13	2000	50	0.7	35.6	15.1	9.0	2.8	2.4
4/10/13	4/12/13	2500	50	1.7	34.6	13.6	7.7	3.5	3.1
4/10/13	4/12/13	3150	50	2.5	41.4	11.0	6.9	4.1	3.8
4/10/13	4/12/13	4000	50	1.7	35.4	8.3	5.8	4.6	4.4
4/10/13	4/12/13	5000	50	0.2	46.6	7.3	5.6	4.9	4.6
4/10/13	4/12/13	6300	50	-0.1	42.6	5.9	5.3	5.0	4.6
4/10/13	4/12/13	8000	50	-0.9	33.4	5.3	5.2	4.9	4.5
4/10/13	4/12/13	10000	50	-0.7	23.6	4.9	5.0	4.7	4.3
4/10/13	4/12/13	12500	50	-0.6	25.4	4.5	4.7	4.4	3.9
4/10/13	4/12/13	16000	50	-0.8	25.1	4.0	4.4	3.9	3.4
4/10/13	4/12/13	20000	50	-0.3	22.5	3.2	4.1	2.8	2.5

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 37. PAPA010 (Stud Horse Butte lek) hourly dBA metrics, April 10-12, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/10/2013	4/12/2013	0	2	19.5	36.7	24.6	26.6	23.4	21.9
4/10/2013	4/12/2013	1	2	18.9	40.1	28.6	29.8	25.8	23.2
4/10/2013	4/12/2013	2	2	19.7	50.0	30.9	31.5	26.5	24.1
4/10/2013	4/12/2013	3	2	18.1	42.0	30.4	29.8	25.8	22.6
4/10/2013	4/12/2013	4	2	20.4	36.2	25.9	27.9	25.0	23.0
4/10/2013	4/12/2013	5	2	21.5	37.4	28.4	29.4	27.1	25.4
4/10/2013	4/12/2013	6	2	22.6	40.1	30.0	31.2	28.1	26.2
4/10/2013	4/12/2013	7	2	22.9	43.4	27.5	29.3	26.7	25.1
4/10/2013	4/12/2013	8	2	19.0	46.0	29.9	31.5	26.6	23.1
4/10/2013	4/12/2013	9	2	19.4	48.5	32.7	33.7	27.6	24.3
4/10/2013	4/12/2013	10	2	20.1	60.3	34.5	36.3	30.3	25.7
4/10/2013	4/12/2013	11	2	19.8	51.6	34.1	35.3	29.2	24.8
4/10/2013	4/12/2013	12	2	19.1	49.9	34.9	35.9	29.4	25.2
4/10/2013	4/12/2013	13	3	19.9	52.0	32.6	33.0	26.6	23.5
4/10/2013	4/12/2013	14	2	23.1	50.8	33.5	34.6	30.3	26.9
4/10/2013	4/12/2013	15	2	22.6	50.4	33.3	34.4	30.1	26.8
4/10/2013	4/12/2013	16	2	22.4	50.6	35.4	36.8	31.0	27.2
4/10/2013	4/12/2013	17	2	22.8	51.7	35.2	37.8	31.9	27.7
4/10/2013	4/12/2013	18	2	24.5	50.0	36.3	39.4	34.1	29.5
4/10/2013	4/12/2013	19	2	22.5	53.8	33.3	35.9	29.9	26.3
4/10/2013	4/12/2013	20	2	22.7	48.9	32.5	34.0	29.2	26.5
4/10/2013	4/12/2013	21	2	22.1	42.4	28.3	31.0	26.7	24.6
4/10/2013	4/12/2013	22	2	22.7	36.6	27.6	29.5	26.9	25.1
4/10/2013	4/12/2013	23	2	20.8	39.4	26.9	28.6	25.8	24.2

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 38. PAPA010 (Stud Horse Butte lek) dBA and one-third octave band metrics, April 10-12, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/10/13	4/12/13	dBA	49	18.1	60.3	32.2	31.6	27.3	25.4
4/10/13	4/12/13	12.5	49	25.2	76.7	57.0	55.3	49.9	45.1
4/10/13	4/12/13	16	49	33.0	74.8	55.9	55.7	52.0	47.6
4/10/13	4/12/13	20	49	34.8	74.5	55.1	56.5	51.9	47.3
4/10/13	4/12/13	25	49	31.6	73.6	51.9	53.0	48.1	44.4
4/10/13	4/12/13	31.5	49	32.9	69.6	49.1	50.7	46.9	42.9
4/10/13	4/12/13	40	49	29.9	65.6	44.8	45.5	42.5	39.1
4/10/13	4/12/13	50	49	25.0	64.1	43.6	45.4	40.8	37.6
4/10/13	4/12/13	63	49	24.6	61.2	40.2	41.9	38.4	35.4
4/10/13	4/12/13	80	49	21.9	70.4	38.3	39.5	35.5	32.6
4/10/13	4/12/13	100	49	18.9	66.3	37.9	37.6	34.0	31.4
4/10/13	4/12/13	125	49	18.6	69.5	34.7	36.4	32.7	29.8
4/10/13	4/12/13	160	49	15.4	63.9	32.7	33.6	30.4	27.6
4/10/13	4/12/13	200	49	14.1	59.4	31.7	33.2	29.2	26.4
4/10/13	4/12/13	250	49	11.5	55.1	29.4	30.8	26.4	23.4
4/10/13	4/12/13	315	49	5.9	44.7	26.9	27.4	22.6	19.0
4/10/13	4/12/13	400	49	3.1	43.4	25.1	25.7	19.5	16.1
4/10/13	4/12/13	500	49	0.0	48.9	22.9	20.8	14.7	11.4
4/10/13	4/12/13	630	49	-1.7	43.8	20.5	18.8	12.5	8.3
4/10/13	4/12/13	800	49	-1.3	41.1	18.3	16.1	9.7	5.5
4/10/13	4/12/13	1000	49	-1.1	40.8	17.9	16.5	8.6	4.8
4/10/13	4/12/13	1250	49	-0.4	37.5	18.3	15.5	7.2	3.6
4/10/13	4/12/13	1600	49	0.2	36.5	18.0	13.0	5.1	2.9
4/10/13	4/12/13	2000	49	1.2	41.2	17.4	9.7	3.7	2.9
4/10/13	4/12/13	2500	49	2.0	58.5	16.4	8.6	3.8	3.4
4/10/13	4/12/13	3150	49	3.0	50.0	12.6	7.0	4.5	4.1
4/10/13	4/12/13	4000	49	3.3	42.6	9.1	6.8	5.1	4.8
4/10/13	4/12/13	5000	49	1.4	50.8	9.6	6.4	5.5	5.3
4/10/13	4/12/13	6300	49	1.6	42.0	6.7	6.1	5.8	5.5
4/10/13	4/12/13	8000	49	-0.2	27.3	6.2	6.0	5.7	5.5
4/10/13	4/12/13	10000	49	-0.3	23.9	5.7	5.7	5.4	5.2
4/10/13	4/12/13	12500	49	-0.6	22.8	5.0	5.2	4.8	4.5
4/10/13	4/12/13	16000	49	-0.9	20.7	4.2	4.5	3.9	3.6
4/10/13	4/12/13	20000	49	-1.1	19.4	3.1	3.1	2.5	2.2

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 39. PAPA011 (Little Saddle lek) hourly dBA metrics, April 12-14, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/12/2013	4/14/2013	0	2	15.3	39.0	21.3	21.8	19.4	17.8
4/12/2013	4/14/2013	1	2	16.0	38.6	21.9	23.5	20.4	18.0
4/12/2013	4/14/2013	2	2	16.0	36.9	22.0	23.2	19.8	18.1
4/12/2013	4/14/2013	3	2	16.0	41.8	24.4	24.4	21.2	19.3
4/12/2013	4/14/2013	4	2	15.8	42.7	25.9	25.7	22.1	20.1
4/12/2013	4/14/2013	5	2	16.0	40.0	26.5	30.5	23.4	19.5
4/12/2013	4/14/2013	6	2	17.2	44.1	29.4	32.3	25.0	19.9
4/12/2013	4/14/2013	7	2	16.8	39.5	24.6	27.6	21.7	19.2
4/12/2013	4/14/2013	8	2	18	49	27	29	22	20
4/13/2013	4/13/2013	9	1	17	50	28	28	21	19
4/12/2013	4/14/2013	10	2	18	57	31	32	27	23
4/12/2013	4/14/2013	11	2	17	52	32	32	26	22
4/12/2013	4/14/2013	12	2	17	51	33	34	27	23
4/12/2013	4/14/2013	13	2	17	55	38	39	33	27
4/12/2013	4/14/2013	14	2	17	49	34	34	27	23
4/12/2013	4/14/2013	15	2	16.6	51.0	35.1	35.3	29.1	23.9
4/12/2013	4/14/2013	16	2	16.1	48.8	30.5	33.5	26.5	20.7
4/12/2013	4/14/2013	17	2	16.0	51.3	26.2	28.0	21.6	18.1
4/12/2013	4/14/2013	18	2	15.5	54.2	28.1	28.3	22.5	19.1
4/12/2013	4/14/2013	19	2	15.1	47.2	24.4	25.2	19.8	17.4
4/12/2013	4/14/2013	20	2	14.9	50.5	26.6	27.3	21.4	17.9
4/12/2013	4/14/2013	21	2	15.3	50.9	29.2	28.0	23.2	20.1
4/12/2013	4/14/2013	22	2	15.2	46.2	26.1	25.6	21.3	18.7
4/12/2013	4/14/2013	23	2	15.1	44.0	27.7	26.9	22.7	18.1

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 40. PAPA011 (Little Saddle lek) dBA and one-third octave band metrics, April 12-14, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/12/13	4/14/13	dBA	47	14.9	57.4	30.2	29.3	22.3	18.8
4/12/13	4/14/13	12.5	47	19.3	77.8	56.2	52.0	40.4	34.7
4/12/13	4/14/13	16	47	20.7	76.6	54.3	48.0	40.3	34.6
4/12/13	4/14/13	20	47	21.2	77.6	52.3	49.0	42.4	37.2
4/12/13	4/14/13	25	47	17.3	71.3	48.1	41.5	35.2	30.8
4/12/13	4/14/13	31.5	47	17.8	69.6	46.1	45.0	39.0	33.3
4/12/13	4/14/13	40	47	13.6	67.4	42.4	37.1	32.7	29.2
4/12/13	4/14/13	50	47	13.4	65.7	39.9	37.0	32.2	28.7
4/12/13	4/14/13	63	47	12.8	64.5	38.1	36.9	31.5	28.4
4/12/13	4/14/13	80	47	13.1	69.3	36.0	34.2	29.9	26.5
4/12/13	4/14/13	100	47	12.5	68.1	35.7	36.7	31.5	27.1
4/12/13	4/14/13	125	47	10.3	73.3	34.1	31.5	26.7	23.0
4/12/13	4/14/13	160	47	6.2	62.7	30.5	30.4	24.7	20.0
4/12/13	4/14/13	200	47	4.2	55.9	28.4	29.2	23.2	18.7
4/12/13	4/14/13	250	47	0.0	60.0	26.4	26.6	19.7	13.7
4/12/13	4/14/13	315	47	-2.3	55.8	25.1	25.2	17.8	10.7
4/12/13	4/14/13	400	47	-3.4	50.1	22.5	23.0	15.2	7.2
4/12/13	4/14/13	500	47	-3.8	44.7	20.2	19.0	11.8	3.2
4/12/13	4/14/13	630	47	-3.5	44.5	17.5	16.3	7.4	0.6
4/12/13	4/14/13	800	47	-3.1	41.5	15.5	14.3	5.1	-0.1
4/12/13	4/14/13	1000	47	-2.1	34.6	15.1	14.0	4.0	0.0
4/12/13	4/14/13	1250	47	-1.2	34.1	15.2	13.1	3.9	0.5
4/12/13	4/14/13	1600	47	-0.3	35.1	15.7	11.8	3.4	1.3
4/12/13	4/14/13	2000	47	0.7	34.7	15.0	10.2	3.4	1.9
4/12/13	4/14/13	2500	47	1.6	34.6	13.4	8.7	3.8	2.7
4/12/13	4/14/13	3150	47	2.2	38.6	11.4	7.7	4.4	3.4
4/12/13	4/14/13	4000	47	1.6	45.5	9.3	6.3	4.6	4.2
4/12/13	4/14/13	5000	47	1.5	49.2	9.9	6.1	5.0	4.7
4/12/13	4/14/13	6300	47	1.5	41.2	7.1	5.8	5.3	5.0
4/12/13	4/14/13	8000	47	1.0	23.4	5.8	5.7	5.3	5.1
4/12/13	4/14/13	10000	47	0.7	27.3	5.5	5.4	5.1	4.9
4/12/13	4/14/13	12500	47	0.4	26.8	5.1	5.0	4.6	4.3
4/12/13	4/14/13	16000	47	0.2	28.5	4.4	4.5	3.8	3.6
4/12/13	4/14/13	20000	47	0.4	27.2	3.5	4.1	2.7	2.4

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 41. PAPA012 (Alkali Draw lek) hourly dBA metrics, April 12-14, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/12/2013	4/14/2013	0	2	16.0	36.0	22.1	23.5	20.7	19.0
4/12/2013	4/14/2013	1	2	18.4	44.2	23.8	24.9	21.6	19.9
4/12/2013	4/14/2013	2	2	16.7	39.7	23.6	24.4	21.2	19.7
4/12/2013	4/14/2013	3	2	16.7	40.5	23.7	24.3	21.2	19.7
4/12/2013	4/14/2013	4	2	16.1	42.0	23.8	25.1	21.3	19.4
4/12/2013	4/14/2013	5	2	17.3	44.0	24.2	27.2	21.8	20.0
4/12/2013	4/14/2013	6	2	19.2	41.0	27.5	30.0	26.1	22.7
4/12/2013	4/14/2013	7	2	18.0	59.5	27.9	28.7	24.3	21.7
4/12/2013	4/14/2013	8	2	19.0	48.9	28.6	31.2	24.5	21.6
4/12/2013	4/14/2013	9	2	17.4	50.6	30.8	31.5	26.0	21.6
4/13/2013	4/13/2013	10	1	17.6	65.5	37.3	33.9	27.1	21.4
4/13/2013	4/13/2013	11	1	19.8	47.0	33.1	36.7	29.8	23.7
4/12/2013	4/14/2013	12	2	17.1	49.0	33.5	35.8	28.6	22.6
4/12/2013	4/14/2013	13	2	17.0	53.2	37.7	39.2	31.7	25.2
4/12/2013	4/14/2013	14	2	16.9	54.5	37.1	36.7	29.8	24.9
4/12/2013	4/14/2013	15	2	16.7	57.0	37.5	37.8	30.1	24.0
4/12/2013	4/14/2013	16	2	16.6	51.2	32.6	35.5	28.1	22.4
4/12/2013	4/14/2013	17	2	15.6	47.0	26.3	29.3	22.1	18.1
4/12/2013	4/14/2013	18	2	14.7	49.8	27.8	28.3	21.9	18.6
4/12/2013	4/14/2013	19	2	14.6	41.7	23.7	25.9	19.6	17.7
4/12/2013	4/14/2013	20	2	15.4	38.2	22.9	25.0	19.7	17.9
4/12/2013	4/14/2013	21	2	15.2	46.7	29.4	28.0	23.0	19.7
4/12/2013	4/14/2013	22	2	15.2	43.1	26.6	25.9	21.9	19.2
4/12/2013	4/14/2013	23	2	15.1	38.9	23.5	24.1	20.6	18.4

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 42. PAPA012 (Alkali Draw lek) dBA and one-third octave band metrics, April 12-14, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/12/13	4/14/13	dBA	46	14.6	65.5	31.4	28.7	23.3	20.4
4/12/13	4/14/13	12.5	46	20.7	73.9	49.7	48.5	43.2	38.1
4/12/13	4/14/13	16	46	23.0	70.9	47.0	47.1	42.3	38.7
4/12/13	4/14/13	20	46	25.3	69.0	48.1	50.5	46.1	41.8
4/12/13	4/14/13	25	46	21.3	67.2	43.2	44.3	38.6	35.1
4/12/13	4/14/13	31.5	46	21.8	67.6	43.4	45.5	40.3	35.8
4/12/13	4/14/13	40	46	16.2	63.5	37.4	38.0	34.2	31.3
4/12/13	4/14/13	50	46	15.2	59.7	36.4	37.3	33.6	30.9
4/12/13	4/14/13	63	46	15.8	57.6	36.4	38.3	33.9	30.7
4/12/13	4/14/13	80	46	14.6	66.2	34.1	35.3	31.5	28.5
4/12/13	4/14/13	100	46	12.6	73.4	34.5	34.9	31.3	28.3
4/12/13	4/14/13	125	46	11.8	77.0	33.7	32.0	28.4	25.5
4/12/13	4/14/13	160	46	9.2	70.0	30.8	30.0	25.6	22.8
4/12/13	4/14/13	200	46	7.4	68.1	28.3	28.5	23.6	20.5
4/12/13	4/14/13	250	46	3.3	66.7	26.6	26.1	20.6	16.5
4/12/13	4/14/13	315	46	-0.3	60.5	24.0	23.7	17.4	12.4
4/12/13	4/14/13	400	46	-3.0	56.7	20.9	20.0	12.5	6.9
4/12/13	4/14/13	500	46	-3.8	55.1	18.2	15.5	8.0	2.1
4/12/13	4/14/13	630	46	-3.7	53.2	16.2	13.8	5.8	-0.3
4/12/13	4/14/13	800	46	-3.7	56.5	17.2	16.1	6.3	-1.0
4/12/13	4/14/13	1000	46	-2.9	54.9	18.6	17.1	6.4	-0.9
4/12/13	4/14/13	1250	46	-2.2	51.2	19.1	16.6	5.3	-0.5
4/12/13	4/14/13	1600	46	-1.4	45.2	19.0	15.0	3.6	0.3
4/12/13	4/14/13	2000	46	-0.7	42.8	18.1	12.7	2.8	0.8
4/12/13	4/14/13	2500	46	0.4	41.9	16.3	10.3	2.3	1.4
4/12/13	4/14/13	3150	46	1.3	42.3	13.4	7.1	2.6	2.2
4/12/13	4/14/13	4000	46	1.4	43.5	10.3	5.7	3.3	3.0
4/12/13	4/14/13	5000	46	1.4	41.0	9.0	4.9	4.0	3.7
4/12/13	4/14/13	6300	46	1.0	43.5	8.1	5.0	4.6	4.4
4/12/13	4/14/13	8000	46	0.4	46.2	8.6	5.3	5.1	4.9
4/12/13	4/14/13	10000	46	0.1	38.4	7.7	5.5	5.3	5.1
4/12/13	4/14/13	12500	46	0.3	39.7	7.7	5.2	4.9	4.7
4/12/13	4/14/13	16000	46	-0.4	36.7	5.7	3.4	2.8	2.7
4/12/13	4/14/13	20000	46	-0.7	29.3	2.3	2.1	0.3	0.1

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 43. PAPA013 (Sand Draw lek) hourly dBA metrics, April 12-14, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/12/2013	4/14/2013	0	2	18.5	36.7	26.3	27.6	24.7	22.2
4/12/2013	4/14/2013	1	2	16.7	36.9	27.0	27.6	24.9	21.6
4/12/2013	4/14/2013	2	2	17.2	39.1	29.2	29.5	25.8	23.8
4/12/2013	4/14/2013	3	2	19.2	41.6	30.5	32.7	28.4	25.6
4/12/2013	4/14/2013	4	2	18.7	42.2	31.1	31.7	27.5	25.2
4/12/2013	4/14/2013	5	2	17.8	38.7	26.4	27.4	23.9	21.0
4/12/2013	4/14/2013	6	2	17.7	53.6	25.1	25.3	22.5	20.3
4/12/2013	4/14/2013	7	2	19.1	63.1	31.7	25.8	23.6	21.2
4/12/2013	4/14/2013	8	2	19.8	75.0	44.8	32.3	26.5	23.2
4/12/2013	4/14/2013	9	2	20.3	50.5	34.1	35.5	29.9	25.1
4/12/2013	4/14/2013	10	2	21.4	51.6	37.7	41.2	35.0	29.3
4/13/2013	4/13/2013	11	1	24.8	49.0	37.8	41.6	35.1	29.5
4/13/2013	4/13/2013	12	1	24.5	51.7	38.8	42.5	36.3	30.3
4/12/2013	4/14/2013	13	2	19.6	53.7	37.6	40.2	33.0	27.4
4/12/2013	4/14/2013	14	2	21.3	56.3	40.2	40.6	34.3	29.4
4/12/2013	4/14/2013	15	2	18.6	56.2	41.5	40.2	33.6	28.8
4/12/2013	4/14/2013	16	2	18.6	57.1	36.5	38.9	30.9	24.4
4/12/2013	4/14/2013	17	2	18.2	48.6	29.2	32.4	24.7	20.4
4/12/2013	4/14/2013	18	2	17.4	44.4	28.6	31.6	24.9	20.5
4/12/2013	4/14/2013	19	2	17.5	39.8	26.0	28.5	23.6	21.2
4/12/2013	4/14/2013	20	2	20.6	47.1	28.1	30.4	26.6	23.7
4/12/2013	4/14/2013	21	2	23.2	53.8	33.2	34.2	29.9	26.6
4/12/2013	4/14/2013	22	2	22.6	47.4	31.4	33.4	29.3	26.3
4/12/2013	4/14/2013	23	2	19.4	45.5	29.0	31.9	27.1	23.1

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 44. PAPA013 (Sand Draw lek) dBA and one-third octave band metrics, April 12-14, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/12/13	4/14/13	dBA	46	16.7	75.0	36.1	32.0	27.3	23.1
4/12/13	4/14/13	12.5	46	23.7	79.5	60.1	56.1	49.9	43.8
4/12/13	4/14/13	16	46	27.0	76.5	57.2	54.8	47.0	41.3
4/12/13	4/14/13	20	46	29.2	73.1	54.4	53.6	48.3	42.4
4/12/13	4/14/13	25	46	24.3	71.3	50.9	50.6	45.5	40.6
4/12/13	4/14/13	31.5	46	28.3	68.3	49.9	51.1	46.4	41.7
4/12/13	4/14/13	40	46	25.6	65.9	45.9	44.3	40.0	36.7
4/12/13	4/14/13	50	46	24.0	65.1	42.9	40.2	35.8	32.5
4/12/13	4/14/13	63	46	24.1	61.9	40.7	39.7	35.3	32.2
4/12/13	4/14/13	80	46	20.6	61.8	38.1	37.1	33.3	30.1
4/12/13	4/14/13	100	46	18.7	63.9	39.8	37.8	33.9	30.5
4/12/13	4/14/13	125	46	16.3	66.3	35.3	35.1	31.2	27.5
4/12/13	4/14/13	160	46	15.1	70.2	32.6	32.1	28.4	24.7
4/12/13	4/14/13	200	46	13.4	55.5	31.1	31.9	27.8	23.5
4/12/13	4/14/13	250	46	9.7	57.3	28.8	29.9	25.3	21.2
4/12/13	4/14/13	315	46	6.4	51.2	26.8	27.2	22.3	17.2
4/12/13	4/14/13	400	46	2.6	50.5	24.8	25.2	19.8	14.5
4/12/13	4/14/13	500	46	-0.7	49.2	22.7	22.8	17.1	11.2
4/12/13	4/14/13	630	46	-2.6	42.7	20.8	20.0	13.5	7.5
4/12/13	4/14/13	800	46	-2.8	38.2	20.5	20.0	12.3	5.5
4/12/13	4/14/13	1000	46	-1.9	38.1	21.2	21.1	12.5	5.4
4/12/13	4/14/13	1250	46	-1.6	38.5	20.9	18.1	8.2	2.4
4/12/13	4/14/13	1600	46	-0.7	39.4	21.0	15.8	6.2	2.0
4/12/13	4/14/13	2000	46	0.4	44.9	20.0	11.8	3.6	1.7
4/12/13	4/14/13	2500	46	1.3	62.8	21.7	10.1	3.2	2.4
4/12/13	4/14/13	3150	46	2.1	71.2	28.4	8.8	3.6	3.1
4/12/13	4/14/13	4000	46	3.1	69.5	24.8	7.0	4.1	3.8
4/12/13	4/14/13	5000	46	2.7	45.2	10.8	6.1	4.5	4.2
4/12/13	4/14/13	6300	46	1.6	46.7	8.6	5.3	4.7	4.5
4/12/13	4/14/13	8000	46	1.6	57.9	11.0	4.8	4.6	4.4
4/12/13	4/14/13	10000	46	0.3	38.0	6.1	4.4	4.2	4.1
4/12/13	4/14/13	12500	46	0.1	34.6	5.3	3.8	3.5	3.3
4/12/13	4/14/13	16000	46	-0.3	35.7	4.4	3.0	2.6	2.4
4/12/13	4/14/13	20000	46	-1.1	29.5	2.7	1.9	1.0	0.7

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 45. PAPA014 (Lovatt West lek) hourly dBA metrics, April 18-21, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/18/2013	4/21/2013	0	3	19.8	36.4	29.3	30.7	29.5	28.5
4/18/2013	4/21/2013	1	3	24.9	38.9	30.9	33.0	30.2	27.3
4/18/2013	4/21/2013	2	3	23.7	41.6	31.5	32.0	30.5	28.9
4/18/2013	4/21/2013	3	3	25.9	42.4	32.9	30.0	28.9	27.7
4/18/2013	4/21/2013	4	3	25.6	43.1	34.0	33.3	29.7	27.3
4/18/2013	4/21/2013	5	3	27.0	46.7	34.0	35.3	32.6	29.7
4/18/2013	4/21/2013	6	3	27.6	43.6	31.9	32.5	30.9	29.6
4/18/2013	4/21/2013	7	3	23.1	43.7	31.2	33.9	30.2	28.4
4/18/2013	4/21/2013	8	3	21.0	52.4	31.4	32.4	28.0	24.1
4/18/2013	4/21/2013	9	3	19.8	48.7	26.4	28.7	24.8	22.6
4/18/2013	4/21/2013	10	3	19.0	58.0	29.8	28.4	25.4	23.1
4/18/2013	4/21/2013	11	3	19.6	47.0	29.4	33.3	26.9	23.3
4/18/2013	4/21/2013	12	4	19.8	56.8	32.5	34.6	28.2	23.9
4/18/2013	4/21/2013	13	4	19.9	58.3	34.1	36.2	29.3	24.9
4/18/2013	4/21/2013	14	4	19.8	49.3	33.9	36.8	30.6	25.4
4/18/2013	4/21/2013	15	3	20.9	55.0	36.3	40.8	31.9	25.0
4/18/2013	4/21/2013	16	3	21.1	59.5	36.8	40.2	34.7	28.9
4/18/2013	4/21/2013	17	3	20.5	55.0	38.1	40.1	34.8	29.8
4/18/2013	4/21/2013	18	3	19.9	50.9	35.7	38.9	33.2	27.8
4/18/2013	4/21/2013	19	3	20.0	52.6	36.0	33.6	28.4	24.5
4/18/2013	4/21/2013	20	3	21.6	51.5	32.8	30.6	28.9	24.5
4/18/2013	4/21/2013	21	3	22.6	44.2	31.2	30.8	29.2	27.1
4/18/2013	4/21/2013	22	3	23.7	44.7	33.1	36.5	30.0	27.0
4/18/2013	4/21/2013	23	3	21.2	38.7	29.2	31.8	29.1	27.2

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 46. PAPA014 (Lovatt West lek) dBA and one-third octave band metrics, April 18-21, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/18/13	4/21/13	dBA	75	19.0	59.5	33.5	33.7	29.6	27.0
4/18/13	4/21/13	12.5	75	20.5	73.7	49.9	45.7	41.4	35.5
4/18/13	4/21/13	16	75	24.6	71.1	49.6	50.6	44.4	40.1
4/18/13	4/21/13	20	75	31.0	76.1	59.9	61.4	52.6	48.4
4/18/13	4/21/13	25	75	23.6	66.3	44.7	46.0	42.4	39.2
4/18/13	4/21/13	31.5	75	26.3	66.1	49.3	51.8	47.5	42.6
4/18/13	4/21/13	40	75	25.6	64.0	45.1	47.0	44.0	41.1
4/18/13	4/21/13	50	75	25.9	67.6	43.7	45.2	41.4	38.8
4/18/13	4/21/13	63	75	25.1	68.3	42.5	43.8	40.0	36.5
4/18/13	4/21/13	80	75	22.8	70.9	39.4	40.3	36.1	33.3
4/18/13	4/21/13	100	75	22.2	72.8	38.7	39.7	36.2	33.0
4/18/13	4/21/13	125	75	21.6	70.4	39.3	40.3	36.8	34.1
4/18/13	4/21/13	160	75	19.1	65.4	34.1	34.8	31.5	28.0
4/18/13	4/21/13	200	75	8.6	66.2	32.6	32.9	28.1	24.2
4/18/13	4/21/13	250	75	5.8	62.0	29.2	29.7	25.2	21.4
4/18/13	4/21/13	315	75	3.4	57.5	27.2	28.2	22.6	18.9
4/18/13	4/21/13	400	75	0.3	50.6	24.2	23.7	19.0	15.5
4/18/13	4/21/13	500	75	-1.6	48.6	21.4	22.9	15.3	10.6
4/18/13	4/21/13	630	75	-2.9	46.9	17.9	18.3	10.3	5.8
4/18/13	4/21/13	800	75	-2.1	41.9	17.8	19.4	8.7	5.4
4/18/13	4/21/13	1000	75	-1.8	38.4	18.8	20.4	8.7	4.7
4/18/13	4/21/13	1250	75	-1.4	42.4	20.9	21.8	11.7	5.1
4/18/13	4/21/13	1600	75	-0.9	48.6	20.9	22.1	11.0	4.2
4/18/13	4/21/13	2000	75	-0.4	51.8	19.6	17.6	8.2	2.8
4/18/13	4/21/13	2500	75	0.3	53.9	17.9	12.8	5.2	2.1
4/18/13	4/21/13	3150	75	1.3	52.6	14.8	12.2	4.5	2.9
4/18/13	4/21/13	4000	75	2.2	52.8	11.2	4.6	3.4	3.0
4/18/13	4/21/13	5000	75	1.9	57.1	12.7	4.3	3.9	3.7
4/18/13	4/21/13	6300	75	1.1	43.7	7.2	4.7	4.5	4.4
4/18/13	4/21/13	8000	75	0.6	40.0	6.3	5.2	5.0	4.9
4/18/13	4/21/13	10000	75	-0.2	31.8	5.9	5.5	5.3	5.2
4/18/13	4/21/13	12500	75	-0.5	33.1	5.6	5.0	4.9	4.7
4/18/13	4/21/13	16000	75	-1.1	29.3	3.6	2.9	2.8	2.6
4/18/13	4/21/13	20000	75	-1.0	22.6	1.3	0.5	0.2	0.1

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 47. PAPA015 (Cat lek) hourly dBA metrics, April 21-23, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/21/2013	4/23/2013	0	2	13.9	44.6	21.3	17.2	15.3	14.6
4/21/2013	4/23/2013	1	2	14.4	44.1	22.7	22.3	16.4	15.3
4/21/2013	4/23/2013	2	2	13.9	48.6	23.7	23.8	16.7	14.9
4/21/2013	4/23/2013	3	2	13.8	35.5	20.9	21.3	17.9	15.1
4/21/2013	4/23/2013	4	2	13.8	50.0	26.6	22.6	19.1	17.8
4/21/2013	4/23/2013	5	2	13.9	36.8	22.0	22.2	18.9	17.2
4/21/2013	4/23/2013	6	2	13.8	34.6	18.0	19.1	16.3	15.2
4/21/2013	4/23/2013	7	2	14.0	46.6	21.8	20.7	16.4	14.7
4/21/2013	4/23/2013	8	2	14.9	47.1	26.8	25.7	20.2	17.0
4/21/2013	4/23/2013	9	2	15.1	40.3	23.3	24.8	18.8	16.3
4/21/2013	4/23/2013	10	2	14.9	45.1	23.6	26.9	17.4	15.7
4/21/2013	4/23/2013	11	2	15.3	50.9	35.4	32.7	24.3	19.5
4/21/2013	4/23/2013	12	3	14.9	49.9	29.2	24.8	19.0	17.2
4/21/2013	4/23/2013	13	2	15.9	51.9	30.0	32.5	24.6	20.2
4/21/2013	4/23/2013	14	2	16.1	53.6	31.0	33.9	26.1	20.1
4/21/2013	4/23/2013	15	2	16.2	51.9	31.4	34.6	26.9	20.7
4/21/2013	4/23/2013	16	2	15.6	49.3	29.9	32.1	24.5	19.1
4/21/2013	4/23/2013	17	2	15.0	52.2	34.0	33.8	24.3	18.6
4/21/2013	4/23/2013	18	2	15.0	55.6	33.3	30.4	22.7	17.1
4/21/2013	4/23/2013	19	2	15.3	44.7	25.1	26.2	20.2	16.8
4/21/2013	4/23/2013	20	2	14.7	42.0	25.3	26.7	19.5	16.3
4/21/2013	4/23/2013	21	2	14.1	38.4	19.2	20.3	15.2	14.4
4/21/2013	4/23/2013	22	2	14.1	41.4	20.5	19.5	15.9	14.9
4/21/2013	4/23/2013	23	2	14.2	41.7	19.9	17.0	15.5	14.8

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 48. PAPA015 (Cat lek) dBA and one-third octave band metrics, April 21-23, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/21/13	4/23/13	dBA	49	13.8	55.6	28.5	24.8	17.5	16.0
4/21/13	4/23/13	12.5	49	16.0	78.4	55.6	43.0	38.5	34.1
4/21/13	4/23/13	16	49	16.8	76.1	52.3	46.4	41.9	35.8
4/21/13	4/23/13	20	49	18.3	74.0	50.3	51.6	44.6	37.4
4/21/13	4/23/13	25	49	14.2	71.8	43.6	40.9	35.0	29.0
4/21/13	4/23/13	31.5	49	13.4	68.3	43.0	42.6	35.2	29.1
4/21/13	4/23/13	40	49	11.5	65.4	37.9	34.7	28.9	24.8
4/21/13	4/23/13	50	49	9.5	64.3	35.7	33.6	27.8	23.9
4/21/13	4/23/13	63	49	8.9	66.8	34.8	33.0	27.2	23.2
4/21/13	4/23/13	80	49	7.3	72.0	35.1	32.0	24.6	20.9
4/21/13	4/23/13	100	49	3.6	71.5	33.0	29.9	23.4	19.1
4/21/13	4/23/13	125	49	1.6	67.9	30.5	28.4	21.8	17.2
4/21/13	4/23/13	160	49	-0.5	60.3	28.0	25.8	19.0	13.5
4/21/13	4/23/13	200	49	-1.2	59.2	26.3	23.7	17.2	11.3
4/21/13	4/23/13	250	49	-3.2	53.3	22.8	21.8	12.4	6.9
4/21/13	4/23/13	315	49	-3.8	45.8	20.0	17.8	8.5	3.5
4/21/13	4/23/13	400	49	-3.7	47.9	19.3	13.3	5.0	1.7
4/21/13	4/23/13	500	49	-4.0	50.0	19.2	9.5	3.3	0.1
4/21/13	4/23/13	630	49	-3.8	46.0	18.3	7.0	1.0	-0.8
4/21/13	4/23/13	800	49	-3.8	41.4	16.8	5.0	-0.5	-1.4
4/21/13	4/23/13	1000	49	-3.3	37.7	16.6	1.9	-0.6	-1.3
4/21/13	4/23/13	1250	49	-2.6	37.1	16.8	0.4	-0.7	-1.1
4/21/13	4/23/13	1600	49	-1.9	38.1	16.1	1.0	0.0	-0.5
4/21/13	4/23/13	2000	49	-0.8	39.8	14.7	1.6	0.9	0.5
4/21/13	4/23/13	2500	49	0.0	39.8	12.4	2.4	1.8	1.3
4/21/13	4/23/13	3150	49	1.2	41.0	10.7	3.2	2.5	2.2
4/21/13	4/23/13	4000	49	2.3	38.3	10.3	3.9	3.4	3.2
4/21/13	4/23/13	5000	49	3.4	43.2	10.8	4.7	4.3	4.1
4/21/13	4/23/13	6300	49	3.8	39.0	11.4	5.4	5.0	4.8
4/21/13	4/23/13	8000	49	3.4	39.4	11.9	5.9	5.5	5.4
4/21/13	4/23/13	10000	49	3.3	45.7	12.0	6.1	5.8	5.5
4/21/13	4/23/13	12500	49	3.0	44.1	11.1	5.5	5.2	4.8
4/21/13	4/23/13	16000	49	1.8	38.5	9.5	3.7	3.3	2.8
4/21/13	4/23/13	20000	49	-0.5	35.6	5.3	1.6	0.6	0.2

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 49. PAPA016 (Tyler Draw North lek) hourly dBA metrics, April 15-17, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/15/2013	4/17/2013	0	2	15.7	32.7	20.3	22.2	19.0	17.6
4/15/2013	4/17/2013	1	2	16.6	57.3	29.7	23.5	20.5	18.5
4/15/2013	4/17/2013	2	2	14.9	31.6	21.6	22.3	20.2	17.9
4/15/2013	4/17/2013	3	2	14.4	45.3	25.7	22.6	20.5	19.3
4/15/2013	4/17/2013	4	2	14.3	38.1	26.7	23.4	21.6	20.6
4/15/2013	4/17/2013	5	2	14.3	41.4	25.0	24.8	21.3	19.8
4/15/2013	4/17/2013	6	2	15.7	45.3	25.0	25.9	22.7	20.8
4/15/2013	4/17/2013	7	2	18.6	41.1	25.7	27.6	24.5	21.9
4/15/2013	4/17/2013	8	2	20.3	43.3	30.5	32.1	28.0	24.4
4/16/2013	4/16/2013	9	1	22.1	41.8	27.8	29.5	26.1	24.3
4/16/2013	4/16/2013	10	1	22.0	39.4	27.5	29.7	26.5	24.4
4/15/2013	4/17/2013	11	2	15.2	43.5	24.1	24.5	19.4	17.6
4/15/2013	4/17/2013	12	2	15.4	45.1	26.2	28.0	19.6	16.3
4/15/2013	4/17/2013	13	2	15.3	54.7	29.7	29.9	19.1	16.2
4/15/2013	4/17/2013	14	2	16.0	43.4	27.4	28.0	22.3	18.7
4/15/2013	4/17/2013	15	2	16.0	42.2	28.1	31.4	23.9	18.9
4/15/2013	4/17/2013	16	2	16.5	46.1	30.5	32.7	25.5	19.7
4/15/2013	4/17/2013	17	2	15.7	53.6	31.6	30.9	23.6	18.6
4/15/2013	4/17/2013	18	2	14.9	48.9	30.4	29.1	22.7	17.1
4/15/2013	4/17/2013	19	2	14.8	48.9	31.3	30.2	22.9	19.2
4/15/2013	4/17/2013	20	2	14.5	40.6	23.7	24.4	19.7	17.7
4/15/2013	4/17/2013	21	2	14.3	42.3	26.1	26.0	20.6	19.1
4/15/2013	4/17/2013	22	2	14.7	38.5	23.4	24.7	19.5	17.1
4/15/2013	4/17/2013	23	2	14.7	40.4	24.3	26.2	20.3	17.4

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 50. PAPA016 (Tyler Draw North lek) dBA and one-third octave band metrics, April 15-17, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/15/13	4/17/13	dBA	46	14.3	57.3	27.7	26.5	21.8	18.5
4/15/13	4/17/13	12.5	46	16.5	74.5	45.6	40.6	35.7	31.1
4/15/13	4/17/13	16	46	22.3	71.8	44.3	43.4	37.0	32.4
4/15/13	4/17/13	20	46	22.9	68.9	49.7	49.1	41.6	36.3
4/15/13	4/17/13	25	46	20.2	65.2	40.9	39.6	33.6	29.9
4/15/13	4/17/13	31.5	46	18.0	65.9	44.8	41.3	34.3	29.8
4/15/13	4/17/13	40	46	15.8	58.3	37.3	35.9	30.6	27.0
4/15/13	4/17/13	50	46	13.9	58.7	37.0	36.4	29.8	25.2
4/15/13	4/17/13	63	46	12.7	66.1	37.6	36.6	29.9	24.9
4/15/13	4/17/13	80	46	9.2	71.4	36.1	35.7	28.9	25.0
4/15/13	4/17/13	100	46	7.0	75.7	36.2	34.6	28.3	24.6
4/15/13	4/17/13	125	46	4.4	73.4	34.5	32.7	26.6	23.1
4/15/13	4/17/13	160	46	2.2	64.3	30.2	29.3	23.7	20.2
4/15/13	4/17/13	200	46	0.2	56.5	26.5	27.8	21.9	17.7
4/15/13	4/17/13	250	46	-3.3	52.6	22.0	21.4	17.1	12.4
4/15/13	4/17/13	315	46	-4.4	46.4	18.1	17.3	13.3	7.7
4/15/13	4/17/13	400	46	-4.5	52.3	16.6	13.1	8.6	2.5
4/15/13	4/17/13	500	46	-4.5	48.1	15.4	9.1	2.5	-0.8
4/15/13	4/17/13	630	46	-4.0	40.4	14.8	9.2	1.1	-1.4
4/15/13	4/17/13	800	46	-3.2	42.0	16.1	9.4	1.5	-1.0
4/15/13	4/17/13	1000	46	-2.4	38.5	16.9	8.3	1.2	-0.5
4/15/13	4/17/13	1250	46	-1.6	38.7	15.9	6.9	1.0	-0.1
4/15/13	4/17/13	1600	46	-0.6	48.1	15.1	6.2	1.5	0.8
4/15/13	4/17/13	2000	46	0.4	37.8	13.3	4.4	2.1	1.5
4/15/13	4/17/13	2500	46	1.3	35.5	10.6	3.8	2.8	2.3
4/15/13	4/17/13	3150	46	2.2	35.0	8.2	4.1	3.5	3.1
4/15/13	4/17/13	4000	46	3.2	33.2	6.5	4.7	4.1	3.9
4/15/13	4/17/13	5000	46	3.6	37.7	6.3	5.3	4.8	4.5
4/15/13	4/17/13	6300	46	3.5	38.0	6.6	5.6	5.2	5.0
4/15/13	4/17/13	8000	46	3.6	41.3	7.5	5.6	5.3	5.1
4/15/13	4/17/13	10000	46	3.1	35.5	6.0	5.4	5.0	4.8
4/15/13	4/17/13	12500	46	2.8	35.7	5.2	4.7	4.3	4.1
4/15/13	4/17/13	16000	46	2.5	33.5	4.5	3.8	3.3	3.1
4/15/13	4/17/13	20000	46	1.2	32.9	3.2	2.6	2.0	1.7

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 51. PAPA017 (Oil Fork Road lek) hourly dBA metrics, April 15-17, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/15/2013	4/17/2013	0	2	20.3	37.0	25.4	27.4	24.7	22.6
4/15/2013	4/17/2013	1	2	19.3	53.6	28.5	27.7	25.3	22.9
4/15/2013	4/17/2013	2	2	18.1	37.5	24.7	26.0	23.6	21.3
4/15/2013	4/17/2013	3	2	17.4	42.6	27.0	28.9	23.6	22.0
4/15/2013	4/17/2013	4	2	15.2	46.5	31.4	28.5	24.6	22.9
4/15/2013	4/17/2013	5	2	15.2	54.3	32.3	31.1	27.3	23.8
4/15/2013	4/17/2013	6	2	17.5	50.1	32.7	33.1	29.7	26.9
4/15/2013	4/17/2013	7	2	18.5	40.8	25.4	27.5	24.5	21.9
4/15/2013	4/17/2013	8	2	18.6	47.0	27.8	29.6	25.4	22.3
4/15/2013	4/17/2013	9	2	17.8	40.8	28.4	30.7	26.5	22.8
4/16/2013	4/16/2013	10	1	19.7	52.4	28.1	31.3	24.4	21.9
4/16/2013	4/16/2013	11	1	19.2	27.5	21.7	23.1	21.3	20.3
4/15/2013	4/17/2013	12	2	18.0	43.7	26.9	29.3	23.7	20.5
4/15/2013	4/17/2013	13	2	19.0	58.2	31.6	29.5	23.7	21.3
4/15/2013	4/17/2013	14	2	19.4	44.1	26.8	28.2	24.4	22.3
4/15/2013	4/17/2013	15	2	19.4	42.1	27.5	30.0	24.3	21.9
4/15/2013	4/17/2013	16	2	19.5	45.4	28.5	30.5	25.4	22.6
4/15/2013	4/17/2013	17	2	19.3	56.7	31.9	30.3	25.4	22.9
4/15/2013	4/17/2013	18	2	18.1	47.7	30.8	30.6	26.3	23.5
4/15/2013	4/17/2013	19	2	18.7	49.4	31.6	31.9	27.3	24.5
4/15/2013	4/17/2013	20	2	18.9	50.4	27.6	28.9	26.6	24.4
4/15/2013	4/17/2013	21	2	17.6	47.7	29.2	29.4	27.0	23.9
4/15/2013	4/17/2013	22	2	16.4	36.2	27.8	27.2	24.7	22.6
4/15/2013	4/17/2013	23	2	18.3	36.0	25.7	27.9	24.9	22.1

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 52. PAPA017 (Oil Fork Road lek) dBA and one-third octave band metrics, April 15-17, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/15/13	4/17/13	dBA	46	15.2	58.2	29.2	28.6	24.9	22.2
4/15/13	4/17/13	12.5	46	25.3	78.3	53.5	50.6	44.1	39.3
4/15/13	4/17/13	16	46	25.1	77.6	51.2	49.7	44.1	39.3
4/15/13	4/17/13	20	46	29.6	75.9	57.6	60.8	50.8	46.2
4/15/13	4/17/13	25	46	27.6	70.6	48.9	50.3	46.3	42.8
4/15/13	4/17/13	31.5	46	26.1	69.4	55.9	58.2	52.7	46.8
4/15/13	4/17/13	40	46	24.6	64.5	43.8	45.1	41.8	38.0
4/15/13	4/17/13	50	46	24.1	63.8	40.7	41.5	37.7	34.8
4/15/13	4/17/13	63	46	21.8	62.8	40.8	40.0	36.8	33.7
4/15/13	4/17/13	80	46	17.2	68.7	38.0	36.7	32.8	29.2
4/15/13	4/17/13	100	46	13.4	69.9	37.4	35.5	30.1	26.7
4/15/13	4/17/13	125	46	7.5	74.7	37.8	34.8	29.2	25.6
4/15/13	4/17/13	160	46	4.5	71.3	32.9	32.3	27.6	24.0
4/15/13	4/17/13	200	46	4.5	57.8	30.9	30.6	26.5	22.5
4/15/13	4/17/13	250	46	1.1	55.1	26.8	26.9	23.0	19.2
4/15/13	4/17/13	315	46	-1.1	47.9	23.1	23.5	18.9	15.6
4/15/13	4/17/13	400	46	-3.0	49.2	19.9	19.1	15.1	11.1
4/15/13	4/17/13	500	46	-3.4	47.3	16.8	14.8	9.3	6.1
4/15/13	4/17/13	630	46	-3.4	41.4	13.9	10.7	4.9	1.2
4/15/13	4/17/13	800	46	-3.1	39.4	12.2	8.5	2.9	-0.1
4/15/13	4/17/13	1000	46	-2.1	50.9	12.2	9.1	1.7	-0.1
4/15/13	4/17/13	1250	46	-1.3	42.2	11.6	7.7	1.3	0.3
4/15/13	4/17/13	1600	46	-0.5	37.5	11.6	5.6	1.6	1.0
4/15/13	4/17/13	2000	46	0.6	33.7	10.1	3.8	2.3	1.7
4/15/13	4/17/13	2500	46	1.6	35.2	8.5	3.6	2.9	2.5
4/15/13	4/17/13	3150	46	2.5	48.5	11.2	4.1	3.7	3.3
4/15/13	4/17/13	4000	46	3.2	38.5	6.6	4.8	4.4	4.1
4/15/13	4/17/13	5000	46	2.7	45.2	7.0	5.3	4.9	4.7
4/15/13	4/17/13	6300	46	2.7	41.5	5.9	5.5	5.2	5.0
4/15/13	4/17/13	8000	46	2.2	29.5	5.7	5.5	5.3	5.1
4/15/13	4/17/13	10000	46	2.4	26.2	5.5	5.2	5.0	4.9
4/15/13	4/17/13	12500	46	1.9	26.2	5.0	4.7	4.5	4.3
4/15/13	4/17/13	16000	46	1.8	23.6	4.3	3.9	3.6	3.5
4/15/13	4/17/13	20000	46	1.7	20.5	3.1	3.0	2.4	2.3

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 53. PAPA018 (Mesa Road 3 lek) hourly dBA metrics, April 15-17, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/15/2013	4/17/2013	0	2	16.2	35.7	26.6	30.1	24.2	20.2
4/15/2013	4/17/2013	1	2	21.6	47.6	28.2	30.2	27.0	25.0
4/15/2013	4/17/2013	2	2	22.4	36.7	28.8	31.0	28.2	25.5
4/15/2013	4/17/2013	3	2	19.0	40.6	29.7	29.4	27.2	25.3
4/15/2013	4/17/2013	4	2	14.9	48.5	33.7	30.5	25.4	23.3
4/15/2013	4/17/2013	5	2	14.4	50.7	33.0	30.5	24.5	23.0
4/15/2013	4/17/2013	6	2	19.6	49.2	33.5	34.7	29.9	26.3
4/15/2013	4/17/2013	7	2	19.2	45.3	31.1	33.3	28.2	23.2
4/15/2013	4/17/2013	8	2	16.7	46.5	26.4	27.6	22.5	20.1
4/15/2013	4/17/2013	9	2	17.4	50.1	27.3	29.7	24.3	19.7
4/15/2013	4/17/2013	10	2	17.4	42.2	26.5	29.7	23.3	19.8
4/16/2013	4/16/2013	11	1	18.0	34.6	21.7	23.4	20.8	19.6
4/15/2013	4/17/2013	12	2	16.4	44.4	27.8	31.2	23.6	19.3
4/15/2013	4/17/2013	13	2	16.5	59.1	33.0	29.3	23.1	19.3
4/15/2013	4/17/2013	14	2	17.1	45.2	26.8	29.7	23.4	19.7
4/15/2013	4/17/2013	15	2	17.3	56.7	30.6	31.4	23.5	19.8
4/15/2013	4/17/2013	16	2	16.9	42.6	27.6	29.5	23.1	19.5
4/15/2013	4/17/2013	17	2	16.8	49.8	30.8	31.9	24.1	19.6
4/15/2013	4/17/2013	18	2	15.3	49.3	34.1	33.4	25.8	22.2
4/15/2013	4/17/2013	19	2	15.1	47.7	30.8	30.1	24.1	20.1
4/15/2013	4/17/2013	20	2	15.6	37.0	23.5	25.9	21.1	18.4
4/15/2013	4/17/2013	21	2	14.5	61.4	33.0	25.2	21.8	18.0
4/15/2013	4/17/2013	22	2	15.2	35.9	24.3	24.7	21.5	20.0
4/15/2013	4/17/2013	23	2	14.8	40.0	25.0	27.7	24.4	19.2

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 54. PAPA018 (Mesa Road 3 lek) dBA and one-third octave band metrics, April 15-17, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/15/13	4/17/13	dBA	47	14.4	61.4	30.2	29.3	24.1	20.1
4/15/13	4/17/13	12.5	47	19.0	78.4	55.6	47.9	41.8	36.8
4/15/13	4/17/13	16	47	23.7	75.3	51.9	50.1	44.7	38.4
4/15/13	4/17/13	20	47	29.4	75.1	56.4	58.5	49.3	45.1
4/15/13	4/17/13	25	47	22.0	70.9	46.4	45.5	41.0	36.5
4/15/13	4/17/13	31.5	47	23.7	69.4	50.8	51.6	45.4	39.5
4/15/13	4/17/13	40	47	21.0	65.1	42.6	42.7	37.8	34.3
4/15/13	4/17/13	50	47	20.6	64.2	40.8	40.6	36.0	32.1
4/15/13	4/17/13	63	47	17.8	66.0	41.0	40.8	34.7	30.7
4/15/13	4/17/13	80	47	14.1	68.8	37.8	37.8	31.5	26.4
4/15/13	4/17/13	100	47	12.9	77.6	38.6	37.3	29.8	25.2
4/15/13	4/17/13	125	47	11.6	76.8	36.6	35.0	28.8	24.0
4/15/13	4/17/13	160	47	8.4	60.3	33.0	32.7	26.1	22.4
4/15/13	4/17/13	200	47	7.6	68.3	33.4	32.4	26.2	21.8
4/15/13	4/17/13	250	47	2.7	63.9	27.9	28.0	22.7	18.0
4/15/13	4/17/13	315	47	-0.1	52.9	25.3	24.3	19.3	15.0
4/15/13	4/17/13	400	47	-3.3	57.8	22.4	19.1	13.9	9.8
4/15/13	4/17/13	500	47	-3.8	59.7	20.4	14.6	9.1	4.7
4/15/13	4/17/13	630	47	-3.9	52.9	16.2	10.8	5.0	1.0
4/15/13	4/17/13	800	47	-3.6	39.9	13.2	10.7	2.8	-0.3
4/15/13	4/17/13	1000	47	-2.9	38.3	12.7	8.3	0.5	-1.1
4/15/13	4/17/13	1250	47	-2.4	34.1	13.1	6.8	-0.2	-0.9
4/15/13	4/17/13	1600	47	-1.5	35.5	13.0	3.8	0.2	-0.4
4/15/13	4/17/13	2000	47	-0.7	37.3	11.8	3.0	0.9	0.3
4/15/13	4/17/13	2500	47	0.2	36.9	9.7	2.6	1.5	1.1
4/15/13	4/17/13	3150	47	1.2	34.4	7.0	2.8	2.2	1.9
4/15/13	4/17/13	4000	47	2.2	43.8	5.9	3.4	3.0	2.8
4/15/13	4/17/13	5000	47	2.9	47.8	7.5	4.1	3.8	3.6
4/15/13	4/17/13	6300	47	2.8	54.3	10.2	4.7	4.5	4.4
4/15/13	4/17/13	8000	47	2.6	55.8	13.4	5.2	5.1	4.9
4/15/13	4/17/13	10000	47	2.7	36.8	5.9	5.5	5.3	5.2
4/15/13	4/17/13	12500	47	2.5	28.0	5.7	5.2	4.8	4.7
4/15/13	4/17/13	16000	47	1.6	33.5	3.9	3.2	2.8	2.6
4/15/13	4/17/13	20000	47	-0.4	19.2	1.1	0.7	0.2	0.0

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 55. PAPA019 (Bloom Reservoir lek) hourly dBA metrics, April 15-17, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/15/2013	4/17/2013	0	2	15.1	37.4	23.7	25.6	21.5	17.9
4/15/2013	4/17/2013	1	2	18.7	42.5	29.4	29.9	25.9	23.1
4/15/2013	4/17/2013	2	2	20.6	38.2	24.7	26.1	24.2	23.0
4/15/2013	4/17/2013	3	2	23.0	43.1	30.0	32.3	27.8	25.5
4/15/2013	4/17/2013	4	2	19.2	44.4	28.8	30.1	27.9	25.6
4/15/2013	4/17/2013	5	2	16.2	60.1	27.0	26.0	23.4	21.8
4/15/2013	4/17/2013	6	2	20.6	37.7	26.2	27.4	25.3	23.8
4/15/2013	4/17/2013	7	2	18.5	39.3	25.7	27.5	24.4	21.3
4/15/2013	4/17/2013	8	2	15.6	43.7	24.0	24.5	20.3	18.4
4/15/2013	4/17/2013	9	2	16.5	38.5	23.4	26.4	21.5	18.0
4/15/2013	4/17/2013	10	2	16.1	41.0	24.8	27.6	21.4	18.2
4/16/2013	4/16/2013	11	1	15.9	36.1	18.9	20.5	17.9	16.8
4/16/2013	4/16/2013	12	1	15.5	42.0	22.2	24.7	19.2	16.6
4/15/2013	4/17/2013	13	2	15.7	55.9	31.2	27.6	21.2	17.5
4/15/2013	4/17/2013	14	2	16.2	43.1	26.2	27.7	21.4	17.6
4/15/2013	4/17/2013	15	2	15.5	52.2	30.0	32.3	22.5	17.9
4/15/2013	4/17/2013	16	2	15.6	47.1	29.1	30.2	23.1	18.6
4/15/2013	4/17/2013	17	2	16.6	51.8	32.1	34.3	26.2	20.5
4/15/2013	4/17/2013	18	2	15.7	53.1	34.1	32.0	26.1	22.2
4/15/2013	4/17/2013	19	2	15.9	48.4	31.0	30.1	24.3	19.3
4/15/2013	4/17/2013	20	2	14.9	53.8	24.8	26.2	19.7	17.5
4/15/2013	4/17/2013	21	2	16.0	61.2	33.2	26.2	21.0	17.9
4/15/2013	4/17/2013	22	2	14.7	35.4	19.0	21.0	17.4	15.5
4/15/2013	4/17/2013	23	2	14.9	29.3	20.0	22.2	19.4	16.7

Appendix B. dBA and One-third Octave Metrics for PAPA Treatment Leks (cont.).

Table 56. PAPA019 (Bloom Reservoir lek) dBA and one-third octave band metrics, April 15-17, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/15/13	4/17/13	dBA	46	14.7	61.2	28.6	26.6	22.0	18.3
4/15/13	4/17/13	12.5	46	16.2	73.2	47.0	43.7	38.5	33.9
4/15/13	4/17/13	16	46	19.9	69.7	46.2	44.9	40.0	34.9
4/15/13	4/17/13	20	46	22.6	71.7	52.3	52.9	43.9	39.5
4/15/13	4/17/13	25	46	20.7	63.8	42.1	42.2	36.7	32.1
4/15/13	4/17/13	31.5	46	20.7	63.6	45.9	45.2	39.5	33.6
4/15/13	4/17/13	40	46	18.5	60.9	39.5	39.1	34.3	29.6
4/15/13	4/17/13	50	46	16.6	59.7	38.4	39.0	33.1	28.8
4/15/13	4/17/13	63	46	18.5	65.6	39.2	38.6	32.9	28.5
4/15/13	4/17/13	80	46	14.5	76.9	37.9	36.8	30.8	26.7
4/15/13	4/17/13	100	46	14.3	74.5	37.1	35.3	28.8	24.9
4/15/13	4/17/13	125	46	11.3	71.6	34.3	33.1	27.1	22.5
4/15/13	4/17/13	160	46	7.8	60.1	30.4	29.4	24.5	20.0
4/15/13	4/17/13	200	46	4.8	68.0	29.5	27.6	22.5	18.2
4/15/13	4/17/13	250	46	1.1	65.3	25.3	23.4	18.5	14.9
4/15/13	4/17/13	315	46	-1.9	52.1	21.3	20.5	14.7	10.8
4/15/13	4/17/13	400	46	-3.3	56.2	19.8	16.1	10.0	5.8
4/15/13	4/17/13	500	46	-3.9	56.8	18.9	12.2	5.4	1.0
4/15/13	4/17/13	630	46	-3.6	52.4	16.2	8.6	1.9	-1.4
4/15/13	4/17/13	800	46	-3.3	48.5	13.7	8.2	0.5	-1.5
4/15/13	4/17/13	1000	46	-2.4	50.7	14.4	7.7	0.2	-1.0
4/15/13	4/17/13	1250	46	-1.6	53.4	15.1	6.9	0.4	-0.3
4/15/13	4/17/13	1600	46	-0.7	54.4	14.7	5.9	1.1	0.5
4/15/13	4/17/13	2000	46	0.3	49.9	12.4	3.5	1.8	1.3
4/15/13	4/17/13	2500	46	1.3	43.8	10.2	3.1	2.5	2.0
4/15/13	4/17/13	3150	46	2.1	35.2	7.4	3.7	3.2	2.9
4/15/13	4/17/13	4000	46	2.0	37.0	5.4	4.3	3.9	3.6
4/15/13	4/17/13	5000	46	2.4	35.9	5.1	4.7	4.4	4.2
4/15/13	4/17/13	6300	46	1.4	37.7	5.1	4.9	4.7	4.5
4/15/13	4/17/13	8000	46	1.1	29.6	4.9	4.8	4.6	4.4
4/15/13	4/17/13	10000	46	0.5	32.1	4.5	4.5	4.2	4.0
4/15/13	4/17/13	12500	46	0.0	28.3	3.8	3.8	3.5	3.3
4/15/13	4/17/13	16000	46	-0.4	26.5	2.9	2.9	2.5	2.3
4/15/13	4/17/13	20000	46	-0.3	26.4	1.3	1.4	0.9	0.6

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites.

Table 57. PAPA201 (Injection Well 100 m) hourly dBA metrics, April 14-15, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/15/2013	4/15/2013	0	1	53.8	58.4	56.0	56.8	55.9	55.1
4/15/2013	4/15/2013	1	1	53.9	58.3	56.2	56.9	56.1	55.4
4/15/2013	4/15/2013	2	1	53.3	58.4	56.2	57.1	56.2	54.9
4/15/2013	4/15/2013	3	1	52.7	57.5	55.3	56.1	55.3	54.4
4/15/2013	4/15/2013	4	1	53.2	58.2	56.3	57.0	56.3	55.4
4/15/2013	4/15/2013	5	1	53.3	57.9	56.3	57.0	56.3	55.6
4/15/2013	4/15/2013	6	1	53.5	57.9	56.1	56.8	56.1	55.4
4/15/2013	4/15/2013	7	1	54.3	58.2	56.4	57.0	56.4	55.8
4/15/2013	4/15/2013	8	1	53.5	58.0	56.2	56.8	56.2	55.4
4/14/2013	4/15/2013	9	2	50.2	58.1	55.3	56.2	55.3	54.3
4/14/2013	4/15/2013	10	2	50.3	66.3	55.5	56.1	55.3	54.3
4/14/2013	4/15/2013	11	2	50.5	58.0	55.3	56.0	55.1	54.0
4/14/2013	4/15/2013	12	2	50.5	60.9	54.9	56.0	55.0	52.7
4/14/2013	4/14/2013	13	1	50.3	57.6	54.5	55.5	54.4	53.2
4/14/2013	4/14/2013	14	1	50.9	62.1	54.6	55.6	54.6	53.3
4/14/2013	4/14/2013	15	1	51.5	57.7	55.6	56.5	55.6	54.4
4/14/2013	4/14/2013	16	1	52.1	58.1	55.6	56.5	55.7	54.5
4/14/2013	4/14/2013	17	1	52.2	57.4	55.6	56.5	55.6	54.4
4/14/2013	4/14/2013	18	1	52.1	57.1	55.2	55.9	55.2	54.3
4/14/2013	4/14/2013	19	1	52.6	57.4	55.6	56.2	55.6	54.9
4/14/2013	4/14/2013	20	1	53.7	59.1	55.9	56.5	55.9	55.2
4/14/2013	4/14/2013	21	1	53.8	64.7	55.9	56.4	55.9	55.2
4/14/2013	4/14/2013	22	1	53.8	57.9	56.2	56.7	56.2	55.6
4/14/2013	4/14/2013	23	1	52.9	57.3	55.6	56.3	55.6	54.9

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 58. PAPA201 (Injection Well 100 m) dBA and one-third octave band metrics, April 14-15, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/14/13	4/15/13	dBA	28	50.2	66.3	55.6	56.5	55.8	54.9
4/14/13	4/15/13	12.5	28	29.0	76.4	56.2	50.5	46.0	42.4
4/14/13	4/15/13	16	28	33.9	76.6	54.7	51.1	47.7	44.7
4/14/13	4/15/13	20	28	40.0	74.9	55.4	54.8	52.0	48.5
4/14/13	4/15/13	25	28	43.0	72.6	54.2	53.9	51.8	49.6
4/14/13	4/15/13	31.5	28	44.7	70.7	56.1	58.0	55.7	52.4
4/14/13	4/15/13	40	28	49.2	77.7	59.3	61.1	59.1	56.3
4/14/13	4/15/13	50	28	49.0	68.2	60.7	61.8	60.7	59.4
4/14/13	4/15/13	63	28	53.9	78.3	67.7	69.2	67.6	65.6
4/14/13	4/15/13	80	28	55.2	77.2	65.9	66.2	65.0	63.9
4/14/13	4/15/13	100	28	56.4	79.0	71.8	73.3	72.4	71.5
4/14/13	4/15/13	125	28	50.8	77.7	60.5	61.9	60.5	59.2
4/14/13	4/15/13	160	28	48.5	73.1	58.4	59.5	58.4	57.3
4/14/13	4/15/13	200	28	45.9	72.8	57.6	58.8	57.7	56.5
4/14/13	4/15/13	250	28	36.9	62.2	49.0	50.3	48.9	47.6
4/14/13	4/15/13	315	28	37.4	53.6	48.4	49.9	48.4	47.0
4/14/13	4/15/13	400	28	30.6	50.0	43.7	45.4	43.7	42.2
4/14/13	4/15/13	500	28	27.3	48.7	38.9	40.5	38.6	36.5
4/14/13	4/15/13	630	28	24.8	47.5	37.6	39.2	37.0	34.4
4/14/13	4/15/13	800	28	17.4	47.0	33.3	35.3	32.6	30.0
4/14/13	4/15/13	1000	28	14.1	47.5	31.6	34.3	30.8	28.0
4/14/13	4/15/13	1250	28	11.7	47.4	31.6	33.6	31.1	28.1
4/14/13	4/15/13	1600	28	9.9	45.8	33.8	35.9	33.4	29.8
4/14/13	4/15/13	2000	28	8.8	47.0	32.8	34.8	32.0	28.2
4/14/13	4/15/13	2500	28	7.5	47.6	32.8	35.0	32.2	27.6
4/14/13	4/15/13	3150	28	8.0	46.5	31.0	34.0	30.7	25.5
4/14/13	4/15/13	4000	28	8.4	44.3	28.7	30.8	27.9	22.1
4/14/13	4/15/13	5000	28	7.4	53.0	26.2	28.1	24.6	19.4
4/14/13	4/15/13	6300	28	6.8	60.0	22.6	24.6	21.3	16.4
4/14/13	4/15/13	8000	28	6.1	37.0	16.5	19.4	16.6	12.0
4/14/13	4/15/13	10000	28	4.6	33.4	12.1	13.8	11.2	8.3
4/14/13	4/15/13	12500	28	3.8	32.7	8.2	9.9	7.2	5.9
4/14/13	4/15/13	16000	28	3.2	28.1	5.5	6.1	4.7	4.1
4/14/13	4/15/13	20000	28	1.8	23.3	4.0	3.3	2.8	2.5

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 59. PAPA202 (Injection Well 200 m) hourly dBA metrics, April 14-15, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/15/2013	4/15/2013	0	1	46.0	51.5	49.2	50.1	49.2	48.2
4/15/2013	4/15/2013	1	1	46.1	51.6	49.4	50.2	49.3	48.4
4/15/2013	4/15/2013	2	1	45.1	52.0	49.3	50.4	49.3	47.7
4/15/2013	4/15/2013	3	1	44.6	51.0	48.4	49.4	48.3	47.1
4/15/2013	4/15/2013	4	1	46.0	51.6	49.2	50.0	49.1	48.2
4/15/2013	4/15/2013	5	1	45.8	51.0	49.3	50.1	49.3	48.2
4/15/2013	4/15/2013	6	1	45.7	51.2	49.0	49.7	48.9	48.1
4/15/2013	4/15/2013	7	1	46.1	50.9	49.3	50.0	49.2	48.4
4/15/2013	4/15/2013	8	1	45.0	51.2	48.8	49.7	48.8	47.9
4/14/2013	4/15/2013	9	2	38.4	51.0	47.4	48.4	47.0	45.4
4/14/2013	4/15/2013	10	2	37.8	52.8	47.4	48.1	46.7	45.3
4/14/2013	4/15/2013	11	2	37.5	53.9	47.4	48.3	46.8	45.2
4/14/2013	4/15/2013	12	2	39.4	51.1	47.1	48.4	46.8	44.2
4/14/2013	4/14/2013	13	1	39.5	61.0	45.9	47.6	45.5	43.2
4/14/2013	4/14/2013	14	1	38.3	59.8	46.1	47.9	45.8	43.2
4/14/2013	4/14/2013	15	1	39.1	51.6	47.9	49.5	47.9	45.4
4/14/2013	4/14/2013	16	1	41.0	51.2	48.1	49.5	48.2	45.5
4/14/2013	4/14/2013	17	1	39.9	51.4	47.9	49.3	47.9	45.3
4/14/2013	4/14/2013	18	1	42.1	50.2	47.2	48.4	47.1	45.4
4/14/2013	4/14/2013	19	1	44.1	52.1	48.0	48.9	47.9	46.9
4/14/2013	4/14/2013	20	1	45.1	52.6	48.4	49.1	48.3	47.6
4/14/2013	4/14/2013	21	1	45.4	62.1	48.8	49.1	48.5	47.7
4/14/2013	4/14/2013	22	1	46.5	50.9	49.2	49.9	49.2	48.3
4/14/2013	4/14/2013	23	1	46.1	50.9	49.1	49.8	49.0	48.3

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 60. PAPA202 (Injection Well 200 m) dBA and one-third octave band metrics, April 14-15, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/14/13	4/15/13	dBA	28	37.5	62.1	48.2	49.5	48.5	47.7
4/14/13	4/15/13	12.5	28	26.5	74.3	52.8	47.1	43.2	39.2
4/14/13	4/15/13	16	28	28.7	71.7	50.0	48.6	44.8	40.4
4/14/13	4/15/13	20	28	31.9	73.5	50.2	52.5	47.3	43.2
4/14/13	4/15/13	25	28	37.2	66.9	47.7	48.3	46.0	43.4
4/14/13	4/15/13	31.5	28	39.8	67.6	50.9	52.9	50.5	47.1
4/14/13	4/15/13	40	28	42.8	71.5	53.2	55.3	53.3	50.5
4/14/13	4/15/13	50	28	44.2	67.8	55.2	56.5	55.4	54.1
4/14/13	4/15/13	63	28	44.2	76.8	63.1	64.7	63.2	61.1
4/14/13	4/15/13	80	28	43.4	77.9	59.4	60.9	59.2	57.7
4/14/13	4/15/13	100	28	44.7	79.5	65.4	67.1	65.9	64.7
4/14/13	4/15/13	125	28	35.8	77.0	53.2	54.7	53.3	51.8
4/14/13	4/15/13	160	28	34.2	70.4	49.7	51.5	50.2	47.5
4/14/13	4/15/13	200	28	30.7	71.6	47.0	48.9	47.3	44.4
4/14/13	4/15/13	250	28	26.0	59.5	39.1	40.9	39.0	36.1
4/14/13	4/15/13	315	28	23.7	49.9	37.3	39.4	37.2	34.3
4/14/13	4/15/13	400	28	17.9	49.3	31.7	33.6	31.1	27.3
4/14/13	4/15/13	500	28	11.5	50.8	26.9	28.8	26.3	22.4
4/14/13	4/15/13	630	28	7.9	44.2	25.1	26.9	23.8	19.7
4/14/13	4/15/13	800	28	3.8	42.6	22.1	24.6	21.0	16.8
4/14/13	4/15/13	1000	28	2.0	44.4	21.0	23.3	19.6	14.4
4/14/13	4/15/13	1250	28	2.5	40.5	22.2	25.0	20.8	14.3
4/14/13	4/15/13	1600	28	3.3	42.7	24.3	27.5	21.7	13.2
4/14/13	4/15/13	2000	28	3.1	37.7	21.9	25.7	19.1	10.2
4/14/13	4/15/13	2500	28	3.0	35.9	20.3	23.6	16.2	8.3
4/14/13	4/15/13	3150	28	3.7	35.1	17.5	20.1	12.7	7.1
4/14/13	4/15/13	4000	28	4.0	37.8	14.2	16.0	9.8	6.3
4/14/13	4/15/13	5000	28	4.3	46.0	10.8	12.1	7.8	5.7
4/14/13	4/15/13	6300	28	3.4	43.5	7.4	8.9	6.6	5.4
4/14/13	4/15/13	8000	28	1.9	60.7	14.2	6.3	5.4	5.1
4/14/13	4/15/13	10000	28	0.8	44.6	5.8	5.3	4.9	4.7
4/14/13	4/15/13	12500	28	0.1	23.9	4.8	4.9	4.4	4.3
4/14/13	4/15/13	16000	28	0.4	39.9	4.4	4.4	3.8	3.5
4/14/13	4/15/13	20000	28	0.7	21.9	3.4	3.4	2.6	2.3

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 61. PAPA203 (Well Pad, 3 wells, 50 m) hourly dBA metrics, April 15-16, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/16/2013	4/16/2013	0	1	34.2	45.1	40.2	42.2	39.8	37.1
4/16/2013	4/16/2013	1	1	33.7	40.9	37.7	39.6	37.3	35.6
4/16/2013	4/16/2013	2	1	32.5	42.6	37.4	39.9	36.6	34.4
4/16/2013	4/16/2013	3	1	31.9	40.8	37.1	39.1	37.0	33.9
4/16/2013	4/16/2013	4	1	32.6	41.3	37.8	39.7	37.6	35.0
4/16/2013	4/16/2013	5	1	32.7	41.5	37.4	39.2	37.2	35.1
4/16/2013	4/16/2013	6	1	33.3	41.1	37.2	38.9	37.0	35.2
4/16/2013	4/16/2013	7	1	31.8	41.6	37.7	39.9	37.4	34.2
4/16/2013	4/16/2013	8	1	32.3	47.5	37.9	40.0	37.3	34.8
4/16/2013	4/16/2013	9	1	32.0	44.1	37.4	39.6	36.9	34.1
4/16/2013	4/16/2013	10	1	31.9	40.3	36.8	38.6	36.7	33.9
4/16/2013	4/16/2013	11	1	30.8	53.9	38.2	39.9	37.1	34.0
4/16/2013	4/16/2013	12	1	32.7	44.2	37.9	39.7	37.6	35.5
4/16/2013	4/16/2013	13	1	32.5	41.7	36.8	38.0	36.8	35.2
4/16/2013	4/16/2013	14	0	NA	NA	NA	NA	NA	NA
4/16/2013	4/16/2013	15	0	NA	NA	NA	NA	NA	NA
4/15/2013	4/15/2013	16	1	35.1	44.0	38.0	39.0	37.9	36.9
4/15/2013	4/15/2013	17	1	35.6	53.4	39.9	41.3	38.9	37.7
4/15/2013	4/15/2013	18	1	36.0	49.6	41.2	42.8	41.1	38.4
4/15/2013	4/15/2013	19	1	35.9	44.5	38.9	39.8	38.7	37.7
4/15/2013	4/15/2013	20	1	34.6	47.0	38.7	39.7	38.3	37.1
4/15/2013	4/15/2013	21	1	35.2	59.0	40.4	40.0	38.5	37.4
4/15/2013	4/15/2013	22	1	35.4	43.9	38.8	40.3	38.5	37.3
4/15/2013	4/15/2013	23	1	34.2	42.2	38.3	40.2	37.9	36.7

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 62. PAPA203 (Well Pad, 3 wells, 50 m) dBA and one-third octave band metrics, April 15-16, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/15/13	4/16/13	dBA	22	30.8	59.0	38.4	39.8	37.5	35.4
4/15/13	4/16/13	12.5	22	29.5	77.5	55.6	53.6	47.6	42.3
4/15/13	4/16/13	16	22	32.2	76.0	54.0	53.1	48.9	44.9
4/15/13	4/16/13	20	22	39.8	74.3	55.5	56.4	53.3	49.2
4/15/13	4/16/13	25	22	39.3	70.1	53.1	54.7	51.3	48.1
4/15/13	4/16/13	31.5	22	37.7	66.7	49.1	50.3	48.0	45.7
4/15/13	4/16/13	40	22	39.9	68.7	54.0	55.4	53.2	50.0
4/15/13	4/16/13	50	22	40.6	66.5	61.4	63.2	61.1	56.3
4/15/13	4/16/13	63	22	32.0	68.3	55.3	60.2	46.7	40.8
4/15/13	4/16/13	80	22	33.2	63.8	47.2	51.0	42.6	40.0
4/15/13	4/16/13	100	22	34.8	67.8	44.7	46.2	44.1	42.3
4/15/13	4/16/13	125	22	36.3	68.0	43.0	43.8	42.1	40.5
4/15/13	4/16/13	160	22	36.9	62.3	44.3	45.3	43.8	42.1
4/15/13	4/16/13	200	22	31.9	66.3	39.0	39.0	37.7	36.6
4/15/13	4/16/13	250	22	26.4	63.8	37.7	39.4	37.0	33.4
4/15/13	4/16/13	315	22	20.8	55.7	29.2	29.0	27.4	26.0
4/15/13	4/16/13	400	22	18.0	48.4	28.0	28.6	27.0	24.9
4/15/13	4/16/13	500	22	14.1	48.2	24.1	23.5	22.0	20.5
4/15/13	4/16/13	630	22	9.8	44.7	20.6	17.9	16.5	15.3
4/15/13	4/16/13	800	22	7.1	39.4	17.4	15.2	13.2	11.8
4/15/13	4/16/13	1000	22	5.4	38.7	15.2	13.0	10.5	9.3
4/15/13	4/16/13	1250	22	3.2	39.7	14.6	11.9	9.4	7.8
4/15/13	4/16/13	1600	22	3.4	43.5	15.3	13.0	10.6	8.9
4/15/13	4/16/13	2000	22	3.3	44.3	15.3	13.4	10.1	8.7
4/15/13	4/16/13	2500	22	3.7	45.9	14.9	13.2	10.1	8.3
4/15/13	4/16/13	3150	22	3.9	46.1	13.9	12.5	9.0	7.2
4/15/13	4/16/13	4000	22	4.4	44.4	11.5	10.2	7.2	5.9
4/15/13	4/16/13	5000	22	4.3	40.1	9.4	8.3	6.0	5.2
4/15/13	4/16/13	6300	22	3.4	40.5	7.5	7.5	5.8	5.2
4/15/13	4/16/13	8000	22	2.1	39.2	6.6	6.3	5.3	5.0
4/15/13	4/16/13	10000	22	1.6	23.2	5.4	5.9	5.0	4.7
4/15/13	4/16/13	12500	22	1.3	18.8	4.7	4.8	4.4	4.1
4/15/13	4/16/13	16000	22	1.0	16.0	4.0	4.2	3.6	3.3
4/15/13	4/16/13	20000	22	1.3	14.1	2.9	3.0	2.4	2.1

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 63. PAPA204 (Well Pad, 3 wells, 100 m) hourly dBA metrics, April 15-16, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/16/2013	4/16/2013	0	1	28.1	38.7	33.6	35.5	33.5	30.4
4/16/2013	4/16/2013	1	1	27.1	39.2	32.1	35.1	30.5	28.9
4/16/2013	4/16/2013	2	1	26.1	37.3	32.3	35.7	30.3	28.0
4/16/2013	4/16/2013	3	1	26.5	36.6	31.7	34.2	30.9	28.6
4/16/2013	4/16/2013	4	1	27.6	39.7	32.7	34.8	31.9	29.9
4/16/2013	4/16/2013	5	1	27.1	38.7	31.8	33.9	31.1	29.1
4/16/2013	4/16/2013	6	1	27.5	36.3	31.9	34.1	31.2	29.5
4/16/2013	4/16/2013	7	1	25.5	37.1	32.3	35.4	30.8	28.1
4/16/2013	4/16/2013	8	1	25.8	44.8	32.5	35.1	31.2	28.8
4/16/2013	4/16/2013	9	1	24.7	41.8	31.5	34.5	29.9	27.3
4/16/2013	4/16/2013	10	1	24.5	36.8	30.5	33.1	29.5	26.6
4/16/2013	4/16/2013	11	1	23.8	43.3	31.7	34.2	30.4	26.8
4/16/2013	4/16/2013	12	1	26.1	40.8	32.7	35.4	31.5	28.6
4/16/2013	4/16/2013	13	1	24.8	38.7	30.4	32.1	30.1	27.9
4/15/2013	4/15/2013	14	0	NA	NA	NA	NA	NA	NA
4/15/2013	4/15/2013	15	0	NA	NA	NA	NA	NA	NA
4/15/2013	4/15/2013	16	1	27.9	46.7	35.3	38.0	33.8	31.1
4/15/2013	4/15/2013	17	1	30.1	55.6	40.2	43.3	38.1	33.8
4/15/2013	4/15/2013	18	1	32.4	51.2	40.6	43.6	39.0	35.7
4/15/2013	4/15/2013	19	1	30.5	47.4	36.5	39.1	35.3	33.1
4/15/2013	4/15/2013	20	1	28.4	48.2	34.3	35.9	32.9	30.9
4/15/2013	4/15/2013	21	1	29.8	60.7	38.3	37.6	34.4	32.0
4/15/2013	4/15/2013	22	1	29.0	41.6	33.8	36.0	32.9	31.0
4/15/2013	4/15/2013	23	1	28.1	39.0	32.7	35.8	31.4	29.9

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 64. PAPA204 (Well Pad, 3 wells, 100 m) dBA and one-third octave band metrics, April 15-16, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/15/13	4/16/13	dBA	22	23.8	60.7	34.8	35.4	31.3	29.3
4/15/13	4/16/13	12.5	22	28.0	78.3	60.1	55.9	49.6	43.6
4/15/13	4/16/13	16	22	32.5	79.7	59.6	53.2	49.8	45.5
4/15/13	4/16/13	20	22	38.0	77.9	57.3	56.2	52.8	48.9
4/15/13	4/16/13	25	22	37.3	72.0	53.3	54.1	50.1	46.4
4/15/13	4/16/13	31.5	22	34.7	68.6	49.3	49.1	46.7	43.6
4/15/13	4/16/13	40	22	36.4	66.7	49.3	49.8	47.4	45.2
4/15/13	4/16/13	50	22	35.8	66.5	55.3	57.0	54.9	50.0
4/15/13	4/16/13	63	22	29.5	65.8	51.8	56.4	45.7	38.3
4/15/13	4/16/13	80	22	30.9	60.9	44.4	48.9	39.7	37.0
4/15/13	4/16/13	100	22	30.4	61.2	40.4	41.3	38.8	36.9
4/15/13	4/16/13	125	22	29.7	68.9	39.5	40.6	38.4	36.3
4/15/13	4/16/13	160	22	27.5	62.3	36.1	36.8	34.6	32.8
4/15/13	4/16/13	200	22	24.4	66.9	34.2	32.6	31.1	29.6
4/15/13	4/16/13	250	22	18.4	66.4	32.0	31.7	29.7	26.9
4/15/13	4/16/13	315	22	10.1	57.3	26.8	24.1	21.2	18.3
4/15/13	4/16/13	400	22	5.9	52.7	24.7	19.0	15.3	13.0
4/15/13	4/16/13	500	22	2.5	50.4	22.9	14.2	10.5	8.0
4/15/13	4/16/13	630	22	-0.1	45.2	20.5	10.6	6.5	4.2
4/15/13	4/16/13	800	22	-0.4	38.6	18.1	10.7	7.4	4.2
4/15/13	4/16/13	1000	22	-0.3	39.8	17.3	10.3	7.5	4.7
4/15/13	4/16/13	1250	22	0.0	36.5	18.4	10.9	8.1	4.7
4/15/13	4/16/13	1600	22	0.9	37.7	19.1	9.9	7.8	5.1
4/15/13	4/16/13	2000	22	1.4	39.3	18.9	10.7	8.2	5.1
4/15/13	4/16/13	2500	22	2.4	39.7	17.8	10.2	7.7	5.2
4/15/13	4/16/13	3150	22	3.1	39.4	15.5	9.0	6.2	4.9
4/15/13	4/16/13	4000	22	3.9	37.0	12.2	6.4	5.4	4.9
4/15/13	4/16/13	5000	22	4.6	33.4	9.5	6.0	5.5	5.2
4/15/13	4/16/13	6300	22	4.9	33.2	8.0	6.2	5.7	5.5
4/15/13	4/16/13	8000	22	4.7	29.3	7.3	6.3	5.7	5.5
4/15/13	4/16/13	10000	22	4.3	24.6	6.4	5.9	5.4	5.2
4/15/13	4/16/13	12500	22	3.9	25.8	5.6	5.3	4.7	4.4
4/15/13	4/16/13	16000	22	3.0	24.6	4.5	4.3	3.6	3.4
4/15/13	4/16/13	20000	22	1.6	21.8	3.1	2.9	2.2	1.9

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 65. PAPA205 (Central Gathering Facility, with generator, 255 m) hourly dBA metrics, April 16-17, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/17/2013	4/17/2013	0	1	33.0	46.3	36.9	38.6	36.4	34.9
4/17/2013	4/17/2013	1	1	31.2	45.0	35.7	37.3	35.2	33.5
4/17/2013	4/17/2013	2	1	31.3	40.7	36.7	38.1	36.7	34.4
4/17/2013	4/17/2013	3	1	32.1	50.5	39.0	42.1	36.8	34.7
4/17/2013	4/17/2013	4	1	29.9	41.9	33.6	35.0	33.2	31.6
4/17/2013	4/17/2013	5	1	32.1	39.9	35.0	36.0	35.0	33.7
4/17/2013	4/17/2013	6	1	33.1	44.1	36.5	37.9	36.2	35.0
4/17/2013	4/17/2013	7	1	25.5	37.6	31.8	33.8	31.5	28.5
4/17/2013	4/17/2013	8	1	25.0	40.8	30.3	32.0	29.9	28.1
4/17/2013	4/17/2013	9	1	25.5	44.1	31.4	33.5	30.3	28.4
4/16/2013	4/16/2013	10	0	NA	NA	NA	NA	NA	NA
4/16/2013	4/16/2013	11	0	NA	NA	NA	NA	NA	NA
4/16/2013	4/16/2013	12	0	NA	NA	NA	NA	NA	NA
4/16/2013	4/16/2013	13	0	NA	NA	NA	NA	NA	NA
4/16/2013	4/16/2013	14	0	NA	NA	NA	NA	NA	NA
4/16/2013	4/16/2013	15	0	NA	NA	NA	NA	NA	NA
4/16/2013	4/16/2013	16	0	NA	NA	NA	NA	NA	NA
4/16/2013	4/16/2013	17	1	30.5	67.8	38.2	36.2	34.2	32.6
4/16/2013	4/16/2013	18	1	32.1	43.6	35.9	37.3	35.6	34.1
4/16/2013	4/16/2013	19	1	31.5	41.7	36.1	37.8	35.7	34.2
4/16/2013	4/16/2013	20	1	33.5	41.5	37.6	39.3	37.2	35.6
4/16/2013	4/16/2013	21	1	35.1	44.2	39.6	40.6	39.6	38.2
4/16/2013	4/16/2013	22	1	33.8	43.4	37.3	38.7	37.0	35.6
4/16/2013	4/16/2013	23	1	32.4	46.2	38.4	40.4	37.9	35.5

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 66. PAPA205 (Central Gathering Facility, with generator, 255 m) dBA and one-third octave band metrics, April 16-17, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/16/13	4/17/13	dBA	17	25.0	67.8	36.6	37.8	35.7	34.2
4/16/13	4/17/13	12.5	17	32.1	71.1	53.4	54.7	53.0	51.6
4/16/13	4/17/13	16	17	32.6	71.5	51.2	53.3	48.1	44.5
4/16/13	4/17/13	20	17	39.8	74.6	61.1	66.4	56.2	51.1
4/16/13	4/17/13	25	17	39.6	69.1	52.4	52.7	50.5	48.2
4/16/13	4/17/13	31.5	17	38.6	78.9	66.4	68.9	64.8	58.4
4/16/13	4/17/13	40	17	35.4	64.3	50.1	52.0	49.1	46.0
4/16/13	4/17/13	50	17	32.0	64.7	49.5	51.6	49.7	47.5
4/16/13	4/17/13	63	17	36.0	62.7	52.4	54.1	51.1	48.0
4/16/13	4/17/13	80	17	35.1	60.8	52.3	54.3	52.4	47.1
4/16/13	4/17/13	100	17	28.8	60.8	43.8	45.5	43.5	41.1
4/16/13	4/17/13	125	17	27.4	62.3	41.6	42.7	40.3	37.6
4/16/13	4/17/13	160	17	24.6	55.9	35.5	36.8	33.8	30.8
4/16/13	4/17/13	200	17	22.0	54.5	33.9	34.6	30.7	28.3
4/16/13	4/17/13	250	17	17.3	54.4	32.9	34.5	30.6	27.7
4/16/13	4/17/13	315	17	12.0	56.1	31.8	34.0	29.8	26.6
4/16/13	4/17/13	400	17	8.8	61.7	30.2	31.4	27.4	23.5
4/16/13	4/17/13	500	17	3.0	60.4	25.5	26.4	22.9	19.5
4/16/13	4/17/13	630	17	-0.1	59.9	21.7	22.9	19.8	14.3
4/16/13	4/17/13	800	17	-0.1	56.3	19.8	21.7	17.8	12.7
4/16/13	4/17/13	1000	17	0.9	54.3	20.2	22.3	17.8	14.0
4/16/13	4/17/13	1250	17	0.9	49.6	20.9	20.7	16.6	12.2
4/16/13	4/17/13	1600	17	1.1	50.9	18.8	19.1	15.1	11.7
4/16/13	4/17/13	2000	17	1.5	50.5	15.2	14.8	11.2	7.6
4/16/13	4/17/13	2500	17	2.2	51.6	12.4	10.7	6.9	4.7
4/16/13	4/17/13	3150	17	2.9	53.5	10.6	6.2	4.7	4.0
4/16/13	4/17/13	4000	17	3.8	53.4	10.2	5.1	4.7	4.4
4/16/13	4/17/13	5000	17	4.5	52.8	10.6	5.6	5.2	5.0
4/16/13	4/17/13	6300	17	5.0	50.4	8.3	5.9	5.6	5.4
4/16/13	4/17/13	8000	17	4.8	45.7	7.2	5.7	5.6	5.4
4/16/13	4/17/13	10000	17	4.5	44.4	6.2	5.4	5.2	5.0
4/16/13	4/17/13	12500	17	3.9	40.2	4.9	4.6	4.4	4.2
4/16/13	4/17/13	16000	17	2.8	34.8	3.6	3.5	3.3	3.1
4/16/13	4/17/13	20000	17	1.4	36.1	2.3	2.2	1.9	1.8

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 67. PAPA206 (Central Gathering Facility, with generator, 555 m) hourly dBA metrics, April 16-17, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/17/2013	4/17/2013	0	1	33.0	44.2	36.7	38.6	36.2	34.8
4/17/2013	4/17/2013	1	1	33.1	46.7	37.5	39.4	36.9	35.2
4/17/2013	4/17/2013	2	1	34.2	42.4	38.1	39.6	37.9	36.0
4/17/2013	4/17/2013	3	1	34.4	53.5	41.5	44.8	38.6	36.4
4/17/2013	4/17/2013	4	1	33.1	44.9	36.5	38.3	35.8	34.8
4/17/2013	4/17/2013	5	1	34.1	39.6	36.4	37.9	36.0	35.2
4/17/2013	4/17/2013	6	1	35.6	43.7	38.1	39.2	37.9	36.8
4/17/2013	4/17/2013	7	1	31.6	50.5	37.4	39.0	35.9	34.1
4/17/2013	4/17/2013	8	1	31.1	44.5	36.7	38.7	36.1	33.8
4/17/2013	4/17/2013	9	1	31.3	43.8	37.2	39.6	36.5	33.9
4/17/2013	4/17/2013	10	0	NA	NA	NA	NA	NA	NA
4/17/2013	4/17/2013	11	0	NA	NA	NA	NA	NA	NA
4/17/2013	4/17/2013	12	0	NA	NA	NA	NA	NA	NA
4/17/2013	4/17/2013	13	0	NA	NA	NA	NA	NA	NA
4/17/2013	4/17/2013	14	0	NA	NA	NA	NA	NA	NA
4/17/2013	4/17/2013	15	0	NA	NA	NA	NA	NA	NA
4/17/2013	4/17/2013	16	0	NA	NA	NA	NA	NA	NA
4/17/2013	4/17/2013	17	0	NA	NA	NA	NA	NA	NA
4/16/2013	4/16/2013	18	1	36.6	47.0	41.0	42.9	40.5	38.6
4/16/2013	4/16/2013	19	1	37.7	50.1	41.6	43.5	41.0	39.2
4/16/2013	4/16/2013	20	1	37.2	45.2	41.5	42.9	41.3	39.7
4/16/2013	4/16/2013	21	1	38.5	44.9	41.7	42.7	41.6	40.5
4/16/2013	4/16/2013	22	1	34.4	41.8	37.8	39.4	37.4	36.1
4/16/2013	4/16/2013	23	1	33.7	47.3	38.2	40.2	37.4	35.7

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 68. PAPA206 (Central Gathering Facility, with generator, 555 m) dBA and one-third octave band metrics, April 16-17, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/16/13	4/17/13	dBA	16	31.1	53.5	39.1	39.5	37.4	35.9
4/16/13	4/17/13	12.5	16	33.9	69.7	59.2	60.5	59.5	58.4
4/16/13	4/17/13	16	16	35.6	69.4	52.2	54.4	49.1	45.5
4/16/13	4/17/13	20	16	44.2	76.0	62.8	67.1	58.6	53.5
4/16/13	4/17/13	25	16	42.3	64.7	57.1	58.5	56.8	54.2
4/16/13	4/17/13	31.5	16	42.8	74.4	63.3	66.3	62.5	57.9
4/16/13	4/17/13	40	16	40.9	63.2	52.0	53.5	51.6	49.5
4/16/13	4/17/13	50	16	38.1	66.0	53.1	55.8	53.4	50.8
4/16/13	4/17/13	63	16	42.1	67.1	54.0	55.1	53.0	51.2
4/16/13	4/17/13	80	16	43.2	60.9	51.8	52.4	50.6	49.2
4/16/13	4/17/13	100	16	36.2	60.5	46.8	47.6	45.3	43.3
4/16/13	4/17/13	125	16	34.9	58.5	45.8	47.4	43.7	41.6
4/16/13	4/17/13	160	16	30.0	57.3	42.0	43.6	39.5	37.3
4/16/13	4/17/13	200	16	29.6	59.3	39.0	41.4	37.2	34.0
4/16/13	4/17/13	250	16	24.6	52.7	35.8	38.0	34.6	31.3
4/16/13	4/17/13	315	16	23.3	51.7	35.1	36.5	33.4	30.7
4/16/13	4/17/13	400	16	18.8	51.4	34.3	34.9	30.8	27.8
4/16/13	4/17/13	500	16	9.9	45.6	28.1	28.0	25.0	22.0
4/16/13	4/17/13	630	16	3.3	36.5	22.1	23.7	20.6	17.6
4/16/13	4/17/13	800	16	1.9	33.9	20.3	22.3	19.1	15.9
4/16/13	4/17/13	1000	16	3.7	42.1	24.3	23.1	19.7	16.8
4/16/13	4/17/13	1250	16	3.7	41.3	23.2	20.2	17.2	14.7
4/16/13	4/17/13	1600	16	2.9	36.9	20.1	18.2	14.6	12.2
4/16/13	4/17/13	2000	16	2.9	35.8	17.7	15.7	11.4	8.6
4/16/13	4/17/13	2500	16	2.7	38.4	12.8	11.2	7.2	5.5
4/16/13	4/17/13	3150	16	2.8	48.9	15.0	10.1	4.6	4.0
4/16/13	4/17/13	4000	16	3.4	42.9	8.2	6.9	4.3	4.0
4/16/13	4/17/13	5000	16	3.2	33.5	5.7	5.2	4.7	4.5
4/16/13	4/17/13	6300	16	3.3	33.6	5.5	5.3	5.0	4.8
4/16/13	4/17/13	8000	16	3.3	38.1	6.3	5.3	5.0	4.8
4/16/13	4/17/13	10000	16	2.6	19.0	4.7	4.9	4.7	4.5
4/16/13	4/17/13	12500	16	2.7	17.7	4.1	4.3	4.1	3.9
4/16/13	4/17/13	16000	16	2.5	15.6	3.4	3.6	3.3	3.1
4/16/13	4/17/13	20000	16	1.5	11.3	2.2	2.3	2.1	1.8

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 69. PAPA207 (Drill Rig, pad 9-24, 2300 m) hourly dBA metrics, April 5-7, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/5/2013	4/7/2013	0	2	24.9	55.2	41.1	39.9	36.2	33.1
4/5/2013	4/7/2013	1	2	25.0	51.4	34.3	34.7	31.8	29.6
4/5/2013	4/7/2013	2	2	24.8	54.9	33.6	34.1	30.8	28.9
4/5/2013	4/7/2013	3	2	26.0	56.4	34.1	34.8	30.9	27.9
4/5/2013	4/7/2013	4	2	26.6	58.0	35.2	34.5	31.9	30.2
4/5/2013	4/7/2013	5	2	28.6	57.7	35.0	35.6	33.2	31.4
4/5/2013	4/7/2013	6	2	28.3	58.9	37.8	38.8	35.5	32.1
4/5/2013	4/7/2013	7	2	24.6	61.1	33.5	35.4	31.5	28.3
4/5/2013	4/7/2013	8	2	24.7	48.1	33.3	35.6	31.7	27.7
4/5/2013	4/7/2013	9	2	19.9	54.8	31.2	32.7	27.7	25.2
4/5/2013	4/7/2013	10	2	20.5	60.9	31.6	30.9	26.8	24.7
4/5/2013	4/7/2013	11	2	21.0	50.2	28.0	29.4	25.8	23.3
4/5/2013	4/7/2013	12	2	20.8	46.6	28.3	30.4	25.9	23.3
4/5/2013	4/7/2013	13	2.0	21.1	47.7	30.3	32.2	27.1	24.3
4/5/2013	4/7/2013	14	2.0	20.3	52.7	33.2	34.8	27.9	24.6
4/5/2013	4/7/2013	15	2.0	22.1	51.5	32.1	33.9	27.2	24.7
4/5/2013	4/7/2013	16	1.0	20.6	47.5	29.8	33.2	27.2	23.3
4/5/2013	4/7/2013	17	2.0	21.3	68.7	40.0	34.6	29.4	26.2
4/5/2013	4/7/2013	18	2.0	22.3	55.3	34.3	33.7	29.9	27.1
4/5/2013	4/7/2013	19	2.0	22.2	51.3	32.9	35.1	30.7	26.2
4/5/2013	4/7/2013	20	2.0	26.0	54.6	34.4	36.3	32.4	29.9
4/5/2013	4/7/2013	21	2.0	21.8	49.6	33.2	34.1	30.3	27.0
4/5/2013	4/7/2013	22	2.0	21.5	49.6	32.6	33.1	30.4	27.7
4/5/2013	4/7/2013	23	2.0	26.0	55.9	37.5	39.3	33.1	30.4

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 70. PAPA207 (Drill Rig, pad 9-24, 2300 m) dBA and one-third octave band metrics, April 5-7, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/5/13	4/7/13	dBA	47	19.9	68.7	34.9	34.8	30.4	27.2
4/5/13	4/7/13	12.5	47	25.1	78.3	50.9	49.4	44.0	38.5
4/5/13	4/7/13	16	47	29.3	74.2	50.7	49.5	45.8	41.9
4/5/13	4/7/13	20	47	34.5	72.2	54.7	55.0	51.1	47.4
4/5/13	4/7/13	25	47	32.3	68.5	52.4	53.2	48.7	44.3
4/5/13	4/7/13	31.5	47	34.8	69.3	57.1	60.2	54.6	49.8
4/5/13	4/7/13	40	47	30.2	64.1	46.3	48.1	45.4	42.8
4/5/13	4/7/13	50	47	30.8	63.0	47.1	49.2	46.0	42.5
4/5/13	4/7/13	63	47	31.4	71.5	45.3	46.4	43.3	40.2
4/5/13	4/7/13	80	47	25.4	69.9	42.8	44.2	39.2	36.1
4/5/13	4/7/13	100	47	22.8	71.7	44.6	42.0	37.4	34.1
4/5/13	4/7/13	125	47	19.8	63.9	40.2	39.8	35.8	32.2
4/5/13	4/7/13	160	47	15.9	66.2	37.8	37.1	32.5	29.6
4/5/13	4/7/13	200	47	14.7	60.5	36.5	35.4	31.1	27.5
4/5/13	4/7/13	250	47	11.4	61.1	33.1	32.8	28.5	25.1
4/5/13	4/7/13	315	47	9.1	59.0	30.2	29.9	25.4	21.8
4/5/13	4/7/13	400	47	7.1	60.1	28.2	28.8	23.1	18.3
4/5/13	4/7/13	500	47	2.3	65.3	25.3	22.9	17.3	12.5
4/5/13	4/7/13	630	47	0.6	63.5	23.5	21.2	15.0	9.9
4/5/13	4/7/13	800	47	0.1	56.9	21.1	20.4	14.1	8.7
4/5/13	4/7/13	1000	47	0.0	55.1	19.3	19.2	12.0	7.9
4/5/13	4/7/13	1250	47	0.0	57.6	17.2	15.6	9.7	6.0
4/5/13	4/7/13	1600	47	0.2	56.6	14.5	10.9	5.4	2.9
4/5/13	4/7/13	2000	47	0.8	54.1	12.9	7.0	3.1	2.1
4/5/13	4/7/13	2500	47	1.4	52.4	12.5	3.4	2.7	2.3
4/5/13	4/7/13	3150	47	2.2	59.1	13.5	3.8	3.2	3.0
4/5/13	4/7/13	4000	47	3.0	50.4	10.8	4.6	3.9	3.6
4/5/13	4/7/13	5000	47	2.8	57.8	14.6	5.2	4.4	4.2
4/5/13	4/7/13	6300	47	1.4	56.5	12.4	4.8	4.6	4.4
4/5/13	4/7/13	8000	47	0.6	51.0	9.4	4.6	4.5	4.4
4/5/13	4/7/13	10000	47	-0.1	51.0	8.2	4.2	4.1	4.0
4/5/13	4/7/13	12500	47	-0.4	50.7	7.1	3.5	3.4	3.3
4/5/13	4/7/13	16000	47	0.0	51.2	6.0	2.5	2.3	2.2
4/5/13	4/7/13	20000	47	0.2	55.9	6.3	0.8	0.7	0.6

Table 71. PAPA208 (Drill Rig, pad 9-24, 300 m) hourly dBA metrics, April 5-7, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/5/2013	4/7/2013	0	2	47.5	61.6	56.3	57.4	55.6	53.0
4/5/2013	4/7/2013	1	2	45.6	60.8	52.7	55.2	51.1	48.4
4/5/2013	4/7/2013	2	2	44.6	61.2	52.0	54.3	51.2	48.6
4/5/2013	4/7/2013	3	2	43.8	63.8	51.1	52.1	50.3	48.0
4/5/2013	4/7/2013	4	2	47.6	62.4	51.8	53.3	51.5	50.0
4/5/2013	4/7/2013	5	2	47.2	61.8	53.0	54.6	52.7	50.9
4/5/2013	4/7/2013	6	2	50.3	84.5	53.9	54.2	53.0	51.8
4/5/2013	4/7/2013	7	2	47.5	59.5	52.1	53.5	51.7	50.5
4/5/2013	4/7/2013	8	2	47.3	57.4	51.9	53.2	51.6	50.1
4/5/2013	4/7/2013	9	2	49.7	59.7	52.3	53.3	52.1	51.2
4/5/2013	4/7/2013	10	2	43.4	58.9	51.4	52.8	51.0	48.6
4/5/2013	4/7/2013	11	2	43.1	60.9	51.1	52.0	50.4	48.1
4/5/2013	4/7/2013	12	2	43.9	58.2	51.5	53.1	51.3	48.3
4/5/2013	4/7/2013	13	2	47.2	60.2	53.1	54.8	52.8	50.9
4/6/2013	4/6/2013	14	1	46.6	64.2	53.3	54.9	53.1	49.9
4/6/2013	4/6/2013	15	1	50.1	66.5	53.3	54.1	53.0	52.0
4/6/2013	4/6/2013	16	1	46.4	57.5	51.3	54.1	50.0	48.2
4/6/2013	4/6/2013	17	1	45.4	64.7	51.2	53.0	51.0	48.3
4/5/2013	4/7/2013	18	2	48.9	58.7	52.5	53.6	52.3	51.2
4/5/2013	4/7/2013	19	2	48.9	61.9	53.7	55.0	53.3	52.0
4/5/2013	4/7/2013	20	2	51.6	64.8	55.6	56.7	55.3	54.1
4/5/2013	4/7/2013	21	2	51.8	63.5	55.2	56.2	55.0	53.7
4/5/2013	4/7/2013	22	2	52.5	63.5	57.0	57.8	56.4	55.2
4/5/2013	4/7/2013	23	2	51.5	65.0	57.7	59.8	57.3	54.0

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 72. PAPA208 (Drill Rig, pad 9-24, 300 m) dBA and one-third octave band metrics, April 5-7, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/5/13	4/7/13	dBA	44	43.1	84.5	53.7	54.2	52.5	51.0
4/5/13	4/7/13	12.5	44	29.9	76.7	51.6	51.4	47.3	43.2
4/5/13	4/7/13	16	44	35.8	73.2	52.3	53.8	49.8	46.0
4/5/13	4/7/13	20	44	39.6	74.9	56.5	58.1	54.7	51.4
4/5/13	4/7/13	25	44	41.0	73.7	54.4	55.5	52.2	49.6
4/5/13	4/7/13	31.5	44	43.8	76.5	67.4	70.4	66.3	61.0
4/5/13	4/7/13	40	44	46.5	74.7	59.1	61.3	58.6	55.5
4/5/13	4/7/13	50	44	54.4	78.0	66.2	67.8	65.9	64.0
4/5/13	4/7/13	63	44	53.0	78.7	65.2	66.8	64.8	62.4
4/5/13	4/7/13	80	44	50.6	77.4	65.8	67.2	65.1	62.9
4/5/13	4/7/13	100	44	35.9	77.8	66.4	67.2	65.0	62.9
4/5/13	4/7/13	125	44	44.1	77.0	62.2	62.8	60.6	58.1
4/5/13	4/7/13	160	44	41.1	79.1	58.5	58.2	56.2	54.2
4/5/13	4/7/13	200	44	38.1	71.7	55.1	54.2	52.0	50.0
4/5/13	4/7/13	250	44	33.5	62.3	46.6	47.8	45.5	43.1
4/5/13	4/7/13	315	44	24.5	59.8	43.6	45.9	42.3	39.4
4/5/13	4/7/13	400	44	21.6	59.3	44.3	47.5	43.7	39.7
4/5/13	4/7/13	500	44	17.7	55.1	36.4	37.3	33.2	30.1
4/5/13	4/7/13	630	44	15.7	55.6	35.5	37.2	32.0	28.2
4/5/13	4/7/13	800	44	13.4	57.5	34.4	36.8	30.5	25.7
4/5/13	4/7/13	1000	44	12.0	56.4	34.5	36.3	30.8	25.2
4/5/13	4/7/13	1250	44	11.3	56.6	35.2	36.2	30.9	24.9
4/5/13	4/7/13	1600	44	11.2	62.6	35.9	37.9	32.1	24.7
4/5/13	4/7/13	2000	44	10.8	57.3	36.4	38.3	32.6	25.4
4/5/13	4/7/13	2500	44	8.0	52.9	33.4	35.7	29.6	21.9
4/5/13	4/7/13	3150	44	5.5	53.1	28.7	30.0	24.9	16.9
4/5/13	4/7/13	4000	44	4.6	55.3	23.8	25.2	18.9	11.8
4/5/13	4/7/13	5000	44	4.3	53.1	17.7	17.1	11.7	7.4
4/5/13	4/7/13	6300	44	4.4	47.9	11.0	10.3	6.6	5.5
4/5/13	4/7/13	8000	44	4.2	35.3	7.1	5.6	5.2	5.0
4/5/13	4/7/13	10000	44	3.8	32.2	6.4	5.0	4.8	4.7
4/5/13	4/7/13	12500	44	3.4	31.8	6.0	4.7	4.6	4.5
4/5/13	4/7/13	16000	44	3.1	32.3	5.2	3.9	3.8	3.7
4/5/13	4/7/13	20000	44	1.6	30.8	3.4	2.5	2.3	2.2

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 73. PAPA209 (Highway 191, 100 m) hourly dBA metrics, April 17-18, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
04/18/13	04/18/13	0	1	15.5	48.8	23.2	19.0	17.0	16.1
04/18/13	04/18/13	1	1	15.3	47.2	23.1	18.4	16.8	15.8
04/18/13	04/18/13	2	1	14.8	46.1	21.1	16.7	15.4	15.1
04/18/13	04/18/13	3	1	15.1	45.0	19.6	17.5	16.3	15.7
04/18/13	04/18/13	4	1	15.8	53.0	32.9	26.0	18.0	16.6
04/18/13	04/18/13	5	1	16.8	58.1	41.5	45.7	26.4	18.0
04/18/13	04/18/13	6	1	16.7	64.0	48.0	52.7	40.7	24.2
04/18/13	04/18/13	7	1	17.3	63.8	45.1	48.9	34.1	21.4
04/18/13	04/18/13	8	1	18.6	55.5	33.7	34.9	24.9	20.6
04/18/13	04/18/13	9	1	18.8	52.2	32.5	34.7	24.5	21.0
04/18/13	04/18/13	10	1	19.1	60.2	35.6	34.8	25.8	22.2
04/18/13	04/18/13	11	1	20.1	59.5	37.5	37.8	27.2	22.6
04/18/13	04/18/13	12	1	18.5	59.2	39.7	42.1	28.3	21.6
04/17/13	04/17/13	13	0	NA	NA	NA	NA	NA	NA
04/17/13	04/17/13	14	1	18.2	60.8	43.5	47.3	31.9	23.0
04/17/13	04/17/13	15	1	20.0	64.2	45.2	46.9	32.4	23.9
04/17/13	04/17/13	16	1	23.4	64.0	43.5	46.9	34.1	26.9
04/17/13	04/17/13	17	1	23.4	65.1	45.1	48.7	35.7	27.8
04/17/13	04/17/13	18	1	23.8	59.8	42.5	46.0	35.0	28.3
04/17/13	04/17/13	19	1	20.0	58.0	38.0	37.7	26.3	22.7
04/17/13	04/17/13	20	1	16.1	54.7	31.4	31.4	20.5	17.5
04/17/13	04/17/13	21	1	15.8	45.3	26.0	28.0	18.6	16.7
04/17/13	04/17/13	22	1	14.9	47.1	24.9	24.3	16.3	15.4
04/17/13	04/17/13	23	1	15.5	41.3	22.8	21.3	18.0	16.5

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 74. PAPA209 (Highway 191, 100 m) dBA and one-third octave band metrics, April 17-18, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/17/13	4/18/13	dBA	23	14.8	65.1	40.7	34.9	25.8	21.0
4/17/13	4/18/13	12.5	23	24.7	77.2	51.8	47.3	42.1	37.9
4/17/13	4/18/13	16	23	27.6	71.7	48.6	47.1	42.8	39.1
4/17/13	4/18/13	20	23	31.3	71.1	49.6	51.6	47.2	43.5
4/17/13	4/18/13	25	23	21.6	71.7	45.1	48.2	41.2	35.4
4/17/13	4/18/13	31.5	23	20.8	75.3	47.0	48.9	41.8	35.8
4/17/13	4/18/13	40	23	18.6	73.2	44.5	48.1	38.7	31.7
4/17/13	4/18/13	50	23	16.5	70.7	44.9	48.4	35.9	30.2
4/17/13	4/18/13	63	23	16.3	82.1	50.0	47.9	35.2	30.1
4/17/13	4/18/13	80	23	12.4	83.4	49.6	43.8	33.7	29.0
4/17/13	4/18/13	100	23	10.7	78.1	48.1	39.7	31.0	27.3
4/17/13	4/18/13	125	23	9.3	80.5	46.7	35.0	29.7	25.5
4/17/13	4/18/13	160	23	6.7	78.2	42.8	31.8	26.1	22.6
4/17/13	4/18/13	200	23	4.9	73.5	38.6	30.7	23.5	19.9
4/17/13	4/18/13	250	23	1.8	66.4	33.1	26.6	20.2	16.2
4/17/13	4/18/13	315	23	0.1	56.8	27.9	23.0	15.9	12.2
4/17/13	4/18/13	400	23	-2.9	54.2	26.4	20.6	13.5	8.4
4/17/13	4/18/13	500	23	-3.3	53.6	27.8	21.0	10.5	4.5
4/17/13	4/18/13	630	23	-3.2	61.0	30.4	23.3	11.7	3.3
4/17/13	4/18/13	800	23	-2.5	58.3	32.2	24.1	12.2	2.5
4/17/13	4/18/13	1000	23	-2.1	59.4	32.0	23.6	11.9	1.4
4/17/13	4/18/13	1250	23	-1.3	59.1	30.8	22.9	9.3	1.3
4/17/13	4/18/13	1600	23	-0.2	53.7	28.5	20.6	6.7	1.3
4/17/13	4/18/13	2000	23	0.8	51.4	25.1	16.2	4.1	1.7
4/17/13	4/18/13	2500	23	1.5	46.8	21.8	11.9	3.5	2.4
4/17/13	4/18/13	3150	23	2.5	47.1	18.4	8.6	4.1	3.2
4/17/13	4/18/13	4000	23	3.3	45.1	14.1	6.9	4.2	3.9
4/17/13	4/18/13	5000	23	3.9	44.3	10.5	7.0	4.7	4.5
4/17/13	4/18/13	6300	23	4.2	41.2	8.2	6.4	5.0	4.7
4/17/13	4/18/13	8000	23	3.8	38.0	6.7	5.9	4.9	4.8
4/17/13	4/18/13	10000	23	3.6	36.1	5.8	5.1	4.6	4.5
4/17/13	4/18/13	12500	23	3.5	35.5	5.1	4.7	4.1	3.9
4/17/13	4/18/13	16000	23	2.6	32.4	4.4	3.8	3.3	3.1
4/17/13	4/18/13	20000	23	1.2	32.9	3.1	2.4	1.9	1.8

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 75. PAPA210 (Highway 191, 200 m) hourly dBA metrics, April 17-18, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
04/18/13	04/18/13	0	1	15.9	40.4	20.3	19.4	17.3	16.4
04/18/13	04/18/13	1	1	15.5	48.0	23.8	18.7	17.1	16.1
04/18/13	04/18/13	2	1	15.2	37.4	18.1	17.1	15.8	15.5
04/18/13	04/18/13	3	1	15.5	38.0	19.1	18.0	16.6	16.0
04/18/13	04/18/13	4	1	16.2	46.9	27.8	26.3	18.4	17.0
04/18/13	04/18/13	5	1	16.9	51.9	37.0	41.6	25.9	18.3
04/18/13	04/18/13	6	1	17.0	55.7	43.2	47.6	39.0	23.9
04/18/13	04/18/13	7	1	17.5	55.9	41.8	46.5	33.6	21.9
04/18/13	04/18/13	8	1	18.9	45.0	29.0	32.6	24.1	20.5
04/18/13	04/18/13	9	1	19.3	45.8	28.3	29.2	24.0	21.0
04/18/13	04/18/13	10	1	20.0	49.2	29.3	30.7	24.9	22.0
04/18/13	04/18/13	11	1	20.8	49.4	30.7	32.6	26.6	22.9
04/18/13	04/18/13	12	1	18.8	51.5	34.2	37.2	27.3	21.3
04/17/13	04/17/13	13	0	NA	NA	NA	NA	NA	NA
04/17/13	04/17/13	14	1	18.3	53.6	38.8	42.9	32.0	22.9
04/17/13	04/17/13	15	1	19.8	56.9	39.3	42.0	31.1	23.6
04/17/13	04/17/13	16	1	23.2	56.1	37.2	40.6	32.0	26.7
04/17/13	04/17/13	17	1	24.2	55.9	39.8	43.7	34.8	27.7
04/17/13	04/17/13	18	1	23.9	56.0	39.6	43.2	35.5	29.0
04/17/13	04/17/13	19	1	20.7	57.5	35.9	34.7	26.5	23.2
04/17/13	04/17/13	20	1	16.4	51.1	29.4	29.8	20.7	17.8
04/17/13	04/17/13	21	1	16.1	44.0	24.5	27.7	19.0	17.1
04/17/13	04/17/13	22	1	15.4	42.7	22.0	23.8	16.7	15.8
04/17/13	04/17/13	23	1	15.9	41.3	22.3	21.8	18.4	16.9

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 76. PAPA210 (Highway 191, 200 m) dBA and one-third octave band metrics, April 17-18, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/17/13	4/18/13	dBA	23	15.2	57.5	36.1	32.6	24.9	21.0
4/17/13	4/18/13	12.5	23	27.2	79.5	54.9	46.8	42.1	37.9
4/17/13	4/18/13	16	23	27.6	76.9	49.8	46.4	42.7	39.2
4/17/13	4/18/13	20	23	31.2	72.2	49.4	50.8	46.6	43.4
4/17/13	4/18/13	25	23	20.8	68.6	44.5	46.4	40.7	35.2
4/17/13	4/18/13	31.5	23	20.5	70.1	45.7	47.4	41.3	35.7
4/17/13	4/18/13	40	23	18.0	67.8	42.5	45.3	37.4	31.7
4/17/13	4/18/13	50	23	16.7	63.9	41.9	43.1	34.9	30.1
4/17/13	4/18/13	63	23	16.2	71.4	43.8	40.3	33.9	30.2
4/17/13	4/18/13	80	23	13.4	76.3	44.9	38.5	32.7	28.7
4/17/13	4/18/13	100	23	12.5	74.1	43.9	34.8	30.4	27.4
4/17/13	4/18/13	125	23	10.0	73.0	41.4	33.5	29.1	24.8
4/17/13	4/18/13	160	23	6.5	68.9	36.1	31.1	25.9	21.7
4/17/13	4/18/13	200	23	5.3	67.1	32.1	29.2	23.0	19.2
4/17/13	4/18/13	250	23	2.1	61.2	27.4	25.5	19.4	15.6
4/17/13	4/18/13	315	23	-0.3	50.3	23.9	21.7	15.3	12.0
4/17/13	4/18/13	400	23	-2.4	50.5	23.9	17.3	12.4	8.2
4/17/13	4/18/13	500	23	-2.8	50.4	25.6	18.2	10.4	4.8
4/17/13	4/18/13	630	23	-2.6	53.6	28.0	19.9	11.2	3.6
4/17/13	4/18/13	800	23	-2.3	54.5	28.8	20.1	11.8	2.4
4/17/13	4/18/13	1000	23	-1.7	51.5	27.5	20.4	10.8	1.6
4/17/13	4/18/13	1250	23	-1.0	53.9	25.8	19.1	8.7	1.7
4/17/13	4/18/13	1600	23	0.0	48.2	23.0	16.6	5.9	1.4
4/17/13	4/18/13	2000	23	1.0	42.9	19.4	12.6	3.5	1.8
4/17/13	4/18/13	2500	23	1.9	44.0	16.2	9.5	3.8	2.6
4/17/13	4/18/13	3150	23	2.8	43.7	12.2	7.6	4.1	3.5
4/17/13	4/18/13	4000	23	3.7	41.4	9.0	7.1	4.6	4.3
4/17/13	4/18/13	5000	23	4.5	37.4	7.3	6.1	5.2	5.0
4/17/13	4/18/13	6300	23	4.7	41.3	7.7	6.1	5.6	5.4
4/17/13	4/18/13	8000	23	4.9	35.4	6.9	6.0	5.7	5.5
4/17/13	4/18/13	10000	23	4.7	33.9	6.3	5.6	5.3	5.1
4/17/13	4/18/13	12500	23	3.8	33.6	5.6	4.9	4.4	4.3
4/17/13	4/18/13	16000	23	2.7	31.1	4.6	3.9	3.4	3.2
4/17/13	4/18/13	20000	23	1.2	34.7	3.2	2.4	1.9	1.7

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 77. PAPA211 (Well heads, 3, and injection well, with generator, 100 m) hourly dBA metrics, April 18-21, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/18/2013	4/21/2013	0	3	42.2	53.3	47.2	48.5	46.3	45.0
4/18/2013	4/21/2013	1	3	43.2	54.0	48.1	49.8	48.0	46.5
4/18/2013	4/21/2013	2	3	43.5	56.4	48.4	49.8	47.5	45.9
4/18/2013	4/21/2013	3	3	44.1	54.7	49.3	51.6	49.3	46.8
4/18/2013	4/21/2013	4	3	43.2	56.9	50.9	53.1	51.8	50.4
4/18/2013	4/21/2013	5	3	45.1	56.1	50.7	53.1	50.0	47.5
4/18/2013	4/21/2013	6	3	41.3	57.2	49.8	50.7	48.6	46.3
4/18/2013	4/21/2013	7	3	42.8	56.5	47.8	50.1	46.3	44.8
4/18/2013	4/21/2013	8	3	40.7	59.5	45.6	46.1	45.1	44.0
4/18/2013	4/21/2013	9	3	38.8	57.2	44.7	46.0	44.4	42.7
4/18/2013	4/21/2013	10	3	34.4	53.2	44.3	46.4	44.5	42.4
4/18/2013	4/21/2013	11	3	34.8	49.7	43.3	45.0	43.0	40.5
4/18/2013	4/21/2013	12	3	32.1	50.4	41.7	43.8	41.4	38.1
4/18/2013	4/21/2013	13	3	32.7	58.3	42.0	44.4	41.5	37.8
4/18/2013	4/21/2013	14	3	30.6	50.6	42.0	44.2	42.2	39.5
4/18/2013	4/21/2013	15	3	35.6	54.5	42.8	44.6	42.3	40.0
4/18/2013	4/21/2013	16	3	35.8	58.1	43.7	45.5	42.4	39.9
4/18/2013	4/21/2013	17	3	37.2	57.8	43.9	46.1	43.1	41.1
4/18/2013	4/21/2013	18	3	38.9	51.4	44.1	45.1	43.6	42.3
4/18/2013	4/21/2013	19	3	39.1	51.4	45.1	45.9	44.6	43.5
4/18/2013	4/21/2013	20	3	42.3	51.0	45.6	46.8	45.6	44.4
4/18/2013	4/21/2013	21	3	42.7	53.2	47.0	47.0	45.7	44.8
4/18/2013	4/21/2013	22	3	43.2	59.6	50.1	53.6	46.3	45.2
4/18/2013	4/21/2013	23	3	42.2	54.4	46.4	48.4	46.1	45.1

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 78. PAPA211 (Well heads, 3, and injection well, with generator, 200 m) dBA and one-third octave band metrics, April 18-21, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/18/13	4/21/13	dBA	72	30.6	59.6	46.9	46.7	45.5	44.3
4/18/13	4/21/13	12.5	72	25.6	73.4	50.4	46.5	42.8	38.4
4/18/13	4/21/13	16	72	34.0	71.6	52.5	54.1	50.1	46.2
4/18/13	4/21/13	20	72	38.2	77.9	61.9	63.3	56.0	52.0
4/18/13	4/21/13	25	72	32.8	68.0	49.4	50.8	47.3	44.0
4/18/13	4/21/13	31.5	72	38.9	72.1	53.6	55.4	51.7	47.9
4/18/13	4/21/13	40	72	38.9	75.1	53.2	54.0	52.5	50.9
4/18/13	4/21/13	50	72	37.8	77.5	52.3	54.0	50.7	48.1
4/18/13	4/21/13	63	72	35.9	77.0	48.5	49.7	47.6	45.8
4/18/13	4/21/13	80	72	32.9	71.6	48.4	49.7	48.0	46.1
4/18/13	4/21/13	100	72	33.3	69.7	49.1	50.3	48.6	47.0
4/18/13	4/21/13	125	72	34.2	69.3	55.5	57.2	55.3	53.1
4/18/13	4/21/13	160	72	31.3	67.9	49.2	50.1	48.8	47.5
4/18/13	4/21/13	200	72	26.9	66.2	47.0	48.2	47.0	45.5
4/18/13	4/21/13	250	72	28.4	63.0	47.2	48.9	47.2	45.3
4/18/13	4/21/13	315	72	22.7	62.0	41.7	42.3	41.1	39.3
4/18/13	4/21/13	400	72	19.9	50.3	37.3	39.1	37.1	34.7
4/18/13	4/21/13	500	72	17.2	53.5	30.2	32.1	29.3	27.0
4/18/13	4/21/13	630	72	9.6	51.8	24.0	24.7	22.3	19.9
4/18/13	4/21/13	800	72	8.1	48.8	27.5	26.0	22.3	18.7
4/18/13	4/21/13	1000	72	6.8	44.2	26.7	24.8	20.3	16.9
4/18/13	4/21/13	1250	72	8.5	52.9	32.1	28.5	23.5	19.3
4/18/13	4/21/13	1600	72	6.9	49.7	31.5	28.4	22.7	18.0
4/18/13	4/21/13	2000	72	6.3	51.1	33.6	28.8	23.5	18.7
4/18/13	4/21/13	2500	72	5.2	54.6	32.4	27.7	22.8	17.3
4/18/13	4/21/13	3150	72	6.3	52.8	36.1	32.3	26.1	20.9
4/18/13	4/21/13	4000	72	4.5	51.3	26.7	22.7	17.3	12.2
4/18/13	4/21/13	5000	72	2.7	52.7	19.6	16.5	12.0	7.8
4/18/13	4/21/13	6300	72	1.6	50.2	15.8	12.3	8.4	6.3
4/18/13	4/21/13	8000	72	0.5	56.6	12.0	7.9	5.9	5.2
4/18/13	4/21/13	10000	72	-0.6	44.5	6.3	6.2	5.1	4.8
4/18/13	4/21/13	12500	72	-1.0	36.2	4.8	4.6	4.2	4.1
4/18/13	4/21/13	16000	72	-1.0	31.1	4.1	3.8	3.4	3.3
4/18/13	4/21/13	20000	72	-0.3	31.5	3.0	2.3	2.1	1.9

Table 79. PAPA212 (Well heads, 3, and injection well, with generator, 200 m) hourly dBA metrics, April 18-21, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/18/2013	4/21/2013	0	3	35.0	45.8	40.1	42.0	39.0	37.5
4/18/2013	4/21/2013	1	3	36.0	47.7	41.1	42.6	40.5	39.2
4/18/2013	4/21/2013	2	3	35.6	50.3	41.9	44.7	41.2	38.7
4/18/2013	4/21/2013	3	3	36.4	49.3	42.4	43.5	40.9	38.8
4/18/2013	4/21/2013	4	3	34.9	51.0	43.7	44.8	42.9	41.2
4/18/2013	4/21/2013	5	3	36.9	48.5	43.1	45.1	43.0	40.8
4/18/2013	4/21/2013	6	3	35.2	51.0	42.1	42.1	40.4	38.7
4/18/2013	4/21/2013	7	3	35.1	51.1	40.5	44.2	39.0	37.4
4/18/2013	4/21/2013	8	3	32.3	50.2	38.6	39.4	37.8	36.4
4/18/2013	4/21/2013	9	2	29.7	51.2	37.4	38.9	37.1	35.1
4/18/2013	4/21/2013	10	2	28.8	45.2	37.2	39.4	36.8	33.8
4/18/2013	4/21/2013	11	2	27.0	54.6	36.0	38.2	34.9	31.9
4/18/2013	4/21/2013	12	2	26.4	47.7	34.8	37.4	33.2	30.1
4/18/2013	4/21/2013	13	2	25.9	56.0	36.4	38.1	33.6	30.4
4/18/2013	4/21/2013	14	2	26.8	55.1	35.8	38.3	34.5	30.8
4/18/2013	4/21/2013	15	2	27.5	53.7	37.3	39.7	34.8	31.7
4/18/2013	4/21/2013	16	3	26.7	57.9	38.0	41.1	36.4	32.7
4/18/2013	4/21/2013	17	3	28.3	55.0	39.1	41.6	37.8	33.7
4/18/2013	4/21/2013	18	3	30.0	51.0	38.2	39.7	36.5	34.4
4/18/2013	4/21/2013	19	3	30.4	53.0	39.5	39.0	37.0	35.6
4/18/2013	4/21/2013	20	3	34.6	49.0	39.1	40.5	38.4	37.0
4/18/2013	4/21/2013	21	3	35.5	46.2	39.5	41.4	39.1	37.7
4/18/2013	4/21/2013	22	3	35.8	51.6	42.2	45.2	39.5	37.9
4/18/2013	4/21/2013	23	3	34.8	48.3	39.3	41.0	39.0	37.8

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 80. PAPA212 (Well heads, 3, and injection well, with generator, 200 m) dBA and one-third octave band metrics, April 18-21, 2013, 0000-2300.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/18/13	4/21/13	dBA	65	25.9	57.9	40.2	41.4	38.6	37.0
4/18/13	4/21/13	12.5	65	24.1	77.9	53.6	46.4	43.2	38.1
4/18/13	4/21/13	16	65	32.5	76.9	53.9	54.0	48.2	44.3
4/18/13	4/21/13	20	65	36.2	77.1	62.1	63.4	57.4	52.3
4/18/13	4/21/13	25	65	31.8	72.0	48.8	49.3	45.9	42.4
4/18/13	4/21/13	31.5	65	33.6	68.2	51.9	54.3	50.3	45.7
4/18/13	4/21/13	40	65	33.9	70.0	49.7	51.0	48.8	46.5
4/18/13	4/21/13	50	65	34.0	70.6	48.7	50.5	47.1	44.7
4/18/13	4/21/13	63	65	32.5	69.5	46.1	47.9	45.1	42.7
4/18/13	4/21/13	80	65	31.2	69.8	44.8	46.0	44.1	41.7
4/18/13	4/21/13	100	65	29.9	66.3	44.9	46.5	44.4	42.7
4/18/13	4/21/13	125	65	28.4	63.0	50.7	52.7	50.4	48.2
4/18/13	4/21/13	160	65	27.1	65.0	43.9	45.4	43.9	42.3
4/18/13	4/21/13	200	65	24.2	98.9	46.6	41.5	40.2	38.4
4/18/13	4/21/13	250	65	22.0	61.3	36.0	37.6	35.0	32.8
4/18/13	4/21/13	315	65	16.8	54.5	30.3	30.7	27.8	25.4
4/18/13	4/21/13	400	65	11.1	47.3	26.6	27.4	23.5	20.8
4/18/13	4/21/13	500	65	7.0	51.7	26.0	26.3	21.4	17.7
4/18/13	4/21/13	630	65	2.4	50.8	22.3	22.7	16.9	13.1
4/18/13	4/21/13	800	65	1.9	45.7	23.9	23.4	17.7	12.6
4/18/13	4/21/13	1000	65	1.9	39.1	22.9	23.4	16.4	11.1
4/18/13	4/21/13	1250	65	3.3	44.4	26.6	25.9	18.1	12.9
4/18/13	4/21/13	1600	65	3.2	43.2	26.9	26.6	17.8	12.4
4/18/13	4/21/13	2000	65	3.2	45.5	25.4	26.3	15.6	10.5
4/18/13	4/21/13	2500	65	3.4	44.8	23.0	25.2	14.1	8.6
4/18/13	4/21/13	3150	65	4.7	47.0	27.0	24.2	17.3	11.7
4/18/13	4/21/13	4000	65	4.4	47.7	17.7	17.7	9.2	6.3
4/18/13	4/21/13	5000	65	4.0	54.2	13.8	10.8	6.5	5.7
4/18/13	4/21/13	6300	65	3.5	43.1	8.6	7.9	6.0	5.7
4/18/13	4/21/13	8000	65	1.4	43.4	6.7	6.1	5.7	5.5
4/18/13	4/21/13	10000	65	1.3	29.5	5.7	5.4	5.3	5.1
4/18/13	4/21/13	12500	65	1.1	28.7	4.9	4.6	4.5	4.4
4/18/13	4/21/13	16000	65	1.1	27.1	4.0	3.6	3.5	3.3
4/18/13	4/21/13	20000	65	1.5	22.8	2.8	2.2	2.1	2.0

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 81. PAPA213 (Gobbler's Knob, north side, liquid stabilizing facility and central gathering facility, 150 m) hourly dBA metrics, April 22-24, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/22/2013	4/24/2013	0	2	35.3	55.9	45.9	48.7	44.9	40.6
4/22/2013	4/24/2013	1	2	35.9	54.3	43.8	45.4	42.8	40.6
4/22/2013	4/24/2013	2	2	34.6	52.7	44.4	46.3	43.6	40.3
4/22/2013	4/24/2013	3	2	34.4	54.8	47.4	45.8	44.1	41.3
4/22/2013	4/24/2013	4	2	34.3	55.3	46.1	46.5	43.1	41.3
4/22/2013	4/24/2013	5	2	37.3	54.3	45.9	47.7	45.5	41.5
4/22/2013	4/24/2013	6	2	37.4	53.7	45.5	47.8	44.9	41.4
4/22/2013	4/24/2013	7	2	37.5	57.6	47.1	49.2	46.6	42.9
4/22/2013	4/24/2013	8	2	36.5	53.6	44.9	47.6	44.1	40.6
4/22/2013	4/24/2013	9	2	35.2	69.5	46.5	46.6	42.4	38.7
4/22/2013	4/24/2013	10	2	36.2	58.4	47.1	46.7	43.9	40.1
4/22/2013	4/24/2013	11	2	37.7	61.0	50.1	49.4	46.9	44.9
4/22/2013	4/24/2013	12	2	38.9	75.7	50.3	49.5	44.8	42.6
4/22/2013	4/24/2013	13	2	33.9	55.3	43.8	45.7	43.5	40.3
4/22/2013	4/24/2013	14	2	33.7	57.1	42.2	43.8	40.8	38.3
4/22/2013	4/24/2013	15	2	34.3	62.0	43.3	44.8	41.2	38.7
4/22/2013	4/24/2013	16	2	34.2	64.5	44.4	45.7	42.5	39.5
4/22/2013	4/24/2013	17	2	33.9	61.6	44.3	46.4	43.4	40.1
4/22/2013	4/24/2013	18	2	36.4	58.8	43.1	44.6	41.7	40.0
4/22/2013	4/24/2013	19	2	37.5	63.2	44.0	45.1	42.5	40.7
4/22/2013	4/24/2013	20	2	38.7	54.6	44.2	46.5	43.2	41.6
4/22/2013	4/24/2013	21	2	37.4	55.8	46.6	48.1	44.9	43.2
4/22/2013	4/24/2013	22	2	36.0	53.8	46.0	48.5	45.0	40.1
4/22/2013	4/24/2013	23	2	34.5	54.2	45.5	48.4	44.5	39.7

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 82. PAPA213 (Gobbler's Knob, north side, liquid stabilizing facility and central gathering facility, 150 m) dBA and one-third octave band metrics, April 22-24, 2013.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/22/13	4/24/13	dBA	48	33.7	75.7	46.0	46.9	43.8	40.3
4/22/13	4/24/13	12.5	48	36.4	75.2	55.3	56.8	53.2	49.7
4/22/13	4/24/13	16	48	44.7	75.9	59.4	61.6	57.4	54.4
4/22/13	4/24/13	20	48	46.1	74.6	61.8	64.3	60.7	57.6
4/22/13	4/24/13	25	48	47.3	76.3	61.5	63.2	59.7	56.5
4/22/13	4/24/13	31.5	48	45.5	75.7	61.4	63.0	59.7	56.7
4/22/13	4/24/13	40	48	47.7	77.6	62.7	64.9	61.2	58.3
4/22/13	4/24/13	50	48	50.9	74.8	64.4	66.5	63.8	61.1
4/22/13	4/24/13	63	48	45.1	78.7	58.6	60.2	56.6	53.5
4/22/13	4/24/13	80	48	38.9	76.5	60.2	62.7	59.8	55.2
4/22/13	4/24/13	100	48	29.6	82.4	54.7	54.8	51.2	47.6
4/22/13	4/24/13	125	48	25.7	85.0	51.9	51.3	45.3	41.5
4/22/13	4/24/13	160	48	22.2	73.1	49.0	47.0	42.1	38.4
4/22/13	4/24/13	200	48	20.4	71.8	44.9	43.5	38.5	35.2
4/22/13	4/24/13	250	48	16.7	65.1	40.9	41.1	35.6	31.8
4/22/13	4/24/13	315	48	14.6	60.7	37.0	37.3	32.3	28.7
4/22/13	4/24/13	400	48	10.4	64.8	33.1	34.3	29.5	25.3
4/22/13	4/24/13	500	48	10.5	57.0	29.5	29.0	25.6	22.2
4/22/13	4/24/13	630	48	9.9	56.6	28.0	27.9	23.5	19.1
4/22/13	4/24/13	800	48	7.6	61.7	29.2	28.2	23.3	18.0
4/22/13	4/24/13	1000	48	10.4	65.2	33.0	31.4	26.6	20.0
4/22/13	4/24/13	1250	48	9.7	67.8	33.9	32.5	27.4	19.6
4/22/13	4/24/13	1600	48	7.8	68.8	33.1	31.6	25.5	17.9
4/22/13	4/24/13	2000	48	5.5	68.7	31.5	28.6	22.3	15.3
4/22/13	4/24/13	2500	48	4.4	66.0	30.6	26.1	19.9	14.0
4/22/13	4/24/13	3150	48	3.4	58.6	23.2	20.7	14.0	7.7
4/22/13	4/24/13	4000	48	3.4	49.6	16.8	13.5	9.0	4.8
4/22/13	4/24/13	5000	48	3.9	42.9	11.2	8.8	5.7	4.7
4/22/13	4/24/13	6300	48	4.1	36.9	6.9	5.3	4.9	4.6
4/22/13	4/24/13	8000	48	4.1	38.1	6.5	4.9	4.7	4.5
4/22/13	4/24/13	10000	48	3.6	40.7	6.1	4.5	4.3	4.2
4/22/13	4/24/13	12500	48	2.8	38.3	5.8	4.1	3.7	3.5
4/22/13	4/24/13	16000	48	1.7	29.7	5.1	3.2	2.8	2.5
4/22/13	4/24/13	20000	48	0.1	29.1	3.6	1.7	1.3	0.9

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 83. PAPA214 (North Anticline Road, east side, 50 m from centerline) hourly dBA metrics, April 22-23, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/23/2013	4/23/2013	0	1	20.8	61.0	36.6	33.4	24.8	22.7
4/23/2013	4/23/2013	1	1	21.5	58.0	35.9	30.6	24.5	23.1
4/23/2013	4/23/2013	2	1	21.5	59.6	35.2	27.1	24.5	23.0
4/23/2013	4/23/2013	3	1	21.0	55.5	33.8	29.6	24.5	23.0
4/23/2013	4/23/2013	4	1	22.2	58.2	37.6	39.0	26.7	24.2
4/23/2013	4/23/2013	5	1	24.6	66.0	43.4	45.6	31.7	27.2
4/23/2013	4/23/2013	6	1	24.9	66.5	44.1	46.0	30.2	27.0
4/23/2013	4/23/2013	7	1	25.4	64.6	44.8	47.2	33.2	27.6
4/23/2013	4/23/2013	8	1	23.4	60.7	39.4	42.5	29.8	25.7
4/22/2013	4/22/2013	9	1	29.4	75.8	50.6	51.3	37.2	31.5
4/22/2013	4/22/2013	10	1	29.2	67.6	48.6	50.8	35.3	31.2
4/22/2013	4/22/2013	11	1	31.4	66.1	47.0	49.0	36.5	34.1
4/22/2013	4/22/2013	12	1	27.2	79.2	50.1	47.0	34.5	29.9
4/22/2013	4/22/2013	13	1	24.4	54.7	38.6	42.2	31.1	27.1
4/22/2013	4/22/2013	14	1	24.2	59.6	42.8	47.7	32.4	27.2
4/22/2013	4/22/2013	15	1	23.6	58.8	40.1	42.5	28.9	25.5
4/22/2013	4/22/2013	16	1	22.2	56.3	35.7	36.8	26.2	24.0
4/22/2013	4/22/2013	17	1	21.9	64.8	39.7	40.3	27.0	24.0
4/22/2013	4/22/2013	18	1	21.8	57.7	37.8	39.3	25.7	23.4
4/22/2013	4/22/2013	19	1	21.2	57.1	38.3	39.4	25.5	23.5
4/22/2013	4/22/2013	20	1	21.7	56.8	37.8	36.2	25.2	23.5
4/22/2013	4/22/2013	21	1	20.9	71.3	44.0	36.4	25.3	23.0
4/22/2013	4/22/2013	22	1	21.2	52.7	32.1	27.9	24.2	22.6
4/22/2013	4/22/2013	23	1	20.0	60.3	37.5	35.5	23.6	21.8

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 84. PAPA214 (North Anticline Road, east side, 50 m from centerline) dBA and one-third octave band metrics, April 22-23, 2013.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/22/13	4/23/13	dBA	24	20.0	79.2	43.6	39.9	26.9	24.1
4/22/13	4/23/13	12.5	24	28.7	76.1	52.7	54.1	48.0	42.9
4/22/13	4/23/13	16	24	35.0	78.6	53.8	55.4	52.1	48.9
4/22/13	4/23/13	20	24	45.2	74.7	60.3	62.4	59.6	56.6
4/22/13	4/23/13	25	24	36.8	79.5	52.0	53.8	49.6	46.6
4/22/13	4/23/13	31.5	24	35.5	75.6	50.5	52.2	47.5	44.4
4/22/13	4/23/13	40	24	37.3	79.0	52.7	54.2	50.6	46.6
4/22/13	4/23/13	50	24	40.1	82.7	54.5	55.0	50.7	47.5
4/22/13	4/23/13	63	24	30.4	85.1	54.5	54.6	43.2	38.7
4/22/13	4/23/13	80	24	24.8	84.8	55.2	53.3	36.9	34.2
4/22/13	4/23/13	100	24	15.8	83.0	51.6	46.5	29.5	26.2
4/22/13	4/23/13	125	24	11.0	83.6	47.9	36.9	25.9	21.6
4/22/13	4/23/13	160	24	8.6	79.7	46.6	32.6	22.1	17.4
4/22/13	4/23/13	200	24	6.5	77.2	43.3	29.4	19.8	16.3
4/22/13	4/23/13	250	24	3.1	73.8	39.9	25.5	16.3	12.4
4/22/13	4/23/13	315	24	4.5	69.9	36.3	21.7	17.8	14.9
4/22/13	4/23/13	400	24	2.1	66.4	31.0	18.4	12.8	10.1
4/22/13	4/23/13	500	24	1.5	63.7	28.1	17.9	11.3	8.5
4/22/13	4/23/13	630	24	1.9	63.6	27.8	19.1	12.4	9.0
4/22/13	4/23/13	800	24	2.1	64.0	28.5	20.8	13.5	9.0
4/22/13	4/23/13	1000	24	2.6	65.1	29.1	22.1	12.2	8.1
4/22/13	4/23/13	1250	24	1.9	67.4	29.7	23.7	11.5	6.9
4/22/13	4/23/13	1600	24	1.9	67.8	30.0	24.6	9.1	5.9
4/22/13	4/23/13	2000	24	1.9	67.2	30.0	23.7	6.3	4.4
4/22/13	4/23/13	2500	24	2.5	66.4	28.8	22.5	5.3	4.2
4/22/13	4/23/13	3150	24	3.3	62.9	27.1	20.7	5.0	4.2
4/22/13	4/23/13	4000	24	3.9	63.2	24.7	18.0	5.1	4.6
4/22/13	4/23/13	5000	24	4.5	62.6	23.7	14.9	5.5	5.2
4/22/13	4/23/13	6300	24	5.0	58.9	19.2	11.0	5.8	5.5
4/22/13	4/23/13	8000	24	5.1	57.0	16.2	8.2	5.8	5.6
4/22/13	4/23/13	10000	24	4.7	53.2	13.5	7.0	5.5	5.3
4/22/13	4/23/13	12500	24	3.9	50.8	10.7	5.8	4.7	4.5
4/22/13	4/23/13	16000	24	2.7	50.3	10.0	4.5	3.8	3.5
4/22/13	4/23/13	20000	24	1.4	49.6	8.0	3.0	2.4	2.1

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 85. PAPA215 (Mesa pad 3-27, 21 wells, with intermittent generator, 200 m) hourly dBA metrics, April 23-24, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/24/2013	4/24/2013	0	1	40.3	58.9	49.0	52.1	47.4	44.1
4/24/2013	4/24/2013	1	1	37.1	52.6	44.2	46.8	43.1	40.4
4/24/2013	4/24/2013	2	1	37.3	60.2	47.0	50.3	43.3	40.0
4/24/2013	4/24/2013	3	1	38.3	56.7	42.2	43.9	41.3	39.8
4/24/2013	4/24/2013	4	1	37.6	47.5	41.1	42.5	40.7	39.4
4/24/2013	4/24/2013	5	1	36.7	56.2	41.1	41.3	40.1	38.7
4/24/2013	4/24/2013	6	1	32.2	48.9	37.8	40.3	36.5	33.8
4/24/2013	4/24/2013	7	1	32.6	45.1	35.8	37.1	35.4	34.1
4/24/2013	4/24/2013	8	1	29.1	43.0	33.5	35.0	33.2	31.5
4/23/2013	4/23/2013	9	1	32.5	50.7	37.1	37.7	36.2	34.6
4/23/2013	4/23/2013	10	1	33.9	45.3	39.8	42.5	39.0	36.4
4/23/2013	4/23/2013	11	1	37.0	49.1	44.6	46.9	44.4	40.8
4/23/2013	4/23/2013	12	1	36.9	56.5	45.0	47.3	44.7	40.3
4/23/2013	4/23/2013	13	1	36.1	49.3	44.9	47.2	44.7	40.4
4/23/2013	4/23/2013	14	1	34.9	49.8	44.6	47.1	44.2	40.3
4/23/2013	4/23/2013	15	1	35.8	58.3	45.1	47.4	44.4	40.9
4/23/2013	4/23/2013	16	1	36.0	51.5	45.6	48.0	45.0	41.4
4/23/2013	4/23/2013	17	1	36.2	50.1	45.2	47.5	44.8	41.5
4/23/2013	4/23/2013	18	1	39.7	52.2	47.6	49.6	47.3	44.6
4/23/2013	4/23/2013	19	1	43.6	52.0	47.5	48.9	47.3	45.6
4/23/2013	4/23/2013	20	1	44.0	53.5	47.6	48.6	47.4	46.5
4/23/2013	4/23/2013	21	1	44.6	56.5	49.9	51.6	49.5	48.0
4/23/2013	4/23/2013	22	1	45.5	57.1	48.7	49.8	48.3	47.1
4/23/2013	4/23/2013	23	1	41.9	60.9	46.6	47.9	45.8	44.4

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 86. PAPA215 (Mesa pad 3-27, 21 wells, with intermittent generator, 200 m) dBA and one-third octave band metrics, April 23-24, 2013.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/23/13	4/24/13	dBA	24	29.1	60.9	45.4	47.3	44.4	40.4
4/23/13	4/24/13	12.5	24	31.5	73.6	49.9	50.7	45.9	42.3
4/23/13	4/24/13	16	24	37.2	73.8	51.5	53.7	50.1	46.7
4/23/13	4/24/13	20	24	41.8	75.5	64.2	65.7	60.5	56.2
4/23/13	4/24/13	25	24	36.1	72.5	48.6	50.6	47.5	44.7
4/23/13	4/24/13	31.5	24	39.5	68.9	51.4	53.2	50.6	47.7
4/23/13	4/24/13	40	24	42.3	73.3	55.0	54.6	51.3	49.1
4/23/13	4/24/13	50	24	43.8	80.8	55.8	56.1	52.7	50.0
4/23/13	4/24/13	63	24	40.5	81.6	59.1	55.5	52.0	48.0
4/23/13	4/24/13	80	24	38.5	76.8	61.7	63.9	61.4	54.4
4/23/13	4/24/13	100	24	35.7	79.9	52.6	53.3	50.5	48.0
4/23/13	4/24/13	125	24	23.9	75.1	51.5	51.3	48.0	45.6
4/23/13	4/24/13	160	24	22.7	71.7	47.2	47.3	44.5	42.0
4/23/13	4/24/13	200	24	25.5	65.9	47.4	47.8	43.8	40.4
4/23/13	4/24/13	250	24	21.7	61.8	44.6	45.2	41.5	37.3
4/23/13	4/24/13	315	24	18.0	60.1	40.5	40.1	36.1	32.7
4/23/13	4/24/13	400	24	14.7	58.5	37.3	36.7	31.8	28.4
4/23/13	4/24/13	500	24	9.4	56.2	32.4	32.3	27.2	23.5
4/23/13	4/24/13	630	24	5.3	55.9	29.2	29.2	24.4	21.1
4/23/13	4/24/13	800	24	2.8	48.9	27.1	27.8	23.5	19.1
4/23/13	4/24/13	1000	24	2.2	44.8	25.8	26.8	22.4	17.9
4/23/13	4/24/13	1250	24	2.1	43.3	24.0	24.9	20.4	15.9
4/23/13	4/24/13	1600	24	1.5	39.1	20.9	22.7	18.7	14.0
4/23/13	4/24/13	2000	24	1.6	32.0	15.8	17.4	12.6	9.1
4/23/13	4/24/13	2500	24	2.2	39.9	13.0	11.3	8.2	6.2
4/23/13	4/24/13	3150	24	2.8	34.4	10.9	8.8	6.5	5.3
4/23/13	4/24/13	4000	24	3.6	50.7	9.4	6.2	5.3	4.9
4/23/13	4/24/13	5000	24	4.3	52.4	11.1	5.6	5.2	5.0
4/23/13	4/24/13	6300	24	4.6	46.0	7.1	5.7	5.5	5.3
4/23/13	4/24/13	8000	24	4.7	27.9	5.6	5.7	5.5	5.3
4/23/13	4/24/13	10000	24	4.6	28.1	5.3	5.4	5.1	5.0
4/23/13	4/24/13	12500	24	4.0	20.5	4.6	4.8	4.5	4.4
4/23/13	4/24/13	16000	24	3.1	20.8	3.8	3.8	3.6	3.5
4/23/13	4/24/13	20000	24	1.7	16.2	2.6	2.8	2.4	2.2

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 87. PAPA216 (Drill rig, pad 5-19, 435 m) hourly dBA metrics, April 23-24, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/24/2013	4/24/2013	0	1	35.5	58.9	41.0	42.2	40.4	38.2
4/24/2013	4/24/2013	1	1	37.4	58.4	42.0	42.7	41.3	39.8
4/24/2013	4/24/2013	2	1	37.6	52.9	42.5	43.8	42.0	40.4
4/24/2013	4/24/2013	3	1	40.3	62.9	44.5	45.5	43.9	42.3
4/24/2013	4/24/2013	4	1	39.7	61.8	44.5	45.2	43.6	41.9
4/24/2013	4/24/2013	5	1	40.7	65.9	46.1	46.0	44.5	43.2
4/24/2013	4/24/2013	6	1	41.4	65.1	46.3	45.9	44.3	43.0
4/24/2013	4/24/2013	7	1	40.1	49.0	43.4	44.6	43.2	41.9
4/24/2013	4/24/2013	8	1	35.9	53.9	41.5	43.4	41.2	38.4
4/24/2013	4/24/2013	9	1	34.0	49.6	39.0	40.6	38.6	36.9
4/24/2013	4/24/2013	10	1	NA	NA	NA	NA	NA	NA
4/23/2013	4/23/2013	11	1	29.9	49.6	36.9	39.1	36.2	33.7
4/23/2013	4/23/2013	12	1	30.3	61.6	39.0	40.5	37.9	34.4
4/23/2013	4/23/2013	13	1	35.5	45.0	40.5	42.0	40.3	38.6
4/23/2013	4/23/2013	14	1	38.1	51.8	41.8	43.0	41.4	40.0
4/23/2013	4/23/2013	15	1	35.5	53.3	42.7	44.4	42.5	39.0
4/23/2013	4/23/2013	16	1	36.1	55.9	41.9	44.1	41.2	38.8
4/23/2013	4/23/2013	17	1	35.3	58.4	41.4	41.8	39.5	37.6
4/23/2013	4/23/2013	18	1	34.0	44.9	39.5	41.0	39.2	37.6
4/23/2013	4/23/2013	19	1	35.8	44.4	39.0	40.2	38.8	37.5
4/23/2013	4/23/2013	20	1	36.7	45.6	39.9	41.0	39.7	38.6
4/23/2013	4/23/2013	21	1	37.1	49.5	40.6	41.8	40.2	38.8
4/23/2013	4/23/2013	22	1	36.9	51.7	41.2	42.4	40.7	39.3
4/23/2013	4/23/2013	23	1	38.5	49.4	41.5	42.5	41.2	40.1

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 88. PAPA216 (Drill rig, pad 5-19, 435 m) dBA and one-third octave band metrics, April 23-24, 2013.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/23/13	4/24/13	dBA	23	29.9	65.9	42.2	42.5	41.2	38.8
4/23/13	4/24/13	12.5	23	32.2	71.0	49.0	50.7	46.4	42.1
4/23/13	4/24/13	16	23	37.9	69.8	52.5	54.6	51.4	47.7
4/23/13	4/24/13	20	23	47.5	73.9	65.0	68.0	64.7	59.9
4/23/13	4/24/13	25	23	43.7	75.0	60.9	64.1	57.4	53.2
4/23/13	4/24/13	31.5	23	52.9	82.4	72.3	74.6	70.3	64.4
4/23/13	4/24/13	40	23	44.3	68.2	58.1	59.7	57.5	55.7
4/23/13	4/24/13	50	23	40.8	69.4	57.5	58.6	55.2	52.7
4/23/13	4/24/13	63	23	36.8	73.4	62.8	64.4	61.6	58.3
4/23/13	4/24/13	80	23	31.2	73.9	55.4	57.4	54.2	51.0
4/23/13	4/24/13	100	23	28.0	76.8	52.2	54.1	51.7	49.1
4/23/13	4/24/13	125	23	25.3	71.5	43.5	44.8	43.2	40.1
4/23/13	4/24/13	160	23	23.0	64.4	42.7	40.9	38.2	35.8
4/23/13	4/24/13	200	23	21.0	65.2	38.1	37.3	34.4	31.8
4/23/13	4/24/13	250	23	16.8	62.4	35.0	34.4	30.7	27.5
4/23/13	4/24/13	315	23	16.8	57.9	34.5	35.2	31.1	27.5
4/23/13	4/24/13	400	23	14.8	53.4	32.8	33.2	29.0	25.2
4/23/13	4/24/13	500	23	8.8	53.8	27.5	27.0	22.3	18.5
4/23/13	4/24/13	630	23	8.9	54.0	26.3	25.1	20.7	17.4
4/23/13	4/24/13	800	23	7.8	50.4	25.5	25.3	21.5	17.4
4/23/13	4/24/13	1000	23	7.6	49.3	24.5	24.1	20.4	16.9
4/23/13	4/24/13	1250	23	7.7	45.9	24.6	22.6	19.5	16.7
4/23/13	4/24/13	1600	23	7.0	44.8	24.6	21.0	18.3	15.5
4/23/13	4/24/13	2000	23	4.4	51.3	20.0	17.2	13.7	10.5
4/23/13	4/24/13	2500	23	3.7	37.9	15.0	15.1	10.3	7.5
4/23/13	4/24/13	3150	23	3.4	44.0	10.8	8.8	5.9	4.9
4/23/13	4/24/13	4000	23	3.6	41.9	7.9	5.8	4.7	4.4
4/23/13	4/24/13	5000	23	4.0	40.6	7.2	5.1	4.7	4.5
4/23/13	4/24/13	6300	23	4.3	37.7	5.6	5.1	4.9	4.7
4/23/13	4/24/13	8000	23	4.4	39.5	5.4	5.0	4.8	4.7
4/23/13	4/24/13	10000	23	4.1	36.0	4.9	4.7	4.6	4.4
4/23/13	4/24/13	12500	23	3.5	28.9	4.3	4.2	4.1	3.9
4/23/13	4/24/13	16000	23	2.7	27.6	3.6	3.5	3.3	3.2
4/23/13	4/24/13	20000	23	1.5	24.9	2.5	2.5	2.2	1.9

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 89. PAPA217 (Johan compressor station, 140 m ESE) hourly dBA metrics, April 23-24, 2013.

Date Start	Date End	Hour	N. Hrs.	Lmin	Lmax	Leq	L10	L50	L90
4/24/2013	4/24/2013	0	1	49.6	68.9	51.9	52.0	51.2	50.5
4/24/2013	4/24/2013	1	1	49.2	55.9	51.3	52.2	51.1	50.4
4/24/2013	4/24/2013	2	1	49.2	60.0	51.3	51.8	51.0	50.4
4/24/2013	4/24/2013	3	1	48.7	59.0	51.0	51.8	50.8	49.9
4/24/2013	4/24/2013	4	1	49.0	54.5	51.0	51.8	50.8	50.0
4/24/2013	4/24/2013	5	1	48.6	59.2	50.6	51.5	50.4	49.6
4/24/2013	4/24/2013	6	1	48.5	56.8	50.7	51.5	50.6	49.8
4/24/2013	4/24/2013	7	1	48.3	63.7	50.6	51.5	50.4	49.5
4/24/2013	4/24/2013	8	1	48.2	54.5	50.4	51.3	50.2	49.4
4/24/2013	4/24/2013	9	1	47.6	62.1	50.1	50.9	49.8	49.0
4/24/2013	4/24/2013	10	1	48.1	55.8	50.8	51.8	50.6	49.6
4/23/2013	4/23/2013	11	1	NA	NA	NA	NA	NA	NA
4/23/2013	4/23/2013	12	1	46.1	60.9	51.7	54.5	50.4	47.7
4/23/2013	4/23/2013	13	1	48.8	59.5	54.8	56.1	55.0	50.5
4/23/2013	4/23/2013	14	1	48.7	60.8	55.9	58.2	56.3	50.4
4/23/2013	4/23/2013	15	1	48.6	66.8	55.0	58.2	53.6	50.5
4/23/2013	4/23/2013	16	1	49.2	58.3	51.1	51.9	51.0	50.2
4/23/2013	4/23/2013	17	1	48.9	58.1	50.9	51.8	50.8	50.0
4/23/2013	4/23/2013	18	1	48.9	56.0	51.0	51.9	50.8	50.0
4/23/2013	4/23/2013	19	1	48.9	55.0	51.0	51.8	50.9	50.1
4/23/2013	4/23/2013	20	1	49.6	54.4	51.2	51.8	51.2	50.6
4/23/2013	4/23/2013	21	1	49.1	64.5	51.2	51.7	50.9	50.3
4/23/2013	4/23/2013	22	1	49.7	65.0	51.9	52.3	51.5	50.9
4/23/2013	4/23/2013	23	1	50.0	60.9	51.8	52.3	51.5	50.9

Appendix C. dBA and One-third Octave Metrics for PAPA Noise Source Sites (cont.).

Table 90. PAPA217 (Johan compressor station, 140 m ESE) dBA and one-third octave band metrics, April 23-24, 2013.

Date Start	Date End	dBA/Freq	N. Hrs	LMin	LMax	Leq	L10	L50	L90
4/23/13	4/24/13	dBA	23	46.1	68.9	51.9	51.8	50.9	50.1
4/23/13	4/24/13	12.5	23	41.8	73.7	56.2	58.1	54.8	50.9
4/23/13	4/24/13	16	23	47.6	78.1	62.6	64.5	61.3	57.2
4/23/13	4/24/13	20	23	49.4	78.8	66.2	68.9	64.5	60.6
4/23/13	4/24/13	25	23	48.6	78.6	59.9	61.6	59.3	56.9
4/23/13	4/24/13	31.5	23	52.6	76.7	62.8	64.6	62.3	59.9
4/23/13	4/24/13	40	23	52.9	79.2	60.6	61.6	59.9	58.0
4/23/13	4/24/13	50	23	55.5	82.7	64.4	64.5	62.9	61.1
4/23/13	4/24/13	63	23	56.2	81.2	64.3	65.3	64.0	62.6
4/23/13	4/24/13	80	23	57.9	80.5	65.5	66.2	64.9	63.6
4/23/13	4/24/13	100	23	53.0	75.4	63.5	62.9	61.4	60.0
4/23/13	4/24/13	125	23	49.1	71.1	57.8	58.5	56.9	55.1
4/23/13	4/24/13	160	23	47.9	75.8	56.4	55.8	54.5	53.4
4/23/13	4/24/13	200	23	41.5	67.2	54.7	55.5	54.2	52.4
4/23/13	4/24/13	250	23	41.2	63.4	50.9	51.7	50.1	48.7
4/23/13	4/24/13	315	23	32.2	63.6	42.1	42.1	40.3	38.5
4/23/13	4/24/13	400	23	28.7	55.9	37.3	37.8	35.7	34.1
4/23/13	4/24/13	500	23	26.3	57.3	34.8	35.7	33.6	31.9
4/23/13	4/24/13	630	23	22.4	56.0	30.9	31.9	30.0	27.9
4/23/13	4/24/13	800	23	19.5	52.3	28.8	30.0	27.3	25.1
4/23/13	4/24/13	1000	23	19.7	55.9	30.6	32.1	29.4	27.0
4/23/13	4/24/13	1250	23	21.5	60.0	33.1	35.2	32.0	29.3
4/23/13	4/24/13	1600	23	22.8	60.9	36.0	38.5	34.9	31.8
4/23/13	4/24/13	2000	23	21.3	60.9	33.7	35.1	32.5	30.0
4/23/13	4/24/13	2500	23	22.2	57.0	33.2	34.4	32.4	30.0
4/23/13	4/24/13	3150	23	18.0	59.7	30.1	31.1	29.3	26.5
4/23/13	4/24/13	4000	23	14.7	52.9	26.2	27.3	25.5	23.1
4/23/13	4/24/13	5000	23	10.7	56.4	21.5	22.2	20.0	17.8
4/23/13	4/24/13	6300	23	6.8	55.7	16.7	15.2	13.6	11.6
4/23/13	4/24/13	8000	23	5.4	49.1	11.1	9.8	8.5	7.3
4/23/13	4/24/13	10000	23	5.2	42.8	7.7	6.9	6.3	5.9
4/23/13	4/24/13	12500	23	4.4	40.6	6.6	5.2	5.0	4.8
4/23/13	4/24/13	16000	23	2.3	33.9	4.1	3.0	2.9	2.7
4/23/13	4/24/13	20000	23	-0.1	30.6	2.1	0.6	0.5	0.3

Appendix D. Influence of Fleece Windscreen on Decibel Data.

In the PAPA area, high winds, animals, and human activity are common. In order to minimize the influence of wind on the decibel data and to protect the equipment, we used a second windscreen in addition to the standard 90 mm foam windscreen. The additional windscreen was made of thin fleece material placed over a 0.4 m (15 in) high and 0.3 m (12 in) wide wire cylindrical cage (Figures 7-8). This approach is similar to the dual-stage windscreen used in noise measurement systems in remote and windy areas of national parks (Miller et al. 1997, Lee et al. 2006).

In order to test the influence of the fleece windscreen on decibel data, we collected data simultaneously using two LD 831 sound level meters at the Big John lek from April 7-10, 2013. One system had the standard 90 mm foam windscreen only and the other system had the 90 mm foam windscreen plus the fleece and wire cage windscreen (Figures 7-8). We tested the influence of the additional windscreen on dBA and one-third octave band decibel data, both daily and for all days, and found the influence to be minimal.

For daily L_{50} dBA levels, the mean difference was 0.0 dBA (min = -0.1, max = +0.2); for daily L_{90} dBA levels, the mean difference was +0.1 dBA (min = +0.3; max = 0.0). For daily L_{eq} levels, the mean difference was -1.5 dBA (min = -2.8; max = -0.1) (Table 92). Overall, for all days, L_{eq} dBA was slightly higher for the system with the foam only windscreen, L_{90} dBA was slightly higher for the system with the foam/fleece windscreen, and L_{50} dBA was the same for both systems.

L_{50} one-third octave band frequency levels were on average +0.1 dB different (min = -1.8; max = +2.1) between the two windscreens; L_{90} levels were on average +0.3 dB different (min = -1.4; max = +2.5); and L_{eq} levels were on average -1.6 dB different (min = -4.5; max = +0.9) (Tables 93-94; Figures 9-13). For all metrics, the largest differences were at low (<40 Hz) or high frequencies (>4000 Hz).

Normally, the addition of windscreen material over a microphone results in lower decibel levels at high frequencies. However, this comparison revealed that the addition of the fleece windscreen did not always result in lower levels for this system, and frequently this system had higher levels. These small differences in dBA levels, with each system occasionally higher or lower, suggest that differences in dBA and dB levels were likely due to localized effects related to wind through vegetation, the presence of insects or other acoustic phenomena. All of the dBA level differences and most of the dB level differences were within the precision limits of the instruments.

Appendix D. Influence of Fleece Windscreen on Decibel Data (cont.).

In addition to providing extra wind protection, the fleece cover also protected the 90 mm foam windscreen from disturbance by mammals in the area. In previous long-term measurements in remote locations, mammals such as deer, moose, bear, and small rodents frequently chewed on or removed the foam windscreen from the microphone, resulting in unusable decibel data. Using the fleece material and cylindrical cage over the microphone prevented damage to the microphones and foam windscreens due to animals. A third benefit of the fleece material was security. We used a camouflage colored fleece material that was similar to the sage land cover, and this made the acoustic systems harder to see. At several measurement locations, acoustic systems were near roads and human activity, and thus susceptible to disturbance or theft. The use of camouflage fleece material minimized the risk of this issue.

Figure 7. Windscreen made of fleece material placed over a 0.4 m (15 in) high and 0.3 m (12 in) wide wire cylindrical cage.

Appendix D. Influence of Fleece Windscreen on Decibel Data (cont.).

Figure 8. Data collection with LD 831 systems using two different types of windscreens, foam only and foam/fleece, both microphones 0.3 m high, 2.0 m apart.

Appendix D. Influence of Fleece Windscreen on Decibel Data (cont.).

Table 91. PAPA101 (foam only windscreen) and PAPA102 (foam/fleece windscreen) L_{10}, L_{50}, L_{90}, and L_{eq} dBA metrics, April 7-10, 2013, 0000-2400.

	Foam	Foam/Fleece	
L10	PAPA101	PAPA102	Difference
4/7/2013	25.3	25.3	0.0
4/8/2013	25.6	25.9	0.3
4/9/2013	25.3	24.3	-1.0
4/10/2013	26.9	26.2	-0.7
Mean	25.8	25.4	

L50	PAPA101	PAPA102	Difference
4/7/2013	21.2	21.2	0.0
4/8/2013	21.9	22.1	0.2
4/9/2013	18.3	18.2	-0.1
4/10/2013	21.0	20.9	-0.1
Mean	20.6	20.6	

L90	PAPA101	PAPA102	Difference
4/7/2013	19.0	19.1	0.1
4/8/2013	19.7	19.9	0.2
4/9/2013	16.1	16.4	0.3
4/10/2013	18.6	18.6	0.0
Mean	18.4	18.5	

Leq	PAPA101	PAPA102	Difference
4/7/2013	28.0	26.3	-1.7
4/8/2013	35.0	32.2	-2.8
4/9/2013	25.6	24.4	-1.2
4/10/2013	31.0	30.9	-0.1
Mean	29.9	28.5	

Appendix D. Influence of Fleece Windscreen on Decibel Data (cont.).

Table 92. PAPA101 (foam only windscreen), dBA and one-third octave band levels, April 7-10, 2013.

Freq./dBA	NHours	LMin	LMax	Leq	L10	L50	L90
dBA	96	13.9	67.6	31.3	25.9	21.2	18.0
20	96	17.2	75.3	52.3	51.2	45.5	40.3
25	96	17.8	74.5	49.0	44.6	39.0	34.6
31.5	96	16.2	71.4	47.0	44.7	39.2	34.6
40	96	13.2	70.7	44.2	39.3	34.6	31.0
50	96	11.1	74.7	41.6	36.8	32.4	29.1
63	96	10.0	81.6	40.1	36.2	31.4	28.4
80	96	9.0	82.2	39.2	35.1	30.0	26.6
100	96	5.7	86.2	38.3	32.9	28.4	25.4
125	96	4.3	74.4	34.4	31.4	26.5	22.9
160	96	1.7	69.3	31.7	30.6	24.7	20.3
200	96	-0.7	71.6	29.3	27.6	21.5	17.0
250	96	-1.9	64.0	26.8	24.6	18.5	13.6
315	96	-3.0	56.1	23.9	21.5	14.7	9.5
400	96	-4.2	57.7	21.2	17.1	10.2	4.5
500	96	-4.2	53.7	19.3	14.6	7.3	0.5
630	96	-4.2	46.2	16.9	7.6	1.4	-1.6
800	96	-4.0	45.7	15.0	6.0	-0.3	-2.0
1000	96	-3.3	41.4	14.6	5.5	-0.6	-1.7
1250	96	-2.6	38.3	14.2	4.8	-0.3	-1.2
1600	96	-1.7	38.5	14.1	3.6	0.2	-0.5
2000	96	-0.8	38.2	13.5	3.8	0.9	0.3
2500	96	0.2	40.5	12.0	3.9	1.6	1.2
3150	96	0.3	42.3	10.3	3.7	2.5	2.1
4000	96	-0.2	44.3	9.9	4.2	3.4	3.1
5000	96	-0.4	46.1	10.6	4.9	4.2	3.9
6300	96	-0.7	45.7	10.8	5.5	5.0	4.7
8000	96	-0.9	46.0	11.1	5.9	5.5	5.3
10000	96	-0.7	45.6	11.0	6.1	5.7	5.4
12500	96	-0.9	44.7	9.8	5.5	5.0	4.6
16000	96	-1.1	44.8	8.2	4.1	3.1	2.6
20000	96	-1.0	41.3	4.9	3.1	0.7	0.1

Appendix D. Influence of Fleece Windscreen on Decibel Data (cont.).

Table 93. PAPA102 (foam/fleece windscreen), dBA and one-third octave band levels, April 7-10, 2013.

Freq./dBA	NHours	LMin	LMax	Leq	L10	L50	L90
dBA	93	14.6	68.5	29.5	25.3	20.9	18.4
20	93	16.9	74.7	49.4	48.9	43.7	39.3
25	93	17.5	70.5	44.6	41.5	37.3	33.8
31.5	93	16.4	67.5	43.0	42.5	37.8	33.2
40	93	14.1	65.9	39.7	37.3	34.0	30.8
50	93	11.3	75.1	37.5	35.3	32.0	28.8
63	93	9.3	80.8	37.6	34.7	30.9	28.0
80	93	8.7	84.1	37.7	33.9	29.1	26.2
100	93	5.4	84.5	38.1	32.4	28.0	25.2
125	93	3.3	72.7	33.5	31.0	26.6	23.0
160	93	1.1	69.5	30.7	30.4	24.4	20.4
200	93	-0.8	69.4	28.1	27.1	21.2	16.9
250	93	-2.8	66.8	25.3	23.0	17.7	12.5
315	93	-3.4	58.2	23.2	20.7	14.5	9.0
400	93	-4.1	58.5	21.0	16.4	10.1	4.6
500	93	-4.1	51.2	18.9	13.9	6.3	0.3
630	93	-3.7	48.4	16.4	5.9	1.3	-1.3
800	93	-3.0	47.2	14.3	5.0	0.1	-1.1
1000	93	-2.3	43.3	14.1	5.0	0.5	-0.6
1250	93	-1.3	40.3	14.3	4.8	1.0	0.1
1600	93	-0.4	37.8	15.0	4.1	1.7	0.9
2000	93	0.6	38.5	14.0	4.0	2.4	1.8
2500	93	1.5	39.6	12.6	4.3	3.1	2.6
3150	93	2.6	40.4	10.6	4.7	3.8	3.4
4000	93	0.6	42.4	9.1	5.2	4.5	4.1
5000	93	0.0	48.7	8.8	5.6	5.0	4.7
6300	93	0.0	42.6	8.2	5.7	5.3	5.1
8000	93	-0.3	39.2	7.9	5.7	5.4	5.1
10000	93	-0.5	38.4	7.2	5.5	5.2	4.9
12500	93	-0.7	36.9	6.3	5.1	4.7	4.4
16000	93	-0.5	34.1	5.5	4.5	3.9	3.6
20000	93	-0.2	30.9	4.2	3.7	2.8	2.6

Appendix D. Influence of Fleece Windscreen on Decibel Data (cont.).

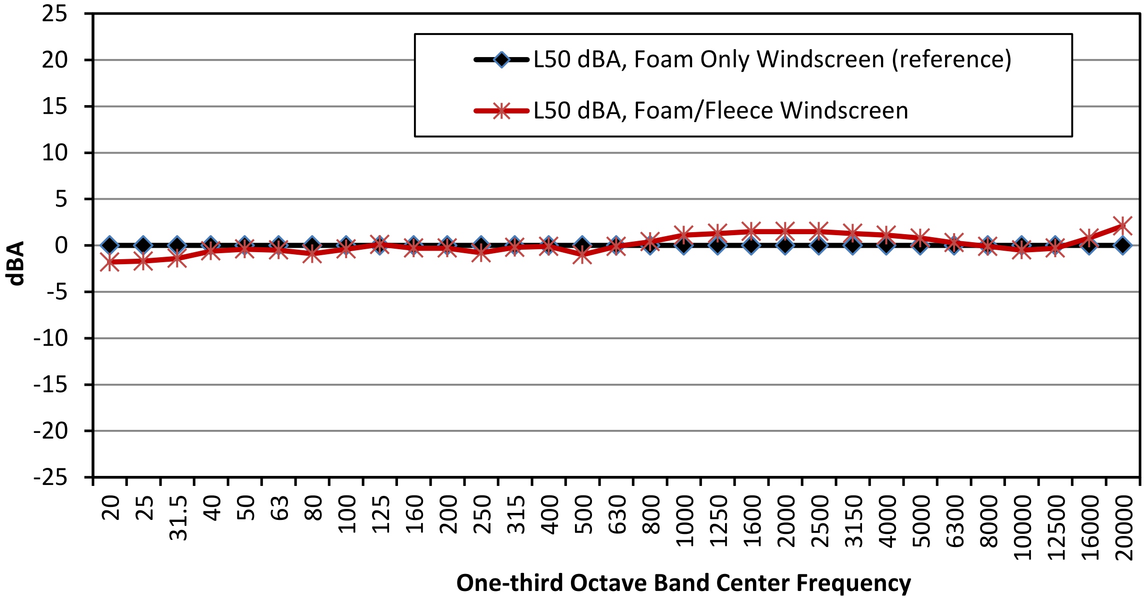

Figure 9. Difference in L_{50} dB levels, 20-20,000 Hz, PAPA101, foam windscreen (reference) and PAPA102, foam/fleece windscreen, April 7-10, 2014 (93 hours).

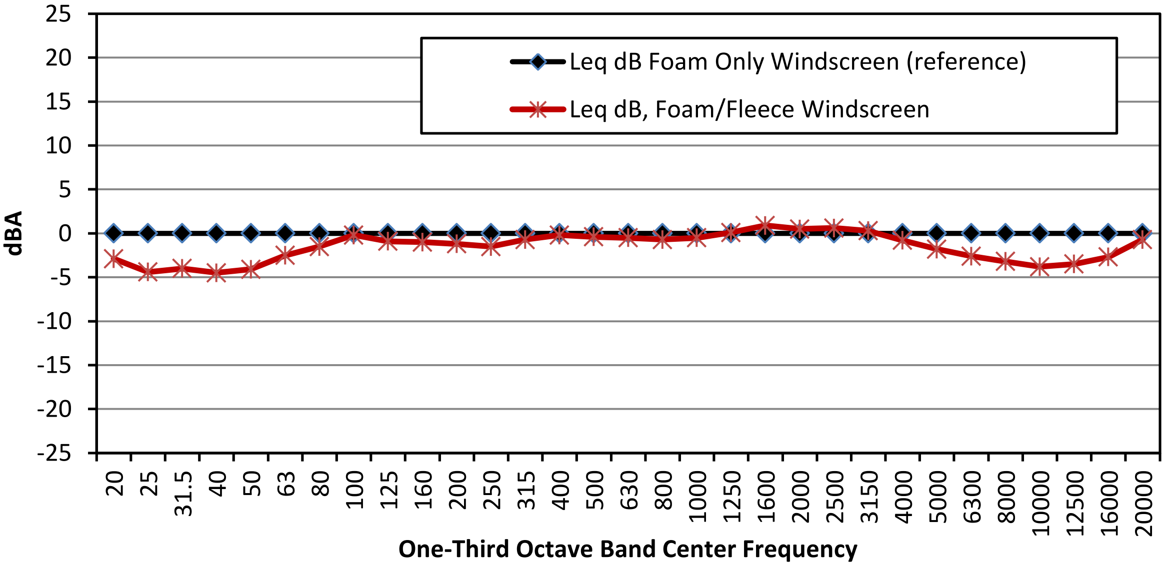

Figure 10. Difference in L_{eq} dB levels, 20-20,000 Hz, PAPA101, foam windscreen (reference) and PAPA102, foam/fleece windscreen, April 7-10, 2014 (93 hours).

Appendix E. Influence of Microphone Height, 1.5 m v. 0.3 m, on dB Data.

In order to test the influence of microphone height on decibel data, we collected data simultaneously using two LD 831 sound level meters. One system had the microphone at 1.5 m and the other system had the microphone at 0.3 m. We compared the L_{eq}, L_{10}, L_{50}, L_{90}, L_{min} and L_{max} dBA metrics for 1 hour on March 13, 2013 (prior to deployment in Wyoming). All metrics of the 1.5 m microphone were slightly higher than metrics of the 0.3 m microphone (Table 92).

Table 94. Influence of microphone height (1.5 m versus 0.3 m) on dBA metrics, March 13, 2013, 1200 hour.

	Mic at 1.5 m	Mic at 0.3 m	Difference.
Date	20130313	20130313	
Hour	1200	1200	
Leq	41.0	38.4	2.6
L10	37.5	36.0	1.5
L50	29.3	28.8	0.5
L90	26.4	25.3	1.1
Lmin	25.0	24.0	1.0
Lmax	73.7	68.9	4.8

Appendix F. Acoustic Primer.

Basic Acoustics

Acoustics is the science of sound. *Sound* can be defined as a pressure variation in air or other media that is within the hearing range of a given species. This pressure variation has two components: amplitude and frequency.

Frequency is the number of times per second that the sine wave of sound repeats itself. It is expressed in cycles per second, or Hertz (Hz). The frequency of a sound determines the tone of a sound (e.g., most aircraft are low frequencies, and most bird calls are high frequencies). Different species of animals hear sounds over a wide range of frequencies. For humans with normal hearing, this range is 20 Hz to 20,000 Hz. Some animals hear better at low frequencies, others at very high frequencies. However, all animals can hear a wide range of frequencies, thus several sounds can be heard at the same time (NPS 2005).

Amplitude is the relative strength of sound waves, which we perceive as loudness or volume. Amplitude is measured in decibels (dB), which refer to the sound pressure level or intensity. The lower threshold of human hearing is 0 dB. Moderate levels of sound (a normal speaking voice, for example) are less than 60 dB. Decibels work on a logarithmic scale, so an increase of 10 dB causes a doubling of perceived loudness and represents a ten-fold increase in sound level (Crocker, 1997).

The acoustical environment is made up of many sounds, and the way animals experience the acoustical environment depends on interactions between the *frequencies* and *amplitudes* of all the sounds. Sound levels are often adjusted (*weighted*) to match the hearing abilities of a given animal. Humans with normal hearing can hear frequencies between 20 Hz and 20,000 Hz, and amplitude as low as 0 dB at 1,000 Hz. Sound levels adjusted for human hearing are expressed as dBA. In Figure 14, sound level thresholds by frequency for humans and some bird species are shown (Fay 1988). We do not have such data for Greater Sage-grouse, but it is likely that thresholds by frequency are similar to other birds.

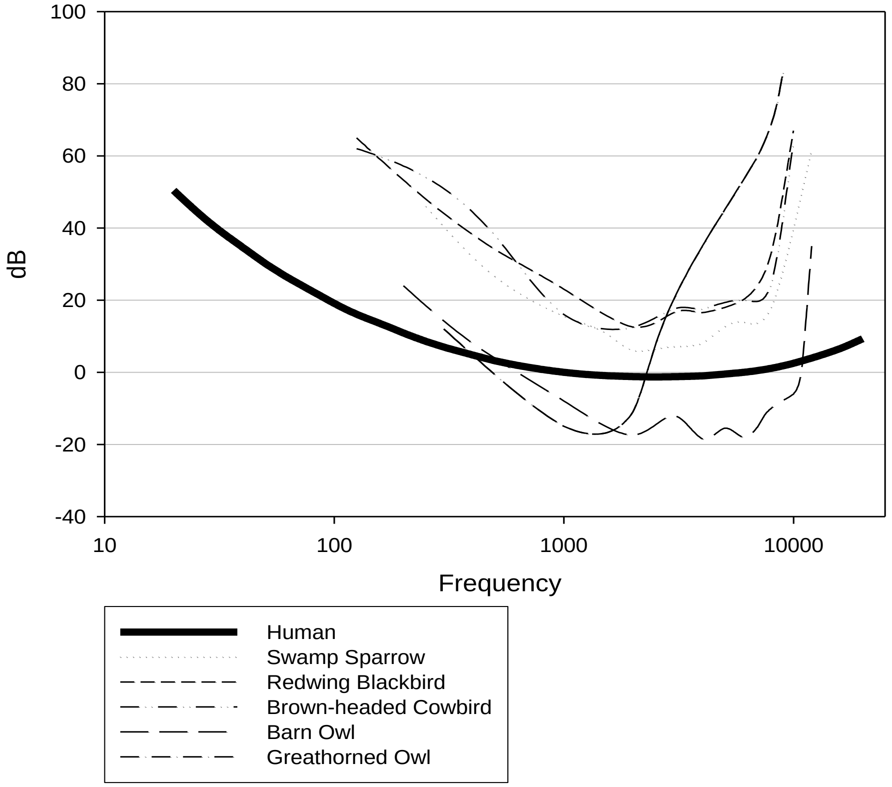

Figure 11. Sound level thresholds by frequency in hearing of humans and bird species.

Visualizing Sounds

Two common methods to visual acoustic data are shown in Figures 15-17. All figures are from recordings at PAPA017 (Oil Road Fork lek). In Figure 15, a 15-second segment of mechanical, Greater Sage-grouse, and coyote sounds is shown. This is called a "spectrogram." The spectrogram plots time along the x-axis and frequency along the y-axis. In this example, only frequencies between 20-5000 Hz are shown. Mechanical sounds are highest at the lower frequencies (<100 Hz), Greater Sage-grouse sounds are highest at frequencies <500 Hz, and coyote sounds dominate at 600 Hz and 1300 Hz. While the Greater Sage-grouse sounds are spread over several frequencies, the coyote sounds are specific to a few frequencies. In Figure 16, a 1-second snapshot of 1/3 octave band data (A-weighted) is shown, with the three sound sources visible at about the same frequencies as in Figure 15 but without as much detail. In this view of a 1-second snapshot, frequency is plotted along the x-axis and amplitude (loudness) is plotted along the y-axis. As in Figure 15, only frequencies between 20-5000 Hz are shown. A more detailed 1-second snapshot is shown in Figure 17. This view shows a narrower band frequency analysis, with finer detail for each frequency. This snapshot corresponds to the 15-second period in Figure 15, with mechanical sounds at about 70 Hz, Greater Sage-grouse sounds at 300-500 Hz, and coyote sounds at about 600 Hz and 1300 Hz.

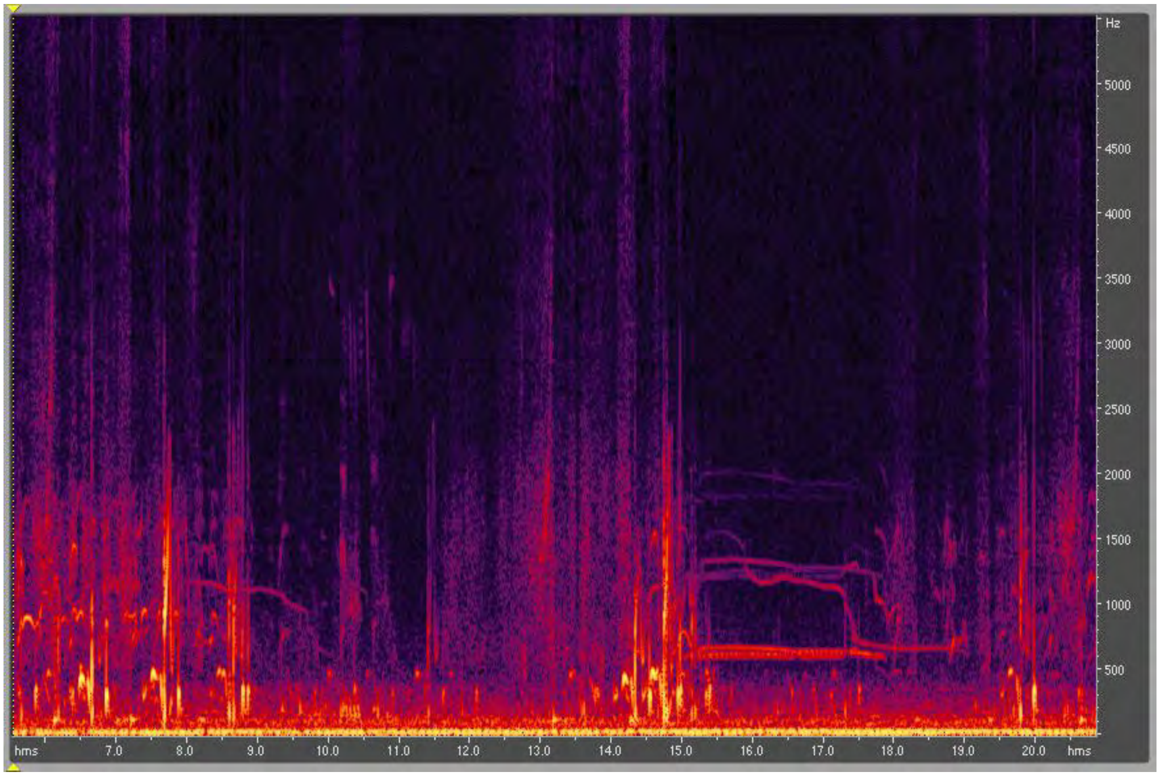

Figure 12. Spectrogram of sounds at PAPA017 (Oil Road Fork lek), with Greater Sage-grouse sounds (20-5,000 Hz), coyote sounds (500-2,000 Hz), and mechanical sounds (<500 Hz).

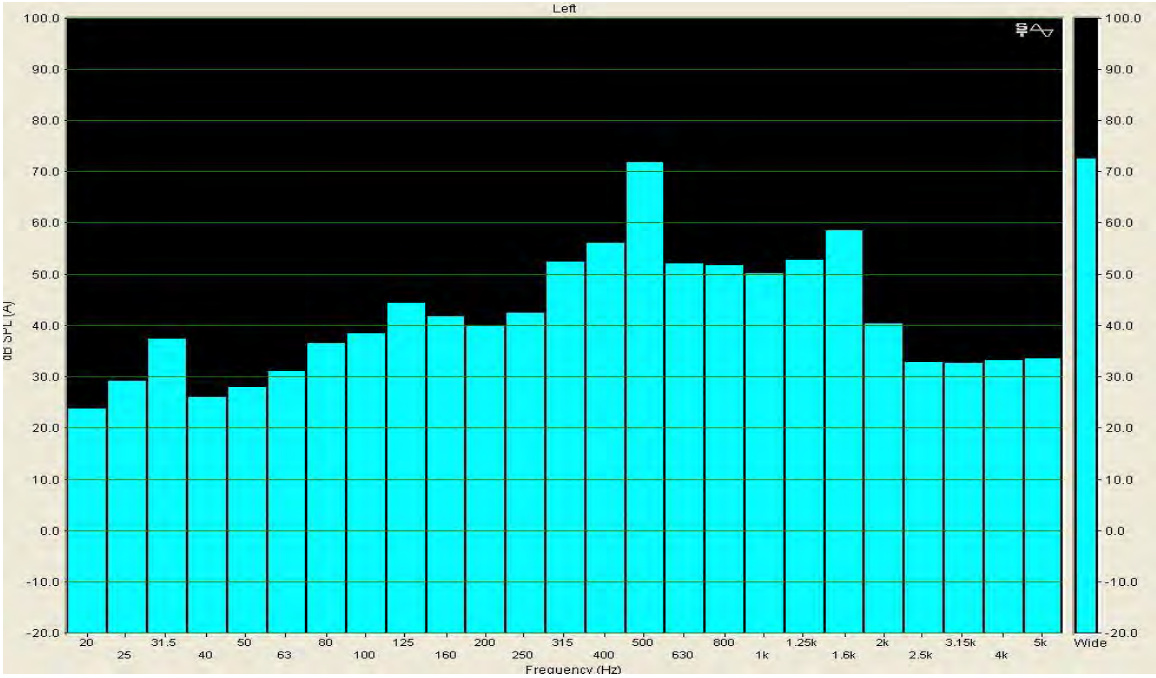

Figure 13. 1-second snapshot sounds at PAPA017 (Oil Road Fork lek), with mechanical sounds, Greater Sage-grouse sounds, and coyote sounds, but with less detail than narrow band analysis.

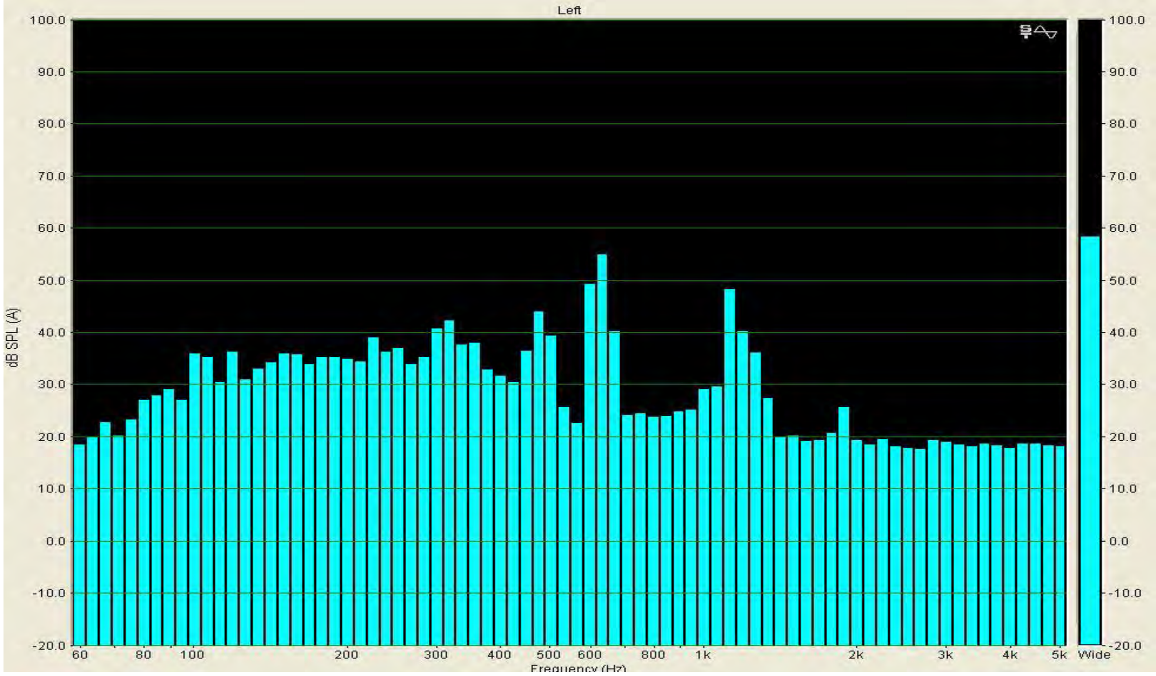

Figure 14. 1-second snapshot of sounds at PAPA017. This view shows a narrower band frequency analysis, with finer detail for each frequency. Mechanical sounds at about 70 Hz, Greater Sage-grouse sounds at 300-500 Hz, and coyote sounds at about 600 Hz and 1300 Hz.

Appendix G. Equipment component list, serial number, and calibration date.

Table 95. Equipment component list, serial number, and calibration date.

SLM LD831 Serial Num.	Calibration Date	PRM831 Serial Num.	Calibration Date	MIC 377B20 Serial Num.	Calibration Date
2201	20130308	12174	20130122	135422	20130122
2258	20130109	19105	20120820	131849	20120820
2544	20130321	23771	20130212	118070	20130212
2573	20120720	19107	20130122	135552	20130122
2661	20121128	19134	20120122	135427	20130122
3140	20130118	23868	20110922	111498	20110922
1304	20110922	0474	20110922	112333	20110922
1308	20110922	0476	20110922	111473	20110922
1311	20110922	0473	20110922	111471	20110922

Calibrators	SN	Calibration Date
B&K 4231	2094637	20100211
B&K 4231	2094432	20100720

Sound Levels at Greater Sage-grouse Leks in the Pinedale Anticline Project Area, WY, April 2013-2014

Dec. 31, 2014

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Sound Levels at Greater Sage-grouse Leks, Pinedale Anticline Project Area, Wyoming, April 2013

Executive Summary

Greater sage-grouse (*Centrocercus urophasianus*) use elaborate audio and visual display behaviors to attract and select mates, and depend on audio communication between females and chicks during brood rearing. A potential threat to greater sage-grouse is anthropogenic noise associated with human activity, including noise from oil and gas development and production. Several greater sage-grouse leks occur in and around the Pinedale Anticline Project Area (PAPA), a large natural gas development area south of Pinedale, WY.

The Bureau of Land Management's Record of Decision specified sound level thresholds above baseline levels that should not be exceeded by industry. Specific changes requiring mitigation are described as follows: "Decibel levels at the lek more than 10 dBA above baseline measured from the edge of the lek." The ROD used 39 dBA as a baseline ambient based on an EPA study that measured sound levels in a rural farming area in California in 1971.

The objective of this project was to monitor sound levels at 19 greater sage-grouse leks in the PAPA area south of Pinedale, WY.

Results

Acoustic data were collected at 19 greater sage-grouse leks in the PAPA in April 2013 and again in 2014. A total of 2087 hours of acoustic data were collected (999 hours 2013 and 1088 in 2014), for an average of 52.5 hours at each lek in 2013 and 57.3 hours at each lek in 2014.

L_{50} dBA at leks in the PAPA ranged from 24.0 dBA to 36.9 dBA for all hours (0000-2400) and from 16.0 dBA to 38.5 dBA for hours important to lek behavior (1800-0800). There was little difference in sound levels at specific leks in 2013 and 2014 except in situations when the type of gas field activity at the closest pad changed significantly. Sound levels at leks were highly correlated with the distance to the nearest pad with gas field activity.

Of the 2087 hours measured at the PAPA leks in 2013 and 2014, no hours exceeded 49 dBA (39 + 10 = 49 dBA). However, results of recent acoustic studies in Wyoming demonstrate that 39 dBA is not an accurate baseline ambient sound level in undeveloped sage habitats of Wyoming.

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Introduction

Greater sage-grouse (*Centrocercus urophasianus*) use elaborate audio and visual display behaviors to attract and select mates, and depend on audio communication between females and chicks during brood rearing. A potential threat to greater sage-grouse is anthropogenic noise associated with human activity, including noise from oil and gas development and production (Holloran 2005, BLM 2008, Patricelli et al. 2013).

The Record of Decision (ROD) (BLM 2008) specified noise thresholds above baseline levels that should not be exceeded by industry. Specific changes requiring mitigation are described as follows: "Decibel levels at the lek more than 10 dBA above baseline measured from the edge of the lek" (BLM 2008)." The ROD also specifies concurrent declines in grouse numbers, but that aspect was not part of this project. The ROD used 39 dBA as a baseline ambient based on an EPA 1971 study that measured sound levels in a rural farming area in California.

Objective

The objective of this project was to measure and document sound levels at 19 leks in the Pinedale Anticline Project Area (PAPA).

Study Area

The study area was south of Pinedale, WY, in the Pinedale Anticline Project Area (Figure 1). The 19 leks studied were in the Mesa, Duke's Triangle, and Yellowpoint complexes.

Methods

Definitions

The following are definitions of the primary acoustic terms used in this report. Additional definitions are provided in Appendix D.

> *A-Weighting (dBA)*: A-weighting is used to account for differences in human hearing sensitivity as a function of frequency. A-weighting de-emphasizes the high (6.3 kHz and above) and low (below 1 kHz) frequencies, and emphasizes the frequencies between 1 kHz and 6.3 kHz, in an effort to simulate the relative response of human hearing.
>
> *Decibel (dB)*: A logarithmic measure commonly used in the measurement of sound. The decibel provides the possibility of representing a large span of signal levels in a simple manner as opposed to using the basic pressure unit Pascal. The difference between the sound pressure of silence versus a loud sound is a factor of 1,000,000:1 or more, therefore it is less cumbersome to use a small range of equivalent values: 0 to 130 decibels.

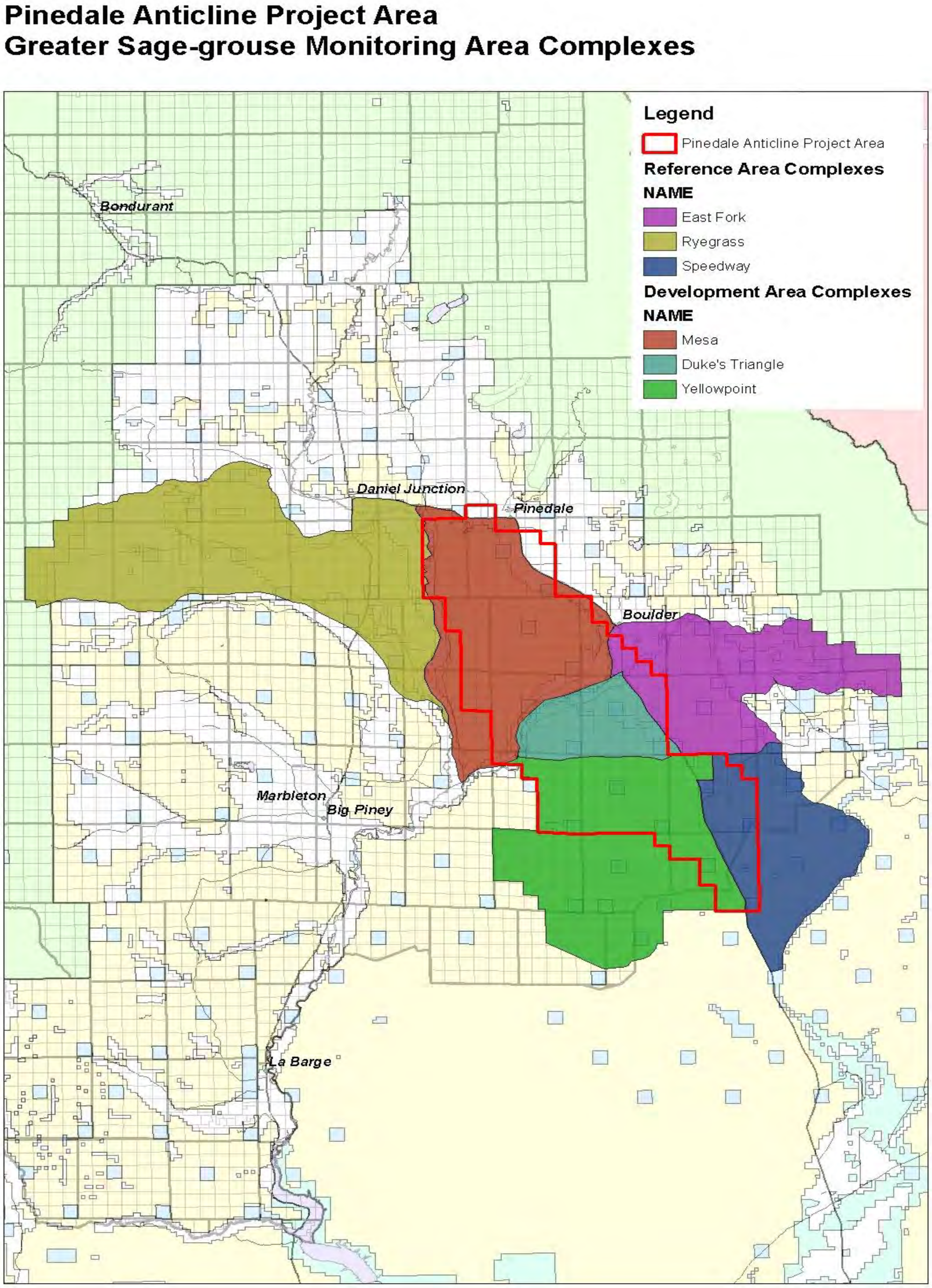

Figure 1. PAPA greater sage-grouse noise monitoring project area and lek complexes.

*L_{eq} (*Equivalent Sound Level): The logarithmic average (i.e., on an energy basis) of sound pressure levels over a specific time period. "Energy averaged" sound levels are logarithmic values, and as such are generally much higher than arithmetic averages. L_{eq} values are typically calculated for a specific time period (1-hour is commonly used). L_{eq} values are computed from all of the 1-second L_{eq} values for the specific time period. L_{eq} must be used carefully in quantifying natural ambient sound levels because occasional loud sound levels may heavily influence (increase) the L_{eq} value, even though sound levels for that period of time are typically lower.

L_x (Exceedance Percentile): This metric is the sound pressure level (L), in decibels, exceeded *x* percent of the time for the specified measurement period. L_{50} is the sound pressure level exceeded 50 percent of the time (L_{50} is the same as the median).

Noise Floor: The lower measurement limit of a sound level meter, also referred to as self-noise or electrical noise of all components of a sound level meter (meter, microphone, and preamplifier).

Sound Level, Baseline Ambient: The sound level in a given location including all sounds of nature but absent most human-caused sounds. L_{90} is the sound pressure level exceeded 90 percent of the time, and is commonly used to establish the baseline ambient sound level.

Sound Level, Existing Ambient: The sound level of all sounds in a given area, including all natural sounds as well as all mechanical, electrical and other human-caused sounds. The existing ambient sound level is generally characterized by the L_{50} exceedance level (i.e., the median).

Measurement Protocol

We followed "Procedures for Outdoor Measurement of Sound Pressure Level" (ANSI 1994) and acoustic measurement protocols developed for the Pinedale Anticline Project Office by Blickley and Patricelli (2012), "Noise monitoring recommendations for Greater Sage Grouse habitat in Wyoming." ANSI procedures recommend microphone heights of 1.2 m to 1.8 m but these were developed to assess noise impacts to humans. ANSI standards also state: "Other heights may be used if they prove to be more practicable or if they are specified in other pertinent standards" (ANSI 1994, Section 7.3.2.4). Several authors recommend that in wildlife acoustic studies, microphones be placed such that sound level measurements accurately reflect sound stimulus to which the target animal is exposed (Pater et al. 2009; Grubb et al. 1998, Delaney et al. 2009, Delaney et al. 2011; Blickley and Patricelli 2013). The approximate ear height of greater sage-grouse is 0.3 m (12"); therefore, microphones were placed 0.3 m above the ground. Standardizing microphone height at 0.3 m for acoustic studies relative to greater sage-grouse is consistent with flexibility and guidance provided by ANSI (1994, Section 7.3.2.4).

Wind can significantly influence sound level measurements in several ways. The sounds of wind through vegetation and rustling leaves are true sounds of nature and should be included in all analysis. The sound of wind against the foam windscreen is not a legitimate environmental sound, nor is the pressure change of wind across the diaphragm of the microphone. These wind-induced equipment sounds can significantly, and falsely, elevate sound levels. ANSI (S12.18-1994) standards suggest two methods to address wind influence on sound level data. Method 1 "General Method for Routine Measurements" requires omitting from analysis 1-second dB data when wind speed exceeds 5 m/s (11 mph). Method 2 "Precision Method for Accurate Measurements" requires omitting from analysis 1-second dB data when wind speed exceeds 3 m/s (6.7 mph). In separate Wyoming studies in 2013 and 2014, we collected wind speed data and sound level data at both 0.3 m and 1.5 m above ground. We found that wind speed very rarely exceeded 5 m/s or 3 m/s at our microphone height of 0.3 m. Wind commonly exceeded 5 m/s at 1.5 m at several locations (Ambrose, unpublished data). We calculated metrics with all seconds as well as with seconds that only included acoustic data during wind speed conditions less than 5 m/s. There was no difference in any metric due to the extreme rarity of elevated wind speed at 0.3 m; therefore we included all data in the analysis regardless of wind speed. Sound levels were often elevated due to wind sounds through vegetation, but these were actual environmental sounds and part of the acoustic environment of greater sage-grouse. We did not place anemometers at 1.5 m in the vicinity of the lek due to concern for potential negative impact on grouse presence and behavior at leks.

Instrumentation

We used two different sound level meters, a Larson-Davis 831 (4 each) and a Cesva SC310 (2 each). The Larson-Davis 831 meters used PCB 377B20 microphones, Larson-Davis PRM831 preamplifiers, and Larson-Davis EPS2106 Environmental Shrouds (foam windscreen and bird spike). The Cesva SC310 meters used Cesva PA13 preamplifiers and microphones. All acoustic equipment used for data collection (sound level meters, microphones, and preamplifiers) met or exceeded ANSI S1.4-1983 Type 1 standards. One-third octave band analyzers and dBA analyzers met ANSI S1.11-2004 and ANSI S1.42-2001, respectively. All acoustic equipment and field calibrators were calibrated to meet ANSI S1.40-2006 prior to deployment. All systems and calibrators were factory calibrated as recommended by the manufacturer, and all systems were field calibrated at the beginning and end of each measurement period at each location using a field calibrator that met ANSI S1.40-1984 standards. All system components (SLM, digital recorder, and anemometer) were synchronized with GPS time, and differences at the end of the measurement period noted. We used a Bruel and Kjaer (B&K) Acoustic Calibrator Type 4231 for field calibration.

We also collected continuous digital recordings at all measurement locations. We used Roland R05 digital recorders, and used the microphone output from the sound level meters for input to the R05 recorder. These recordings were used to review unusual sound events and to determine sound sources and the percent time that various sound sources were audible.

Sound level meters were set to collect 1-second dBA, dBF, and dBC, as well as unweighted one-third octave band data, 12.5-20,000 Hz. We expected sound levels at some locations to be very low (<15 dBA), so sound level meters were set to "low-range" with a gain of +20 dB. These settings ensured meters would collect data at the lowest measurement limit for these systems.

Figures 2 and 3 show typical deployment, with equipment case (sound level meter, recorder, and battery) and microphone with foam wind screen and bird spike.

Figure 2. Typical equipment deployment near lek, showing case (sound level meter, recorder, and battery) and microphone with foam windscreen and bird spike at 0.3 m above ground.

Figure 3. Typical equipment deployment near lek.

Data Analysis
In acoustic studies, it is common to report hourly L_{min}, L_{max}, L_{eq}, L_{10}, L_{50}, and L_{90} metrics. Two different methods have generally been used to compute hourly metrics. The first is referred to as the "unpooled" approach, and the second as the "pooled" approach. Both approaches report hourly statistics, but the computational methods differ. The "unpooled" approach computes metrics for each individual hour, and summary metrics for a given hour are the medians of all the hourly metrics for that hour. The "pooled" approach combines all 1-second data for a given hour (such as all 0800 hours) into a single data set, and averages, medians, variances, etc., are computed from the pooled data. Prior studies have shown that results for pooled analyses are generally more conservative (i.e., lower) than results for unpooled analysis (Plotkin 2002). However, many management decisions are based on specific periods of the day, and analyzing data by hour helps to ensure hour-to-hour and day-to-day variation is addressed. In the case of greater sage-grouse, for example, "lekking" hours often receive special consideration.

We used the unpooled approach and analyzed sound level data as follows. For every hour (3600 seconds of data), L_{min}, L_{max}, L_{eq}, L_{10}, L_{50}, and L_{90} were calculated. L_{min} and L_{max} were the minimum and maximum levels for that hour. L_{eq} was the energy average (a logarithmic average) of that hour. L_{10}, L_{50}, and L_{90} were levels exceeded 10%, 50%, and 90% of the time during that hour. All of our data sets were for multi-day periods, and summary hourly metrics for each site were calculated as follows. L_{min} and L_{max} were the minimum and maximum levels of all 0800 hours, all 0900 hours, all 1000 hours, etc., during the measurement period. Summary hourly and summary site metrics (L_{eq}, L_{10}, L_{50}, and L_{90}) for each hour of day (0800, 0900, 1000, etc.), were calculated using the median L_{eq}, L_{10}, L_{50}, and L_{90} of all 0800 hours, all 0900 hours, all 1000 hours, etc. The computation of dBA metrics included all data points regardless of wind speed due to the extreme rarity of wind speeds >5 m/s at 0.3 m (<0.02% of all seconds).

For each site, summary metrics for three time periods were calculated, all hours (0000-2400), daytime hours (0800-1800), and nighttime hours (1800-0800). The time period 1800-0800 is specified in the Wyoming Governor's Executive Order 2011-5 relative to greater sage-grouse and noise.

We compared sound levels at leks relative to distance to the closest pad in the PAPA. We considered only those pads with some type of current gas field activity. Such activities included drilling, assembly/disassembly of drill rig, compressor station, central gathering facility, well head and pump facilities, and injection wells (both alone and in association with well pump facilities. Some pads had off-site electricity, while others relied on on-site generators for power. Sound levels for each gas field activity varied. In addition to different types of activities at pads (and resulting different sound levels), attenuation factors varied at each lek (such factors include terrain, land cover, wind speed and direction, and meteorological conditions). Although activity type, distance, and attenuation factors varied at each lek and pad, sound level data collected at each lek represented actual acoustic conditions experienced by greater sage-grouse at that lek.

Measurement Locations

We collected acoustic data at 19 greater sage-grouse leks in the PAPA in April 2013 and 2014 (Table 1). All of the locations were in the Mesa, Duke's Triangle, and Yellowpoint complexes. For those leks where grouse had not been observed in recent years, we placed the sound level meters within or at the perimeter of the lek as defined by WGFD. For those leks where greater sage-grouse had been observed in recent years, we placed the sound level meters >250 m from the edge of the lek to ensure that grouse display sounds did not have a significant influence on dB data. In situations where the equipment was some distance from the lek, we placed the equipment such that the distance between the acoustic equipment and the primary gas field sound source was the same as the distance from the center of the lek and the primary sound source. Exact measurement locations are not provided in this report due to security concerns regarding lek locations. Map datum NAD83 was used for this project.

Measurement Schedule

All measurements were made in April 2013 and April 2014, the primary lekking period for greater sage-grouse in the PAPA area. Our goal was to collect a minimum of 48 hours at each lek in each year in order to account for variability in sound levels due to natural causes (meteorological conditions, birds singing near the equipment, etc.). Very short measurement periods of only a few hours could significantly over- or under-estimate actual long-term sound levels.

Results

Data Collection

Acoustic data were collected at 19 greater sage-grouse leks in the PAPA in April 2013 and 2014. A total of 2087 hours of acoustic data were collected (999 hours 2013 and 1088 in 2014) (Table 1). Mean number of hours at each lek was 53 hours in 2013 and 57 hours in 2014.

Sound Levels

L_{50} dBA values at leks in the PAPA ranged from 24.0 dBA to 36.9 dBA for all hours (0000-2400), and from 16.0 dBA to 38.5 dBA for nighttime hours (1800-0800) in 2013 and 2014. In general, sound levels at leks varied according to the distance and type of gas field activity. We provide examples of acoustic metrics (L_{min}, L_{max}, and L_{50}) at two leks that were different distances from pads in Figures 4 and 5. On lek (Big Fred, PAPA001) was 720 m (2360 ft) from a pad (with drill rig), and the other lek (Cat, PAPA015) was 3080 m (10,110 ft) from a pad (with well heads and pumps).

L_{50} dBA site summary metrics for three time periods (0000-2400, 0800-1800, and 1800-0800) for PAPA leks, April 2013 and 2014, are shown in Table 2. Hourly and summary dBA metrics and one-third octave band metrics for each lek for 2013 and 2014 year are presented in Appendices A, B, C, and D. At three locations, PAPA001, PAPA002, and PAPA017, activities at the nearest pads changed significantly from 2013 to 2014. As a results, sound levels at these locations changed significantly from 2013 to 2014.

Table 1. Measurement site number, lek name, date-time start, date-time end, and number of hours, PAPA, April 2013 and 2014.

Site Num.	Lek Name	Date_Time Start	Date_Time End	Hrs		Date_Time Start	Date_Time End	Hrs
PAPA001	Big Fred	20130405_1450	20130407_1520	47		20140412_1200	20140414_0820	43
PAPA002	Little Fred	20130405_1150	20130407_1235	47		20140412_1040	20140414_0935	45
PAPA003	Lower Sand Springs	20130405_1305	20130407_1645	50		20140416_1200	20140418_1355	48
PAPA004	Two Buttes	20130418_0910	20120421_1345	75		20140415_1010	20140417_0905	46
PAPA005	Mesa Spring	20130418_0950	20130421_1410	75		20140417_0955	20140420_0715	68
PAPA006	Lovatt Draw Res.	20130418_1025	20130421_1433	59		20140414_1150	20140416_0755	43
PAPA007	Shelter Cabin Res.	20130410_0855	20130412_1145	49		20140414_1530	20140416_1110	43
PAPA008	The Rocks	20130410_1015	20130412_1330	50		20140424_1625	20140430_1520	98
PAPA009	South Rocks	20130410_1115	20130412_1404	50		20140420_1040	20140424_1525	61
PAPA010	Stud Horse Butte	20130410_1200	20130412_1434	49		20140420_1108	20140424_1540	99
PAPA011	Little Saddle	20130412_0910	20130414_0910	47		20140410_1305	20140412_0920	18
PAPA012	Alkali Draw	20130412_1100	20130414_1020	46		20140411_1605	20140414_1350	68
PAPA013	Sand Draw	20130412_1245	20130414_1135	46		20140411_1715	20140414_1445	68
PAPA014	Lovatt West	20130418_1105	20130421_1456	75		20140414_1230	20140416_0820	43
PAPA015	Cat	20130421_1100	20130423_1300	49		20140410_1145	20140412_0820	44
PAPA016	Tyler Draw North	20130415_1000	20130417_0920	46		20140424_1815	20140501_0914	108
PAPA017	Oil Fork Road	20130415_1100	20130417_1005	46		20140416_0905	20140418_1605	54
PAPA018	Mesa Road 3	20130415_1145	20130417_1115	47		20140408_1010	20140410_0945	46
PAPA019	Bloom Res. Sat.	20130415_1230	20130417_1134	46		20140408_1055	20140410_1010	46

Table 2. L_{50} dBA at 19 PAPA leks, April 2013 and 2014, for three time periods (0000-2400, 0800-1800, and 1800-0800).

L50		0000-2400		0800-1800		1800-0800	
Site Num.	Lek Name	2013	2014	2013	2014	2013	2014
PAPA001*	Big Fred	36.9	27.1	32.9	28.0	39.1	26.6
PAPA002*	Little Fred	29.2	23.8	30.4	23.6	28.6	24.4
PAPA003	Lower Sand Springs	29.0	28.8	27.9	27.5	29.3	29.9
PAPA004	Two Buttes	26.4	25.4	28.1	26.3	26.1	25.2
PAPA005	Mesa Spring	29.9	27.0	30.6	23.9	29.9	28.3
PAPA006	Lovatt Draw Res.	32.1	31.3	31.1	31.9	32.8	31.4
PAPA007	Shelter Cabin Res.	26.6	26.9	29.2	27.9	24.1	26.4
PAPA008	The Rocks	26.3	26.5	29.5	29.6	24.3	23.6
PAPA009	South Rocks	26.2	24.7	29.0	24.1	25.2	25.1
PAPA010	Stud Horse Butte	27.3	29.7	29.7	29.7	26.7	29.4
PAPA011	Little Saddle	22.4	18.4	26.6	21.8	21.5	17.7
PAPA012	Alkali Draw	22.6	19.0	28.3	18.4	21.5	18.4
PAPA013	Sand Draw	27.3	25.1	33.3	21.6	25.4	25.8
PAPA014	Lovatt West	29.6	30.7	28.7	32.4	29.9	31.0
PAPA015	Cat	19.0	19.3	24.3	22.1	16.5	17.4
PAPA016	Tyler Draw North	21.5	24.5	23.7	29.8	20.6	20.3
PAPA017*	Oil Fork Road	24.8	28.8	24.4	26.2	25.1	31.5
PAPA018	Mesa Road 3	24.1	20.1	23.3	20.5	24.9	17.5
PAPA019	Bloom Res. Sat.	22.0	19.1	21.4	20.8	24.3	16.4

*Gas field activities at pads nearest these leks changed significantly from 2013 to 2014, thus sound levels changed also.

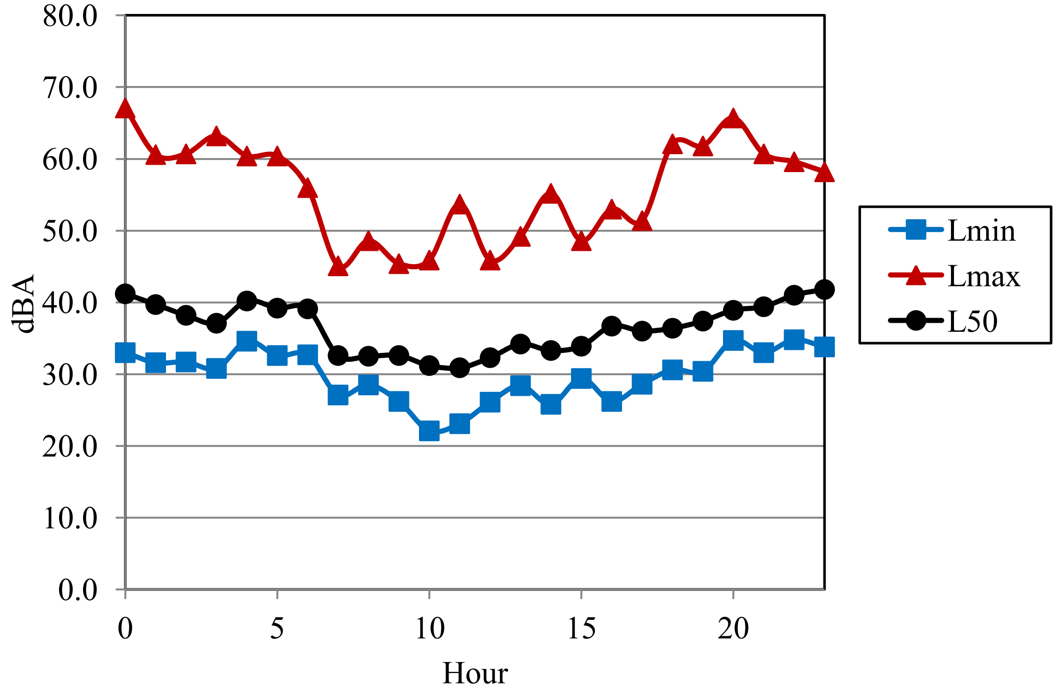

Figure 4. L_{min}, L_{max}, and L_{50}, PAPA001 (Big Fred Lek, close to pad), April 2013.

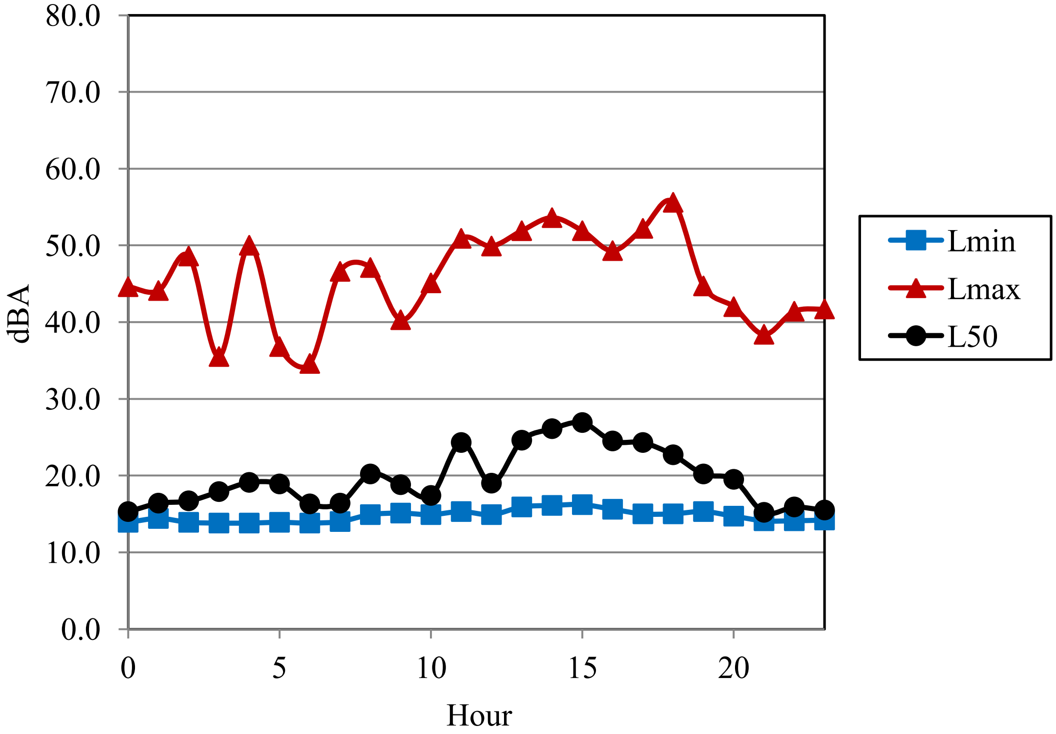

Figure 5. L_{min}, L_{max}, and L_{50}, PAPA015 (Cat Lek, far from pad), April 2013.

Discussion

Sound Levels at PAPA Leks, 2013 and 2014

Sound levels at each lek in the PAPA in 2013 were generally similar to sound levels at that same lek in 2014, with the exception of three locations where nearby gas field operations changed significantly. Excluding these three locations, the mean difference in L_{50} dBA from 2013 to 2014 for all hours (0000-2400) was 1.0 dBA (higher in 2013; SD=2.17 dBA). The mean difference in L_{50} dBA for nighttime hours (1800-0800) was 1.2 dBA (higher in 2013, SD 3.05 dBA).

At some leks, sound levels differed in 2013 and 2014 but gas field activity and distance had not changed. In these cases, we suspect the differences in sound levels were due to different meteorological conditions during the measurement period, primarily wind. Wind can elevate sound levels at leks in three ways: (1) wind on the foam wind screen and wind pressure on the microphone diaphragm; (2) wind through vegetation; and (3) wind direction (sound levels at leks downwind from gas field activities will be greater than those upwind). Wind speed at 0.3 m (microphone height) rarely exceeds 1-2 m, thus wind on the foam windscreen or microphone diaphragm is generally not a concern. The prevailing wind direction in the PAPA area in April is from the northwest (NOAA 2014), thus we would expect similar directional influences in most years. The primary influence of wind on dB data (when microphone is 0.3 m) is the sound of wind through the vegetation. In order to better assess changes in sound levels at leks (and to account for different meteorological conditions) and to minimize negative influence on grouse presence and behavior (no equipment >0.3 m), longer measurement periods should be considered.

Sound Levels and Distance to Pad

L_{50} dBA and distance to pad were highly correlated (2013: $R = -0.71$, $P = 0.001$; 2014: $R = -0.82$, $P < 0.000$) (Figures 6 and 7). Although sound levels at each pad varied due to the type of activity at that pad, and attenuation rates at each lek varied due to terrain and other variables, the closer the lek was to a pad with some type of activity, the higher the L_{50} dBA.

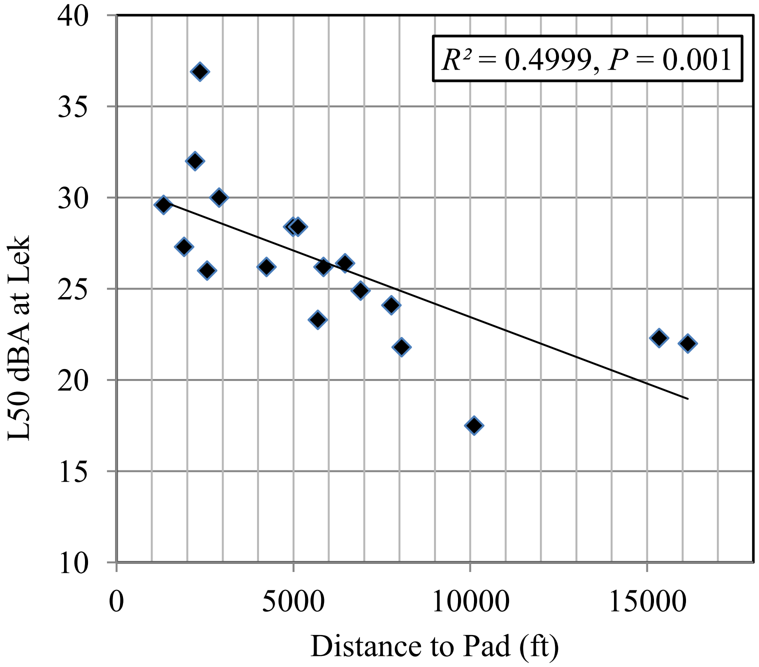

Figure 6. L_{50} dBA at leks relative to distance to pad with some type of gas field activity, PAPA, 2013.

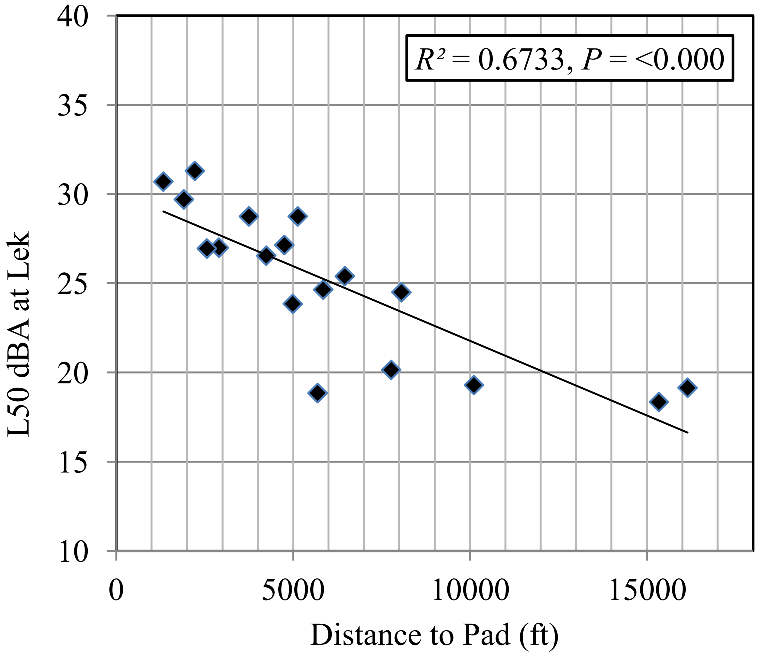

Figure 7. L_{50} dBA at leks relative to distance to pad with some type of gas field activity, PAPA, 2014.

Hours Exceeding Baseline Ambient + 10 dBA

The Record of Decision (ROD) (BLM 2008) specified noise thresholds above baseline levels that should not be exceeded by industry. Specific changes requiring mitigation are described as follows: “Decibel levels at the lek more than 10 dBA above baseline measured from the edge of the lek” (BLM 2008).” The ROD also specifies concurrent declines in grouse numbers, but that aspect was not part of this project. The ROD used 39 dBA as a baseline ambient based on an EPA 1971 study that measured sound levels in a farming area in California (EPA 1971). Of the 2087 hours measured at the PAPA leks in 2013 and 2014, no hours exceeded 49 dBA (39 + 10 = 49 dBA). However, results of recent acoustic studies in Wyoming demonstrate that 39 dBA is not an accurate baseline ambient sound level in undeveloped sage habitats of Wyoming (KC Harvey 2005; Patricelli et al. 2013; Ambrose et al. 2014).

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Appendix A. Definitions of Common Acoustic Terms.

Audibility: Audibility is the ability of animals with normal hearing, including humans, to hear a given sound. Audibility is affected by the hearing ability of the animal, other simultaneous interfering sounds or stimuli, and by the frequency content and amplitude of the sound.

A-Weighting (dBA): A-weighting is used to account for differences in human hearing sensitivity as a function of frequency. A-weighting de-emphasizes the high (6.3 kHz and above) and low (below 1 kHz) frequencies, and emphasizes the frequencies between 1 kHz and 6.3 kHz, in an effort to simulate the relative response of human hearing.

Decibel (dB): A logarithmic measure commonly used in the measurement of sound. The decibel provides the possibility of representing a large span of signal levels in a simple manner as opposed to using the basic pressure unit Pascal. The difference between the sound pressure of silence versus a loud sound is a factor of 1,000,000:1 or more, therefore it is less cumbersome to use a small range of equivalent values: 0 to 130 decibels.

Frequency: The number of times per second that the sine wave of sound repeats itself. It can be expressed in cycles per second, or Hertz (Hz). Frequency equals Speed of Sound / Wavelength.

L_{eq} *(*Equivalent Sound Level): The logarithmic average (i.e., on an energy basis) of sound pressure levels over a specific time period. “Energy averaged” sound levels are logarithmic values, and as such are generally much higher than arithmetic averages. L_{eq} values are typically calculated for a specific time period (1-hour and 12-hour time periods are often used). L_{eq} values are computed from all of the 1-second L_{eq} values for the specific time period. L_{eq} must be used carefully in quantifying natural ambient sound levels because occasional loud sound levels may heavily influence (increase) the L_{eq} value, even though sound levels for that period of time are typically lower.

L_{max}: The maximum sound pressure level for a given period.

L_{min}: The minimum sound pressure level for a given period.

L_x *(Exceedance Percentile)*: This metric is the sound pressure level (L), in decibels, exceeded *x* percent of the time for the specified measurement period. L_{50} is the sound pressure level exceeded 50 percent of the time (L_{50} is the same as the median).

Noise Floor: The lower measurement limit of a sound level meter, also referred to as self-noise or electrical noise of all components of a sound level meter (meter, microphone, and preamplifier).

Sound Level: Generally, *sound level* refers to the *weighted* sound pressure level obtained by frequency weighting, usually A- or C-weighted.

Sound Level, Baseline Ambient: The sound level in a given location including all sounds of nature but absent most human-caused sounds. L_{90} is the sound pressure level exceeded 90 percent of the time, and is commonly used to establish the baseline ambient sound level.

Sound Level, Existing Ambient: The sound level of all sounds in a given area, including all natural sounds as well as all mechanical, electrical and other human-caused sounds. The existing ambient sound level is generally characterized by the L_{50} exceedance level (i.e., the median).

Sound Pressure: Sound pressure is the instantaneous difference between the actual pressure produced by a sound wave and the average barometric pressure at a given point in space. Not all pressure fluctuations detected by a microphone are sound (e.g., wind over the microphone). Sound pressure is measured in Pascals (Pa), Newtons per square meter, which is the metric equivalent of pounds per square inch.

Sound Pressure Level (SPL): The logarithmic form of sound pressure. Generally, sound pressure level refers to unweighted sound pressure levels of one-third octave bands.

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Time Weighting: The response speed of a sound level meter. Fast and slow time response were developed primarily to slow needle movement in analog meters so investigators could read and record sound levels. This is not needed with modern digital sound level meters. Both fast and slow time response add a decay factor. Decay factors can induce some error, although over time there is little difference in fast, slow, or actual sound levels.

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA001	2013	0	33.0	67.1	42.6	44.0	41.2	36.6
PAPA001	2013	1	31.6	60.6	42.2	44.0	39.7	37.2
PAPA001	2013	2	31.7	60.7	41.0	43.6	38.2	35.8
PAPA001	2013	3	30.8	63.2	38.9	39.3	37.1	34.8
PAPA001	2013	4	34.6	60.4	41.8	44.4	40.2	37.1
PAPA001	2013	5	32.6	60.4	41.1	44.3	39.2	37.3
PAPA001	2013	6	32.7	56.0	40.2	42.0	39.1	36.2
PAPA001	2013	7	27.1	45.1	33.8	36.5	32.6	29.4
PAPA001	2013	8	28.5	48.6	33.4	34.9	32.5	31.0
PAPA001	2013	9	26.2	45.4	33.2	34.6	32.6	30.8
PAPA001	2013	10	22.1	45.9	32.3	34.2	31.2	28.6
PAPA001	2013	11	23.1	53.7	34.1	35.4	30.9	27.9
PAPA001	2013	12	26.1	45.9	33.4	35.5	32.3	29.3
PAPA001	2013	13	28.4	49.2	35.4	37.6	34.2	31.7
PAPA001	2013	14	25.8	55.2	36.0	37.8	33.3	29.3
PAPA001	2013	15	29.4	48.6	34.8	36.1	33.9	32.0
PAPA001	2013	16	26.2	53.0	38.1	40.9	36.7	33.8
PAPA001	2013	17	28.6	51.4	36.8	38.8	36.0	33.7
PAPA001	2013	18	30.6	62.1	37.5	39.2	36.4	34.4
PAPA001	2013	19	30.4	61.8	39.5	40.9	37.4	34.7
PAPA001	2013	20	34.7	65.7	41.0	41.9	38.9	37.1
PAPA001	2013	21	33.0	60.7	40.6	41.8	39.4	37.3
PAPA001	2013	22	34.8	59.6	42.0	43.6	41.0	39.3
PAPA001	2013	23	33.8	58.2	43.1	45.3	41.8	38.7
PAPA002	2013	0	20.6	47.7	29.2	31.4	27.6	25.1
PAPA002	2013	1	22.4	49.3	29.4	31.0	26.9	24.9
PAPA002	2013	2	23.9	52.1	32.0	34.5	30.5	26.0
PAPA002	2013	3	24.3	55.9	31.0	31.0	28.8	27.2
PAPA002	2013	4	25.6	48.4	31.4	33.2	29.8	27.4
PAPA002	2013	5	25.9	50.3	33.9	35.6	32.6	29.6
PAPA002	2013	6	26.0	46.3	32.4	34.1	31.1	29.1
PAPA002	2013	7	24.8	49.4	33.8	36.0	32.3	28.9
PAPA002	2013	8	24.6	55.7	34.7	36.8	32.4	29.2
PAPA002	2013	9	24.3	57.0	32.9	35.1	31.5	28.7
PAPA002	2013	10	21.2	46.6	30.2	32.9	27.8	25.0
PAPA002	2013	11	19.5	52.9	28.4	28.4	25.1	23.4
PAPA002	2013	12	20.1	39.6	25.7	27.4	23.5	21.7

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA002	2013	13	20.1	48.6	32.7	35.9	27.0	23.2
PAPA002	2013	14	21.9	49.2	32.0	34.6	29.7	25.8
PAPA002	2013	15	20.6	56.8	35.9	39.5	31.1	23.9
PAPA002	2013	16	19.5	60.2	37.5	39.1	33.8	29.1
PAPA002	2013	17	19.6	56.9	35.4	38.1	31.5	26.9
PAPA002	2013	18	19.1	55.6	34.9	37.8	32.5	26.4
PAPA002	2013	19	18.8	51.3	33.6	36.8	28.5	22.2
PAPA002	2013	20	20.9	51.4	28.6	29.7	25.8	23.6
PAPA002	2013	21	19.0	46.4	25.6	26.9	24.0	21.4
PAPA002	2013	22	19.2	41.7	26.0	28.1	24.1	21.9
PAPA002	2013	23	20.5	47.4	29.4	32.2	26.8	23.8
PAPA003	2013	0	21.5	49.0	32.3	35.0	29.6	26.5
PAPA003	2013	1	21.9	51.3	30.4	31.5	29.0	25.7
PAPA003	2013	2	22.5	47.8	32.5	35.1	30.8	26.8
PAPA003	2013	3	23.8	52.2	30.4	31.0	28.1	26.1
PAPA003	2013	4	25.0	49.6	32.9	34.4	31.6	27.5
PAPA003	2013	5	24.9	51.7	34.5	36.3	33.3	30.8
PAPA003	2013	6	26.9	50.5	33.5	34.7	32.3	30.9
PAPA003	2013	7	26.5	54.3	35.7	37.8	34.1	30.3
PAPA003	2013	8	28.1	59.1	36.6	38.3	34.5	31.9
PAPA003	2013	9	22.2	53.0	34.7	37.8	33.6	27.4
PAPA003	2013	10	18.6	50.5	27.6	29.3	26.2	22.7
PAPA003	2013	11	19.4	47.8	28.6	29.7	25.6	23.4
PAPA003	2013	12	19.9	48.7	28.7	31.5	24.8	22.1
PAPA003	2013	13	19.2	49.4	28.6	30.5	25.1	22.1
PAPA003	2013	14	19.2	48.6	30.9	32.9	28.9	24.9
PAPA003	2013	15	20.3	52.2	35.0	36.6	26.8	23.9
PAPA003	2013	16	19.4	52.7	32.9	35.6	30.5	26.2
PAPA003	2013	17	18.8	51.9	32.5	35.5	29.6	25.7
PAPA003	2013	18	19.4	53.5	33.4	35.9	30.5	25.6
PAPA003	2013	19	18.5	54.5	32.0	34.6	28.3	22.8
PAPA003	2013	20	22.7	51.4	30.5	31.6	28.1	25.7
PAPA003	2013	21	20.0	46.9	27.1	28.0	25.1	23.1
PAPA003	2013	22	17.4	43.3	27.0	28.7	25.5	22.1
PAPA003	2013	23	20.3	52.3	31.1	32.7	28.3	25.1
PAPA004	2013	0	18.0	41.1	26.6	30.6	24.9	23.7
PAPA004	2013	1	16.5	48.5	24.2	26.2	23.8	21.2
PAPA004	2013	2	16.1	39.8	28.0	30.3	26.8	24.5
PAPA004	2013	3	14.8	49.6	27.0	29.3	26.7	23.1

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA004	2013	4	15.0	43.6	26.6	29.4	25.5	22.2
PAPA004	2013	5	18.3	57.1	27.1	30.0	26.0	23.0
PAPA004	2013	6	17.0	43.1	27.8	29.7	27.2	23.5
PAPA004	2013	7	20.0	44.0	27.6	29.9	26.1	23.0
PAPA004	2013	8	16.8	52.4	29.9	28.5	22.6	19.8
PAPA004	2013	9	17.3	43.6	24.5	26.8	22.7	19.6
PAPA004	2013	10	17.2	52.1	23.9	24.5	21.2	19.6
PAPA004	2013	11	16.3	51.2	26.6	29.7	23.5	20.4
PAPA004	2013	12	19.8	49.2	30.4	33.8	27.2	23.0
PAPA004	2013	13	19.2	51.3	32.3	35.9	29.0	23.1
PAPA004	2013	14	19.7	54.9	35.0	38.0	31.4	25.4
PAPA004	2013	15	19.0	52.7	36.8	40.6	33.5	27.7
PAPA004	2013	16	19.1	52.8	36.0	39.5	32.7	26.3
PAPA004	2013	17	18.5	58.7	37.9	41.2	34.5	28.4
PAPA004	2013	18	16.6	52.8	37.4	41.0	33.5	27.7
PAPA004	2013	19	16.4	55.4	31.7	35.1	28.8	25.2
PAPA004	2013	20	16.4	61.5	28.9	30.5	28.1	26.1
PAPA004	2013	21	15.3	43.7	28.3	31.3	24.7	22.3
PAPA004	2013	22	14.6	50.7	27.3	29.6	24.2	21.1
PAPA004	2013	23	15.1	44.4	26.4	28.7	24.7	21.9
PAPA005	2013	0	22.2	53.6	32.4	34.4	31.8	30.0
PAPA005	2013	1	21.7	50.5	28.3	30.9	27.6	24.1
PAPA005	2013	2	21.4	45.3	30.9	34.4	29.3	26.7
PAPA005	2013	3	19.7	47.1	30.1	32.5	29.2	26.8
PAPA005	2013	4	18.3	46.4	30.7	33.2	29.8	27.5
PAPA005	2013	5	22.9	45.7	30.5	32.4	29.3	27.2
PAPA005	2013	6	21.8	45.5	31.9	32.8	29.3	25.0
PAPA005	2013	7	21.1	44.0	29.9	32.8	28.3	24.3
PAPA005	2013	8	20.4	50.9	31.7	33.9	29.2	26.5
PAPA005	2013	9	20.1	45.7	30.2	33.6	27.7	23.7
PAPA005	2013	10	20.5	51.9	28.6	30.8	27.5	24.7
PAPA005	2013	11	17.2	51.6	28.3	30.1	26.2	23.8
PAPA005	2013	12	20.1	62.2	34.9	35.7	29.9	26.7
PAPA005	2013	13	21.4	56.8	35.4	38.6	31.4	27.0
PAPA005	2013	14	22.8	63.6	37.4	41.0	34.5	28.4
PAPA005	2013	15	22.3	66.6	40.0	42.5	35.6	28.9
PAPA005	2013	16	23.6	57.1	39.5	42.8	36.9	31.6
PAPA005	2013	17	21.6	60.2	41.9	45.4	39.4	33.7
PAPA005	2013	18	21.2	54.5	41.0	44.5	37.9	32.9

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA005	2013	19	22.5	52.5	35.5	38.9	32.8	29.4
PAPA005	2013	20	22.9	51.0	36.7	39.7	34.7	28.6
PAPA005	2013	21	18.3	43.8	31.2	33.0	30.3	28.6
PAPA005	2013	22	18.1	50.3	31.0	32.1	29.9	28.4
PAPA005	2013	23	17.4	53.7	30.9	32.4	30.6	28.8
PAPA006	2013	0	22.0	49.8	31.8	33.2	30.3	27.6
PAPA006	2013	1	25.7	45.1	32.0	33.8	31.2	29.0
PAPA006	2013	2	27.9	47.1	33.8	35.7	32.9	31.2
PAPA006	2013	3	27.0	41.4	33.5	35.6	32.9	30.6
PAPA006	2013	4	29.5	42.0	34.0	35.8	33.4	31.7
PAPA006	2013	5	28.7	52.6	33.5	34.8	32.7	30.9
PAPA006	2013	6	31.4	60.4	47.5	52.9	37.3	33.4
PAPA006	2013	7	28.4	54.4	35.7	37.0	34.4	32.5
PAPA006	2013	8	26.8	53.0	33.7	35.2	31.1	28.8
PAPA006	2013	9	25.4	47.7	30.6	32.6	29.4	27.7
PAPA006	2013	10	24.8	46.6	31.1	32.6	29.8	28.0
PAPA006	2013	11	23.2	50.9	32.2	34.0	30.2	28.2
PAPA006	2013	12	23.8	60.6	34.8	35.2	31.0	28.1
PAPA006	2013	13	25.1	58.0	33.3	36.1	31.2	28.6
PAPA006	2013	14	25.1	50.7	34.6	37.3	33.0	29.8
PAPA006	2013	15	24.8	55.5	37.3	41.1	33.9	29.9
PAPA006	2013	16	23.7	55.4	35.8	38.7	34.1	31.4
PAPA006	2013	17	23.2	54.9	36.6	39.5	34.8	30.7
PAPA006	2013	18	22.6	52.9	36.4	39.4	35.0	31.5
PAPA006	2013	19	22.4	54.2	31.2	33.7	29.8	27.1
PAPA006	2013	20	25.0	51.3	31.5	33.8	31.5	26.9
PAPA006	2013	21	24.6	47.0	33.8	35.6	33.2	31.4
PAPA006	2013	22	23.7	45.9	32.1	33.6	30.1	28.1
PAPA006	2013	23	21.4	51.6	31.2	32.9	28.7	26.1
PAPA007	2013	0	18.1	38.6	23.1	24.4	21.8	20.1
PAPA007	2013	1	18.0	32.8	23.0	24.9	22.6	20.3
PAPA007	2013	2	17.1	40.5	24.1	25.2	22.0	20.6
PAPA007	2013	3	18.3	39.2	23.2	24.9	22.7	20.7
PAPA007	2013	4	17.9	39.1	23.5	25.4	22.6	20.9
PAPA007	2013	5	19.4	44.0	25.8	27.6	24.3	22.1
PAPA007	2013	6	21.8	38.5	27.6	29.6	26.9	24.7
PAPA007	2013	7	22.3	46.2	27.3	28.8	26.1	24.3
PAPA007	2013	8	19.5	49.3	28.1	30.2	26.3	23.4
PAPA007	2013	9	18.6	48.9	30.4	33.1	25.5	22.4

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA007	2013	10	19.7	52.0	32.4	35.8	29.7	24.5
PAPA007	2013	11	22.1	52.8	33.1	34.8	29.9	26.0
PAPA007	2013	12	21.7	73.2	39.4	34.0	29.4	25.8
PAPA007	2013	13	21.4	50.8	30.6	33.6	28.5	24.6
PAPA007	2013	14	20.9	47.7	30.9	33.8	28.5	24.7
PAPA007	2013	15	21.4	50.8	31.6	34.6	29.0	25.5
PAPA007	2013	16	19.6	50.0	34.6	38.4	30.7	25.3
PAPA007	2013	17	20.4	49.1	34.8	38.3	31.6	26.3
PAPA007	2013	18	23.1	54.3	37.5	41.1	34.8	29.8
PAPA007	2013	19	19.5	50.0	34.2	37.6	31.5	26.7
PAPA007	2013	20	20.8	49.6	31.1	34.0	28.8	25.6
PAPA007	2013	21	20.0	44.1	27.2	29.6	25.8	23.6
PAPA007	2013	22	20.2	45.0	26.3	28.7	24.0	22.1
PAPA007	2013	23	20.4	36.7	24.0	25.9	23.2	21.9
PAPA008	2013	0	19.7	36.5	23.7	25.0	22.5	21.1
PAPA008	2013	1	20.4	34.5	24.3	25.9	23.6	21.9
PAPA008	2013	2	19.5	46.0	25.2	26.6	23.9	22.4
PAPA008	2013	3	19.5	36.2	24.5	25.8	24.0	22.4
PAPA008	2013	4	18.8	34.7	23.7	25.7	22.8	21.1
PAPA008	2013	5	20.2	36.7	24.5	26.2	23.8	22.0
PAPA008	2013	6	21.3	51.5	26.9	28.4	25.2	23.3
PAPA008	2013	7	21.2	43.8	27.3	29.3	26.1	24.1
PAPA008	2013	8	19.2	53.6	29.2	30.2	25.6	23.5
PAPA008	2013	9	18.9	50.9	29.9	31.7	26.5	23.5
PAPA008	2013	10	20.9	47.1	32.9	36.0	30.8	26.2
PAPA008	2013	11	19.2	49.5	28.9	32.3	26.5	25.1
PAPA008	2013	12	18.0	64.5	35.9	31.3	26.5	25.0
PAPA008	2013	13	22.4	49.8	31.6	34.4	29.9	25.8
PAPA008	2013	14	20.5	52.6	31.7	34.2	30.0	26.4
PAPA008	2013	15	21.5	47.6	31.3	34.2	29.1	25.5
PAPA008	2013	16	22.3	49.0	33.4	36.9	30.7	26.4
PAPA008	2013	17	22.9	47.6	35.0	38.2	32.7	27.8
PAPA008	2013	18	21.2	49.6	36.0	39.5	33.8	27.9
PAPA008	2013	19	22.4	51.7	35.2	38.5	33.1	28.1
PAPA008	2013	20	21.5	49.9	32.6	35.8	30.3	26.3
PAPA008	2013	21	20.9	42.9	25.9	28.2	24.8	22.8
PAPA008	2013	22	21.2	38.6	26.2	28.6	24.7	23.1
PAPA008	2013	23	20.3	35.2	24.2	25.8	23.5	22.3
PAPA009	2013	0	18.6	34.8	24.2	26.6	23.1	21.0

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA009	2013	1	17.2	40.1	25.2	27.6	23.8	22.1
PAPA009	2013	2	17.6	49.2	26.1	27.8	25.2	23.4
PAPA009	2013	3	18.1	38.8	26.2	29.0	24.9	22.2
PAPA009	2013	4	19.4	33.6	25.0	27.1	24.3	22.1
PAPA009	2013	5	21.6	32.9	25.9	28.0	25.3	23.3
PAPA009	2013	6	21.5	39.8	25.4	26.9	25.1	23.5
PAPA009	2013	7	21.8	44.6	27.1	28.6	26.3	24.4
PAPA009	2013	8	18.7	46.2	28.7	30.5	26.2	23.0
PAPA009	2013	9	18.8	47.6	30.0	32.3	26.6	23.9
PAPA009	2013	10	19.9	47.6	31.9	35.1	29.8	25.6
PAPA009	2013	11	19.6	50.4	31.2	34.6	28.7	24.6
PAPA009	2013	12	18.2	59.0	34.1	30.0	23.5	22.1
PAPA009	2013	13	18.4	54.2	30.4	32.9	26.2	23.3
PAPA009	2013	14	22.1	47.3	31.0	33.6	29.5	26.1
PAPA009	2013	15	21.5	47.7	31.3	33.9	29.4	25.9
PAPA009	2013	16	23.5	49.6	32.5	35.6	30.0	26.1
PAPA009	2013	17	22.9	48.3	33.8	37.1	31.5	27.3
PAPA009	2013	18	22.3	48.7	35.0	38.2	33.1	28.2
PAPA009	2013	19	22.1	52.1	33.2	36.2	31.1	27.1
PAPA009	2013	20	21.6	45.0	31.4	34.3	29.8	27.0
PAPA009	2013	21	20.8	38.7	26.1	28.3	25.0	23.1
PAPA009	2013	22	21.6	37.0	26.3	28.3	25.5	23.6
PAPA009	2013	23	20.0	39.8	26.7	28.6	25.7	23.7
PAPA010	2013	0	19.5	36.7	24.6	26.6	23.4	21.9
PAPA010	2013	1	18.9	40.1	27.1	29.8	25.8	23.2
PAPA010	2013	2	19.7	50.0	28.8	31.5	26.5	24.1
PAPA010	2013	3	18.1	42.0	27.1	29.8	25.8	22.6
PAPA010	2013	4	20.4	36.2	25.9	27.9	25.0	23.0
PAPA010	2013	5	21.5	37.4	27.6	29.4	27.1	25.4
PAPA010	2013	6	22.6	40.1	29.3	31.2	28.1	26.2
PAPA010	2013	7	22.9	43.4	27.5	29.3	26.7	25.1
PAPA010	2013	8	19.0	46.0	29.7	31.5	26.6	23.1
PAPA010	2013	9	19.4	48.5	31.1	33.7	27.6	24.3
PAPA010	2013	10	20.1	60.3	34.1	36.3	30.3	25.7
PAPA010	2013	11	19.8	51.6	31.9	35.3	29.2	24.8
PAPA010	2013	12	19.1	49.9	32.5	35.9	29.4	25.2
PAPA010	2013	13	19.9	52.0	30.0	33.0	26.6	23.5
PAPA010	2013	14	23.1	50.8	32.1	34.6	30.3	26.9
PAPA010	2013	15	22.6	50.4	31.9	34.4	30.1	26.8

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA010	2013	16	22.4	50.6	33.5	36.8	31.0	27.2
PAPA010	2013	17	22.8	51.7	34.5	37.8	31.9	27.7
PAPA010	2013	18	24.5	50.0	36.2	39.4	34.1	29.5
PAPA010	2013	19	22.5	53.8	33.0	35.9	29.9	26.3
PAPA010	2013	20	22.7	48.9	31.2	34.0	29.2	26.5
PAPA010	2013	21	22.1	42.4	28.3	31.0	26.7	24.6
PAPA010	2013	22	22.7	36.6	27.6	29.5	26.9	25.1
PAPA010	2013	23	20.8	39.4	26.9	28.6	25.8	24.2
PAPA011	2013	0	15.3	39.0	20.2	21.8	19.4	17.8
PAPA011	2013	1	16.0	38.6	21.5	23.5	20.4	18.0
PAPA011	2013	2	16.0	36.9	21.1	23.2	19.8	18.1
PAPA011	2013	3	16.0	41.8	22.4	24.4	21.2	19.3
PAPA011	2013	4	15.8	42.7	23.6	25.7	22.1	20.1
PAPA011	2013	5	16.0	40.0	26.5	30.5	23.4	19.5
PAPA011	2013	6	17.2	44.1	28.4	32.3	25.0	19.9
PAPA011	2013	7	16.8	39.5	24.6	27.6	21.7	19.2
PAPA011	2013	8	17.7	48.9	27.2	29.3	22.3	20.0
PAPA011	2013	9	17.1	49.5	28.1	28.1	21.0	18.7
PAPA011	2013	10	17.8	57.4	30.2	32.2	26.8	22.7
PAPA011	2013	11	16.6	51.6	29.0	31.9	25.9	21.9
PAPA011	2013	12	16.5	50.6	32.1	34.2	27.2	22.6
PAPA011	2013	13	16.8	54.7	35.3	38.8	32.7	26.9
PAPA011	2013	14	16.5	49.2	30.0	33.5	27.3	23.2
PAPA011	2013	15	16.6	51.0	32.0	35.3	29.1	23.9
PAPA011	2013	16	16.1	48.8	30.3	33.5	26.5	20.7
PAPA011	2013	17	16.0	51.3	26.2	28.0	21.6	18.1
PAPA011	2013	18	15.5	54.2	27.1	28.3	22.5	19.1
PAPA011	2013	19	15.1	47.2	23.9	25.2	19.8	17.4
PAPA011	2013	20	14.9	50.5	26.2	27.3	21.4	17.9
PAPA011	2013	21	15.3	50.9	25.4	28.0	23.2	20.1
PAPA011	2013	22	15.2	46.2	23.4	25.6	21.3	18.7
PAPA011	2013	23	15.1	44.0	24.3	26.9	22.7	18.1
PAPA012	2013	0	16.0	36.0	21.6	23.5	20.7	19.0
PAPA012	2013	1	18.4	44.2	23.4	24.9	21.6	19.9
PAPA012	2013	2	16.7	39.7	22.4	24.4	21.2	19.7
PAPA012	2013	3	16.7	40.5	22.6	24.3	21.2	19.7
PAPA012	2013	4	16.1	42.0	23.2	25.1	21.3	19.4
PAPA012	2013	5	17.3	44.0	24.1	27.2	21.8	20.0
PAPA012	2013	6	19.2	41.0	27.5	30.0	26.1	22.7

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA012	2013	7	18.0	59.5	27.9	28.7	24.3	21.7
PAPA012	2013	8	19.0	48.9	28.6	31.2	24.5	21.6
PAPA012	2013	9	17.4	50.6	29.1	31.5	26.0	21.6
PAPA012	2013	10	17.6	65.5	37.3	33.9	27.1	21.4
PAPA012	2013	11	19.8	47.0	33.1	36.7	29.8	23.7
PAPA012	2013	12	17.1	49.0	32.2	35.8	28.6	22.6
PAPA012	2013	13	17.0	53.2	35.5	39.2	31.7	25.2
PAPA012	2013	14	16.9	54.5	33.0	36.7	29.8	24.9
PAPA012	2013	15	16.7	57.0	34.1	37.8	30.1	24.0
PAPA012	2013	16	16.6	51.2	32.2	35.5	28.1	22.4
PAPA012	2013	17	15.6	47.0	26.2	29.3	22.1	18.1
PAPA012	2013	18	14.7	49.8	27.0	28.3	21.9	18.6
PAPA012	2013	19	14.6	41.7	23.5	25.9	19.6	17.7
PAPA012	2013	20	15.4	38.2	22.6	25.0	19.7	17.9
PAPA012	2013	21	15.2	46.7	25.4	28.0	23.0	19.7
PAPA012	2013	22	15.2	43.1	23.7	25.9	21.9	19.2
PAPA012	2013	23	15.1	38.9	22.0	24.1	20.6	18.4
PAPA013	2013	0	18.5	36.7	25.5	27.6	24.7	22.2
PAPA013	2013	1	16.7	36.9	25.8	27.6	24.9	21.6
PAPA013	2013	2	17.2	39.1	27.2	29.5	25.8	23.8
PAPA013	2013	3	19.2	41.6	30.0	32.7	28.4	25.6
PAPA013	2013	4	18.7	42.2	29.3	31.7	27.5	25.2
PAPA013	2013	5	17.8	38.7	24.9	27.4	23.9	21.0
PAPA013	2013	6	17.7	53.6	24.8	25.3	22.5	20.3
PAPA013	2013	7	19.1	63.1	31.0	25.8	23.6	21.2
PAPA013	2013	8	19.8	75.0	39.4	32.3	26.5	23.2
PAPA013	2013	9	20.3	50.5	32.3	35.5	29.9	25.1
PAPA013	2013	10	21.4	51.6	37.7	41.2	35.0	29.3
PAPA013	2013	11	24.8	49.0	37.8	41.6	35.1	29.5
PAPA013	2013	12	24.5	51.7	38.8	42.5	36.3	30.3
PAPA013	2013	13	19.6	53.7	36.6	40.2	33.0	27.4
PAPA013	2013	14	21.3	56.3	37.1	40.6	34.3	29.4
PAPA013	2013	15	18.6	56.2	36.8	40.2	33.6	28.8
PAPA013	2013	16	18.6	57.1	36.2	38.9	30.9	24.4
PAPA013	2013	17	18.2	48.6	29.1	32.4	24.7	20.4
PAPA013	2013	18	17.4	44.4	28.6	31.6	24.9	20.5
PAPA013	2013	19	17.5	39.8	25.8	28.5	23.6	21.2
PAPA013	2013	20	20.6	47.1	28.1	30.4	26.6	23.7
PAPA013	2013	21	23.2	53.8	31.7	34.2	29.9	26.6

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA013	2013	22	22.6	47.4	30.9	33.4	29.3	26.3
PAPA013	2013	23	19.4	45.5	28.8	31.9	27.1	23.1
PAPA014	2013	0	19.8	36.4	29.7	30.7	29.5	28.5
PAPA014	2013	1	24.9	38.9	31.4	33.0	30.2	27.3
PAPA014	2013	2	23.7	41.6	30.7	32.0	30.5	28.9
PAPA014	2013	3	25.9	42.4	29.0	30.0	28.9	27.7
PAPA014	2013	4	25.6	43.1	30.8	33.3	29.7	27.3
PAPA014	2013	5	27.0	46.7	33.0	35.3	32.6	29.7
PAPA014	2013	6	27.6	43.6	31.1	32.5	30.9	29.6
PAPA014	2013	7	23.1	43.7	31.3	33.9	30.2	28.4
PAPA014	2013	8	21.0	52.4	31.1	32.4	28.0	24.1
PAPA014	2013	9	19.8	48.7	26.4	28.7	24.8	22.6
PAPA014	2013	10	19.0	58.0	28.6	28.4	25.4	23.1
PAPA014	2013	11	19.6	47.0	30.4	33.3	26.9	23.3
PAPA014	2013	12	19.8	56.8	32.0	34.6	28.2	23.9
PAPA014	2013	13	19.9	58.3	33.2	36.2	29.3	24.9
PAPA014	2013	14	19.8	49.3	33.3	36.8	30.6	25.4
PAPA014	2013	15	20.9	55.0	37.2	40.8	31.9	25.0
PAPA014	2013	16	21.1	59.5	36.8	40.2	34.7	28.9
PAPA014	2013	17	20.5	55.0	37.0	40.1	34.8	29.8
PAPA014	2013	18	19.9	50.9	35.4	38.9	33.2	27.8
PAPA014	2013	19	20.0	52.6	30.2	33.6	28.4	24.5
PAPA014	2013	20	21.6	51.5	29.9	30.6	28.9	24.5
PAPA014	2013	21	22.6	44.2	29.1	30.8	29.2	27.1
PAPA014	2013	22	23.7	44.7	32.4	36.5	30.0	27.0
PAPA014	2013	23	21.2	38.7	29.8	31.8	29.1	27.2
PAPA015	2013	0	13.9	44.6	19.3	17.2	15.3	14.6
PAPA015	2013	1	14.4	44.1	21.8	22.3	16.4	15.3
PAPA015	2013	2	13.9	48.6	21.5	23.8	16.7	14.9
PAPA015	2013	3	13.8	35.5	19.1	21.3	17.9	15.1
PAPA015	2013	4	13.8	50.0	26.3	22.6	19.1	17.8
PAPA015	2013	5	13.9	36.8	20.2	22.2	18.9	17.2
PAPA015	2013	6	13.8	34.6	17.5	19.1	16.3	15.2
PAPA015	2013	7	14.0	46.6	20.5	20.7	16.4	14.7
PAPA015	2013	8	14.9	47.1	23.4	25.7	20.2	17.0
PAPA015	2013	9	15.1	40.3	22.0	24.8	18.8	16.3
PAPA015	2013	10	14.9	45.1	23.5	26.9	17.4	15.7
PAPA015	2013	11	15.3	50.9	29.0	32.7	24.3	19.5
PAPA015	2013	12	14.9	49.9	29.4	24.8	19.0	17.2

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA015	2013	13	15.9	51.9	30.0	32.5	24.6	20.2
PAPA015	2013	14	16.1	53.6	30.8	33.9	26.1	20.1
PAPA015	2013	15	16.2	51.9	31.3	34.6	26.9	20.7
PAPA015	2013	16	15.6	49.3	28.3	32.1	24.5	19.1
PAPA015	2013	17	15.0	52.2	32.4	33.8	24.3	18.6
PAPA015	2013	18	15.0	55.6	27.4	30.4	22.7	17.1
PAPA015	2013	19	15.3	44.7	23.6	26.2	20.2	16.8
PAPA015	2013	20	14.7	42.0	25.1	26.7	19.5	16.3
PAPA015	2013	21	14.1	38.4	19.2	20.3	15.2	14.4
PAPA015	2013	22	14.1	41.4	20.5	19.5	15.9	14.9
PAPA015	2013	23	14.2	41.7	19.4	17.0	15.5	14.8
PAPA016	2013	0	15.7	32.7	20.1	22.2	19.0	17.6
PAPA016	2013	1	16.6	57.3	27.2	23.5	20.5	18.5
PAPA016	2013	2	14.9	31.6	20.6	22.3	20.2	17.9
PAPA016	2013	3	14.4	45.3	25.6	22.6	20.5	19.3
PAPA016	2013	4	14.3	38.1	23.6	23.4	21.6	20.6
PAPA016	2013	5	14.3	41.4	22.6	24.8	21.3	19.8
PAPA016	2013	6	15.7	45.3	24.9	25.9	22.7	20.8
PAPA016	2013	7	18.6	41.1	25.5	27.6	24.5	21.9
PAPA016	2013	8	20.3	43.3	29.8	32.1	28.0	24.4
PAPA016	2013	9	22.1	41.8	27.8	29.5	26.1	24.3
PAPA016	2013	10	22.0	39.4	27.5	29.7	26.5	24.4
PAPA016	2013	11	15.2	43.5	24.0	24.5	19.4	17.6
PAPA016	2013	12	15.4	45.1	25.9	28.0	19.6	16.3
PAPA016	2013	13	15.3	54.7	27.6	29.9	19.1	16.2
PAPA016	2013	14	16.0	43.4	25.8	28.0	22.3	18.7
PAPA016	2013	15	16.0	42.2	27.6	31.4	23.9	18.9
PAPA016	2013	16	16.5	46.1	29.0	32.7	25.5	19.7
PAPA016	2013	17	15.7	53.6	28.5	30.9	23.6	18.6
PAPA016	2013	18	14.9	48.9	27.0	29.1	22.7	17.1
PAPA016	2013	19	14.8	48.9	27.6	30.2	22.9	19.2
PAPA016	2013	20	14.5	40.6	22.1	24.4	19.7	17.7
PAPA016	2013	21	14.3	42.3	23.5	26.0	20.6	19.1
PAPA016	2013	22	14.7	38.5	21.8	24.7	19.5	17.1
PAPA016	2013	23	14.7	40.4	23.3	26.2	20.3	17.4
PAPA017	2013	0	20.3	37.0	25.4	27.4	24.7	22.6
PAPA017	2013	1	19.3	53.6	27.1	27.7	25.3	22.9
PAPA017	2013	2	18.1	37.5	24.1	26.0	23.6	21.3
PAPA017	2013	3	17.4	42.6	26.9	28.9	23.6	22.0

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA017	2013	4	15.2	46.5	27.1	28.5	24.6	22.9
PAPA017	2013	5	15.2	54.3	28.8	31.1	27.3	23.8
PAPA017	2013	6	17.5	50.1	32.3	33.1	29.7	26.9
PAPA017	2013	7	18.5	40.8	25.3	27.5	24.5	21.9
PAPA017	2013	8	18.6	47.0	27.7	29.6	25.4	22.3
PAPA017	2013	9	17.8	40.8	27.9	30.7	26.5	22.8
PAPA017	2013	10	19.7	52.4	28.1	31.3	24.4	21.9
PAPA017	2013	11	19.2	27.5	21.7	23.1	21.3	20.3
PAPA017	2013	12	18.0	43.7	26.8	29.3	23.7	20.5
PAPA017	2013	13	19.0	58.2	28.7	29.5	23.7	21.3
PAPA017	2013	14	19.4	44.1	26.6	28.2	24.4	22.3
PAPA017	2013	15	19.4	42.1	27.1	30.0	24.3	21.9
PAPA017	2013	16	19.5	45.4	27.6	30.5	25.4	22.6
PAPA017	2013	17	19.3	56.7	29.0	30.3	25.4	22.9
PAPA017	2013	18	18.1	47.7	28.0	30.6	26.3	23.5
PAPA017	2013	19	18.7	49.4	29.4	31.9	27.3	24.5
PAPA017	2013	20	18.9	50.4	27.3	28.9	26.6	24.4
PAPA017	2013	21	17.6	47.7	27.7	29.4	27.0	23.9
PAPA017	2013	22	16.4	36.2	25.2	27.2	24.7	22.6
PAPA017	2013	23	18.3	36.0	25.7	27.9	24.9	22.1
PAPA018	2013	0	16.2	35.7	26.4	30.1	24.2	20.2
PAPA018	2013	1	21.6	47.6	28.2	30.2	27.0	25.0
PAPA018	2013	2	22.4	36.7	28.8	31.0	28.2	25.5
PAPA018	2013	3	19.0	40.6	28.1	29.4	27.2	25.3
PAPA018	2013	4	14.9	48.5	28.8	30.5	25.4	23.3
PAPA018	2013	5	14.4	50.7	26.9	30.5	24.5	23.0
PAPA018	2013	6	19.6	49.2	31.7	34.7	29.9	26.3
PAPA018	2013	7	19.2	45.3	30.2	33.3	28.2	23.2
PAPA018	2013	8	16.7	46.5	25.7	27.6	22.5	20.1
PAPA018	2013	9	17.4	50.1	26.8	29.7	24.3	19.7
PAPA018	2013	10	17.4	42.2	26.4	29.7	23.3	19.8
PAPA018	2013	11	18.0	34.6	21.7	23.4	20.8	19.6
PAPA018	2013	12	16.4	44.4	27.8	31.2	23.6	19.3
PAPA018	2013	13	16.5	59.1	29.2	29.3	23.1	19.3
PAPA018	2013	14	17.1	45.2	26.6	29.7	23.4	19.7
PAPA018	2013	15	17.3	56.7	30.6	31.4	23.5	19.8
PAPA018	2013	16	16.9	42.6	26.2	29.5	23.1	19.5
PAPA018	2013	17	16.8	49.8	28.2	31.9	24.1	19.6
PAPA018	2013	18	15.3	49.3	29.9	33.4	25.8	22.2

Appendix B. Hourly dBA Metrics, PAPA Leks, April 2013.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA018	2013	19	15.1	47.7	27.2	30.1	24.1	20.1
PAPA018	2013	20	15.6	37.0	23.3	25.9	21.1	18.4
PAPA018	2013	21	14.5	61.4	27.9	25.2	21.8	18.0
PAPA018	2013	22	15.2	35.9	22.5	24.7	21.5	20.0
PAPA018	2013	23	14.8	40.0	25.0	27.7	24.4	19.2
PAPA019	2013	0	15.1	37.4	23.0	25.6	21.5	17.9
PAPA019	2013	1	18.7	42.5	27.5	29.9	25.9	23.1
PAPA019	2013	2	20.6	38.2	24.7	26.1	24.2	23.0
PAPA019	2013	3	23.0	43.1	29.5	32.3	27.8	25.5
PAPA019	2013	4	19.2	44.4	28.8	30.1	27.9	25.6
PAPA019	2013	5	16.2	60.1	26.9	26.0	23.4	21.8
PAPA019	2013	6	20.6	37.7	25.8	27.4	25.3	23.8
PAPA019	2013	7	18.5	39.3	25.2	27.5	24.4	21.3
PAPA019	2013	8	15.6	43.7	23.7	24.5	20.3	18.4
PAPA019	2013	9	16.5	38.5	23.4	26.4	21.5	18.0
PAPA019	2013	10	16.1	41.0	24.7	27.6	21.4	18.2
PAPA019	2013	11	15.9	36.1	18.9	20.5	17.9	16.8
PAPA019	2013	12	15.5	42.0	22.2	24.7	19.2	16.6
PAPA019	2013	13	15.7	55.9	28.1	27.6	21.2	17.5
PAPA019	2013	14	16.2	43.1	24.9	27.7	21.4	17.6
PAPA019	2013	15	15.5	52.2	29.8	32.3	22.5	17.9
PAPA019	2013	16	15.6	47.1	26.6	30.2	23.1	18.6
PAPA019	2013	17	16.6	51.8	30.6	34.3	26.2	20.5
PAPA019	2013	18	15.7	53.1	28.5	32.0	26.1	22.2
PAPA019	2013	19	15.9	48.4	26.9	30.1	24.3	19.3
PAPA019	2013	20	14.9	53.8	24.0	26.2	19.7	17.5
PAPA019	2013	21	16.0	61.2	29.7	26.2	21.0	17.9
PAPA019	2013	22	14.7	35.4	19.0	21.0	17.4	15.5
PAPA019	2013	23	14.9	29.3	20.0	22.2	19.4	16.7

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA001	2014	0	22.0	51.8	29.4	28.2	25.6	24.2
PAPA001	2014	1	22.9	37.9	26.7	28.0	26.2	24.9
PAPA001	2014	2	23.0	47.3	27.9	28.8	26.5	25.0
PAPA001	2014	3	23.0	44.6	27.7	29.1	26.6	24.8
PAPA001	2014	4	21.1	49.4	28.0	30.1	26.8	24.8
PAPA001	2014	5	21.0	38.0	26.8	28.6	26.3	24.6
PAPA001	2014	6	20.9	41.0	26.2	28.0	25.6	23.7
PAPA001	2014	7	20.6	42.7	26.4	28.2	25.6	23.6
PAPA001	2014	8	25.4	43.2	33.0	35.5	32.1	28.7
PAPA001	2014	9	24.0	40.8	31.7	34.3	31.0	27.7
PAPA001	2014	10	22.7	44.1	33.1	36.2	31.0	27.0
PAPA001	2014	11	21.9	40.4	29.6	32.1	28.7	25.2
PAPA001	2014	12	21.6	55.6	30.7	31.9	27.7	24.8
PAPA001	2014	13	22.3	53.2	28.5	31.0	26.7	24.5
PAPA001	2014	14	22.0	54.7	30.7	31.7	28.0	24.8
PAPA001	2014	15	20.6	52.3	32.7	35.0	30.6	26.9
PAPA001	2014	16	20.7	46.7	30.9	33.3	30.1	27.2
PAPA001	2014	17	20.7	42.6	29.1	31.5	28.3	25.8
PAPA001	2014	18	20.7	45.2	28.1	30.0	27.0	24.7
PAPA001	2014	19	21.4	54.2	30.6	30.2	27.1	25.1
PAPA001	2014	20	20.7	47.8	29.3	30.1	27.2	25.2
PAPA001	2014	21	20.5	46.7	30.5	31.2	28.0	26.2
PAPA001	2014	22	21.2	52.4	31.1	30.7	28.0	25.5
PAPA001	2014	23	22.2	47.8	27.6	28.6	26.3	24.7
PAPA002	2014	0	22.3	58.8	31.5	29.1	26.9	25.2
PAPA002	2014	1	21.9	45.0	28.0	29.6	27.0	24.9
PAPA002	2014	2	21.7	44.8	26.8	27.0	24.9	23.6
PAPA002	2014	3	21.8	50.7	28.9	30.4	25.6	24.0
PAPA002	2014	4	21.0	51.1	28.4	30.5	26.8	24.8
PAPA002	2014	5	20.7	45.8	26.1	27.6	25.3	24.1
PAPA002	2014	6	20.7	40.8	24.5	26.0	23.8	22.1
PAPA002	2014	7	20.8	45.0	23.0	23.6	22.4	21.7
PAPA002	2014	8	21.0	40.8	24.0	25.2	22.7	21.8
PAPA002	2014	9	20.3	40.1	25.8	27.5	23.9	21.7
PAPA002	2014	10	20.1	45.6	29.4	31.4	23.4	21.0
PAPA002	2014	11	20.5	62.6	32.8	29.9	23.6	21.2
PAPA002	2014	12	20.7	53.2	31.4	32.4	23.4	22.1
PAPA002	2014	13	20.6	46.2	29.0	31.1	24.2	22.5

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA002	2014	14	20.4	56.7	30.0	28.7	23.5	22.1
PAPA002	2014	15	20.3	53.8	32.6	34.6	28.5	23.9
PAPA002	2014	16	20.6	52.2	30.3	33.2	27.8	24.0
PAPA002	2014	17	20.5	46.6	25.4	27.4	23.1	21.7
PAPA002	2014	18	20.4	41.8	25.5	28.1	22.7	21.2
PAPA002	2014	19	20.6	51.0	28.2	28.6	23.6	22.1
PAPA002	2014	20	19.9	46.1	26.4	26.3	23.2	22.0
PAPA002	2014	21	19.9	48.4	27.0	29.1	23.6	21.6
PAPA002	2014	22	20.8	47.5	26.0	26.9	23.9	22.5
PAPA002	2014	23	21.6	47.8	28.1	29.4	26.6	24.5
PAPA003	2014	0	25.9	49.5	31.7	33.2	30.8	29.0
PAPA003	2014	1	22.2	48.7	31.0	34.2	28.7	26.0
PAPA003	2014	2	20.4	51.3	30.0	32.3	28.8	26.5
PAPA003	2014	3	22.2	43.1	29.9	31.8	28.3	26.6
PAPA003	2014	4	21.8	44.5	31.7	33.3	30.9	29.0
PAPA003	2014	5	22.8	47.0	32.2	34.5	31.4	29.0
PAPA003	2014	6	26.5	42.6	33.7	35.8	33.1	30.6
PAPA003	2014	7	29.1	43.9	33.2	34.7	32.9	31.2
PAPA003	2014	8	25.5	45.9	31.3	33.3	30.6	28.2
PAPA003	2014	9	20.2	43.3	29.2	31.2	27.9	25.1
PAPA003	2014	10	20.1	47.2	28.1	30.1	25.8	23.9
PAPA003	2014	11	21.8	58.1	33.9	36.8	30.7	26.2
PAPA003	2014	12	20.4	62.1	35.8	37.3	31.9	28.0
PAPA003	2014	13	21.6	59.8	32.0	33.3	27.5	24.6
PAPA003	2014	14	20.7	53.6	31.7	32.4	26.9	23.7
PAPA003	2014	15	20.0	53.0	30.8	31.3	25.8	23.5
PAPA003	2014	16	20.6	49.7	29.8	31.3	26.1	23.2
PAPA003	2014	17	20.9	46.9	28.9	31.1	26.4	23.8
PAPA003	2014	18	19.0	56.3	28.3	28.9	24.7	22.1
PAPA003	2014	19	19.2	47.3	27.4	29.0	25.2	22.1
PAPA003	2014	20	22.9	48.3	29.4	30.7	28.4	26.5
PAPA003	2014	21	20.6	46.1	30.2	31.7	29.2	25.7
PAPA003	2014	22	19.7	50.8	31.9	34.5	30.6	26.3
PAPA003	2014	23	26.5	48.2	32.5	34.3	32.0	29.9
PAPA004	2014	0	16.5	37.6	23.4	26.1	22.2	18.6
PAPA004	2014	1	17.1	39.8	22.9	25.4	21.1	18.8
PAPA004	2014	2	18.8	35.8	24.5	26.7	23.9	20.6
PAPA004	2014	3	18.9	39.2	25.4	28.1	23.8	21.4
PAPA004	2014	4	17.3	43.6	27.4	29.6	25.6	22.3
PAPA004	2014	5	15.6	37.0	26.1	28.3	25.3	22.9

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA004	2014	6	16.9	55.9	27.7	28.5	25.5	23.4
PAPA004	2014	7	17.1	43.9	27.7	29.0	25.2	23.4
PAPA004	2014	8	19.6	70.5	37.5	32.4	27.4	25.0
PAPA004	2014	9	17.7	64.9	40.0	29.6	21.2	18.9
PAPA004	2014	10	16.6	51.4	28.9	31.0	22.4	18.4
PAPA004	2014	11	17.1	62.1	33.9	28.4	23.6	20.4
PAPA004	2014	12	17.8	45.4	27.7	30.5	23.9	20.2
PAPA004	2014	13	19.7	56.0	34.4	32.0	27.1	23.4
PAPA004	2014	14	19.7	53.8	35.0	38.7	31.4	24.2
PAPA004	2014	15	19.1	56.9	36.1	39.7	32.9	27.3
PAPA004	2014	16	18.7	57.4	36.4	40.2	32.0	25.1
PAPA004	2014	17	18.7	55.9	34.9	38.5	31.6	26.0
PAPA004	2014	18	17.4	47.5	31.1	34.5	27.6	22.8
PAPA004	2014	19	16.6	54.5	31.9	34.3	26.3	22.7
PAPA004	2014	20	16.4	59.3	32.8	35.1	28.3	24.7
PAPA004	2014	21	17.5	52.8	30.2	32.1	26.2	20.6
PAPA004	2014	22	15.1	37.9	24.0	25.6	21.4	18.9
PAPA004	2014	23	15.6	40.9	21.7	23.3	20.2	18.6
PAPA005	2014	0	21.3	36.2	28.3	30.6	27.8	25.2
PAPA005	2014	1	20.1	39.1	29.1	30.9	28.6	27.2
PAPA005	2014	2	18.9	40.6	31.3	33.4	30.7	28.9
PAPA005	2014	3	19.9	40.3	32.6	34.1	32.4	29.2
PAPA005	2014	4	18.9	43.9	32.3	34.7	31.1	29.4
PAPA005	2014	5	19.9	49.2	34.8	35.8	32.2	30.1
PAPA005	2014	6	21.3	48.2	32.5	34.1	31.6	30.0
PAPA005	2014	7	23.7	43.8	33.5	35.0	33.0	30.9
PAPA005	2014	8	21.3	55.4	35.4	37.1	33.3	28.4
PAPA005	2014	9	19.1	53.6	31.2	32.4	29.7	27.5
PAPA005	2014	10	18.4	66.5	36.2	30.7	26.1	23.5
PAPA005	2014	11	19.5	57.6	24.1	25.8	22.6	21.4
PAPA005	2014	12	19.8	57.0	34.8	30.9	23.5	22.2
PAPA005	2014	13	20.1	56.4	31.3	29.2	23.9	22.1
PAPA005	2014	14	19.7	62.8	33.1	30.1	23.6	22.0
PAPA005	2014	15	19.7	57.0	30.7	33.4	27.2	22.8
PAPA005	2014	16	18.4	61.7	35.5	33.8	26.8	23.1
PAPA005	2014	17	18.3	47.4	29.0	29.4	24.5	21.4
PAPA005	2014	18	18.1	53.1	30.3	27.2	22.8	20.9
PAPA005	2014	19	17.7	55.2	31.4	24.3	21.3	19.7
PAPA005	2014	20	18.0	56.3	34.1	36.6	22.1	20.3
PAPA005	2014	21	17.7	42.4	25.1	25.8	21.7	20.2

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA005	2014	22	18.9	38.3	25.7	28.0	24.8	22.3
PAPA005	2014	23	20.6	38.2	29.7	33.0	27.9	25.4
PAPA006	2014	0	27.2	48.5	31.9	33.6	31.3	29.7
PAPA006	2014	1	26.1	48.1	32.3	34.2	31.5	29.8
PAPA006	2014	2	27.0	47.0	31.7	33.1	31.0	29.6
PAPA006	2014	3	26.6	43.7	30.9	32.0	30.7	29.5
PAPA006	2014	4	27.8	40.9	31.4	32.7	31.1	29.9
PAPA006	2014	5	28.9	48.0	33.2	34.9	32.3	30.5
PAPA006	2014	6	28.4	41.8	33.3	34.7	32.9	31.5
PAPA006	2014	7	27.3	41.5	31.7	33.5	31.3	29.2
PAPA006	2014	8	25.3	50.7	32.3	33.4	30.1	27.0
PAPA006	2014	9	23.5	47.1	30.8	32.3	29.0	25.5
PAPA006	2014	10	23.5	67.3	46.6	29.4	25.7	24.6
PAPA006	2014	11	23.2	37.8	26.5	28.0	25.5	24.4
PAPA006	2014	12	23.7	68.2	37.2	28.2	25.4	24.5
PAPA006	2014	13	23.1	68.3	35.0	30.5	25.5	24.3
PAPA006	2014	14	24.1	60.3	36.1	38.1	33.3	29.9
PAPA006	2014	15	23.6	64.3	36.7	39.0	34.2	30.2
PAPA006	2014	16	23.2	63.7	37.7	39.9	33.8	29.7
PAPA006	2014	17	23.3	57.4	34.9	37.7	32.7	28.8
PAPA006	2014	18	24.8	56.6	34.6	37.0	31.1	28.3
PAPA006	2014	19	25.4	59.8	36.6	39.3	33.5	29.5
PAPA006	2014	20	27.8	59.6	37.7	40.3	35.0	30.9
PAPA006	2014	21	26.9	55.0	35.3	37.8	33.4	30.3
PAPA006	2014	22	28.0	47.6	32.9	34.2	31.9	30.2
PAPA006	2014	23	28.1	42.8	31.5	32.8	31.0	29.9
PAPA007	2014	0	18.2	39.5	25.0	27.1	24.1	22.1
PAPA007	2014	1	18.8	43.3	25.0	26.7	24.5	22.7
PAPA007	2014	2	20.4	47.0	27.0	28.7	25.3	23.1
PAPA007	2014	3	20.3	42.4	26.0	27.8	25.3	23.2
PAPA007	2014	4	20.9	39.6	27.4	29.6	26.7	23.6
PAPA007	2014	5	20.4	41.3	26.8	28.9	25.5	23.8
PAPA007	2014	6	23.7	59.7	32.1	32.5	28.3	26.1
PAPA007	2014	7	22.1	57.8	33.7	32.0	27.2	25.3
PAPA007	2014	8	20.7	66.7	38.2	33.4	28.3	25.2
PAPA007	2014	9	20.2	61.5	32.0	31.3	26.2	23.2
PAPA007	2014	10	20.1	68.3	34.0	31.2	25.3	22.4
PAPA007	2014	11	19.8	57.1	28.8	29.1	23.6	21.3
PAPA007	2014	12	18.6	65.9	40.0	31.9	25.0	21.3
PAPA007	2014	13	20.7	55.5	40.6	44.6	37.5	24.0

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA007	2014	14	28.8	58.9	43.7	47.3	41.0	35.4
PAPA007	2014	15	29.6	59.6	43.6	47.1	41.2	35.5
PAPA007	2014	16	21.8	58.6	39.0	37.1	32.7	29.0
PAPA007	2014	17	20.4	60.6	35.3	37.4	32.6	28.4
PAPA007	2014	18	19.0	59.2	34.3	36.8	32.5	29.0
PAPA007	2014	19	20.6	53.6	32.8	35.3	27.9	24.4
PAPA007	2014	20	22.7	53.3	33.5	36.6	31.0	26.6
PAPA007	2014	21	21.0	48.6	29.5	31.5	27.8	25.3
PAPA007	2014	22	20.1	47.5	28.4	31.0	26.1	23.5
PAPA007	2014	23	17.3	41.7	24.9	27.0	23.9	21.6
PAPA008	2014	0	18.6	42.0	23.0	24.2	21.5	20.5
PAPA008	2014	1	18.0	48.9	23.8	25.3	22.7	21.2
PAPA008	2014	2	17.9	45.5	25.7	27.9	24.3	22.3
PAPA008	2014	3	18.3	42.8	26.0	28.2	24.7	22.5
PAPA008	2014	4	19.1	43.6	26.7	28.7	25.1	22.7
PAPA008	2014	5	19.7	50.7	33.7	37.4	28.7	23.5
PAPA008	2014	6	18.9	49.2	27.6	29.4	25.7	23.6
PAPA008	2014	7	20.5	49.0	28.7	31.1	27.4	24.3
PAPA008	2014	8	19.2	52.0	31.5	34.2	29.5	26.0
PAPA008	2014	9	20.1	54.5	33.5	37.0	29.9	25.3
PAPA008	2014	10	17.9	58.0	32.8	35.9	30.2	25.9
PAPA008	2014	11	17.1	58.3	32.9	35.8	30.9	26.1
PAPA008	2014	12	17.0	59.0	35.1	36.8	29.6	25.3
PAPA008	2014	13	17.1	58.6	37.1	40.8	34.2	27.6
PAPA008	2014	14	16.4	58.3	38.1	40.6	33.6	27.2
PAPA008	2014	15	17.1	60.0	35.2	38.7	32.0	26.6
PAPA008	2014	16	15.7	60.3	41.6	45.2	38.8	32.5
PAPA008	2014	17	15.4	58.5	32.8	36.7	29.5	22.6
PAPA008	2014	18	15.5	59.3	23.1	25.2	20.4	18.2
PAPA008	2014	19	16.2	53.0	28.0	28.7	23.1	20.2
PAPA008	2014	20	17.0	51.1	31.9	36.2	22.1	19.3
PAPA008	2014	21	16.7	45.1	25.9	28.1	23.7	20.7
PAPA008	2014	22	16.2	41.8	25.1	27.0	23.5	20.6
PAPA008	2014	23	19.4	39.5	24.0	25.4	23.1	21.7
PAPA009	2014	0	19.1	32.6	24.6	26.2	24.4	22.6
PAPA009	2014	1	18.3	35.7	24.5	26.6	23.7	21.7
PAPA009	2014	2	18.4	36.6	25.3	27.2	24.8	23.0
PAPA009	2014	3	17.6	38.0	26.7	29.3	25.6	23.0
PAPA009	2014	4	19.5	40.4	29.0	31.9	27.3	24.4
PAPA009	2014	5	24.8	46.7	31.4	33.5	29.7	27.8

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA009	2014	6	23.5	42.8	30.6	33.7	28.5	26.3
PAPA009	2014	7	20.5	34.8	27.3	28.8	26.8	25.2
PAPA009	2014	8	17.0	40.7	27.0	29.5	25.7	23.0
PAPA009	2014	9	15.7	53.1	25.9	26.9	24.1	22.7
PAPA009	2014	10	16.8	45.4	24.3	25.3	22.5	20.8
PAPA009	2014	11	16.3	46.2	24.0	27.0	21.2	18.2
PAPA009	2014	12	16.9	55.3	30.7	31.4	22.9	19.6
PAPA009	2014	13	17.7	56.5	30.6	30.9	22.9	19.8
PAPA009	2014	14	17.6	62.5	29.7	33.8	25.9	20.6
PAPA009	2014	15	16.7	48.6	26.9	29.9	24.3	19.6
PAPA009	2014	16	17.0	65.4	32.3	35.9	29.1	22.7
PAPA009	2014	17	15.6	53.9	32.1	35.6	28.5	22.6
PAPA009	2014	18	15.9	54.8	28.5	31.9	26.0	21.1
PAPA009	2014	19	15.2	51.1	25.6	29.0	21.4	18.6
PAPA009	2014	20	15.9	60.7	27.5	30.2	25.4	21.3
PAPA009	2014	21	17.3	58.5	24.9	26.4	24.1	22.8
PAPA009	2014	22	17.9	55.2	23.6	25.5	23.0	21.1
PAPA009	2014	23	17.8	46.0	24.6	26.5	24.5	21.6
PAPA010	2014	0	20.6	47.0	30.1	32.0	29.5	25.3
PAPA010	2014	1	18.8	39.0	28.7	31.1	27.4	25.1
PAPA010	2014	2	18.4	39.6	28.2	30.3	27.1	23.2
PAPA010	2014	3	20.6	42.8	29.3	32.4	27.9	24.7
PAPA010	2014	4	20.7	44.0	30.8	33.4	29.5	26.7
PAPA010	2014	5	23.7	49.0	33.1	36.3	31.3	27.9
PAPA010	2014	6	20.3	42.8	31.2	33.4	30.3	28.6
PAPA010	2014	7	22.6	39.9	31.3	33.6	30.6	28.2
PAPA010	2014	8	19.9	42.7	32.2	35.9	30.2	26.4
PAPA010	2014	9	19.3	51.1	32.5	35.0	30.8	27.3
PAPA010	2014	10	19.7	58.1	33.1	35.9	30.0	25.1
PAPA010	2014	11	19.3	94.0	35.4	37.1	31.2	25.4
PAPA010	2014	12	20.5	62.2	37.2	37.7	31.7	25.5
PAPA010	2014	13	20.7	70.4	37.9	37.5	32.6	27.5
PAPA010	2014	14	20.0	55.9	33.4	36.7	30.3	25.0
PAPA010	2014	15	18.9	56.4	32.8	35.7	27.6	23.1
PAPA010	2014	16	19.0	61.5	36.4	39.6	29.8	24.0
PAPA010	2014	17	17.8	53.7	32.5	36.0	29.4	24.7
PAPA010	2014	18	17.4	58.2	30.2	33.7	27.5	22.4
PAPA010	2014	19	16.8	53.4	29.5	32.3	26.8	23.5
PAPA010	2014	20	17.6	45.5	29.9	32.9	29.0	21.8
PAPA010	2014	21	18.6	51.8	30.4	32.7	29.7	27.0

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA010	2014	22	18.7	56.5	30.6	33.7	29.4	25.8
PAPA010	2014	23	19.5	50.2	30.8	32.8	29.7	26.4
PAPA011	2014	0	16.2	45.7	25.9	21.2	17.7	17.0
PAPA011	2014	1	15.7	35.0	17.4	18.1	17.2	16.2
PAPA011	2014	2	16.1	40.6	20.1	17.8	17.0	16.5
PAPA011	2014	3	16.1	45.4	31.2	36.4	17.6	16.8
PAPA011	2014	4	15.3	40.7	19.6	17.7	16.7	15.9
PAPA011	2014	5	15.8	44.1	26.3	29.7	18.3	16.5
PAPA011	2014	6	18.1	50.5	34.7	38.6	29.1	21.5
PAPA011	2014	7	18.1	53.1	36.3	39.4	24.0	20.0
PAPA011	2014	8	NA	NA	NA	NA	NA	NA
PAPA011	2014	9	NA	NA	NA	NA	NA	NA
PAPA011	2014	10	NA	NA	NA	NA	NA	NA
PAPA011	2014	11	NA	NA	NA	NA	NA	NA
PAPA011	2014	12	NA	NA	NA	NA	NA	NA
PAPA011	2014	13	NA	NA	NA	NA	NA	NA
PAPA011	2014	14	16.9	59.2	35.4	36.7	28.6	21.1
PAPA011	2014	15	16.8	75.9	55.5	37.9	26.4	19.3
PAPA011	2014	16	16.7	60.4	31.6	33.3	25.9	19.8
PAPA011	2014	17	16.5	59.6	32.7	32.1	25.5	20.4
PAPA011	2014	18	16.9	66.4	45.0	31.4	23.9	19.4
PAPA011	2014	19	15.1	53.4	32.3	29.1	19.6	15.9
PAPA011	2014	20	15.0	48.7	21.5	21.2	16.3	15.4
PAPA011	2014	21	15.1	33.5	17.7	18.5	16.5	15.7
PAPA011	2014	22	15.1	47.1	24.3	19.7	17.5	15.6
PAPA011	2014	23	16.8	37.1	19.3	20.3	18.4	17.5
PAPA012	2014	0	14.9	50.6	22.4	19.4	17.9	16.9
PAPA012	2014	1	14.4	55.2	21.9	23.7	17.7	16.1
PAPA012	2014	2	14.6	39.5	20.5	23.3	17.8	15.5
PAPA012	2014	3	14.2	47.6	20.9	22.9	19.3	17.5
PAPA012	2014	4	14.5	44.5	21.9	23.8	21.1	18.5
PAPA012	2014	5	15.3	42.3	24.4	27.2	23.2	19.3
PAPA012	2014	6	15.2	71.6	25.9	28.5	24.0	21.5
PAPA012	2014	7	15.1	63.3	25.4	27.3	22.5	18.9
PAPA012	2014	8	15.0	51.0	29.3	29.9	21.4	17.2
PAPA012	2014	9	15.3	64.2	27.5	29.0	17.3	16.2
PAPA012	2014	10	14.9	54.3	27.3	26.7	17.3	16.4
PAPA012	2014	11	15.2	45.9	22.2	21.4	18.3	16.5
PAPA012	2014	12	15.2	56.8	27.3	25.0	18.4	16.6
PAPA012	2014	13	15.9	59.8	31.4	29.1	22.1	18.6

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA012	2014	14	15.4	51.7	32.2	32.0	24.8	19.0
PAPA012	2014	15	15.6	49.5	27.8	31.8	23.3	18.5
PAPA012	2014	16	14.5	53.7	28.0	29.4	23.1	19.2
PAPA012	2014	17	14.2	66.3	26.2	29.5	23.0	18.4
PAPA012	2014	18	14.4	68.8	24.5	23.6	18.1	16.1
PAPA012	2014	19	14.7	47.7	24.3	23.8	19.7	17.8
PAPA012	2014	20	14.3	46.5	22.9	18.5	16.3	15.1
PAPA012	2014	21	14.5	41.2	21.2	22.8	18.0	16.6
PAPA012	2014	22	14.2	61.3	22.2	23.2	17.1	15.8
PAPA012	2014	23	14.7	44.0	23.8	21.0	18.7	16.3
PAPA013	2014	0	22.0	44.8	29.1	31.4	27.6	24.5
PAPA013	2014	1	20.4	38.5	27.1	29.0	26.7	24.7
PAPA013	2014	2	20.8	43.3	29.7	32.5	28.8	25.8
PAPA013	2014	3	16.7	50.5	27.2	30.1	25.9	23.7
PAPA013	2014	4	16.7	40.7	29.1	31.3	27.8	25.5
PAPA013	2014	5	17.3	41.2	28.1	30.4	27.0	23.8
PAPA013	2014	6	17.3	48.0	29.3	30.8	27.4	24.7
PAPA013	2014	7	15.7	70.9	42.1	30.1	25.7	24.2
PAPA013	2014	8	15.2	60.5	33.0	31.0	24.8	19.3
PAPA013	2014	9	15.2	53.6	27.6	27.3	20.1	17.4
PAPA013	2014	10	15.7	54.7	26.6	24.8	17.7	16.8
PAPA013	2014	11	16.7	65.8	21.4	22.3	19.5	18.0
PAPA013	2014	12	16.8	66.4	26.8	26.1	21.8	20.0
PAPA013	2014	13	16.6	51.1	25.8	27.1	23.5	21.6
PAPA013	2014	14	16.3	52.7	31.8	32.9	25.9	21.4
PAPA013	2014	15	16.2	52.6	29.2	32.2	26.6	22.1
PAPA013	2014	16	15.9	56.5	29.1	31.3	25.7	21.5
PAPA013	2014	17	15.1	50.3	27.4	28.6	22.3	17.7
PAPA013	2014	18	14.5	59.9	23.1	25.1	18.9	16.5
PAPA013	2014	19	14.3	46.8	22.4	24.8	20.4	18.2
PAPA013	2014	20	14.9	52.9	29.4	28.8	21.6	17.3
PAPA013	2014	21	15.8	45.4	23.0	24.6	19.9	17.7
PAPA013	2014	22	16.8	65.1	27.6	26.2	21.4	19.2
PAPA013	2014	23	18.0	45.8	28.7	31.0	25.4	21.8
PAPA014	2014	0	25.1	39.7	29.7	31.5	29.1	26.8
PAPA014	2014	1	24.7	37.4	28.6	30.2	28.3	26.6
PAPA014	2014	2	24.5	39.4	28.3	29.7	28.0	26.5
PAPA014	2014	3	24.9	41.3	30.1	31.8	29.6	27.1
PAPA014	2014	4	26.3	40.4	32.0	33.4	31.7	30.3
PAPA014	2014	5	25.8	43.4	32.7	34.8	31.9	29.7

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA014	2014	6	27.2	44.0	30.9	32.5	30.4	28.9
PAPA014	2014	7	26.6	43.6	34.0	36.7	33.1	30.0
PAPA014	2014	8	27.3	43.4	32.1	34.7	31.0	28.6
PAPA014	2014	9	23.3	41.5	28.4	30.1	27.7	25.0
PAPA014	2014	10	21.0	30.4	25.0	26.9	25.2	21.5
PAPA014	2014	11	21.0	34.0	22.6	23.7	22.0	21.4
PAPA014	2014	12	21.3	38.7	24.2	26.1	22.9	21.9
PAPA014	2014	13	21.3	59.2	32.0	34.6	23.0	22.1
PAPA014	2014	14	22.4	60.0	36.7	38.5	35.4	31.7
PAPA014	2014	15	21.6	63.7	36.5	38.7	35.2	30.1
PAPA014	2014	16	21.9	65.2	39.8	40.0	35.6	30.9
PAPA014	2014	17	21.9	61.6	35.6	37.9	34.5	30.5
PAPA014	2014	18	21.8	62.1	37.9	39.1	32.4	28.1
PAPA014	2014	19	23.3	63.3	39.1	42.6	37.1	28.6
PAPA014	2014	20	25.5	59.7	38.3	41.4	35.4	29.8
PAPA014	2014	21	26.0	56.6	36.6	39.7	33.9	29.4
PAPA014	2014	22	23.8	48.4	30.3	32.1	29.1	27.1
PAPA014	2014	23	24.2	42.7	30.3	31.7	29.6	28.1
PAPA015	2014	0	13.5	38.0	18.1	19.2	17.2	16.2
PAPA015	2014	1	13.6	42.4	21.3	20.3	17.5	16.1
PAPA015	2014	2	13.5	40.8	18.4	17.6	16.0	14.5
PAPA015	2014	3	13.7	37.5	17.5	18.6	17.0	15.2
PAPA015	2014	4	15.7	24.8	18.4	19.5	18.2	17.0
PAPA015	2014	5	15.8	41.8	21.2	22.7	19.4	17.7
PAPA015	2014	6	16.2	59.8	30.7	26.8	21.2	18.7
PAPA015	2014	7	15.3	38.3	24.3	27.8	20.1	18.2
PAPA015	2014	8	16.7	37.7	24.0	27.0	20.2	18.2
PAPA015	2014	9	17.1	56.2	32.8	32.2	22.1	18.7
PAPA015	2014	10	15.5	39.8	20.2	21.4	17.7	16.2
PAPA015	2014	11	15.1	62.0	33.3	23.4	17.2	15.9
PAPA015	2014	12	15.2	59.0	33.5	33.4	23.7	17.7
PAPA015	2014	13	15.2	51.1	31.7	35.4	26.0	18.9
PAPA015	2014	14	15.9	51.9	32.6	36.4	27.4	19.9
PAPA015	2014	15	15.6	56.4	35.6	39.0	31.3	22.5
PAPA015	2014	16	19.8	54.2	36.9	40.5	33.2	26.8
PAPA015	2014	17	16.4	49.9	34.5	38.2	30.9	24.6
PAPA015	2014	18	16.5	47.0	32.7	36.2	29.8	24.1
PAPA015	2014	19	13.8	57.5	27.4	29.6	19.2	14.4
PAPA015	2014	20	13.7	40.8	15.6	16.0	14.5	14.0
PAPA015	2014	21	13.6	42.7	19.5	15.8	14.4	13.9

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA015	2014	22	13.5	52.3	22.5	19.5	14.9	13.9
PAPA015	2014	23	13.6	33.8	17.9	18.9	17.3	16.3
PAPA016	2014	0	14.7	49.7	20.5	22.8	18.5	16.3
PAPA016	2014	1	15.2	50.2	23.3	27.0	19.9	16.5
PAPA016	2014	2	15.2	44.4	21.7	24.2	20.6	17.9
PAPA016	2014	3	15.1	42.5	20.3	22.8	18.4	17.5
PAPA016	2014	4	15.1	41.4	20.9	23.3	18.8	16.5
PAPA016	2014	5	15.2	43.4	27.7	29.5	23.9	19.7
PAPA016	2014	6	15.3	49.8	23.7	25.3	22.3	19.7
PAPA016	2014	7	15.6	70.5	30.1	27.3	25.1	23.0
PAPA016	2014	8	16.0	47.5	29.1	31.7	26.1	23.1
PAPA016	2014	9	16.2	55.7	28.8	31.3	27.2	23.7
PAPA016	2014	10	17.5	55.4	33.5	36.9	30.6	21.3
PAPA016	2014	11	17.5	55.5	36.6	40.1	33.3	27.0
PAPA016	2014	12	17.0	57.5	33.3	35.9	29.9	26.0
PAPA016	2014	13	16.4	91.5	43.7	47.3	34.2	26.6
PAPA016	2014	14	16.4	81.5	42.3	42.4	33.4	27.7
PAPA016	2014	15	16.7	55.7	36.1	38.2	34.0	29.6
PAPA016	2014	16	15.6	73.2	41.0	39.9	33.0	28.0
PAPA016	2014	17	15.4	92.8	41.7	42.1	29.8	24.3
PAPA016	2014	18	16.2	56.6	29.5	32.2	25.7	21.0
PAPA016	2014	19	15.3	52.5	25.3	28.1	23.1	19.4
PAPA016	2014	20	15.1	57.2	25.8	27.4	20.6	17.1
PAPA016	2014	21	14.9	49.2	25.4	24.5	19.3	16.4
PAPA016	2014	22	14.8	46.1	24.9	23.9	18.2	16.1
PAPA016	2014	23	14.8	46.0	21.3	20.6	17.3	15.8
PAPA017	2014	0	23.5	40.7	31.5	33.2	31.1	29.3
PAPA017	2014	1	24.4	40.9	31.8	33.7	31.4	29.3
PAPA017	2014	2	27.7	45.8	33.6	35.3	33.3	31.4
PAPA017	2014	3	28.1	43.4	34.5	37.0	33.5	31.7
PAPA017	2014	4	26.3	45.3	34.1	36.5	32.9	30.6
PAPA017	2014	5	29.5	42.6	34.8	36.3	34.4	32.8
PAPA017	2014	6	28.9	55.9	36.4	37.9	35.1	32.8
PAPA017	2014	7	29.9	59.0	36.2	37.2	35.0	33.3
PAPA017	2014	8	28.5	56.9	36.2	37.9	35.1	32.2
PAPA017	2014	9	22.9	52.9	31.9	32.9	28.7	26.3
PAPA017	2014	10	17.4	51.3	29.1	30.7	26.2	24.5
PAPA017	2014	11	16.7	68.0	31.3	28.3	22.8	21.2
PAPA017	2014	12	17.9	61.8	36.1	31.3	24.7	20.7
PAPA017	2014	13	19.4	62.5	36.2	36.2	28.8	23.8

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA017	2014	14	18.9	48.0	29.9	33.2	26.4	22.1
PAPA017	2014	15	17.6	47.0	24.3	26.1	22.8	20.1
PAPA017	2014	16	18.3	54.9	29.8	31.5	26.4	22.8
PAPA017	2014	17	17.9	64.0	32.0	30.0	24.1	21.0
PAPA017	2014	18	16.9	51.5	28.4	29.5	22.9	20.3
PAPA017	2014	19	15.2	53.8	29.8	29.7	23.1	20.4
PAPA017	2014	20	18.2	49.0	29.3	29.8	25.9	24.3
PAPA017	2014	21	19.9	45.2	28.7	30.1	26.6	25.0
PAPA017	2014	22	21.8	38.2	29.4	31.2	28.9	26.7
PAPA017	2014	23	24.4	38.5	32.0	34.0	31.7	29.3
PAPA018	2014	0	13.8	44.6	20.8	22.7	18.1	15.1
PAPA018	2014	1	13.5	37.9	18.0	19.4	16.6	15.0
PAPA018	2014	2	13.6	20.2	15.2	16.0	15.1	14.6
PAPA018	2014	3	13.6	26.9	15.8	16.7	15.2	14.7
PAPA018	2014	4	13.8	32.9	16.4	17.4	15.6	14.5
PAPA018	2014	5	14.0	34.2	17.3	18.9	16.1	15.0
PAPA018	2014	6	15.8	45.1	28.9	32.7	25.6	19.8
PAPA018	2014	7	15.6	66.6	38.4	36.6	26.3	20.7
PAPA018	2014	8	16.9	64.5	36.9	32.6	22.8	19.4
PAPA018	2014	9	15.9	73.1	53.9	38.8	20.5	18.1
PAPA018	2014	10	15.3	51.0	26.7	27.6	19.2	16.5
PAPA018	2014	11	15.4	46.8	24.8	26.7	20.1	17.5
PAPA018	2014	12	16.7	51.3	30.0	32.2	24.9	19.9
PAPA018	2014	13	16.0	48.0	27.9	31.4	23.9	19.2
PAPA018	2014	14	16.6	49.5	32.0	35.9	28.1	22.1
PAPA018	2014	15	15.9	49.9	31.2	34.9	27.5	21.3
PAPA018	2014	16	15.9	48.8	31.6	34.3	26.7	21.2
PAPA018	2014	17	15.6	46.1	30.0	33.4	25.4	20.0
PAPA018	2014	18	14.7	56.2	31.2	31.6	23.9	20.1
PAPA018	2014	19	14.0	50.2	27.3	27.7	20.2	16.5
PAPA018	2014	20	14.8	62.8	30.0	30.0	18.9	16.7
PAPA018	2014	21	14.4	45.0	22.3	22.2	18.7	15.5
PAPA018	2014	22	14.1	46.3	21.6	23.8	16.5	15.1
PAPA018	2014	23	13.9	22.4	17.3	19.0	16.9	15.4
PAPA019	2014	0	14.5	48.3	25.2	26.6	21.3	16.1
PAPA019	2014	1	14.5	44.9	21.4	23.3	18.0	16.4
PAPA019	2014	2	14.5	28.7	16.3	17.3	15.9	15.2
PAPA019	2014	3	14.5	33.6	16.3	16.3	15.2	14.8
PAPA019	2014	4	14.6	28.5	15.7	16.0	15.3	14.9
PAPA019	2014	5	14.7	54.5	22.3	17.6	15.5	15.0

Appendix C. Hourly dBA Metrics, PAPA Leks, April 2014.

Site	Year	Hour	Lmin	Lmax	Leq	L10	L50	L90
PAPA019	2014	6	15.9	50.4	31.0	32.6	20.7	17.7
PAPA019	2014	7	15.7	67.3	38.8	30.9	21.8	17.9
PAPA019	2014	8	16.1	53.6	32.4	29.7	18.5	17.1
PAPA019	2014	9	16.2	55.3	32.0	27.8	18.6	17.1
PAPA019	2014	10	16.5	60.1	36.7	25.6	19.7	17.6
PAPA019	2014	11	16.4	45.4	28.9	32.5	20.8	17.8
PAPA019	2014	12	16.1	52.2	31.7	34.1	25.8	20.3
PAPA019	2014	13	15.8	59.3	33.5	31.4	23.5	19.2
PAPA019	2014	14	16.2	52.4	33.2	35.4	27.8	21.7
PAPA019	2014	15	15.8	51.0	31.0	34.8	26.6	20.4
PAPA019	2014	16	15.9	47.9	30.5	33.9	26.6	20.7
PAPA019	2014	17	15.4	55.0	33.1	33.7	26.3	21.0
PAPA019	2014	18	15.3	54.9	31.9	29.6	23.0	19.1
PAPA019	2014	19	15.1	47.3	24.3	24.1	17.3	15.7
PAPA019	2014	20	14.8	37.6	19.2	20.7	16.8	15.5
PAPA019	2014	21	14.7	40.9	21.2	18.7	15.8	15.2
PAPA019	2014	22	14.6	51.9	21.2	21.4	15.2	14.8
PAPA019	2014	23	14.6	26.7	16.2	17.0	16.0	15.1

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.								
Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA001	2013	12.5	44.9	48.2	43.3	38.7	22.0	73.0
PAPA001	2013	15.8	47.0	49.6	46.0	42.2	27.0	70.5
PAPA001	2013	20	53.2	56.0	52.2	48.1	34.6	74.0
PAPA001	2013	25	50.6	53.2	49.0	45.7	34.9	67.2
PAPA001	2013	31.5	63.0	66.4	61.5	56.1	40.2	75.0
PAPA001	2013	40	50.2	52.5	49.8	47.3	32.8	66.1
PAPA001	2013	50	53.3	55.5	52.9	50.1	35.5	68.7
PAPA001	2013	63	52.5	54.8	52.0	49.6	34.9	69.5
PAPA001	2013	80	49.5	51.4	48.3	45.9	29.0	71.7
PAPA001	2013	100	47.2	49.4	45.9	43.0	28.8	66.5
PAPA001	2013	125	42.8	44.6	40.4	37.6	23.7	67.1
PAPA001	2013	160	39.7	41.3	36.7	32.2	19.5	67.1
PAPA001	2013	200	38.8	39.8	35.4	30.1	17.7	66.6
PAPA001	2013	250	37.1	38.3	33.2	28.5	13.7	61.5
PAPA001	2013	315	34.2	36.3	31.6	26.1	10.8	57.2
PAPA001	2013	400	32.7	35.0	30.4	24.8	8.0	55.6
PAPA001	2013	500	24.9	27.6	22.7	16.5	3.5	53.2
PAPA001	2013	630	22.1	23.0	18.5	13.5	1.8	50.8
PAPA001	2013	800	22.7	24.5	19.8	14.7	2.1	49.8
PAPA001	2013	1000	24.4	26.0	21.0	15.8	2.4	48.3
PAPA001	2013	1250	23.2	26.3	20.7	14.9	2.2	46.8
PAPA001	2013	1600	21.7	24.5	19.4	13.1	1.6	44.8
PAPA001	2013	2000	20.5	21.8	17.3	12.6	1.8	58.6
PAPA001	2013	2500	12.8	15.2	10.2	6.3	2.3	63.1
PAPA001	2013	3150	8.6	9.7	5.2	4.1	3.0	57.3
PAPA001	2013	4000	5.3	5.2	4.5	4.2	3.7	47.8
PAPA001	2013	5000	5.4	5.3	5.0	4.8	4.3	47.3
PAPA001	2013	6300	5.4	5.5	5.3	5.2	4.2	44.6
PAPA001	2013	8000	5.4	5.5	5.3	5.2	3.4	43.8
PAPA001	2013	10000	5.0	5.1	5.0	4.8	2.3	41.6
PAPA001	2013	12500	4.2	4.3	4.2	4.1	1.6	39.8
PAPA001	2013	16000	3.2	3.3	3.2	3.1	0.6	37.4
PAPA001	2013	20000	1.8	1.9	1.8	1.7	1.3	33.4
PAPA002	2013	12.5	50.8	54.5	47.3	41.0	23.9	78.7
PAPA002	2013	15.8	49.3	51.9	48.1	44.3	29.8	75.3
PAPA002	2013	20	55.9	58.2	54.8	50.6	36.9	77.4
PAPA002	2013	25	51.7	55.7	46.5	42.7	30.4	74.0
PAPA002	2013	31.5	48.9	52.2	47.1	43.0	31.2	72.5

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA002	2013	40	44.3	46.5	43.5	40.8	29.4	70.4
PAPA002	2013	50	44.2	46.2	43.3	40.8	30.6	67.4
PAPA002	2013	63	41.9	44.2	40.2	37.0	27.7	65.6
PAPA002	2013	80	39.6	42.5	37.2	34.0	23.3	71.6
PAPA002	2013	100	37.6	39.9	35.6	32.2	21.6	70.5
PAPA002	2013	125	35.6	37.2	32.9	30.0	18.9	62.4
PAPA002	2013	160	35.3	36.5	31.5	27.4	16.7	62.1
PAPA002	2013	200	31.5	32.5	28.8	25.4	13.6	59.3
PAPA002	2013	250	28.7	31.4	25.9	22.2	12.2	55.4
PAPA002	2013	315	26.3	29.0	24.5	20.8	10.3	55.0
PAPA002	2013	400	23.6	25.8	20.9	16.4	5.0	54.0
PAPA002	2013	500	19.7	21.5	16.7	12.2	1.0	51.5
PAPA002	2013	630	17.1	19.9	13.4	9.0	-0.7	46.9
PAPA002	2013	800	14.6	18.0	9.9	5.5	-1.5	42.0
PAPA002	2013	1000	12.7	15.2	7.1	2.8	-1.3	42.5
PAPA002	2013	1250	9.7	10.6	4.0	1.5	-0.9	40.5
PAPA002	2013	1600	6.1	8.1	2.5	1.5	-0.2	41.8
PAPA002	2013	2000	3.9	4.5	2.5	1.8	0.6	42.4
PAPA002	2013	2500	4.3	4.4	2.9	2.5	1.5	44.2
PAPA002	2013	3150	4.0	4.1	3.4	3.1	2.3	41.9
PAPA002	2013	4000	5.7	4.8	4.0	3.7	3.1	43.5
PAPA002	2013	5000	6.7	5.1	4.4	4.2	3.7	53.6
PAPA002	2013	6300	5.4	4.9	4.6	4.4	2.7	53.7
PAPA002	2013	8000	4.6	4.7	4.5	4.4	2.1	38.2
PAPA002	2013	10000	4.3	4.4	4.3	4.1	1.8	36.1
PAPA002	2013	12500	3.8	3.9	3.8	3.6	0.4	35.8
PAPA002	2013	16000	3.0	3.1	3.0	2.9	0.3	34.9
PAPA002	2013	20000	1.8	1.8	1.8	1.7	1.1	34.8
PAPA003	2013	12.5	49.1	51.4	44.9	39.1	21.8	81.6
PAPA003	2013	15.8	48.8	51.3	46.5	42.0	29.0	77.8
PAPA003	2013	20	53.1	56.2	51.3	47.0	34.9	74.4
PAPA003	2013	25	48.5	51.9	46.2	42.3	31.3	73.2
PAPA003	2013	31.5	52.7	56.1	51.5	46.3	33.3	68.2
PAPA003	2013	40	45.1	47.8	44.1	40.0	27.5	66.4
PAPA003	2013	50	43.4	45.8	42.1	37.7	26.9	64.8
PAPA003	2013	63	42.9	45.4	41.1	37.2	24.8	67.1
PAPA003	2013	80	40.9	43.4	39.0	34.1	14.5	69.1
PAPA003	2013	100	38.6	40.8	36.4	32.3	16.9	70.5
PAPA003	2013	125	36.5	38.0	33.9	30.5	16.4	63.0
PAPA003	2013	160	35.0	36.0	31.5	27.8	16.0	65.3

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA003	2013	200	32.4	33.1	29.1	25.3	13.7	60.1
PAPA003	2013	250	29.2	31.2	25.9	22.7	8.7	56.4
PAPA003	2013	315	27.2	29.1	24.5	20.3	7.3	53.8
PAPA003	2013	400	23.9	26.4	21.0	17.0	2.9	50.7
PAPA003	2013	500	21.0	22.8	16.8	12.4	-0.1	50.8
PAPA003	2013	630	18.3	20.2	13.9	8.6	-1.4	47.6
PAPA003	2013	800	15.0	17.7	10.7	5.3	-2.0	41.6
PAPA003	2013	1000	12.7	15.2	8.5	3.5	-1.5	39.4
PAPA003	2013	1250	9.7	12.2	5.1	1.8	-1.0	39.4
PAPA003	2013	1600	6.8	9.3	2.8	1.5	-0.2	36.4
PAPA003	2013	2000	5.0	7.1	2.4	1.8	0.5	39.4
PAPA003	2013	2500	3.8	4.8	3.0	2.5	1.5	39.6
PAPA003	2013	3150	5.0	4.4	3.5	3.2	2.3	38.6
PAPA003	2013	4000	5.7	5.0	4.2	4.0	3.3	50.8
PAPA003	2013	5000	6.1	5.4	4.8	4.6	3.6	57.9
PAPA003	2013	6300	5.5	5.4	5.1	4.9	3.5	48.8
PAPA003	2013	8000	5.3	5.3	5.1	5.0	1.7	41.3
PAPA003	2013	10000	4.9	5.0	4.8	4.7	1.4	38.4
PAPA003	2013	12500	4.2	4.3	4.2	4.1	1.1	37.8
PAPA003	2013	16000	3.3	3.4	3.3	3.2	0.4	35.7
PAPA003	2013	20000	2.0	2.1	1.9	1.8	0.9	31.8
PAPA004	2013	12.5	45.3	47.7	41.6	37.4	15.8	81.6
PAPA004	2013	15.8	44.6	47.0	42.3	38.9	24.7	78.0
PAPA004	2013	20	55.1	58.6	52.9	46.8	31.2	75.9
PAPA004	2013	25	42.3	44.9	40.4	36.4	24.2	72.8
PAPA004	2013	31.5	47.1	50.5	42.5	36.4	22.3	70.6
PAPA004	2013	40	41.0	43.8	38.6	34.2	21.9	69.3
PAPA004	2013	50	39.9	42.4	36.8	32.8	18.8	67.9
PAPA004	2013	63	38.3	40.8	35.4	31.7	15.4	66.3
PAPA004	2013	80	36.1	38.5	33.6	30.2	11.8	69.1
PAPA004	2013	100	36.4	38.7	33.2	29.0	10.8	69.4
PAPA004	2013	125	35.0	37.0	31.4	27.6	9.0	65.8
PAPA004	2013	160	31.0	33.3	28.5	24.7	5.0	61.9
PAPA004	2013	200	29.6	32.5	27.1	23.2	4.5	62.8
PAPA004	2013	250	26.5	29.1	24.4	20.6	2.0	58.9
PAPA004	2013	315	24.2	27.1	22.3	18.0	0.7	53.3
PAPA004	2013	400	22.2	24.7	19.8	15.5	-1.0	50.3
PAPA004	2013	500	18.8	21.5	15.9	12.2	-3.0	47.4
PAPA004	2013	630	15.5	18.3	11.2	7.6	-3.5	44.3
PAPA004	2013	800	12.2	14.8	8.5	5.1	-3.2	47.1

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA004	2013	1000	12.8	12.8	5.7	2.4	-2.6	51.1
PAPA004	2013	1250	9.9	10.5	4.7	1.2	-1.5	50.7
PAPA004	2013	1600	6.5	7.2	2.2	1.1	-0.6	52.2
PAPA004	2013	2000	6.4	5.8	2.2	1.7	0.3	53.5
PAPA004	2013	2500	5.8	5.8	2.9	2.5	1.2	43.2
PAPA004	2013	3150	4.3	5.1	3.5	3.2	2.1	39.7
PAPA004	2013	4000	4.4	4.8	4.1	3.8	1.2	37.2
PAPA004	2013	5000	4.7	4.8	4.5	4.3	0.3	35.5
PAPA004	2013	6300	4.7	4.9	4.7	4.5	-0.1	33.7
PAPA004	2013	8000	4.6	4.7	4.6	4.4	-0.6	36.3
PAPA004	2013	10000	4.2	4.3	4.2	4.0	-0.4	29.5
PAPA004	2013	12500	3.5	3.7	3.5	3.4	-0.5	27.8
PAPA004	2013	16000	2.6	2.7	2.5	2.4	-1.1	25.9
PAPA004	2013	20000	0.9	1.1	0.8	0.7	-0.8	20.2
PAPA005	2013	12.5	43.2	45.8	41.8	37.8	23.5	78.5
PAPA005	2013	15.8	48.0	50.2	46.3	42.5	29.2	78.0
PAPA005	2013	20	59.0	62.9	57.0	51.6	36.4	73.6
PAPA005	2013	25	45.7	48.0	44.0	40.5	29.7	71.2
PAPA005	2013	31.5	48.3	51.2	45.3	41.1	29.3	67.9
PAPA005	2013	40	44.9	47.1	43.1	40.3	29.1	66.7
PAPA005	2013	50	46.0	48.4	45.2	41.3	24.8	63.8
PAPA005	2013	63	42.8	45.2	41.0	37.2	22.5	68.5
PAPA005	2013	80	40.6	42.8	37.9	33.3	18.6	77.5
PAPA005	2013	100	39.6	42.0	36.7	33.1	16.2	73.8
PAPA005	2013	125	36.7	38.4	34.6	31.0	15.7	72.4
PAPA005	2013	160	33.6	36.2	31.3	27.6	9.6	64.1
PAPA005	2013	200	32.6	35.2	30.7	26.8	7.1	60.0
PAPA005	2013	250	29.4	31.8	27.7	24.3	4.3	62.9
PAPA005	2013	315	27.0	30.1	25.6	21.6	1.4	56.3
PAPA005	2013	400	24.7	28.0	22.5	18.3	-0.4	53.0
PAPA005	2013	500	23.0	25.5	19.5	13.2	-1.9	56.4
PAPA005	2013	630	20.5	23.5	16.5	10.2	-2.4	53.7
PAPA005	2013	800	20.1	23.5	15.6	8.5	-2.4	45.3
PAPA005	2013	1000	19.5	22.9	14.1	7.5	-1.4	44.7
PAPA005	2013	1250	16.9	20.4	12.0	5.6	-0.9	43.0
PAPA005	2013	1600	13.9	16.8	8.6	3.2	-0.2	44.7
PAPA005	2013	2000	8.7	9.3	4.1	2.7	0.9	44.1
PAPA005	2013	2500	6.6	6.3	3.4	3.0	1.9	43.0
PAPA005	2013	3150	5.7	5.7	4.1	3.7	2.8	42.2
PAPA005	2013	4000	6.0	5.5	4.7	4.4	3.7	40.7

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA005	2013	5000	7.6	5.8	5.2	5.0	4.4	62.1
PAPA005	2013	6300	6.0	5.8	5.5	5.4	3.3	66.6
PAPA005	2013	8000	5.6	5.8	5.6	5.4	3.1	45.7
PAPA005	2013	10000	5.4	5.5	5.3	5.2	2.5	41.9
PAPA005	2013	12500	4.8	4.9	4.8	4.7	2.0	50.9
PAPA005	2013	16000	4.0	4.1	4.0	3.9	1.6	31.7
PAPA005	2013	20000	2.9	3.0	2.8	2.7	1.9	31.8
PAPA006	2013	12.5	46.7	48.5	44.5	40.3	27.7	74.8
PAPA006	2013	15.8	50.5	52.3	48.4	45.1	33.9	74.2
PAPA006	2013	20	60.0	63.4	58.5	54.6	42.2	75.8
PAPA006	2013	25	50.2	52.5	49.0	46.1	35.8	70.1
PAPA006	2013	31.5	56.0	59.0	55.1	48.4	36.2	71.1
PAPA006	2013	40	50.2	52.7	49.0	46.0	33.2	75.1
PAPA006	2013	50	48.2	50.4	46.1	43.0	29.5	73.6
PAPA006	2013	63	47.2	49.4	45.7	42.3	28.5	69.4
PAPA006	2013	80	42.2	43.7	39.7	36.7	22.9	75.3
PAPA006	2013	100	39.8	41.9	38.1	35.3	23.6	72.5
PAPA006	2013	125	37.9	39.4	35.9	32.0	22.4	72.2
PAPA006	2013	160	35.3	36.7	33.7	30.8	14.2	66.4
PAPA006	2013	200	34.2	35.8	32.2	28.7	11.1	66.5
PAPA006	2013	250	30.9	32.5	29.2	26.4	8.0	60.7
PAPA006	2013	315	27.4	29.3	26.1	23.4	6.3	56.6
PAPA006	2013	400	24.8	27.3	23.5	20.4	3.8	52.1
PAPA006	2013	500	21.5	23.6	19.5	16.1	0.4	52.9
PAPA006	2013	630	18.3	21.4	16.4	12.6	-0.9	50.3
PAPA006	2013	800	18.3	21.1	15.8	11.8	-0.6	53.4
PAPA006	2013	1000	19.0	22.3	15.3	11.1	-0.4	52.0
PAPA006	2013	1250	18.5	20.4	12.9	8.3	0.1	54.8
PAPA006	2013	1600	15.8	17.5	10.7	6.0	0.5	53.9
PAPA006	2013	2000	12.9	14.9	7.5	4.3	0.9	54.6
PAPA006	2013	2500	10.1	11.1	5.5	3.7	1.6	51.3
PAPA006	2013	3150	8.2	7.3	4.4	3.8	2.4	51.2
PAPA006	2013	4000	5.9	6.0	4.6	4.3	3.4	47.0
PAPA006	2013	5000	5.5	5.3	5.0	4.9	3.5	41.7
PAPA006	2013	6300	5.5	5.6	5.4	5.2	3.5	38.3
PAPA006	2013	8000	5.6	5.6	5.4	5.3	2.9	40.8
PAPA006	2013	10000	5.2	5.3	5.2	5.0	1.5	39.6
PAPA006	2013	12500	4.6	4.7	4.6	4.4	1.2	40.0
PAPA006	2013	16000	3.7	3.9	3.7	3.5	0.5	37.1
PAPA006	2013	20000	2.4	2.6	2.4	2.2	1.0	34.8

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA007	2013	12.5	51.1	53.8	47.2	41.8	24.4	78.3
PAPA007	2013	15.8	48.3	50.9	45.4	41.2	29.0	76.0
PAPA007	2013	20	55.7	58.3	54.8	50.5	36.8	73.9
PAPA007	2013	25	48.1	50.6	46.6	43.1	33.9	70.6
PAPA007	2013	31.5	46.3	49.3	43.2	39.2	30.4	69.3
PAPA007	2013	40	42.7	44.5	40.6	37.3	27.8	68.6
PAPA007	2013	50	40.2	42.5	38.1	35.2	26.5	75.7
PAPA007	2013	63	39.5	41.8	36.9	34.2	23.9	80.7
PAPA007	2013	80	37.5	39.6	34.6	31.5	22.1	85.3
PAPA007	2013	100	35.5	37.5	33.3	30.2	20.7	83.3
PAPA007	2013	125	34.4	36.7	32.6	29.4	20.8	73.3
PAPA007	2013	160	30.8	33.0	29.3	26.3	14.5	73.6
PAPA007	2013	200	28.6	30.4	26.6	24.1	11.9	78.8
PAPA007	2013	250	25.2	27.3	23.5	21.0	10.3	63.6
PAPA007	2013	315	22.2	25.1	20.5	17.6	7.1	65.9
PAPA007	2013	400	19.1	20.6	15.8	12.7	1.2	68.6
PAPA007	2013	500	16.8	19.2	12.7	8.8	-1.5	65.3
PAPA007	2013	630	14.8	17.7	10.0	5.4	-2.4	56.9
PAPA007	2013	800	14.2	17.3	9.0	3.9	-2.4	53.8
PAPA007	2013	1000	12.4	14.9	7.0	2.2	-1.9	49.6
PAPA007	2013	1250	10.7	11.6	4.6	1.1	-1.2	48.6
PAPA007	2013	1600	9.0	10.4	4.3	1.8	-0.2	43.8
PAPA007	2013	2000	8.4	9.7	3.5	2.1	0.5	41.5
PAPA007	2013	2500	7.4	8.2	3.7	2.8	1.3	38.4
PAPA007	2013	3150	7.1	7.7	3.8	3.4	2.3	46.6
PAPA007	2013	4000	6.4	6.3	4.3	4.0	2.0	46.8
PAPA007	2013	5000	6.6	5.2	4.6	4.4	1.3	41.7
PAPA007	2013	6300	5.1	5.0	4.7	4.5	0.2	34.4
PAPA007	2013	8000	4.7	4.9	4.6	4.4	0.1	25.5
PAPA007	2013	10000	4.4	4.5	4.3	4.0	-0.6	23.5
PAPA007	2013	12500	3.8	4.0	3.7	3.4	-1.3	21.9
PAPA007	2013	16000	3.0	3.2	2.8	2.5	-1.3	21.1
PAPA007	2013	20000	1.6	2.0	1.2	0.9	-1.2	25.8
PAPA008	2013	12.5	50.6	53.5	47.5	41.7	26.7	78.6
PAPA008	2013	15.8	49.5	52.2	46.2	41.0	24.1	75.8
PAPA008	2013	20	53.0	55.5	51.2	47.3	32.2	73.6
PAPA008	2013	25	47.7	50.7	45.0	41.4	28.7	71.0
PAPA008	2013	31.5	45.6	48.1	44.1	41.0	28.9	69.1
PAPA008	2013	40	43.3	45.7	42.0	38.8	29.7	66.8
PAPA008	2013	50	39.2	41.2	37.5	34.9	26.1	66.7

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA008	2013	63	39.1	41.9	37.6	34.6	24.3	85.0
PAPA008	2013	80	36.2	38.4	34.1	31.0	22.7	84.1
PAPA008	2013	100	34.5	37.1	33.2	30.2	21.1	79.3
PAPA008	2013	125	33.1	35.5	31.7	29.0	20.0	66.9
PAPA008	2013	160	30.2	32.4	28.4	25.6	16.9	70.4
PAPA008	2013	200	28.7	31.2	27.1	24.0	14.9	65.3
PAPA008	2013	250	26.0	28.3	24.0	21.3	13.0	53.3
PAPA008	2013	315	22.7	25.0	21.2	18.2	9.8	46.0
PAPA008	2013	400	19.1	21.3	16.5	12.9	4.9	47.5
PAPA008	2013	500	17.6	19.1	14.3	10.4	1.6	52.4
PAPA008	2013	630	15.4	17.4	11.2	6.5	-1.9	48.6
PAPA008	2013	800	14.8	16.7	9.5	4.4	-1.7	43.5
PAPA008	2013	1000	12.9	16.0	7.9	3.3	-1.0	46.5
PAPA008	2013	1250	11.9	14.8	5.5	1.5	-0.9	48.7
PAPA008	2013	1600	10.0	12.6	4.1	1.6	-0.2	36.1
PAPA008	2013	2000	7.3	9.7	3.3	2.2	0.5	36.7
PAPA008	2013	2500	6.2	8.1	3.4	3.0	1.5	35.9
PAPA008	2013	3150	6.4	7.2	4.1	3.7	2.4	34.8
PAPA008	2013	4000	5.4	5.9	4.7	4.4	2.2	49.3
PAPA008	2013	5000	6.4	6.4	5.2	4.8	2.3	52.5
PAPA008	2013	6300	5.9	5.9	5.4	5.1	2.6	38.1
PAPA008	2013	8000	5.6	5.9	5.4	5.2	2.2	26.1
PAPA008	2013	10000	5.4	5.6	5.2	4.9	0.7	28.8
PAPA008	2013	12500	4.9	5.1	4.7	4.4	0.4	23.9
PAPA008	2013	16000	4.1	4.4	3.9	3.5	-0.3	22.7
PAPA008	2013	20000	2.9	3.4	2.7	2.3	0.5	22.3
PAPA009	2013	12.5	53.8	56.9	50.5	45.6	26.6	77.2
PAPA009	2013	15.8	52.5	55.3	50.6	45.7	30.2	73.1
PAPA009	2013	20	52.9	55.4	50.8	46.6	33.0	71.5
PAPA009	2013	25	48.8	51.5	47.2	43.4	30.5	68.1
PAPA009	2013	31.5	47.7	50.7	45.8	41.4	30.7	66.9
PAPA009	2013	40	43.4	45.5	41.8	38.2	28.8	64.0
PAPA009	2013	50	40.7	42.7	38.0	33.6	24.0	73.6
PAPA009	2013	63	40.2	42.5	37.9	34.1	24.6	75.9
PAPA009	2013	80	38.2	40.1	35.5	31.7	21.6	75.3
PAPA009	2013	100	35.8	38.0	34.2	31.2	20.5	73.8
PAPA009	2013	125	35.1	37.7	32.6	29.7	19.6	66.0
PAPA009	2013	160	31.5	33.7	30.1	27.8	16.0	68.3
PAPA009	2013	200	29.5	31.7	27.5	24.9	13.8	66.1
PAPA009	2013	250	26.0	28.3	24.6	21.6	11.6	56.4

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA009	2013	315	22.3	25.0	20.8	16.8	5.9	45.9
PAPA009	2013	400	19.7	22.6	17.5	13.4	2.2	43.4
PAPA009	2013	500	17.3	19.8	14.0	9.7	-0.2	49.1
PAPA009	2013	630	13.5	15.5	9.7	5.5	-1.9	45.4
PAPA009	2013	800	12.1	14.0	7.0	3.3	-2.3	40.7
PAPA009	2013	1000	10.5	13.1	5.7	1.9	-1.6	37.3
PAPA009	2013	1250	10.4	12.4	3.4	1.5	-1.1	40.3
PAPA009	2013	1600	8.8	11.1	2.4	1.7	-0.2	40.0
PAPA009	2013	2000	6.6	9.0	2.8	2.4	0.7	35.6
PAPA009	2013	2500	6.0	7.7	3.5	3.1	1.7	34.6
PAPA009	2013	3150	5.5	6.9	4.1	3.8	2.5	41.4
PAPA009	2013	4000	6.1	5.8	4.6	4.4	1.7	35.4
PAPA009	2013	5000	6.1	5.6	4.9	4.6	0.2	46.6
PAPA009	2013	6300	5.3	5.3	5.0	4.6	-0.1	42.6
PAPA009	2013	8000	5.1	5.2	4.9	4.5	-0.9	33.4
PAPA009	2013	10000	4.8	5.0	4.7	4.3	-0.7	23.6
PAPA009	2013	12500	4.5	4.7	4.4	3.9	-0.6	25.4
PAPA009	2013	16000	4.0	4.4	3.9	3.4	-0.8	25.1
PAPA009	2013	20000	3.0	4.1	2.8	2.5	-0.3	22.5
PAPA010	2013	12.5	52.2	55.3	49.9	45.1	25.2	76.7
PAPA010	2013	15.8	53.1	55.7	52.0	47.6	33.0	74.8
PAPA010	2013	20	53.7	56.5	51.9	47.3	34.8	74.5
PAPA010	2013	25	50.2	53.0	48.1	44.4	31.6	73.6
PAPA010	2013	31.5	48.1	50.7	46.9	42.9	32.9	69.6
PAPA010	2013	40	43.4	45.5	42.5	39.1	29.9	65.6
PAPA010	2013	50	42.6	45.4	40.8	37.6	25.0	64.1
PAPA010	2013	63	40.0	41.9	38.4	35.4	24.6	61.2
PAPA010	2013	80	37.5	39.5	35.5	32.6	21.9	70.4
PAPA010	2013	100	35.9	37.6	34.0	31.4	18.9	66.3
PAPA010	2013	125	33.9	36.4	32.7	29.8	18.6	69.5
PAPA010	2013	160	31.4	33.6	30.4	27.6	15.4	63.9
PAPA010	2013	200	30.8	33.2	29.2	26.4	14.1	59.4
PAPA010	2013	250	27.8	30.8	26.4	23.4	11.5	55.1
PAPA010	2013	315	24.0	27.4	22.6	19.0	5.9	44.7
PAPA010	2013	400	21.7	25.7	19.5	16.1	3.1	43.4
PAPA010	2013	500	18.5	20.8	14.7	11.4	0.0	48.9
PAPA010	2013	630	16.0	18.8	12.5	8.3	-1.7	43.8
PAPA010	2013	800	14.1	16.1	9.7	5.5	-1.3	41.1
PAPA010	2013	1000	13.7	16.5	8.6	4.8	-1.1	40.8
PAPA010	2013	1250	12.4	15.5	7.2	3.6	-0.4	37.5

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA010	2013	1600	10.2	13.0	5.1	2.9	0.2	36.5
PAPA010	2013	2000	7.7	9.7	3.7	2.9	1.2	41.2
PAPA010	2013	2500	8.1	8.6	3.8	3.4	2.0	58.5
PAPA010	2013	3150	6.6	7.0	4.5	4.1	3.0	50.0
PAPA010	2013	4000	6.4	6.8	5.1	4.8	3.3	42.6
PAPA010	2013	5000	7.2	6.4	5.5	5.3	1.4	50.8
PAPA010	2013	6300	6.0	6.1	5.8	5.5	1.6	42.0
PAPA010	2013	8000	5.8	6.0	5.7	5.5	-0.2	27.3
PAPA010	2013	10000	5.5	5.7	5.4	5.2	-0.3	23.9
PAPA010	2013	12500	4.9	5.2	4.8	4.5	-0.6	22.8
PAPA010	2013	16000	4.1	4.5	3.9	3.6	-0.9	20.7
PAPA010	2013	20000	2.7	3.1	2.5	2.2	-1.1	19.4
PAPA011	2013	12.5	48.3	52.0	40.4	34.7	19.3	77.8
PAPA011	2013	15.8	45.7	48.0	40.3	34.6	20.7	76.6
PAPA011	2013	20	46.1	49.0	42.4	37.2	21.2	77.6
PAPA011	2013	25	39.5	41.5	35.2	30.8	17.3	71.3
PAPA011	2013	31.5	42.7	45.0	39.0	33.3	17.8	69.6
PAPA011	2013	40	34.9	37.1	32.7	29.2	13.6	67.4
PAPA011	2013	50	34.4	37.0	32.2	28.7	13.4	65.7
PAPA011	2013	63	34.2	36.9	31.5	28.4	12.8	64.5
PAPA011	2013	80	32.0	34.2	29.9	26.5	13.1	69.3
PAPA011	2013	100	34.7	36.7	31.5	27.1	12.5	68.1
PAPA011	2013	125	29.3	31.5	26.7	23.0	10.3	73.3
PAPA011	2013	160	28.1	30.4	24.7	20.0	6.2	62.7
PAPA011	2013	200	26.6	29.2	23.2	18.7	4.2	55.9
PAPA011	2013	250	24.2	26.6	19.7	13.7	0.0	60.0
PAPA011	2013	315	22.4	25.2	17.8	10.7	-2.3	55.8
PAPA011	2013	400	19.4	23.0	15.2	7.2	-3.4	50.1
PAPA011	2013	500	16.1	19.0	11.8	3.2	-3.8	44.7
PAPA011	2013	630	12.6	16.3	7.4	0.6	-3.5	44.5
PAPA011	2013	800	10.5	14.3	5.1	-0.1	-3.1	41.5
PAPA011	2013	1000	10.0	14.0	4.0	0.0	-2.1	34.6
PAPA011	2013	1250	9.2	13.1	3.9	0.5	-1.2	34.1
PAPA011	2013	1600	8.8	11.8	3.4	1.3	-0.3	35.1
PAPA011	2013	2000	7.4	10.2	3.4	1.9	0.7	34.7
PAPA011	2013	2500	6.6	8.7	3.8	2.7	1.6	34.6
PAPA011	2013	3150	6.7	7.7	4.4	3.4	2.2	38.6
PAPA011	2013	4000	6.3	6.3	4.6	4.2	1.6	45.5
PAPA011	2013	5000	6.0	6.1	5.0	4.7	1.5	49.2
PAPA011	2013	6300	5.6	5.8	5.3	5.0	1.5	41.2

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA011	2013	8000	5.5	5.7	5.3	5.1	1.0	23.4
PAPA011	2013	10000	5.2	5.4	5.1	4.9	0.7	27.3
PAPA011	2013	12500	4.8	5.0	4.6	4.3	0.4	26.8
PAPA011	2013	16000	4.2	4.5	3.8	3.6	0.2	28.5
PAPA011	2013	20000	3.4	4.1	2.7	2.4	0.4	27.2
PAPA012	2013	12.5	45.6	48.5	43.2	38.1	20.7	73.9
PAPA012	2013	15.8	44.4	47.1	42.3	38.7	23.0	70.9
PAPA012	2013	20	47.6	50.5	46.1	41.8	25.3	69.0
PAPA012	2013	25	41.1	44.3	38.6	35.1	21.3	67.2
PAPA012	2013	31.5	42.5	45.5	40.3	35.8	21.8	67.6
PAPA012	2013	40	35.8	38.0	34.2	31.3	16.2	63.5
PAPA012	2013	50	35.0	37.3	33.6	30.9	15.2	59.7
PAPA012	2013	63	35.2	38.3	33.9	30.7	15.8	57.6
PAPA012	2013	80	33.5	35.3	31.5	28.5	14.6	66.2
PAPA012	2013	100	33.2	34.9	31.3	28.3	12.6	73.4
PAPA012	2013	125	30.4	32.0	28.4	25.5	11.8	77.0
PAPA012	2013	160	27.9	30.0	25.6	22.8	9.2	70.0
PAPA012	2013	200	26.5	28.5	23.6	20.5	7.4	68.1
PAPA012	2013	250	23.8	26.1	20.6	16.5	3.3	66.7
PAPA012	2013	315	20.7	23.7	17.4	12.4	-0.3	60.5
PAPA012	2013	400	16.5	20.0	12.5	6.9	-3.0	56.7
PAPA012	2013	500	13.3	15.5	8.0	2.1	-3.8	55.1
PAPA012	2013	630	11.0	13.8	5.8	-0.3	-3.7	53.2
PAPA012	2013	800	12.2	16.1	6.3	-1.0	-3.7	56.5
PAPA012	2013	1000	12.6	17.1	6.4	-0.9	-2.9	54.9
PAPA012	2013	1250	12.4	16.6	5.3	-0.5	-2.2	51.2
PAPA012	2013	1600	11.5	15.0	3.6	0.3	-1.4	45.2
PAPA012	2013	2000	9.8	12.7	2.8	0.8	-0.7	42.8
PAPA012	2013	2500	7.9	10.3	2.3	1.4	0.4	41.9
PAPA012	2013	3150	5.3	7.1	2.6	2.2	1.3	42.3
PAPA012	2013	4000	5.2	5.7	3.3	3.0	1.4	43.5
PAPA012	2013	5000	4.8	4.9	4.0	3.7	1.4	41.0
PAPA012	2013	6300	5.0	5.0	4.6	4.4	1.0	43.5
PAPA012	2013	8000	5.3	5.3	5.1	4.9	0.4	46.2
PAPA012	2013	10000	5.4	5.5	5.3	5.1	0.1	38.4
PAPA012	2013	12500	5.0	5.2	4.9	4.7	0.3	39.7
PAPA012	2013	16000	3.1	3.4	2.8	2.7	-0.4	36.7
PAPA012	2013	20000	0.8	2.1	0.3	0.1	-0.7	29.3
PAPA013	2013	12.5	53.0	56.1	49.9	43.8	23.7	79.5
PAPA013	2013	15.8	51.6	54.8	47.0	41.3	27.0	76.5

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA013	2013	20	50.8	53.6	48.3	42.4	29.2	73.1
PAPA013	2013	25	47.5	50.6	45.5	40.6	24.3	71.3
PAPA013	2013	31.5	48.3	51.1	46.4	41.7	28.3	68.3
PAPA013	2013	40	41.6	44.3	40.0	36.7	25.6	65.9
PAPA013	2013	50	38.2	40.2	35.8	32.5	24.0	65.1
PAPA013	2013	63	37.3	39.7	35.3	32.2	24.1	61.9
PAPA013	2013	80	34.7	37.1	33.3	30.1	20.6	61.8
PAPA013	2013	100	36.7	37.8	33.9	30.5	18.7	63.9
PAPA013	2013	125	33.6	35.1	31.2	27.5	16.3	66.3
PAPA013	2013	160	30.5	32.1	28.4	24.7	15.1	70.2
PAPA013	2013	200	29.4	31.9	27.8	23.5	13.4	55.5
PAPA013	2013	250	27.0	29.9	25.3	21.2	9.7	57.3
PAPA013	2013	315	24.1	27.2	22.3	17.2	6.4	51.2
PAPA013	2013	400	21.7	25.2	19.8	14.5	2.6	50.5
PAPA013	2013	500	19.0	22.8	17.1	11.2	-0.7	49.2
PAPA013	2013	630	16.9	20.0	13.5	7.5	-2.6	42.7
PAPA013	2013	800	16.3	20.0	12.3	5.5	-2.8	38.2
PAPA013	2013	1000	17.2	21.1	12.5	5.4	-1.9	38.1
PAPA013	2013	1250	14.1	18.1	8.2	2.4	-1.6	38.5
PAPA013	2013	1600	12.6	15.8	6.2	2.0	-0.7	39.4
PAPA013	2013	2000	10.7	11.8	3.6	1.7	0.4	44.9
PAPA013	2013	2500	11.1	10.1	3.2	2.4	1.3	62.8
PAPA013	2013	3150	8.8	8.8	3.6	3.1	2.1	71.2
PAPA013	2013	4000	6.8	7.0	4.1	3.8	3.1	69.5
PAPA013	2013	5000	6.3	6.1	4.5	4.2	2.7	45.2
PAPA013	2013	6300	5.3	5.3	4.7	4.5	1.6	46.7
PAPA013	2013	8000	4.9	4.8	4.6	4.4	1.6	57.9
PAPA013	2013	10000	4.5	4.4	4.2	4.1	0.3	38.0
PAPA013	2013	12500	3.7	3.8	3.5	3.3	0.1	34.6
PAPA013	2013	16000	2.9	3.0	2.6	2.4	-0.3	35.7
PAPA013	2013	20000	1.5	1.9	1.0	0.7	-1.1	29.5
PAPA014	2013	12.5	43.7	45.7	41.4	35.5	20.5	73.7
PAPA014	2013	15.8	48.8	50.6	44.4	40.1	24.6	71.1
PAPA014	2013	20	57.8	61.4	52.6	48.4	31.0	76.1
PAPA014	2013	25	43.2	46.0	42.4	39.2	23.6	66.3
PAPA014	2013	31.5	48.6	51.8	47.5	42.6	26.3	66.1
PAPA014	2013	40	44.9	47.0	44.0	41.1	25.6	64.0
PAPA014	2013	50	43.0	45.2	41.4	38.8	25.9	67.6
PAPA014	2013	63	42.0	43.8	40.0	36.5	25.1	68.3
PAPA014	2013	80	38.1	40.3	36.1	33.3	22.8	70.9

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA014	2013	100	37.9	39.7	36.2	33.0	22.2	72.8
PAPA014	2013	125	38.8	40.3	36.8	34.1	21.6	70.4
PAPA014	2013	160	32.6	34.8	31.5	28.0	19.1	65.4
PAPA014	2013	200	30.5	32.9	28.1	24.2	8.6	66.2
PAPA014	2013	250	27.3	29.7	25.2	21.4	5.8	62.0
PAPA014	2013	315	24.7	28.2	22.6	18.9	3.4	57.5
PAPA014	2013	400	21.3	23.7	19.0	15.5	0.3	50.6
PAPA014	2013	500	19.2	22.9	15.3	10.6	-1.6	48.6
PAPA014	2013	630	14.9	18.3	10.3	5.8	-2.9	46.9
PAPA014	2013	800	15.4	19.4	8.7	5.4	-2.1	41.9
PAPA014	2013	1000	16.1	20.4	8.7	4.7	-1.8	38.4
PAPA014	2013	1250	17.7	21.8	11.7	5.1	-1.4	42.4
PAPA014	2013	1600	18.2	22.1	11.0	4.2	-0.9	48.6
PAPA014	2013	2000	14.3	17.6	8.2	2.8	-0.4	51.8
PAPA014	2013	2500	10.5	12.8	5.2	2.1	0.3	53.9
PAPA014	2013	3150	9.4	12.2	4.5	2.9	1.3	52.6
PAPA014	2013	4000	4.8	4.6	3.4	3.0	2.2	52.8
PAPA014	2013	5000	4.6	4.3	3.9	3.7	1.9	57.1
PAPA014	2013	6300	4.8	4.7	4.5	4.4	1.1	43.7
PAPA014	2013	8000	5.2	5.2	5.0	4.9	0.6	40.0
PAPA014	2013	10000	5.3	5.5	5.3	5.2	-0.2	31.8
PAPA014	2013	12500	4.9	5.0	4.9	4.7	-0.5	33.1
PAPA014	2013	16000	2.8	2.9	2.8	2.6	-1.1	29.3
PAPA014	2013	20000	0.2	0.5	0.2	0.1	-1.0	22.6
PAPA015	2013	12.5	40.9	43.0	38.5	34.1	16.0	78.4
PAPA015	2013	15.8	44.0	46.4	41.9	35.8	16.8	76.1
PAPA015	2013	20	48.7	51.6	44.6	37.4	18.3	74.0
PAPA015	2013	25	38.3	40.9	35.0	29.0	14.2	71.8
PAPA015	2013	31.5	39.8	42.6	35.2	29.1	13.4	68.3
PAPA015	2013	40	32.5	34.7	28.9	24.8	11.5	65.4
PAPA015	2013	50	31.5	33.6	27.8	23.9	9.5	64.3
PAPA015	2013	63	30.8	33.0	27.2	23.2	8.9	66.8
PAPA015	2013	80	30.3	32.0	24.6	20.9	7.3	72.0
PAPA015	2013	100	28.0	29.9	23.4	19.1	3.6	71.5
PAPA015	2013	125	27.2	28.4	21.8	17.2	1.6	67.9
PAPA015	2013	160	24.8	25.8	19.0	13.5	-0.5	60.3
PAPA015	2013	200	23.2	23.7	17.2	11.3	-1.2	59.2
PAPA015	2013	250	19.7	21.8	12.4	6.9	-3.2	53.3
PAPA015	2013	315	16.5	17.8	8.5	3.5	-3.8	45.8
PAPA015	2013	400	14.9	13.3	5.0	1.7	-3.7	47.9

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA015	2013	500	13.5	9.5	3.3	0.1	-4.0	50.0
PAPA015	2013	630	11.5	7.0	1.0	-0.8	-3.8	46.0
PAPA015	2013	800	7.8	5.0	-0.5	-1.4	-3.8	41.4
PAPA015	2013	1000	3.2	1.9	-0.6	-1.3	-3.3	37.7
PAPA015	2013	1250	1.0	0.4	-0.7	-1.1	-2.6	37.1
PAPA015	2013	1600	1.0	1.0	0.0	-0.5	-1.9	38.1
PAPA015	2013	2000	2.2	1.6	0.9	0.5	-0.8	39.8
PAPA015	2013	2500	2.3	2.4	1.8	1.3	0.0	39.8
PAPA015	2013	3150	3.1	3.2	2.5	2.2	1.2	41.0
PAPA015	2013	4000	4.0	3.9	3.4	3.2	2.3	38.3
PAPA015	2013	5000	4.7	4.7	4.3	4.1	3.4	43.2
PAPA015	2013	6300	5.2	5.4	5.0	4.8	3.8	39.0
PAPA015	2013	8000	5.8	5.9	5.5	5.4	3.4	39.4
PAPA015	2013	10000	5.9	6.1	5.8	5.5	3.3	45.7
PAPA015	2013	12500	5.4	5.5	5.2	4.8	3.0	44.1
PAPA015	2013	16000	3.6	3.7	3.3	2.8	1.8	38.5
PAPA015	2013	20000	0.9	1.6	0.6	0.2	-0.5	35.6
PAPA016	2013	12.5	39.5	40.6	35.7	31.1	16.5	74.5
PAPA016	2013	15.8	41.2	43.4	37.0	32.4	22.3	71.8
PAPA016	2013	20	46.2	49.1	41.6	36.3	22.9	68.9
PAPA016	2013	25	37.9	39.6	33.6	29.9	20.2	65.2
PAPA016	2013	31.5	38.9	41.3	34.3	29.8	18.0	65.9
PAPA016	2013	40	34.7	35.9	30.6	27.0	15.8	58.3
PAPA016	2013	50	33.4	36.4	29.8	25.2	13.9	58.7
PAPA016	2013	63	34.0	36.6	29.9	24.9	12.7	66.1
PAPA016	2013	80	33.3	35.7	28.9	25.0	9.2	71.4
PAPA016	2013	100	32.6	34.6	28.3	24.6	7.0	75.7
PAPA016	2013	125	30.5	32.7	26.6	23.1	4.4	73.4
PAPA016	2013	160	28.4	29.3	23.7	20.2	2.2	64.3
PAPA016	2013	200	25.6	27.8	21.9	17.7	0.2	56.5
PAPA016	2013	250	20.7	21.4	17.1	12.4	-3.3	52.6
PAPA016	2013	315	15.4	17.3	13.3	7.7	-4.4	46.4
PAPA016	2013	400	12.9	13.1	8.6	2.5	-4.5	52.3
PAPA016	2013	500	11.0	9.1	2.5	-0.8	-4.5	48.1
PAPA016	2013	630	9.7	9.2	1.1	-1.4	-4.0	40.4
PAPA016	2013	800	6.4	9.4	1.5	-1.0	-3.2	42.0
PAPA016	2013	1000	5.7	8.3	1.2	-0.5	-2.4	38.5
PAPA016	2013	1250	5.6	6.9	1.0	-0.1	-1.6	38.7
PAPA016	2013	1600	5.1	6.2	1.5	0.8	-0.6	48.1
PAPA016	2013	2000	4.0	4.4	2.1	1.5	0.4	37.8

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA016	2013	2500	3.4	3.8	2.8	2.3	1.3	35.5
PAPA016	2013	3150	3.8	4.1	3.5	3.1	2.2	35.0
PAPA016	2013	4000	4.5	4.7	4.1	3.9	3.2	33.2
PAPA016	2013	5000	5.2	5.3	4.8	4.5	3.6	37.7
PAPA016	2013	6300	5.4	5.6	5.2	5.0	3.5	38.0
PAPA016	2013	8000	5.4	5.6	5.3	5.1	3.6	41.3
PAPA016	2013	10000	5.1	5.4	5.0	4.8	3.1	35.5
PAPA016	2013	12500	4.4	4.7	4.3	4.1	2.8	35.7
PAPA016	2013	16000	3.4	3.8	3.3	3.1	2.5	33.5
PAPA016	2013	20000	2.2	2.6	2.0	1.7	1.2	32.9
PAPA017	2013	12.5	48.5	50.6	44.1	39.3	25.3	78.3
PAPA017	2013	15.8	46.8	49.7	44.1	39.3	25.1	77.6
PAPA017	2013	20	56.3	60.8	50.8	46.2	29.6	75.9
PAPA017	2013	25	47.7	50.3	46.3	42.8	27.6	70.6
PAPA017	2013	31.5	54.5	58.2	52.7	46.8	26.1	69.4
PAPA017	2013	40	42.7	45.1	41.8	38.0	24.6	64.5
PAPA017	2013	50	39.1	41.5	37.7	34.8	24.1	63.8
PAPA017	2013	63	37.9	40.0	36.8	33.7	21.8	62.8
PAPA017	2013	80	34.1	36.7	32.8	29.2	17.2	68.7
PAPA017	2013	100	32.7	35.5	30.1	26.7	13.4	69.9
PAPA017	2013	125	31.8	34.8	29.2	25.6	7.5	74.7
PAPA017	2013	160	30.0	32.3	27.6	24.0	4.5	71.3
PAPA017	2013	200	28.5	30.6	26.5	22.5	4.5	57.8
PAPA017	2013	250	24.5	26.9	23.0	19.2	1.1	55.1
PAPA017	2013	315	20.6	23.5	18.9	15.6	-1.1	47.9
PAPA017	2013	400	17.2	19.1	15.1	11.1	-3.0	49.2
PAPA017	2013	500	13.8	14.8	9.3	6.1	-3.4	47.3
PAPA017	2013	630	8.5	10.7	4.9	1.2	-3.4	41.4
PAPA017	2013	800	6.7	8.5	2.9	-0.1	-3.1	39.4
PAPA017	2013	1000	6.1	9.1	1.7	-0.1	-2.1	50.9
PAPA017	2013	1250	5.2	7.7	1.3	0.3	-1.3	42.2
PAPA017	2013	1600	4.7	5.6	1.6	1.0	-0.5	37.5
PAPA017	2013	2000	3.8	3.8	2.3	1.7	0.6	33.7
PAPA017	2013	2500	3.6	3.6	2.9	2.5	1.6	35.2
PAPA017	2013	3150	3.9	4.1	3.7	3.3	2.5	48.5
PAPA017	2013	4000	4.8	4.8	4.4	4.1	3.2	38.5
PAPA017	2013	5000	5.6	5.3	4.9	4.7	2.7	45.2
PAPA017	2013	6300	5.5	5.5	5.2	5.0	2.7	41.5
PAPA017	2013	8000	5.3	5.5	5.3	5.1	2.2	29.5
PAPA017	2013	10000	5.1	5.2	5.0	4.9	2.4	26.2

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA017	2013	12500	4.6	4.7	4.5	4.3	1.9	26.2
PAPA017	2013	16000	3.8	3.9	3.6	3.5	1.8	23.6
PAPA017	2013	20000	2.6	3.0	2.4	2.3	1.7	20.5
PAPA018	2013	12.5	46.5	47.9	41.8	36.8	19.0	78.4
PAPA018	2013	15.8	47.7	50.1	44.7	38.4	23.7	75.3
PAPA018	2013	20	54.0	58.5	49.3	45.1	29.4	75.1
PAPA018	2013	25	43.3	45.5	41.0	36.5	22.0	70.9
PAPA018	2013	31.5	48.1	51.6	45.4	39.5	23.7	69.4
PAPA018	2013	40	40.6	42.7	37.8	34.3	21.0	65.1
PAPA018	2013	50	38.1	40.6	36.0	32.1	20.6	64.2
PAPA018	2013	63	38.0	40.8	34.7	30.7	17.8	66.0
PAPA018	2013	80	34.9	37.8	31.5	26.4	14.1	68.8
PAPA018	2013	100	34.6	37.3	29.8	25.2	12.9	77.6
PAPA018	2013	125	32.2	35.0	28.8	24.0	11.6	76.8
PAPA018	2013	160	30.8	32.7	26.1	22.4	8.4	60.3
PAPA018	2013	200	29.6	32.4	26.2	21.8	7.6	68.3
PAPA018	2013	250	24.8	28.0	22.7	18.0	2.7	63.9
PAPA018	2013	315	21.8	24.3	19.3	15.0	-0.1	52.9
PAPA018	2013	400	16.6	19.1	13.9	9.8	-3.3	57.8
PAPA018	2013	500	11.5	14.6	9.1	4.7	-3.8	59.7
PAPA018	2013	630	8.7	10.8	5.0	1.0	-3.9	52.9
PAPA018	2013	800	7.7	10.7	2.8	-0.3	-3.6	39.9
PAPA018	2013	1000	6.0	8.3	0.5	-1.1	-2.9	38.3
PAPA018	2013	1250	4.4	6.8	-0.2	-0.9	-2.4	34.1
PAPA018	2013	1600	3.5	3.8	0.2	-0.4	-1.5	35.5
PAPA018	2013	2000	2.6	3.0	0.9	0.3	-0.7	37.3
PAPA018	2013	2500	2.4	2.6	1.5	1.1	0.2	36.9
PAPA018	2013	3150	2.7	2.8	2.2	1.9	1.2	34.4
PAPA018	2013	4000	3.4	3.4	3.0	2.8	2.2	43.8
PAPA018	2013	5000	4.4	4.1	3.8	3.6	2.9	47.8
PAPA018	2013	6300	4.7	4.7	4.5	4.4	2.8	54.3
PAPA018	2013	8000	5.1	5.2	5.1	4.9	2.6	55.8
PAPA018	2013	10000	5.4	5.5	5.3	5.2	2.7	36.8
PAPA018	2013	12500	5.0	5.2	4.8	4.7	2.5	28.0
PAPA018	2013	16000	2.9	3.2	2.8	2.6	1.6	33.5
PAPA018	2013	20000	0.4	0.7	0.2	0.0	-0.4	19.2
PAPA019	2013	12.5	41.5	43.7	38.5	33.9	16.2	73.2
PAPA019	2013	15.8	42.2	44.9	40.0	34.9	19.9	69.7
PAPA019	2013	20	49.9	52.9	43.9	39.5	22.6	71.7
PAPA019	2013	25	39.6	42.2	36.7	32.1	20.7	63.8

Appendix D. One-third Octave Band Metrics, PAPA Leks, April 2013.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA019	2013	31.5	42.2	45.2	39.5	33.6	20.7	63.6
PAPA019	2013	40	36.8	39.1	34.3	29.6	18.5	60.9
PAPA019	2013	50	36.1	39.0	33.1	28.8	16.6	59.7
PAPA019	2013	63	36.4	38.6	32.9	28.5	18.5	65.6
PAPA019	2013	80	34.0	36.8	30.8	26.7	14.5	76.9
PAPA019	2013	100	32.7	35.3	28.8	24.9	14.3	74.5
PAPA019	2013	125	31.0	33.1	27.1	22.5	11.3	71.6
PAPA019	2013	160	28.6	29.4	24.5	20.0	7.8	60.1
PAPA019	2013	200	25.6	27.6	22.5	18.2	4.8	68.0
PAPA019	2013	250	21.1	23.4	18.5	14.9	1.1	65.3
PAPA019	2013	315	18.0	20.5	14.7	10.8	-1.9	52.1
PAPA019	2013	400	13.1	16.1	10.0	5.8	-3.3	56.2
PAPA019	2013	500	9.8	12.2	5.4	1.0	-3.9	56.8
PAPA019	2013	630	7.4	8.6	1.9	-1.4	-3.6	52.4
PAPA019	2013	800	5.9	8.2	0.5	-1.5	-3.3	48.5
PAPA019	2013	1000	6.6	7.7	0.2	-1.0	-2.4	50.7
PAPA019	2013	1250	6.2	6.9	0.4	-0.3	-1.6	53.4
PAPA019	2013	1600	4.8	5.9	1.1	0.5	-0.7	54.4
PAPA019	2013	2000	3.0	3.5	1.8	1.3	0.3	49.9
PAPA019	2013	2500	2.8	3.1	2.5	2.0	1.3	43.8
PAPA019	2013	3150	3.4	3.7	3.2	2.9	2.1	35.2
PAPA019	2013	4000	4.0	4.3	3.9	3.6	2.0	37.0
PAPA019	2013	5000	4.5	4.7	4.4	4.2	2.4	35.9
PAPA019	2013	6300	4.8	4.9	4.7	4.5	1.4	37.7
PAPA019	2013	8000	4.7	4.8	4.6	4.4	1.1	29.6
PAPA019	2013	10000	4.2	4.5	4.2	4.0	0.5	32.1
PAPA019	2013	12500	3.6	3.8	3.5	3.3	0.0	28.3
PAPA019	2013	16000	2.7	2.9	2.5	2.3	-0.4	26.5
PAPA019	2013	20000	1.1	1.4	0.9	0.6	-0.3	26.4

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA001	2014	12.5	47.9	50.3	44.9	39.9	25.2	83.9
PAPA001	2014	15.8	54.6	57.4	53.8	49.6	30.7	79.1
PAPA001	2014	20	56.9	59.3	55.7	51.9	35.8	81.9
PAPA001	2014	25	51.2	53.2	50.1	47.5	34.2	73.0
PAPA001	2014	31.5	61.9	65.3	60.8	54.2	37.5	78.1
PAPA001	2014	40	44.4	46.5	43.1	40.4	28.4	68.2
PAPA001	2014	50	40.4	42.8	39.4	36.9	20.4	63.2
PAPA001	2014	63	40.3	43.4	38.2	34.3	18.5	69.5
PAPA001	2014	80	37.4	38.6	31.5	29.1	13.3	69.5
PAPA001	2014	100	34.2	36.2	31.8	28.2	11.0	72.3
PAPA001	2014	125	31.3	33.2	28.6	25.1	7.7	62.2
PAPA001	2014	160	27.8	28.5	23.6	20.9	4.7	58.9
PAPA001	2014	200	26.0	26.5	22.2	18.9	0.0	60.8
PAPA001	2014	250	23.8	23.9	18.9	16.3	0.0	55.9
PAPA001	2014	315	21.3	19.8	16.8	14.2	0.0	51.8
PAPA001	2014	400	19.1	18.6	14.2	11.9	0.0	57.4
PAPA001	2014	500	16.5	16.2	10.7	7.7	0.0	53.6
PAPA001	2014	630	13.9	15.1	8.3	4.7	0.0	48.7
PAPA001	2014	800	12.6	14.5	8.3	5.9	0.0	43.8
PAPA001	2014	1000	11.2	12.2	7.7	5.9	0.0	49.2
PAPA001	2014	1250	8.0	9.4	5.9	4.7	2.9	50.3
PAPA001	2014	1600	7.2	8.3	5.9	4.7	2.9	37.9
PAPA001	2014	2000	7.3	7.7	6.9	5.9	4.7	51.9
PAPA001	2014	2500	7.6	7.7	6.9	6.9	5.9	50.5
PAPA001	2014	3150	8.3	8.3	7.7	7.7	6.9	41.8
PAPA001	2014	4000	8.7	8.9	8.3	8.3	7.7	37.7
PAPA001	2014	5000	9.1	9.4	8.9	8.9	8.3	37.7
PAPA001	2014	6300	9.4	9.4	9.4	8.9	8.3	46.4
PAPA001	2014	8000	9.3	9.4	9.4	8.9	8.9	40.7
PAPA001	2014	10000	9.2	9.4	8.9	8.9	8.3	34.7
PAPA001	2014	12500	9.3	9.4	9.4	8.9	8.9	35.8
PAPA001	2014	16000	9.9	9.9	9.9	9.4	8.9	37.2
PAPA001	2014	20000	12.9	13.1	12.9	12.7	11.9	44.7
PAPA002	2014	12.5	53.4	56.0	49.0	41.9	25.9	90.6
PAPA002	2014	15.8	55.0	57.8	53.3	49.0	32.2	88.0
PAPA002	2014	20	57.2	59.8	56.4	52.7	35.1	85.6
PAPA002	2014	25	49.9	53.7	45.0	41.1	30.3	82.7
PAPA002	2014	31.5	48.0	51.0	46.3	41.8	28.5	77.7

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA002	2014	40	41.7	44.4	40.5	36.6	25.6	75.7
PAPA002	2014	50	39.4	41.8	37.9	34.6	23.4	71.0
PAPA002	2014	63	36.8	39.0	34.2	31.5	20.0	68.0
PAPA002	2014	80	33.7	36.2	31.2	28.0	14.6	74.9
PAPA002	2014	100	32.3	33.6	28.6	25.2	11.9	66.1
PAPA002	2014	125	30.4	31.8	26.2	23.3	9.5	60.4
PAPA002	2014	160	27.1	28.7	23.5	20.2	6.5	56.6
PAPA002	2014	200	25.8	26.9	21.9	18.6	5.3	58.2
PAPA002	2014	250	23.3	25.4	19.0	15.5	3.5	55.6
PAPA002	2014	315	20.7	22.9	17.8	14.3	0.0	55.8
PAPA002	2014	400	20.1	18.5	13.5	9.5	0.0	56.5
PAPA002	2014	500	19.1	16.4	8.9	5.3	0.0	59.5
PAPA002	2014	630	16.2	15.0	7.5	3.5	0.0	55.3
PAPA002	2014	800	11.6	13.3	6.5	3.5	0.0	45.6
PAPA002	2014	1000	7.7	10.5	5.3	3.5	0.0	42.6
PAPA002	2014	1250	6.2	7.5	5.3	3.5	0.0	43.0
PAPA002	2014	1600	7.0	7.5	5.3	5.3	3.5	47.5
PAPA002	2014	2000	7.6	8.3	6.5	6.5	3.5	57.6
PAPA002	2014	2500	8.1	8.3	7.5	7.5	5.3	57.7
PAPA002	2014	3150	8.6	8.9	8.3	8.3	6.5	47.5
PAPA002	2014	4000	9.6	9.5	8.9	8.9	7.5	48.1
PAPA002	2014	5000	10.4	9.5	9.5	8.9	8.3	48.7
PAPA002	2014	6300	9.8	10.0	9.5	9.5	8.3	49.2
PAPA002	2014	8000	10.0	10.0	9.5	9.5	8.3	50.4
PAPA002	2014	10000	9.9	10.0	10.0	9.5	8.3	37.3
PAPA002	2014	12500	10.0	10.0	10.0	9.5	8.9	37.7
PAPA002	2014	16000	10.4	10.5	10.0	10.0	9.5	38.3
PAPA002	2014	20000	13.0	12.8	12.8	12.5	12.2	44.4
PAPA003	2014	12.5	49.1	52.2	46.4	41.1	22.4	76.9
PAPA003	2014	15.8	54.4	57.4	53.5	48.5	29.6	76.1
PAPA003	2014	20	57.0	59.4	55.5	51.8	35.9	73.4
PAPA003	2014	25	51.5	54.5	48.9	44.0	30.4	71.9
PAPA003	2014	31.5	53.3	56.4	52.4	48.2	34.4	71.3
PAPA003	2014	40	45.4	47.6	44.4	40.8	32.3	69.0
PAPA003	2014	50	45.4	48.1	43.8	40.5	31.0	67.2
PAPA003	2014	63	45.5	48.4	43.8	39.8	28.7	66.1
PAPA003	2014	80	41.4	43.1	37.4	34.3	22.8	75.0
PAPA003	2014	100	40.2	41.4	36.0	32.3	21.1	70.4
PAPA003	2014	125	37.2	39.1	34.5	30.6	17.5	65.2
PAPA003	2014	160	34.1	36.3	31.1	27.4	16.3	63.8

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA003	2014	200	31.2	33.4	28.6	25.0	14.2	64.7
PAPA003	2014	250	28.3	30.5	25.9	22.2	12.0	56.9
PAPA003	2014	315	25.9	28.2	23.8	20.0	9.5	51.3
PAPA003	2014	400	22.6	24.7	20.0	16.2	6.0	48.6
PAPA003	2014	500	19.8	20.7	16.1	12.0	1.8	50.4
PAPA003	2014	630	16.6	17.4	12.9	8.7	-0.5	47.1
PAPA003	2014	800	12.5	14.1	9.2	4.5	-1.8	47.7
PAPA003	2014	1000	9.5	11.2	6.1	1.8	-1.8	45.7
PAPA003	2014	1250	5.3	7.8	3.1	0.4	-1.3	37.1
PAPA003	2014	1600	3.6	4.6	1.3	0.6	-0.7	40.4
PAPA003	2014	2000	3.5	5.3	1.7	1.2	0.0	35.3
PAPA003	2014	2500	3.7	5.0	2.3	1.8	-0.1	42.3
PAPA003	2014	3150	3.5	3.9	2.7	2.3	-0.1	36.0
PAPA003	2014	4000	5.0	4.7	3.0	2.6	-0.8	41.2
PAPA003	2014	5000	6.2	4.3	3.1	2.8	-1.2	45.8
PAPA003	2014	6300	3.9	3.5	3.2	2.9	-1.5	42.3
PAPA003	2014	8000	3.2	3.4	3.2	3.1	-1.6	28.4
PAPA003	2014	10000	3.6	3.7	3.6	3.4	-1.6	31.1
PAPA003	2014	12500	3.8	3.9	3.8	3.5	-1.5	31.7
PAPA003	2014	16000	1.9	2.0	1.9	1.8	-1.7	32.0
PAPA003	2014	20000	-1.5	-1.3	-1.6	-1.7	-2.2	29.3
PAPA004	2014	12.5	48.8	51.3	43.9	36.1	21.7	76.8
PAPA004	2014	15.8	49.7	52.5	45.2	39.1	26.1	73.9
PAPA004	2014	20	51.8	54.7	49.0	45.2	30.1	75.6
PAPA004	2014	25	45.3	47.9	40.2	36.4	23.8	71.0
PAPA004	2014	31.5	46.9	50.2	44.1	38.5	23.9	71.4
PAPA004	2014	40	40.8	43.4	38.4	34.2	21.6	67.3
PAPA004	2014	50	38.7	41.2	34.9	31.5	17.8	66.2
PAPA004	2014	63	36.9	39.4	34.5	30.3	18.2	67.0
PAPA004	2014	80	35.4	37.5	32.3	29.0	13.7	68.0
PAPA004	2014	100	34.2	36.5	31.8	28.2	15.1	79.5
PAPA004	2014	125	33.0	34.2	29.3	26.2	10.4	80.5
PAPA004	2014	160	30.2	31.5	26.0	22.7	7.7	76.3
PAPA004	2014	200	27.5	29.7	23.8	20.1	4.6	69.2
PAPA004	2014	250	25.5	26.3	22.1	17.8	4.2	69.5
PAPA004	2014	315	22.3	22.8	18.8	15.1	-0.3	63.1
PAPA004	2014	400	19.1	19.4	15.1	12.1	-2.2	66.0
PAPA004	2014	500	14.1	15.0	10.3	6.7	-3.1	68.8
PAPA004	2014	630	10.9	13.5	6.6	3.2	-3.3	66.1
PAPA004	2014	800	11.8	15.6	4.7	0.8	-3.1	60.7

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA004	2014	1000	13.3	15.1	3.4	0.1	-2.5	54.4
PAPA004	2014	1250	12.3	12.7	2.7	0.4	-1.7	57.5
PAPA004	2014	1600	10.1	10.3	2.1	0.8	-0.8	52.8
PAPA004	2014	2000	7.8	9.6	2.3	1.3	0.1	53.4
PAPA004	2014	2500	6.7	6.3	2.7	2.0	1.0	50.5
PAPA004	2014	3150	7.9	5.1	3.1	2.8	1.5	59.9
PAPA004	2014	4000	5.3	4.3	3.9	3.7	0.9	51.9
PAPA004	2014	5000	5.1	4.9	4.7	4.5	1.4	39.9
PAPA004	2014	6300	5.4	5.5	5.3	5.2	1.2	30.7
PAPA004	2014	8000	5.9	6.0	5.8	5.7	1.5	28.8
PAPA004	2014	10000	6.3	6.4	6.2	6.1	0.6	29.5
PAPA004	2014	12500	6.3	6.4	6.2	6.0	0.7	30.1
PAPA004	2014	16000	5.6	5.9	5.6	5.4	0.8	31.3
PAPA004	2014	20000	3.8	4.5	3.6	3.3	0.6	25.3
PAPA005	2014	12.5	44.3	47.3	41.1	36.4	21.6	78.3
PAPA005	2014	15.8	48.6	51.2	47.0	42.7	27.0	75.9
PAPA005	2014	20	57.5	59.5	56.3	52.4	33.6	73.9
PAPA005	2014	25	60.9	63.5	59.7	55.7	27.6	76.1
PAPA005	2014	31.5	48.5	51.6	46.4	41.6	27.7	70.6
PAPA005	2014	40	43.6	45.7	41.7	39.3	25.7	68.6
PAPA005	2014	50	46.3	49.1	46.2	40.4	27.6	66.8
PAPA005	2014	63	39.7	42.4	37.9	34.6	23.7	69.6
PAPA005	2014	80	37.7	40.2	34.4	31.0	21.4	74.5
PAPA005	2014	100	36.4	35.9	31.2	28.5	17.0	78.1
PAPA005	2014	125	33.8	34.9	29.4	25.7	12.9	76.5
PAPA005	2014	160	31.3	32.7	27.5	23.2	10.1	74.5
PAPA005	2014	200	29.0	30.3	24.9	20.6	6.5	64.1
PAPA005	2014	250	26.6	27.8	21.5	18.4	4.4	67.3
PAPA005	2014	315	23.0	24.7	19.1	15.5	1.8	61.5
PAPA005	2014	400	18.6	20.8	14.4	11.3	-0.2	61.2
PAPA005	2014	500	17.2	17.4	10.4	6.9	-2.3	64.7
PAPA005	2014	630	14.3	15.0	7.0	3.2	-2.9	63.2
PAPA005	2014	800	9.0	11.2	3.6	0.7	-2.9	57.0
PAPA005	2014	1000	4.7	6.0	1.6	0.1	-2.3	45.6
PAPA005	2014	1250	2.6	3.1	0.9	0.4	-1.6	47.6
PAPA005	2014	1600	2.8	3.2	1.3	0.7	-0.8	41.4
PAPA005	2014	2000	7.7	8.5	2.4	1.8	0.1	41.8
PAPA005	2014	2500	8.5	9.3	3.2	2.6	1.0	47.4
PAPA005	2014	3150	9.7	6.5	3.8	3.3	1.9	55.1
PAPA005	2014	4000	12.5	7.4	4.5	4.0	1.3	53.0

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA005	2014	5000	11.3	7.6	5.0	4.6	1.4	61.6
PAPA005	2014	6300	7.8	6.1	5.4	5.2	1.3	50.2
PAPA005	2014	8000	6.1	6.1	5.9	5.7	0.5	41.4
PAPA005	2014	10000	6.4	6.4	6.2	6.1	0.2	31.3
PAPA005	2014	12500	6.5	6.5	6.3	6.1	0.0	31.9
PAPA005	2014	16000	5.9	5.9	5.7	5.5	0.3	33.1
PAPA005	2014	20000	3.7	3.8	3.6	3.5	0.0	35.2
PAPA006	2014	12.5	51.9	55.2	48.1	42.3	27.3	96.7
PAPA006	2014	15.8	53.6	56.0	52.9	48.7	32.9	93.4
PAPA006	2014	20	61.3	63.3	61.0	57.6	43.2	94.5
PAPA006	2014	25	56.3	57.8	55.6	52.4	40.9	89.1
PAPA006	2014	31.5	51.9	53.9	50.8	46.8	35.1	86.2
PAPA006	2014	40	50.1	52.2	48.7	45.0	34.9	86.7
PAPA006	2014	50	47.1	48.6	45.8	42.1	34.4	79.4
PAPA006	2014	63	45.0	47.0	44.4	42.0	33.1	79.1
PAPA006	2014	80	41.7	43.2	40.6	37.8	29.4	76.1
PAPA006	2014	100	40.6	42.6	39.9	37.2	26.9	71.3
PAPA006	2014	125	37.8	39.4	36.9	34.1	25.4	69.0
PAPA006	2014	160	34.9	36.5	33.9	31.2	21.6	64.7
PAPA006	2014	200	32.1	33.9	31.0	28.4	18.1	66.6
PAPA006	2014	250	29.0	31.1	27.6	24.9	14.5	63.9
PAPA006	2014	315	28.7	30.7	27.9	25.5	11.0	59.0
PAPA006	2014	400	24.1	25.9	22.8	19.9	7.1	59.9
PAPA006	2014	500	17.4	18.7	15.1	12.6	2.3	64.9
PAPA006	2014	630	13.6	15.0	9.9	7.4	0.0	60.4
PAPA006	2014	800	11.7	13.3	6.3	4.1	0.0	51.4
PAPA006	2014	1000	8.5	7.7	4.1	2.3	0.0	51.6
PAPA006	2014	1250	8.7	6.7	4.1	4.1	2.3	51.4
PAPA006	2014	1600	11.1	8.0	5.3	4.1	4.1	51.5
PAPA006	2014	2000	9.5	9.3	6.3	5.3	4.1	51.0
PAPA006	2014	2500	10.3	9.9	7.1	6.3	5.3	62.5
PAPA006	2014	3150	8.6	8.3	7.7	7.1	6.3	65.8
PAPA006	2014	4000	8.7	8.3	8.3	7.7	7.1	60.4
PAPA006	2014	5000	9.0	8.8	8.3	8.3	7.7	44.5
PAPA006	2014	6300	8.8	8.8	8.8	8.3	8.3	42.6
PAPA006	2014	8000	8.9	8.8	8.8	8.3	8.3	40.0
PAPA006	2014	10000	8.7	8.8	8.8	8.3	8.3	37.1
PAPA006	2014	12500	8.8	8.8	8.8	8.3	8.3	36.7
PAPA006	2014	16000	9.7	9.3	9.3	8.8	8.8	38.3
PAPA006	2014	20000	12.2	12.1	12.1	11.8	11.3	44.5

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA007	2014	12.5	49.0	51.8	45.8	40.2	27.5	76.2
PAPA007	2014	15.8	51.0	53.7	49.0	44.8	30.0	74.3
PAPA007	2014	20	52.0	53.8	50.7	47.5	34.6	72.0
PAPA007	2014	25	50.2	53.7	47.7	43.7	31.1	72.1
PAPA007	2014	31.5	49.8	52.9	48.1	43.9	32.7	69.1
PAPA007	2014	40	44.1	46.9	42.6	39.9	29.2	67.1
PAPA007	2014	50	44.6	47.5	40.8	37.1	28.2	69.4
PAPA007	2014	63	40.7	43.3	38.3	35.1	24.1	70.8
PAPA007	2014	80	39.1	41.0	35.7	32.5	23.4	76.9
PAPA007	2014	100	37.5	40.4	35.2	31.9	21.6	66.3
PAPA007	2014	125	34.3	36.7	32.1	28.9	20.8	65.4
PAPA007	2014	160	31.6	34.4	29.7	26.7	16.4	58.9
PAPA007	2014	200	29.6	32.4	28.2	25.1	13.5	57.6
PAPA007	2014	250	26.5	28.4	25.0	22.3	10.8	56.1
PAPA007	2014	315	23.3	25.6	22.3	18.8	4.2	54.2
PAPA007	2014	400	20.6	23.5	19.6	16.0	-0.8	50.6
PAPA007	2014	500	16.9	19.5	14.9	11.7	-2.6	45.5
PAPA007	2014	630	11.8	15.1	10.5	5.7	-3.9	42.9
PAPA007	2014	800	9.8	11.5	7.6	2.7	-3.3	39.6
PAPA007	2014	1000	6.8	8.5	5.4	1.7	-2.7	48.0
PAPA007	2014	1250	6.0	6.1	2.1	0.5	-1.6	45.9
PAPA007	2014	1600	5.3	6.5	2.4	1.2	-0.9	36.7
PAPA007	2014	2000	7.5	7.8	2.0	1.3	-0.6	43.9
PAPA007	2014	2500	11.6	9.6	2.3	1.9	-1.0	58.1
PAPA007	2014	3150	8.3	6.3	2.7	2.2	-1.5	63.6
PAPA007	2014	4000	7.7	5.1	3.0	2.5	-1.8	63.7
PAPA007	2014	5000	4.2	3.5	3.0	2.7	-1.8	56.5
PAPA007	2014	6300	4.2	3.4	3.1	2.9	-1.8	51.2
PAPA007	2014	8000	3.3	3.4	3.2	3.0	-2.0	58.4
PAPA007	2014	10000	3.6	3.7	3.5	3.3	-2.0	34.1
PAPA007	2014	12500	3.6	3.9	3.6	3.3	-2.2	31.9
PAPA007	2014	16000	2.1	2.3	1.9	1.5	-2.7	36.4
PAPA007	2014	20000	-0.3	0.3	-1.1	-1.6	-3.1	29.4
PAPA008	2014	12.5	51.0	54.5	48.0	41.8	23.2	76.0
PAPA008	2014	15.8	53.9	57.0	52.1	46.4	28.5	73.9
PAPA008	2014	20	54.2	57.6	52.1	47.5	34.1	72.4
PAPA008	2014	25	48.2	51.4	46.6	42.8	27.5	71.4
PAPA008	2014	31.5	47.0	49.9	45.3	41.8	28.0	70.2
PAPA008	2014	40	45.3	47.7	44.6	41.0	24.6	71.7
PAPA008	2014	50	39.8	42.1	37.5	34.6	20.5	71.6

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA008	2014	63	38.2	40.4	36.1	33.1	18.7	69.1
PAPA008	2014	80	36.2	38.7	33.9	30.6	17.7	67.7
PAPA008	2014	100	36.1	38.6	34.3	31.3	15.3	68.6
PAPA008	2014	125	32.2	34.2	29.9	27.5	13.3	63.2
PAPA008	2014	160	29.6	31.2	27.0	24.0	11.0	61.0
PAPA008	2014	200	27.3	29.5	25.2	22.2	9.3	60.7
PAPA008	2014	250	24.8	26.7	22.7	19.3	6.7	54.7
PAPA008	2014	315	21.9	24.3	19.4	16.2	2.5	52.2
PAPA008	2014	400	18.8	21.3	15.8	12.4	0.1	49.0
PAPA008	2014	500	16.4	17.6	12.1	8.5	-1.8	47.1
PAPA008	2014	630	13.8	15.4	9.2	5.3	-2.6	44.6
PAPA008	2014	800	11.8	14.4	8.5	4.1	-2.8	46.9
PAPA008	2014	1000	10.3	13.0	6.8	2.4	-2.1	46.2
PAPA008	2014	1250	8.2	11.1	4.1	1.2	-1.8	52.0
PAPA008	2014	1600	6.3	9.1	2.6	1.0	-0.8	46.7
PAPA008	2014	2000	9.3	10.0	3.0	1.6	-1.5	47.9
PAPA008	2014	2500	9.1	10.6	3.6	2.1	-2.6	47.0
PAPA008	2014	3150	8.2	8.3	3.2	2.4	-2.3	44.4
PAPA008	2014	4000	7.5	6.7	3.0	2.6	-2.4	48.5
PAPA008	2014	5000	7.4	5.6	3.1	2.8	-2.3	49.3
PAPA008	2014	6300	5.5	4.2	3.2	2.9	-2.0	43.9
PAPA008	2014	8000	3.7	3.6	3.3	3.1	-2.2	54.5
PAPA008	2014	10000	3.7	3.9	3.7	3.4	-2.6	36.6
PAPA008	2014	12500	3.8	4.2	3.7	3.4	-3.4	35.1
PAPA008	2014	16000	1.8	2.3	1.8	1.2	-4.4	37.1
PAPA008	2014	20000	0.2	1.5	-0.3	-1.1	-4.5	31.6
PAPA009	2014	12.5	51.5	54.3	48.7	42.3	22.7	75.9
PAPA009	2014	15.8	53.1	56.6	51.1	46.4	29.9	74.3
PAPA009	2014	20	56.5	59.5	55.2	50.4	33.6	73.8
PAPA009	2014	25	48.6	51.8	46.4	41.3	27.0	72.4
PAPA009	2014	31.5	47.5	50.5	45.8	41.9	28.7	70.6
PAPA009	2014	40	42.6	44.8	39.8	36.3	22.8	68.6
PAPA009	2014	50	40.2	43.0	37.0	33.6	21.0	67.4
PAPA009	2014	63	37.8	40.7	34.8	31.2	16.4	65.0
PAPA009	2014	80	35.7	38.3	33.1	29.1	14.1	62.9
PAPA009	2014	100	34.0	36.7	31.8	28.9	14.2	64.2
PAPA009	2014	125	33.3	36.1	30.6	26.2	12.6	68.3
PAPA009	2014	160	31.1	33.0	28.3	23.6	10.0	57.7
PAPA009	2014	200	27.2	29.8	25.3	21.9	8.5	55.1
PAPA009	2014	250	24.4	27.5	22.5	17.7	6.8	55.4

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA009	2014	315	21.7	24.4	19.6	15.3	1.5	50.7
PAPA009	2014	400	19.7	22.8	17.4	12.5	-1.3	48.6
PAPA009	2014	500	14.3	17.5	11.7	7.6	-3.9	47.4
PAPA009	2014	630	10.3	13.4	7.2	2.7	-4.0	45.1
PAPA009	2014	800	8.3	11.1	5.0	1.1	-3.4	42.2
PAPA009	2014	1000	7.0	10.9	3.1	0.7	-2.6	39.3
PAPA009	2014	1250	4.2	6.6	1.7	0.4	-1.8	38.6
PAPA009	2014	1600	5.3	6.0	1.5	0.8	-0.9	39.6
PAPA009	2014	2000	8.0	10.6	2.4	1.5	-0.1	52.0
PAPA009	2014	2500	9.1	10.5	2.7	2.1	-0.5	58.8
PAPA009	2014	3150	5.8	7.1	2.9	2.5	-1.8	52.7
PAPA009	2014	4000	6.1	6.3	3.1	2.7	-1.5	46.1
PAPA009	2014	5000	6.2	4.7	3.2	2.8	-1.9	46.7
PAPA009	2014	6300	3.6	3.7	3.2	2.9	-1.8	39.7
PAPA009	2014	8000	3.4	3.5	3.3	3.1	-1.8	31.8
PAPA009	2014	10000	3.7	4.0	3.7	3.5	-2.2	31.1
PAPA009	2014	12500	3.9	4.3	3.9	3.5	-2.3	26.4
PAPA009	2014	16000	2.1	2.5	2.0	1.5	-2.7	24.2
PAPA009	2014	20000	-0.2	0.6	-0.7	-1.0	-2.9	22.1
PAPA010	2014	12.5	51.8	54.8	49.2	42.2	11.7	78.9
PAPA010	2014	15.8	54.7	57.8	52.4	47.7	9.5	76.9
PAPA010	2014	20	59.7	62.4	58.7	53.6	16.7	73.3
PAPA010	2014	25	48.0	50.4	45.7	41.3	2.0	72.4
PAPA010	2014	31.5	48.2	50.6	46.7	42.8	14.1	69.0
PAPA010	2014	40	42.9	45.1	40.6	37.4	4.9	69.3
PAPA010	2014	50	40.1	42.6	38.1	34.7	-7.3	66.5
PAPA010	2014	63	37.5	40.1	35.5	32.1	-6.8	64.2
PAPA010	2014	80	35.8	38.4	33.8	30.1	-7.0	63.3
PAPA010	2014	100	36.6	38.8	33.6	29.9	9.9	67.3
PAPA010	2014	125	38.7	41.4	36.4	33.2	16.3	73.8
PAPA010	2014	160	33.5	35.8	31.6	27.8	3.2	64.9
PAPA010	2014	200	29.7	32.4	27.7	24.4	-9.8	61.9
PAPA010	2014	250	28.6	31.1	26.4	22.3	-10.4	66.9
PAPA010	2014	315	25.2	28.3	22.8	18.3	-10.1	57.6
PAPA010	2014	400	23.5	26.3	19.6	15.0	-9.8	59.5
PAPA010	2014	500	19.6	22.2	16.4	11.4	-9.3	57.6
PAPA010	2014	630	17.2	19.8	13.6	7.9	-9.2	58.1
PAPA010	2014	800	16.4	19.4	12.8	6.1	-8.4	62.8
PAPA010	2014	1000	14.2	17.6	11.2	4.9	-8.1	88.2
PAPA010	2014	1250	12.2	15.8	8.7	2.9	-7.6	69.2

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA010	2014	1600	8.8	11.2	4.6	1.8	-7.1	71.0
PAPA010	2014	2000	7.9	10.8	3.8	2.1	-6.2	74.6
PAPA010	2014	2500	7.4	9.8	3.6	2.7	-5.5	64.4
PAPA010	2014	3150	8.3	8.7	4.0	3.3	-4.9	76.7
PAPA010	2014	4000	9.1	7.6	4.5	4.1	-4.4	67.3
PAPA010	2014	5000	8.9	6.9	5.1	4.8	-3.9	67.1
PAPA010	2014	6300	6.4	6.1	5.6	5.3	-3.7	62.4
PAPA010	2014	8000	6.1	6.2	6.0	5.7	-3.6	60.3
PAPA010	2014	10000	6.3	6.5	6.3	6.1	-3.8	57.9
PAPA010	2014	12500	6.4	6.6	6.4	6.1	-4.2	57.6
PAPA010	2014	16000	5.9	6.2	5.9	5.5	-4.9	60.8
PAPA010	2014	20000	4.1	4.5	3.9	3.6	-5.6	66.3
PAPA011	2014	12.5	44.3	47.1	42.8	37.5	21.3	79.9
PAPA011	2014	15.8	46.7	49.2	45.4	38.9	23.8	75.2
PAPA011	2014	20	47.1	49.7	45.4	39.0	26.8	73.9
PAPA011	2014	25	41.2	43.5	39.5	34.1	18.2	72.0
PAPA011	2014	31.5	43.7	46.8	40.4	35.1	18.7	67.8
PAPA011	2014	40	35.8	38.1	34.8	29.8	15.7	66.8
PAPA011	2014	50	32.3	34.5	31.1	26.9	12.6	64.1
PAPA011	2014	63	31.0	33.6	29.2	25.4	12.2	63.8
PAPA011	2014	80	29.2	31.7	27.5	23.5	12.9	63.3
PAPA011	2014	100	27.3	29.5	25.2	21.7	9.3	67.0
PAPA011	2014	125	26.1	27.5	22.0	19.7	7.4	69.4
PAPA011	2014	160	23.2	23.5	18.0	15.8	3.8	72.2
PAPA011	2014	200	20.8	20.3	16.7	13.8	2.0	63.8
PAPA011	2014	250	16.1	15.6	11.9	9.0	-1.1	58.2
PAPA011	2014	315	12.9	14.1	8.8	5.7	-2.1	56.5
PAPA011	2014	400	6.9	8.3	4.1	1.6	-3.3	58.9
PAPA011	2014	500	2.6	5.0	0.1	-1.5	-3.8	59.8
PAPA011	2014	630	-1.2	-0.3	-1.7	-2.3	-3.7	57.8
PAPA011	2014	800	-0.9	-0.2	-1.4	-2.0	-3.3	52.3
PAPA011	2014	1000	0.2	1.2	-0.9	-1.5	-2.5	46.3
PAPA011	2014	1250	1.0	1.9	-0.2	-0.8	-1.7	46.4
PAPA011	2014	1600	9.0	6.9	0.7	0.2	-0.9	56.4
PAPA011	2014	2000	15.0	15.4	1.5	1.1	0.1	69.8
PAPA011	2014	2500	20.2	15.7	2.3	2.0	1.0	70.9
PAPA011	2014	3150	13.5	11.6	3.1	2.9	0.8	71.0
PAPA011	2014	4000	9.7	8.1	4.0	3.7	1.1	69.5
PAPA011	2014	5000	6.3	6.3	4.7	4.5	0.1	64.1
PAPA011	2014	6300	6.2	5.8	5.4	5.0	0.0	54.5

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA011	2014	8000	6.0	6.0	5.8	5.6	0.0	57.9
PAPA011	2014	10000	6.3	6.4	6.2	6.0	0.5	46.8
PAPA011	2014	12500	6.2	6.3	6.2	6.0	0.9	43.6
PAPA011	2014	16000	5.5	5.6	5.5	5.3	1.0	40.0
PAPA011	2014	20000	3.3	3.4	3.3	3.3	1.5	40.6
PAPA012	2014	12.5	44.0	46.7	41.2	36.4	18.3	72.4
PAPA012	2014	15.8	47.8	50.6	46.5	42.0	24.5	71.5
PAPA012	2014	20	48.9	51.7	47.8	43.9	27.0	71.9
PAPA012	2014	25	42.1	44.9	39.5	36.0	19.8	69.3
PAPA012	2014	31.5	44.5	47.7	43.1	38.5	22.2	65.6
PAPA012	2014	40	35.6	37.8	34.2	31.1	18.9	63.6
PAPA012	2014	50	33.1	35.7	30.4	26.6	11.3	62.0
PAPA012	2014	63	33.2	35.7	29.9	25.8	8.1	67.7
PAPA012	2014	80	30.6	32.6	27.6	23.4	5.7	75.2
PAPA012	2014	100	29.3	31.2	25.7	22.2	3.8	76.5
PAPA012	2014	125	26.6	27.6	20.2	17.2	0.4	74.9
PAPA012	2014	160	24.7	25.6	16.2	13.1	-1.4	68.8
PAPA012	2014	200	22.9	23.4	15.1	11.6	-2.1	69.1
PAPA012	2014	250	20.2	20.5	10.7	6.9	-3.3	65.3
PAPA012	2014	315	17.5	16.2	6.3	3.5	-4.0	58.6
PAPA012	2014	400	14.6	12.7	4.2	1.4	-4.5	62.2
PAPA012	2014	500	12.2	8.1	1.3	-0.9	-4.2	63.7
PAPA012	2014	630	9.7	5.5	-0.1	-1.6	-4.1	58.3
PAPA012	2014	800	6.4	4.2	-0.5	-1.7	-4.1	49.2
PAPA012	2014	1000	2.2	2.3	-0.8	-1.4	-3.4	50.1
PAPA012	2014	1250	1.3	1.3	-0.5	-1.0	-2.8	44.7
PAPA012	2014	1600	1.9	2.2	0.2	-0.3	-1.9	51.3
PAPA012	2014	2000	3.1	3.0	1.1	0.6	-0.9	54.3
PAPA012	2014	2500	4.9	4.7	1.9	1.5	0.0	59.9
PAPA012	2014	3150	4.6	4.3	2.7	2.3	1.1	63.5
PAPA012	2014	4000	5.0	5.5	3.6	3.2	1.2	68.8
PAPA012	2014	5000	5.3	5.4	4.3	4.0	1.6	62.8
PAPA012	2014	6300	5.6	5.2	4.9	4.7	1.5	52.6
PAPA012	2014	8000	5.5	5.5	5.3	5.1	1.3	51.4
PAPA012	2014	10000	5.6	5.6	5.4	5.3	0.9	49.7
PAPA012	2014	12500	5.1	5.2	4.9	4.7	0.8	51.7
PAPA012	2014	16000	3.4	3.5	3.1	2.9	0.2	44.0
PAPA012	2014	20000	0.7	0.7	0.4	0.1	-0.8	47.5
PAPA013	2014	12.5	52.5	55.8	50.5	43.6	20.1	75.1
PAPA013	2014	15.8	55.7	59.4	53.9	49.0	29.0	73.0

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA013	2014	20	52.4	55.0	49.5	45.5	30.9	74.1
PAPA013	2014	25	47.3	50.5	44.9	39.8	25.7	70.4
PAPA013	2014	31.5	44.4	46.8	43.0	39.2	24.6	67.7
PAPA013	2014	40	38.6	40.8	37.3	34.3	19.6	65.1
PAPA013	2014	50	37.0	38.8	35.2	31.9	16.7	65.3
PAPA013	2014	63	36.9	39.1	34.4	30.6	12.2	78.8
PAPA013	2014	80	34.3	36.4	31.6	27.3	12.2	80.0
PAPA013	2014	100	37.0	38.3	33.0	28.6	12.0	75.3
PAPA013	2014	125	31.3	32.9	28.2	22.7	8.9	78.5
PAPA013	2014	160	27.9	29.5	24.5	19.2	6.1	68.6
PAPA013	2014	200	28.4	30.4	24.3	18.6	5.2	71.1
PAPA013	2014	250	23.3	24.6	20.2	15.5	2.2	67.3
PAPA013	2014	315	22.0	22.1	17.1	12.2	-0.8	58.6
PAPA013	2014	400	17.7	17.7	12.5	7.2	-2.4	57.2
PAPA013	2014	500	17.0	16.9	11.0	6.2	-3.5	56.4
PAPA013	2014	630	13.7	13.5	7.7	3.6	-3.4	54.0
PAPA013	2014	800	11.9	14.2	7.4	3.4	-2.7	45.8
PAPA013	2014	1000	12.2	15.6	8.8	4.1	-2.1	39.6
PAPA013	2014	1250	6.8	9.5	3.9	1.3	-1.3	40.0
PAPA013	2014	1600	3.9	5.7	1.9	0.9	-0.9	37.7
PAPA013	2014	2000	2.5	3.1	1.7	1.2	-0.6	46.9
PAPA013	2014	2500	3.2	2.8	2.0	1.6	-0.3	62.2
PAPA013	2014	3150	4.0	3.5	2.5	2.2	-0.6	69.0
PAPA013	2014	4000	4.1	3.9	2.9	2.6	-0.9	60.9
PAPA013	2014	5000	4.3	4.1	3.1	2.8	-1.0	56.5
PAPA013	2014	6300	4.1	3.7	3.2	2.9	-1.5	64.9
PAPA013	2014	8000	3.6	3.5	3.3	3.1	-1.6	59.0
PAPA013	2014	10000	3.9	3.8	3.6	3.4	-1.7	40.9
PAPA013	2014	12500	4.2	4.3	3.9	3.6	-1.5	45.5
PAPA013	2014	16000	2.7	2.8	2.1	1.9	-1.9	39.3
PAPA013	2014	20000	-0.6	-0.3	-1.2	-1.5	-2.4	42.0
PAPA014	2014	12.5	44.9	47.7	41.6	37.5	22.7	101.5
PAPA014	2014	15.8	49.6	52.0	48.0	44.7	27.7	99.4
PAPA014	2014	20	61.5	64.0	60.9	55.2	35.9	97.4
PAPA014	2014	25	49.9	52.2	48.2	45.4	29.2	95.5
PAPA014	2014	31.5	51.5	54.4	50.0	44.7	28.0	90.8
PAPA014	2014	40	47.4	49.4	46.2	42.4	23.8	89.4
PAPA014	2014	50	46.6	48.7	44.9	39.5	24.5	87.0
PAPA014	2014	63	44.4	45.5	42.1	39.4	26.5	81.8
PAPA014	2014	80	39.2	40.6	38.9	35.2	22.9	78.4

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA014	2014	100	38.9	40.5	38.0	35.6	22.6	74.5
PAPA014	2014	125	35.5	37.7	34.8	32.1	18.3	73.7
PAPA014	2014	160	31.8	33.8	30.8	27.8	14.6	68.3
PAPA014	2014	200	28.6	29.9	26.6	23.9	8.1	66.7
PAPA014	2014	250	27.9	30.2	25.2	22.7	3.3	64.0
PAPA014	2014	315	23.3	25.4	22.0	19.3	0.0	58.4
PAPA014	2014	400	21.2	23.4	18.3	15.3	0.0	54.1
PAPA014	2014	500	18.5	21.3	14.6	10.7	0.0	56.0
PAPA014	2014	630	14.2	16.1	9.8	6.3	0.0	55.1
PAPA014	2014	800	14.6	17.5	9.3	6.3	0.0	51.7
PAPA014	2014	1000	16.0	18.0	9.3	6.3	0.0	49.4
PAPA014	2014	1250	19.2	23.4	10.7	7.3	3.3	50.3
PAPA014	2014	1600	13.9	17.8	9.3	6.3	3.3	50.7
PAPA014	2014	2000	11.5	13.7	8.1	7.3	5.1	50.6
PAPA014	2014	2500	8.5	9.3	8.1	7.3	6.3	49.8
PAPA014	2014	3150	8.7	8.7	8.7	8.1	7.3	48.3
PAPA014	2014	4000	9.1	9.3	8.7	8.7	8.1	46.4
PAPA014	2014	5000	9.5	9.3	9.3	9.3	8.7	44.7
PAPA014	2014	6300	9.6	9.8	9.8	9.3	8.7	43.7
PAPA014	2014	8000	9.7	9.8	9.8	9.3	9.3	41.8
PAPA014	2014	10000	9.7	9.8	9.8	9.3	9.3	40.5
PAPA014	2014	12500	9.8	9.8	9.8	9.8	9.3	40.0
PAPA014	2014	16000	10.3	10.3	10.3	9.8	9.8	39.7
PAPA014	2014	20000	12.9	13.1	12.8	12.6	12.3	44.8
PAPA015	2014	12.5	38.7	41.7	36.6	32.0	13.9	76.0
PAPA015	2014	15.8	43.6	45.9	41.5	33.5	18.7	72.1
PAPA015	2014	20	48.9	51.4	46.8	41.6	26.2	71.3
PAPA015	2014	25	40.3	43.1	38.0	31.7	17.1	68.1
PAPA015	2014	31.5	45.1	48.2	37.1	30.5	15.1	66.0
PAPA015	2014	40	36.9	39.4	33.2	27.8	9.6	65.1
PAPA015	2014	50	36.4	38.8	31.5	26.5	9.9	62.9
PAPA015	2014	63	35.6	38.3	30.5	26.3	10.2	65.3
PAPA015	2014	80	34.1	36.7	29.2	24.8	8.5	72.8
PAPA015	2014	100	30.7	32.8	27.4	22.9	6.0	71.6
PAPA015	2014	125	27.7	28.6	24.7	20.7	4.0	67.7
PAPA015	2014	160	25.5	25.2	20.7	16.9	1.6	64.3
PAPA015	2014	200	20.9	21.4	17.2	13.4	-0.3	65.7
PAPA015	2014	250	18.3	18.5	14.0	9.7	-1.9	57.5
PAPA015	2014	315	14.5	14.8	9.0	5.7	-3.7	49.1
PAPA015	2014	400	12.6	10.6	5.3	1.8	-4.3	53.0

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA015	2014	500	10.7	6.8	1.8	-0.9	-4.5	53.6
PAPA015	2014	630	5.3	3.7	-0.6	-1.8	-4.5	50.1
PAPA015	2014	800	2.7	3.2	-1.0	-2.0	-3.6	41.6
PAPA015	2014	1000	0.9	1.7	-1.0	-1.8	-3.1	40.9
PAPA015	2014	1250	-0.6	0.1	-0.9	-1.3	-2.6	44.0
PAPA015	2014	1600	2.2	0.5	-0.2	-0.6	-1.7	36.3
PAPA015	2014	2000	5.5	2.9	1.0	0.4	-0.8	45.5
PAPA015	2014	2500	11.8	5.8	1.9	1.2	0.1	53.3
PAPA015	2014	3150	9.1	7.5	2.5	2.0	0.7	59.3
PAPA015	2014	4000	4.0	3.9	2.9	2.6	0.9	43.8
PAPA015	2014	5000	4.0	3.9	3.4	3.2	0.3	52.5
PAPA015	2014	6300	4.3	4.2	3.9	3.8	0.0	42.3
PAPA015	2014	8000	4.4	4.5	4.4	4.2	-0.9	41.1
PAPA015	2014	10000	4.7	4.8	4.7	4.5	-0.9	41.0
PAPA015	2014	12500	4.1	4.2	4.1	3.9	-1.1	42.5
PAPA015	2014	16000	1.2	1.3	1.2	1.1	-2.1	35.3
PAPA015	2014	20000	-1.0	-0.9	-1.0	-1.1	-2.0	34.2
PAPA016	2014	12.5	43.6	45.8	36.0	30.5	13.8	74.9
PAPA016	2014	15.8	43.3	46.2	38.0	32.3	13.4	75.8
PAPA016	2014	20	43.4	46.8	39.2	34.2	16.6	74.1
PAPA016	2014	25	37.3	39.5	34.1	29.8	14.1	76.6
PAPA016	2014	31.5	39.1	42.0	37.0	31.7	14.0	76.6
PAPA016	2014	40	35.0	37.7	32.3	28.7	12.2	76.6
PAPA016	2014	50	34.2	36.5	31.3	27.4	10.4	78.7
PAPA016	2014	63	34.0	36.3	31.2	27.5	8.7	79.2
PAPA016	2014	80	32.6	35.2	29.2	25.5	8.2	79.7
PAPA016	2014	100	31.9	34.0	28.0	24.0	6.9	78.7
PAPA016	2014	125	30.7	32.9	26.6	22.9	4.8	81.3
PAPA016	2014	160	28.7	30.5	24.4	20.4	1.9	79.1
PAPA016	2014	200	27.0	28.5	22.6	19.2	-0.1	79.4
PAPA016	2014	250	24.1	25.9	20.5	16.4	-1.9	79.3
PAPA016	2014	315	20.6	22.8	17.9	12.8	-3.2	75.1
PAPA016	2014	400	17.0	19.5	14.2	9.5	-3.6	72.6
PAPA016	2014	500	15.0	16.7	9.6	4.8	-3.9	75.9
PAPA016	2014	630	14.2	15.7	5.5	1.3	-3.4	77.1
PAPA016	2014	800	13.1	14.7	4.4	0.7	-2.7	76.1
PAPA016	2014	1000	12.0	13.4	4.3	1.2	-2.0	73.5
PAPA016	2014	1250	10.7	12.1	3.9	1.0	-1.5	74.0
PAPA016	2014	1600	8.5	10.0	2.5	1.1	-0.7	72.9
PAPA016	2014	2000	7.7	7.5	2.4	1.6	0.1	70.5

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA016	2014	2500	6.9	6.2	3.1	2.3	1.0	69.1
PAPA016	2014	3150	5.3	5.4	3.6	3.0	1.4	65.9
PAPA016	2014	4000	5.7	5.8	4.2	3.8	0.9	62.8
PAPA016	2014	5000	6.0	6.0	4.9	4.6	1.4	59.8
PAPA016	2014	6300	5.8	6.0	5.4	5.2	1.4	56.6
PAPA016	2014	8000	6.1	6.3	5.9	5.8	-0.2	53.3
PAPA016	2014	10000	6.5	6.7	6.3	6.1	0.7	50.4
PAPA016	2014	12500	6.5	6.8	6.4	6.2	0.0	47.4
PAPA016	2014	16000	5.9	6.3	5.7	5.6	1.5	45.0
PAPA016	2014	20000	3.9	4.6	3.6	3.4	0.5	53.0
PAPA017	2014	12.5	43.2	45.4	41.5	34.3	19.8	75.6
PAPA017	2014	15.8	49.2	51.8	45.3	38.0	22.0	72.0
PAPA017	2014	20	51.0	55.0	47.6	40.6	25.1	69.2
PAPA017	2014	25	48.5	52.0	45.4	40.2	24.0	67.6
PAPA017	2014	31.5	57.0	60.6	54.8	48.2	25.5	73.0
PAPA017	2014	40	47.8	51.0	45.5	41.8	20.7	64.1
PAPA017	2014	50	46.6	49.1	45.3	41.6	20.5	63.5
PAPA017	2014	63	42.0	44.4	40.3	37.2	19.9	67.6
PAPA017	2014	80	39.4	41.1	37.8	34.7	17.9	72.5
PAPA017	2014	100	39.0	39.5	35.4	31.3	16.8	81.0
PAPA017	2014	125	35.5	36.0	31.0	27.0	10.8	77.2
PAPA017	2014	160	33.8	34.0	28.9	24.9	5.7	71.5
PAPA017	2014	200	30.7	32.8	27.7	23.6	3.0	63.1
PAPA017	2014	250	28.5	29.9	25.6	21.5	1.2	63.2
PAPA017	2014	315	25.2	27.1	22.9	18.8	-1.3	64.0
PAPA017	2014	400	22.0	24.3	19.9	15.6	-2.1	56.9
PAPA017	2014	500	19.0	20.9	15.4	11.6	-3.4	54.1
PAPA017	2014	630	15.7	18.1	12.6	7.1	-3.7	52.1
PAPA017	2014	800	13.4	15.3	10.1	4.6	-3.5	49.2
PAPA017	2014	1000	12.0	14.0	8.1	3.1	-2.7	44.8
PAPA017	2014	1250	9.1	10.4	3.9	1.0	-2.1	44.4
PAPA017	2014	1600	6.9	6.5	2.0	0.7	-1.5	50.5
PAPA017	2014	2000	10.4	9.5	1.9	1.1	-0.5	60.8
PAPA017	2014	2500	10.5	6.9	2.5	1.9	0.4	65.3
PAPA017	2014	3150	7.1	5.0	3.1	2.5	0.3	61.1
PAPA017	2014	4000	5.0	4.2	3.6	3.3	-0.2	56.1
PAPA017	2014	5000	4.8	4.6	4.2	4.0	-1.0	55.1
PAPA017	2014	6300	5.0	5.1	4.8	4.6	-1.0	50.3
PAPA017	2014	8000	5.3	5.5	5.3	5.1	-1.1	50.7
PAPA017	2014	10000	5.4	5.5	5.4	5.2	-0.8	34.5

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.

Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA017	2014	12500	5.0	5.1	4.9	4.6	-1.2	37.9
PAPA017	2014	16000	3.2	3.4	3.1	3.0	-1.8	30.6
PAPA017	2014	20000	0.4	0.6	0.4	0.1	-1.4	28.2
PAPA018	2014	12.5	38.3	40.2	35.2	31.0	16.2	75.1
PAPA018	2014	15.8	41.2	43.7	38.9	33.4	20.5	73.5
PAPA018	2014	20	50.2	54.2	47.3	39.9	23.1	73.4
PAPA018	2014	25	45.7	49.2	40.5	34.2	20.1	70.0
PAPA018	2014	31.5	41.0	44.5	38.5	33.4	19.6	67.6
PAPA018	2014	40	36.1	38.9	33.4	28.9	18.4	65.2
PAPA018	2014	50	33.9	36.7	30.0	26.2	15.5	62.8
PAPA018	2014	63	32.8	35.6	29.1	24.7	10.5	63.5
PAPA018	2014	80	30.1	32.7	26.0	21.6	4.7	71.8
PAPA018	2014	100	29.5	31.8	25.0	20.4	3.4	68.8
PAPA018	2014	125	26.8	29.2	23.7	19.4	3.2	67.2
PAPA018	2014	160	25.1	27.5	21.0	15.6	1.9	67.0
PAPA018	2014	200	22.6	24.8	18.8	13.4	0.2	57.4
PAPA018	2014	250	19.7	22.1	16.1	11.6	-0.3	56.8
PAPA018	2014	315	17.4	18.6	13.3	8.6	-2.6	51.3
PAPA018	2014	400	13.5	14.7	9.1	5.1	-3.5	47.2
PAPA018	2014	500	11.4	11.6	4.2	1.1	-4.2	51.6
PAPA018	2014	630	6.7	6.1	0.4	-1.2	-4.1	54.7
PAPA018	2014	800	3.4	3.4	-0.9	-1.8	-3.9	52.3
PAPA018	2014	1000	2.0	1.8	-0.8	-1.6	-3.1	46.5
PAPA018	2014	1250	2.1	1.8	-0.5	-1.1	-2.3	43.5
PAPA018	2014	1600	4.0	2.4	0.3	-0.3	-1.6	46.6
PAPA018	2014	2000	5.9	7.5	1.5	0.8	-0.6	56.1
PAPA018	2014	2500	7.8	9.5	2.4	1.5	-0.8	63.4
PAPA018	2014	3150	11.5	11.4	2.8	2.2	-1.3	69.5
PAPA018	2014	4000	7.7	7.5	3.1	2.8	-1.4	66.3
PAPA018	2014	5000	4.7	4.5	3.5	3.2	-1.7	60.3
PAPA018	2014	6300	4.6	4.2	3.8	3.6	-1.9	62.4
PAPA018	2014	8000	4.3	4.4	4.2	4.0	-1.9	56.0
PAPA018	2014	10000	4.5	4.7	4.6	4.3	-2.1	33.2
PAPA018	2014	12500	4.4	4.5	4.3	4.0	-2.3	40.7
PAPA018	2014	16000	2.1	2.1	1.9	1.7	-2.6	37.6
PAPA018	2014	20000	-0.7	-0.5	-1.0	-1.2	-2.8	30.5
PAPA019	2014	12.5	36.6	38.3	32.1	28.1	15.3	74.4
PAPA019	2014	15.8	36.4	38.2	33.3	29.3	15.7	73.6
PAPA019	2014	20	44.5	47.0	41.0	33.0	17.2	72.4
PAPA019	2014	25	38.0	40.8	35.6	29.6	15.8	66.3

Appendix E. One-third Octave Band Metrics, PAPA Leks, April 2014.								
Site	Year	Freq	Leq	L10	L50	L90	LMin	LMax
PAPA019	2014	31.5	33.9	36.4	30.9	26.5	14.1	65.7
PAPA019	2014	40	31.1	33.9	27.7	23.5	10.3	63.6
PAPA019	2014	50	30.5	33.2	25.9	21.3	8.8	60.9
PAPA019	2014	63	30.8	33.4	25.7	22.2	7.9	68.4
PAPA019	2014	80	30.4	31.8	23.8	19.5	4.9	69.8
PAPA019	2014	100	29.3	29.9	22.2	19.1	2.8	70.7
PAPA019	2014	125	27.0	28.3	21.0	17.2	2.0	66.7
PAPA019	2014	160	24.0	25.4	18.2	14.8	0.0	65.0
PAPA019	2014	200	21.1	22.1	14.6	10.8	-1.3	54.6
PAPA019	2014	250	18.6	18.6	11.3	8.0	-2.6	56.7
PAPA019	2014	315	15.8	17.0	9.9	5.6	-3.3	51.0
PAPA019	2014	400	12.8	13.1	6.2	2.4	-3.7	49.6
PAPA019	2014	500	12.8	11.8	3.7	0.2	-3.8	51.2
PAPA019	2014	630	7.4	5.2	0.3	-1.3	-3.5	50.3
PAPA019	2014	800	4.3	4.1	-0.3	-1.3	-3.2	48.0
PAPA019	2014	1000	3.1	3.6	0.1	-0.8	-2.5	48.2
PAPA019	2014	1250	2.9	2.5	0.5	-0.3	-1.5	50.9
PAPA019	2014	1600	3.0	2.7	1.1	0.5	-0.9	44.3
PAPA019	2014	2000	7.3	4.4	2.0	1.5	0.1	51.5
PAPA019	2014	2500	7.2	6.4	3.0	2.4	1.1	61.9
PAPA019	2014	3150	6.0	6.5	3.8	3.3	1.9	63.7
PAPA019	2014	4000	5.0	5.0	4.2	3.9	1.9	39.5
PAPA019	2014	5000	5.3	5.3	4.8	4.6	1.2	38.7
PAPA019	2014	6300	5.7	5.7	5.4	5.2	0.9	47.9
PAPA019	2014	8000	5.9	6.0	5.9	5.7	0.9	47.6
PAPA019	2014	10000	6.2	6.3	6.2	6.1	1.1	24.3
PAPA019	2014	12500	6.3	6.4	6.3	6.1	1.4	29.4
PAPA019	2014	16000	5.8	5.9	5.7	5.6	1.6	27.6
PAPA019	2014	20000	3.9	4.0	3.8	3.6	1.7	29.8

Appendix F. Credentials of Authors

The three authors of this report have over 75 years combined experience working in the field of acoustics, sound level measurements, and assessing impacts on wildlife resources. All three were involved in initial measurements National Parks in an effort to determine existing ambient and baseline ambient sound levels in order to assess impacts of anthropogenic sounds on resources. This work involved sound level measurements in remote places with little human activity for long periods of time, and consequently very, very low sound levels. This work required development of new tools and techniques, many of which were pioneered by the authors. In total, these three individuals have collected data at over 250 locations throughout North America.

Skip Ambrose

Clemson University, B.S., 1969

Mr. Ambrose worked for the Fish and Wildlife Service in Alaska for 28 years as head of the Endangered Species Program in Fairbanks, AK. Much of this work involved assessing and protecting listed species from human impacts, including impacts from anthropogenic sounds. In 2001, Mr. Ambrose began working for the National Park Service to development the Acoustic Division of the Natural Sounds Program. The work involved developing new tools and techniques to study sound levels in very remote and very quiet places, and working with acousticians from other federal, state, and private organizations. In 2005, Mr. Ambrose retired from the National Park Service and co-founded Sandhill Company, a consulting firm specializing in avian and acoustic studies. Mr. Ambrose has participated in over 50 sound level measurement studies throughout North America, and has authored over 30 reports on sound level measurements in national parks and other rural and remote locations.

Christine Florian

Northern Arizona University, B.S., 1994.

Beginning in 1993, Ms. Florian worked for the National Park Service in Arizona surveying and studying wildlife resources in northern Arizona parks, primary avian species. In 1997, she began working in Alaska conducting avian and acoustic surveys in national parks in interior Alaska. In 2001, Ms. Florian started working for the National Park Service's new Natural Sounds Program, and participated in equipment and software development for sound level measurements and acoustic studies in National Parks throughout North America. She retired from the National Park Service in 2005 and co-founded Sandhill Company, a consulting firm specializing in avian and acoustic studies. Ms. Florian has participated in over 50 sound level studies throughout North America, and co-authored over 25 reports on this work.

John MacDonald

General Motors Engineering and Management Institute, B.S. Electrical Engineering, 1990
University of Central Florida, Master of Science, Environmental Engineering, 1996
University of Central Florida, Ph.D., Environmental Engineering, 2001
Licensed Professional Engineer; State of Florida; PE# 63038

Dr. MacDonald has been performing engineering tests and analyzing engineering data since 1986 when he worked as an engineer at General Motors in Flint, Michigan. He began performing environmental noise measurements in 1995 and has conducted environmental noise and vibration studies since that time. Dr. MacDonald developed the "Community Noise Model" that was in use at one time in 35 different countries. The CNM was a PC based simulation program that predicted sound levels at residential receivers from common sources of environmental noise such as automobiles, aircraft, rail operations, and point sources of sound such as HVAC, generators, exhaust ports, etc. Dr. MacDonald has conducted long term environmental sound surveys in 40 National Parks and has developed numerous custom software methods to analyze environmental acoustic data. He is a computer modeling expert, a programmer and has developed custom data acquisition systems for his engineering work.

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RON LOVERCHECK
ED MIGNERY

January 29, 2008

MEMORANDUM

TO: Terry Cleveland and John Emmerich

FROM: Tom Christiansen and Joe Bohne

COPY TO: Jay Lawson, Bill Rudd, Reg Rothwell, Bob Oakleaf

SUBJECT: Multi-State Sage-Grouse Coordination and Research-based Recommendations

As assigned by Assistant Director Emmerich, we have been working with other state fish and wildlife agencies in WAFWA Sage-Grouse Management Zones 1 and 2 (MT, CO, UT, SD, ND, WY) in order to coordinate interpretation of recent sage-grouse research related to oil and gas development.

Attached for your review, please find the latest and final document capturing the multi-state interpretation of the recent science related to sage-grouse conservation and oil and gas development. It has been well scrutinized by staff from MT, WY, CO, ND and UT and there is consensus on the content by the participants. South Dakota was unable to attend the initial meeting in Salt Lake City on January 8-9, but they have been provided with meeting notes and the resulting document.

It is our recommendation that WGFD acknowledge this document as the correct interpretation of the recently published sage-grouse research and use this information to update and augment department documents and policies. It should be used in the forthcoming discussions with the BLM regarding their update to their sage-grouse Instruction Memorandum. In addition, we suggest that in order for this document to serve the broadest purpose for sage-grouse conservation four additional actions are needed. First, the document should be shared with Governor Freudenthal's staff. Second, we recommend that the Director's Office enter into discussions with MT FWP Director Jeff Hagener to ensure consistency in the application of these recommendations between our border states, and especially with the WY and MT BLM State Field Offices. Third, we recommend the document be submitted to WAFWA's Sage-Grouse Technical Committee as well as the WAFWA Executive Committee for their consideration and use. Finally, we recommend this document be included with other materials sent to the USFWS for consideration in their review of the status of sage-grouse and measures in place to conserve those populations.

We look forward to your direction on how to proceed.

"Conserving Wildlife - Serving People"

Using the Best Available Science to Coordinate Conservation Actions that Benefit Greater Sage-Grouse Across States Affected by Oil & Gas Development in Management Zones I-II (Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming)

Background

Greater Sage-grouse are widely considered in scientific and public policy arenas to be a species of significant conservation concern. Loss, degradation and fragmentation of important sagebrush grassland habitats have negatively impacted sage-grouse populations. Much of this loss of habitat function is occurring in Sage-grouse Management Zones (MZ) 1 and 2 (Stiver et al. 2006) in Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming as a result of oil and gas development (Connelly et al. 2004). Oil and gas development is rapidly increasing within these areas. In response to those concerns, states and provinces are in various stages of completing or updating management plans in order to provide for long-term sage-grouse conservation. Special emphasis is being placed on oil and gas development as it rapidly spreads across much of the eastern range of sage-grouse.

The recent decision by B. Lynn Winmill, Chief U.S. District Judge (2007), which remands the original 2005 not warranted decision back to the USFWS for reconsideration, has highlighted the need for States to coordinate their application of best available science. Representatives from the state agencies with authority for managing fish and wildlife from the major sage-grouse and energy producing states comprising MZ 1 and 2 and sage-grouse researchers who have published new findings, met on January 8 and 9, 2008 in Salt Lake City. The objectives of the meeting were to better understand the application of most recent peer-reviewed science within the context of oil and gas development and coordinate and compare implementation of conservation actions utilizing that information.

Review Process

The participants at this meeting represented technical science and management advisors from each of the states. Researchers having the most recently peer reviewed and published articles concerning sage grouse and oil and gas development were invited to present their findings and answer questions. State agency participants agreed that the goal was not to establish state or regional policy or to determine the management actions that will be implemented in any or all states within MZ 1 or 2. Rather, the goal was to reach agreement on the conservation concepts and strategies related to oil and gas development that are supported by current published peer-reviewed and unpublished literature. If implemented, these concepts and strategies likely will not eliminate impacts to sage-grouse populations that result from energy development. However, when used in combination with other conservation measures, these actions may enhance the likelihood that sage-grouse populations will persist at levels that allow historical uses such as grazing and agriculture and maintain their current distribution and abundance, thereby avoiding the need to list sage-grouse under the federal Endangered Species Act.

Each researcher was invited to present their findings and to answer questions posed by the states. Following this, each state provided an overview of their review of the science and their resulting management actions and recommendations. The group then collectively reviewed, debated and agreed on the concepts and strategies supported by that science. The focus of the meeting was on five key issues: core areas, no-surface-occupancy zones, phased development, timing stipulations, well-pad densities, and restoration. Scientific data are available to inform many other issues related to sage-grouse management and conservation that were not reviewed (e.g., BMPs).

Core Areas

Identification and protection of core areas, sometimes also referred to as crucial areas, will help maintain or achieve target goals for populations including distribution and abundance.

Full field energy development appears to have severe negative impacts on sage-grouse populations under current lease stipulations (Lyon and Anderson 2003, Holloran 2005, Kaiser 2006, Holloran et al. 2007, Aldridge and Boyce 2007, Walker et al 2007, Doherty et al. 2008). Much of greater sage-grouse habitat in MZ 1 and 2 has already been leased for oil and gas development. These leases carry stipulations that have been shown to be inadequate for protecting breeding and wintering sage-grouse populations during full field development. (Holloran 2005, Walker et. al. 2007, Doherty et al. 2008) New leases continue to be issued utilizing these same stipulations. To ensure long-term persistence of populations and meet goals set by the states for sage-grouse, identifying and implementing greater protection within core areas from impacts of oil and gas development is a high priority.

In order to conserve core areas it is essential that they be identified and delineated. Sage-grouse populations occur over large landscapes comprising a series of leks and lek complexes with associated seasonal habitats. Therefore, core areas should capture the range required by a defined population to maintain itself. This concept is consistent with Crucial Wildlife Habitats recently endorsed by the Western Governor's Association (2007). Criteria that could be used to identify and map core areas include, but are not limited to: (1) lek densities, (2) displaying male densities, (3) sagebrush patch sizes, (4) seasonal habitats (breeding, summering, wintering areas), (5) seasonal linkages, or (6) appropriate buffers around important seasonal habitats.

Research indicates that oil or gas development exceeding approximately 1 well pad per square mile with the associated infrastructure, results in calculable impacts on breeding populations, as measured by the number of male sage-grouse attending leks (Holloran 2005, Naugle et al. 2006). Because breeding, summer, and winter habitats are essential to populations, development within these areas should be avoided. If development cannot be avoided within core areas, infrastructure should be minimized and the area should be managed in a manner that effectively conserves sagebrush habitats within that area.

No Surface Occupancy (NSO)

At the scale that NSOs are established, they alone will not conserve sage-grouse populations without being used in combination with core areas. The intent of NSOs is to maintain sage-grouse distribution and a semblance of habitat integrity as an area is developed.

Breeding Habitat - Leks

Research in Montana and Wyoming in coal-bed methane natural gas (CBNG) and deep-well fields suggests that impacts to leks from energy development are discernable out to a minimum of 4 miles, and that some leks within this radius have been extirpated as a direct result of energy development (Holloran 2005, Walker et al. 2007). Walker et al. (2007) indicates that the current 0.25-mile buffer lease stipulation is insufficient to adequately conserve breeding sage-grouse populations in areas having full CBNG development. A 0.25-mi. buffer leaves 98% of the landscape within 2 miles open to full-scale energy development. In a typical landscape in the Powder River Basin, 98% CBNG development within 2 miles of leks is projected to reduce the average probability of lek persistence from 87% to 5% (Walker et al. 2007). Only 38% of 26 leks inside of CBNG development remained active compared to 84% of 250 leks outside of development (Walker et al. 2007). Of leks that persisted, the numbers of attending males were reduced by approximately 50% when compared to those outside of CBNG development (Walker et al. 2007).

The impact analyses provided in Walker et al. (2007) are based on a 7-year dataset where probability of lek persistence is strongly related to extent of sagebrush habitat and the extent of energy development within 4 miles of the lek and the extent of agricultural tillage in the surrounding landscape. The estimated probabilities of lek persistence are only reliable for the length of the dataset, and it is not understood how other stressors (e.g., West Nile virus [Naugle et al. 2004], invasive weeds [Bergquist et al. 2007]) will cumulatively impact sage-grouse over longer time periods. While increased NSO buffers alone are unlikely to conserve sage-grouse populations, results from Walker et al. 2007 suggest they will increase the likelihood of maintaining the distribution and abundance of grouse and should increase the likelihood of successful restoration following energy development.

Additional information provided in Walker et al. (2007) allows managers and policy makers to estimate trade-offs associated with allowing development within a range of different distances from leks (Figures 1a and 1b). These probabilities will also need to be applied over larger landscapes in future analyses to better understand projected region- and state-wide population impacts under current and future development scenarios. Walker et al. (2007) studied lek persistence from 1997-2005 in relation to coal bed natural gas (CBNG) development in the Powder River Basin. These models are based on projected impacts of full-field development within (a) 2 miles and (b) 4 miles of the lek. We present results from these models (rather than models with impacts at smaller scales) because development within 2 and 4 miles of leks are known to decrease breeding populations as measured by the number of displaying males (Holloran et al. 2005, Walker et al. 2007), and 52% and 74-80% of hens are known to nest within 2 and 4 miles of leks, respectively (Holloran and Anderson 2005, Colorado Greater Sage-Grouse Conservation Plan Steering Committee 2008). Sizes of NSO buffers required to protect breeding populations may be underestimated because leks in CBNG fields have fewer males per lek and a time lag occurs (avg. 3-4 years) between development and when leks go inactive. As a result, it is expected that not only will lek persistence decline, the number of males per lek will also decline. In contrast, sizes may be overestimated where high lek densities cause buffers from adjacent leks to overlap. Additional time is required to develop models demonstrating the probabilities of lek persistence at well-pad densities less than full development.

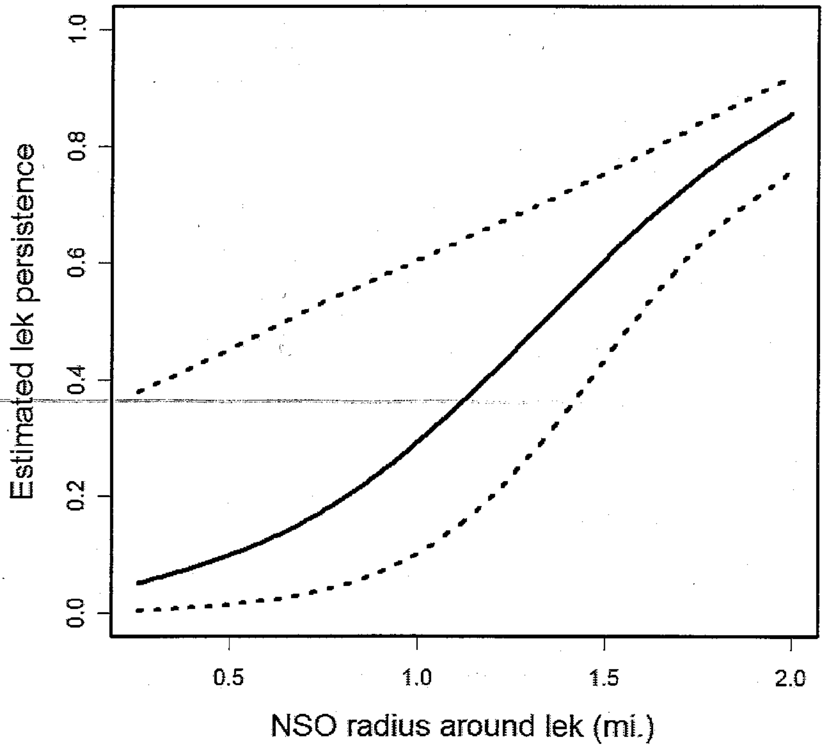

Figure 1a. Estimated probability of lek persistence (dashed lines represent 95% CIs) in fully-developed[1] coal-bed natural gas fields within an average landscape in the Powder River Basin (74% sagebrush habitat, 26% other habitats types) with different sizes of no-surface-occupancy (NSO) buffers around leks, assuming that only CBNG within 2 miles of the lek affects persistence. Buffer sizes of 0.25 mi., 0.5 mi., 0.6 mi., and 1.0 mi. result in estimated lek persistence of 5%, 11%, 14%, and 30%. Lek persistence in the absence of CBNG averages ~85%.

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[1] Defined as entire area outside the NSO buffer, but within 2 miles, being within 350 meters of a well.

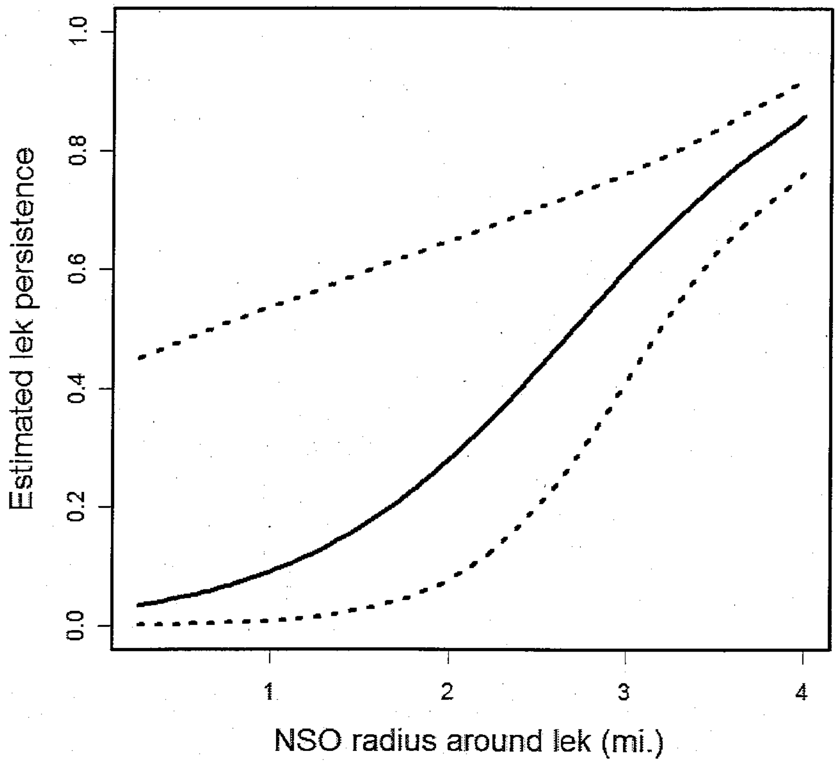

Figure 1b. Estimated probability of lek persistence (dashed lines represent 95% CIs) in fully-developed[2] coal-bed natural gas fields within an average landscape in the Powder River Basin (74% sagebrush habitat, 26% other habitats types) with different sizes of no-surface-occupancy (NSO) buffers around leks, assuming that only CBNG within 4 miles of the lek affects persistence. Buffer sizes of 0.25 mi., 0.5 mi., 0.6 mi., 1.0 mi., and 2.0 mi. result in estimated lek persistence of 4%, 5%, 6%, 10%, and 28%. Lek persistence in the absence of CBNG averages ~85%.

Figures 1a and 1b provide an illustration of the trade-offs between differing NSO buffers in relation to lek persistence in developing CBNG fields. The group does not offer a specific NSO recommendation but provides these graphs to guide decision-making.

Breeding Habitat - Nesting and Early Brood-rearing

Yearling female greater sage-grouse avoid nesting in areas within 0.6 miles of producing well pads (Holloran et al. 2007), and brood-rearing females avoid areas within 0.6 miles of producing wells (Aldridge and Boyce 2007). This suggests a 0.6-mile NSO around all suitable nesting and brood-rearing habitats is required to minimize impacts to females during these seasonal periods. In areas where nesting habitats have not been delineated, research suggests that greater sage-grouse nests are not randomly distributed. Rather, they are spatially associated with lek location within 3.1 miles in Wyoming (Holloran and Anderson 2005). However, a 4-mile buffer is needed to encompass 74-80% (Moynahan

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[2] Defined as entire area outside the NSO buffer, but within 4 miles, being within 350 meters of a well.

2004, Holloran and Anderson 2005, Colorado Greater Sage-Grouse Conservation Plan Steering Committee 2008). These suggest that all areas within at least 4-miles of a lek should be considered nesting and brood-rearing habitats in the absence of mapping.

Winter Habitat

NSO or other protections may also need to be considered for crucial winter range. Survival of juvenile, yearling, and adult females are the three most important vital rates that drive population growth in greater sage-grouse (Holloran 2005, Colorado Greater Sage-Grouse Conservation Plan Steering Committee 2008). Although overwinter survival in sage-grouse is typically high, severe winter conditions can decrease hen survival (Moynahan et al 2006). Crucial wintering habitats can constitute a small part of the overall landscape (Beck 1977, Hupp and Braun 1989). Doherty et al. (2008) demonstrated that sage-grouse avoided otherwise suitable wintering habitats once they have been developed for energy production, even after timing and lek buffer stipulations had been applied (Doherty et al. 2008). For this reason, increased levels of protection may need to be considered in crucial winter habitats.

Phased Development

Population-level impacts and avoidance associated with energy development have been documented (Braun et al. 2002, Lyon and Anderson 2003, Holloran 2005, Kaiser 2006, Holloran et al. 2007, Aldridge and Boyce 2007, Walker et al 2007, Doherty et al. 2008). Phased development maximizes the amount of area within a landscape that is not being impacted by development at any one time, and can occur at multiple spatial scales (e.g., phased development of separate fields in a landscape, phased development of infrastructure within a single unit or field, or phased development within a single lease). Unitization, clustering, and geographically staggered development are all forms of phased development. As a tool to minimize impacts to sage-grouse, developing oil and gas resources by employing one of these phased methods may help maintain large, functional blocks of sage-grouse habitat.

Timing Stipulations

As with NSOs, at the scale that timing stipulations are established, they alone will not conserve sage-grouse populations without being used in combination with core areas. The intent of timing stipulations is to help maintain sage-grouse distribution and a semblance of habitat integrity as an area is developed. Timing stipulations are of lesser value at the scale of full-field development.

Breeding Habitat - Leks

Traffic during the strutting period when males are on a lek results in declines in male attendance when road-related disturbance is within 0.8 miles (Holloran 2005). The distance traveled by males from the lek during the breeding season has been reported in varying ways but generally averages 0.6 miles from a lek (Colorado Greater Sage-Grouse

Conservation Plan Steering Committee 2008 - see Appendix B). Additionally, females breeding on leks within 1.9 miles of natural gas development had lower nest initiation rates and nested farther from the lek compared to non-impacted individuals (Lyon and Anderson 2003), suggesting disturbance to leks influence females as well. Local variations may influence the application of specific dates, which are typically within a window of March 1 and May 31.

Breeding Habitat - Nesting and Early Brood-rearing

Often, timing stipulations (periods where no activity that creates disturbance are allowed) for breeding habitat have been applied using a radius around a lek. However, nesting and brood-rearing habitat is not uniformly distributed around the lek. Mapping of habitat would allow for more accurate application of this stipulation. Research on the distribution of nests relative to leks and on the timing of nesting indicates that timing stipulations to protect nesting hens and their habitat should be in place from March through June in mapped breeding habitat or (when nesting habitat has not been mapped) within 4 miles of active lek sites (Moynahan 2004, Holloran et al. 2005, Colorado Greater Sage-Grouse Conservation Plan Steering Committee 2008).

Winter Habitat

Research suggests that no surface occupancy should also be applied to important wintering habitats (Doherty et al. 2008), but if development occurs, impacts would be reduced if development activities were avoided between December 1 and March 15.

Well-Pad Densities

Leks tend to remain active when well-pad densities within 1.9 miles of leks are less than 1 pad per square mile (Holloran 2005) but leks tend to go inactive at higher pad densities (Holloran 2005, Naugle et al. 2006).

Restoration

The purpose of restoration in sage-grouse habitat should be the removal of infrastructure associated with energy development from the land surface and subsequent re-establishment of native grasses, forbs, and shrubs, including sagebrush, to promote natural ecological function. Restoration should reestablish functionality of seasonal habitats for sage-grouse. Thus a field should not be considered restored until sagebrush-grassland habitats have been reestablished.

Future Needs

Time did not allow for a detailed discussion of specific Best Management Practices for oil and gas development and restoration, seasonal habitat mapping, or future research. These topics are all recognized as needing action in the immediate future.

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Impacts of Anthropogenic Noise on Wildlife: Research Priorities for the Development of Standards and Mitigation

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1. INTRODUCTION

Human development introduces anthropogenic noise sources into the environment across many elements of the modern terrestrial landscape, including roads, airports, military bases, and cities. The impacts of these introduced noise sources on wildlife are less well studied than many of the other effects human activities have on wildlife, the most well known of which are habitat fragmentation and the introduction of invasive species. A growing and substantial body of literature suggests, however, that noise impacts may be more important and widespread than previously imagined.[3] They range in effects from mild to severe. They can impact wildlife species at both the individual and population levels. The types of impacts run the gamut from damage to the auditory system, the masking of sounds important to survival and reproduction, the imposition of chronic stress and associated physiological responses, startling, interference with mating, and population declines.

Anthropogenic noise is a global phenomenon, with the potential to affect wildlife across all continents and habitat types. Despite the widespread

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[3] For a review of noise impacts on birds and other wildlife, see P. A. KASELOO & K. O. TYSON, SYNTHESIS OF NOISE EFFECTS ON WILDLIFE POPULATIONS (U.S. Department of Transportation, Federal Highway Administration, 2004); ROBERT J. DOOLING & ARTHUR N. POPPER, THE EFFECTS OF HIGHWAY NOISE ON BIRDS (California Department of Transportation, Division of Environmental Analysis, 2007).

distribution of noise, the bulk of research on the effects of noise on terrestrial wildlife has been limited to European countries and the United States. This geographic bias in research may limit the application of the results from previous studies on a global basis, since the impacts may differ among habitats and species.[4]

Since much human development involves the introduction of noise, separating out and understanding the impacts of noise pollution is a critical step in developing effective wildlife policy, particularly the setting of standards and the use of mitigation measures. The first step typically is to determine the overall impact on the population demography of a species, by measuring population declines and birth rates. Mitigation requires that the mechanisms of this effect then be understood. From an initial determination, for example, that roads decrease songbird population densities, there must next be an estimation of the extent to which noise, dust, chemical pollution, habitat fragmentation, invasive weeds, visual disturbance, or road mortality are partial and contributory causes of that impact before effective mitigation measures aimed at noise can be chosen. Quieter pavements will not help songbirds if the true cause of the problem is visual disturbance. The key challenge, then, is to measure the contribution of noise to observed impacts on animal populations while controlling for other variables.

In this article, we address three questions: what are the common sources of anthropogenic noise; what is known about the mechanisms by which noise impacts wildlife; and how can we use observational and experimental approaches to estimate the impacts of noise on whatever species are of concern?

In answering these questions we deal at length with both observational and experimental methods, the latter including both laboratory and field work. We describe observational field studies on animal abundance and reproduction in impacted areas and a method for estimating the potential of noise sources to mask animal vocalizations. We address both the feasibility and value of laboratory and field experiments and describe a case study based on an ongoing noise-playback experiment we have designed to quantify the impacts of noise from energy development on greater sage-grouse (*Centrocercus urophasianus)* in Wyoming.

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[4] The geographic bias in research has lead to a focus on species that live in temperate zones, with little to no study of tropical species. Also of concern, many of the landscapes that have been the focus of research on noise and wildlife in these industrialized nations have already been profoundly influenced by human development such that the species or individuals living in these areas may be more tolerant of disturbance. Application of the results of studies from developed to less developed landscapes would potentially lead to an underestimation of the effects of noise. Anthropogenic changes to the environment are occurring at an unprecedented rate in developing nations in tropical latitudes, however, we do not yet know whether the results from existing research are applicable in these regions.

Our focus, then, is on noise impacts on animals in the terrestrial environment,[5,6] especially birds, which are the subjects of most terrestrial studies.[7] We also outline directions for future research and in a final section emphasize the importance of this research for developing flexible wildlife management strategies in landscapes that are increasingly subject to human encroachment.

2. SOURCES OF NOISE

Noise is associated with most phases in the cycle of human development activity, from early construction to the daily operation of a completed project. Transportation systems are one of the most pervasive sources of noise across all landscapes, including common sources like roads and their associated vehicular traffic, airports and airplanes, off-road vehicles, trains, and ships. Roads deserve special attention, because they are a widespread and rapidly increasing terrestrial noise source. Although the surface area covered by roads is relatively small, the ecological effects of roads, including noise, extend far beyond the road itself, impacting up to one-fifth of the land area of the United States, for example.[8] Industrial noise sources, such as military bases, factories, mining operations, and wind farms may be more localized in the landscape, but are problematic for wildlife because the noise produced can be very loud.

The characteristics of noise vary substantially among sources. Each source type exhibits variance in amplitude (i.e., loudness), frequency profile

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[5] Many terrestrial noise sources produce noise that travels through the ground as well as the air. Seismic noise is likely to impact fossorial animals and animals that possess specialized receptors for seismic detection, many of which communicate by seismic signals. We do not address seismic noise in this paper, but it is an issue that warrants further discussion.

[6] For recent treatments of noise in the marine environment, its impacts on marine species, and legal and policy responses, see *Noise Pollution and the Oceans: Legal and Policy Responses Part 1*, 10 J. INT'L WILDLIFE L. & POL'Y (2007) 101–199 and *Noise Pollution and the Oceans: Legal and Policy Responses Part 2*, 10 J. INT'L WILDLIFE L. & POL'Y (2007) 219–288. See also, Committee on Characterizing Biologically Significant Marine Mammal Behavior, Marine Mammal Populations and Ocean Noise, DETERMINING WHEN NOISE CAUSES BIOLOGICALLY SIGNIFICANT EFFECTS 142 (Ocean Studies Board, Division on Earth and Life Studies, National Research Council, The National Academies, 2005).

[7] Birds have often been used in noise research because birds are generally easy to study due to their high detectability, most species use vocal communication (making them likely to be impacted by noise) and they are generally of high conservation importance.

[8] R.T.T. Forman & R.D. Deblinger, *The Ecological Road-Effect Zone of a Massachusetts (U.S.A.) Suburban Highway*, 14 CONS. BIOL. 36–46 (2000); R.T.T. Forman, *Estimate of the Area Affected Ecologically by the Road System in the United States*, 14 CONS. BIOL. 31–35 (2000); R.T.T. Forman, B. Reineking, and A.M. Hersberger, *Road Traffic and Nearby Grassland Bird Patterns in a Suburbanizing Landscape*, 29 ENVT'L. MGMT. 782–800 (2002). Due to its ubiquity, road noise is the most commonly studied type of terrestrial noise. Road noise is, in general, similar to other types of anthropogenic noise and affects a wide range of species and habitat types, so the research techniques and results can be applied to many other types of anthropogenic noise.

(i.e., pitch), and spatial and temporal patterns. The interaction of these characteristics is what determines in a narrow sense the impact of noise on wildlife, setting aside the possibly confounding influence of contextual variables.

Intuitively, loud noise is more disruptive than quiet noise[9] and noise with frequencies similar to animal vocalizations is more likely to interfere with (i.e., mask) communication than noise with different frequencies.[10] Most anthropogenic noise sources have energy concentrated in low frequencies (<250 Hz), which can travel long distances with relatively little energy loss. Such noise is also more difficult to control using traditional noise-abatement structures, such as noise reflecting or absorbing walls along highways or surrounding other fixed noise sources, such as industrial sites.[11] Spatial patterning of noise may also affect the level of disturbance. A highly localized point source, like a drilling rig, will generally impact a smaller area than a linear source, such as a highway, although the area of impact will also depend on the amplitude and frequency structure of the noise. The temporal patterning of noise can also be important, because animal behaviors are often temporally patterned. Rush hour traffic, for example, often coincides with the dawn chorus of bird song,[12] an important time for birds because this is when mates are attracted and territories defended.[13]

Environmental noise is not an entirely new problem for animals, nor is human activity the exclusive cause of it. Natural environments have numerous sources of ambient noise, such as wind, moving water, and sounds produced by other animals. There is also evidence that animals living in naturally noisy areas have made adaptations through the use of signals and signaling behaviors to overcome the masking impacts of noise.[14] However, if anthropogenic noise

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[9] M.E. Weisenberger et al., *Effects of Simulated Jet Aircraft Noise on Heart Rate and Behavior of Desert Ungulates*, 60 J. WILDLIFE MGMT. 52–61 (1996).

[10] Bernard Lohr et al., *Detection and Discrimination of Natural Calls in Masking Noise by Birds: Estimating the Active Space of a Signal*, 66 ANIMAL BEHAV. 703–710 (2003).

[11] S.P. SINGAL, NOISE POLLUTION AND CONTROL STRATEGY (2005).

[12] R.A. Fuller et al., *Daytime Noise Predicts Nocturnal Singing in Urban Robins*, 3 BIOL. LETTERS 368–370 (2007).

[13] C.K. CATCHPOLE & PETER J.B. SLATER, BIRD SONG: THEMES AND VARIATIONS (1995).

[14] For example, the structural and temporal properties of many acoustic signals are adapted—by evolution or through individual plasticity—to maximize the propagation distance and/or minimize interference from natural noise sources. R. Haven Wiley & Douglas G. Richards, *Adaptations for Acoustic Communication in Birds: Sound Transmission and Signal Detection*, *in* 1 ACOUSTIC COMMUNICATION IN BIRDS 131–181 (D. Kroodsma & E.H. Miller eds., 1982); H. Brumm, *Signalling through Acoustic Windows: Nightingales Avoid interspecific Competition by Short-Term Adjustment of Song Timing*, 192 J. COMP. PHYSIOL. A 1279–1285 (2006); Henrik Brumm & Hans Slabbekoorn, *Acoustic Communication in Noise*, 35 ADVANCES STUDY BEHAV. 151–209 (2005); Hans Slabbekoorn & Thomas B. Smith, *Habitat-Dependent Song Divergence in the Little Greenbul: An Analysis of Environmental Selection Pressures on Acoustic Signals*, 56 EVOLUTION 1849–1858 (2002); G.M. Klump, *Bird Communication in the Noisy World*, *in* ECOLOGY AND EVOLUTION OF ACOUSTIC COMMUNICATION IN BIRDS 321–338 (D. Kroodsma & E.H. Miller eds., 1996); Eugene S. Morton, *Ecological Sources of Selection on Avian Sounds*, 109 AM. NATURALIST 17–34 (1975).

differs enough from natural noise in frequency, amplitude, or daily/seasonal patterns, animal adaptations to natural noise can be overwhelmed. Furthermore, the extensive introduction of anthropogenic noise into the environment on a large scale is a relatively recent phenomenon, so that animals have had only a limited opportunity to adapt to widespread and sometimes drastic changes in their acoustic environments.[15]

3. THE POTENTIAL IMPACTS OF NOISE ON WILDLIFE

Animals exhibit a variety of responses to noise pollution (also called introduced noise), depending on the characteristics of the noise and the animal's ability to tolerate or adapt to it. Noise impacts on wildlife can be observed at the individual and population levels, which we now consider in turn.

3.1 Individual-Level Impacts

Some of the most dramatic impacts of noise on individuals are acute and need to be distinguished from chronic effects. Acute impacts include physiological damage, masking of communication, disruption of behavior, and startling. The most direct physiological impact affects an animal's ability to hear, either by permanently damaging the auditory system, in which case it produces what is called a permanent threshold shift (PTS) in hearing, or by causing temporary decreases in hearing sensitivity, which are called temporary threshold shifts (TTS).[16] The noise levels required for PTS and TTS are quite loud,[17] making hearing damage unlikely in most terrestrial situations. Even extremely loud sound sources will only cause PTS and TTS over a small area, because on land sound attenuates very quickly with distance.[18] This is why most studies

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[15] G. Patricelli & J. Blickley, *Avian Communication in Urban Noise: Causes and Consequences of Vocal Adjustment*, 123 THE AUK 639–649 (2006); Paige S. Warren et al., *Urban Bioacoustics: It's Not Just Noise*, 71 ANIMAL BEHAV. 491–502 (2006); Lawrence A. Rabin et al., *Anthropogenic Noise and Its Effects on Animal Communication: An Interface Between Comparative Psychology and Conservation Biology*, 16 INT'L J. COMP. PSYCHOL. 172–192 (2003); Lawrence A. Rabin & Correigh M. Greene, *Changes to Acoustic Communication Systems in Human-Altered Environments*, 116 J. COMP. PSYCHOL. 137–141 (2002); H. Slabbekorn & E.A.P. Ripmeester, *Birdsong and Anthropogenic Noise: Implications and Applications for Conservation*, 17 MOLECULAR ECOLOGY 72–83 (2008).

[16] P. Marler et al., *Effects of Continuous Noise on Avian Hearing and Vocal Development*, 70 PROC. NAT'L ACAD. SCI. 1393–1396 (1973); J. Saunders & R. Dooling, *Noise-Induced Threshold Shift in the Parakeet (*Melopsittacus undulatus), 71 PROC. NAT'L ACAD. SCI. 1962–1965 (1974); Brenda M. Ryals et al., *Avian Species Differences in Susceptibility to Noise Exposure*, 131 HEARING RES. 71–88 (1999).

[17] PTS in birds may result from sound levels of ∼125 dBA SPL for multiple impulsive sounds and ∼140 dBA SPL for a single impulsive sound. TTS can result from continuous noise levels of ∼93 dBA SPL. The term "dBA SPL" refers to the A-weighted decibel, the most common unit for noise measurements. It adjusts for human perception of sound and is scaled relative to the threshold for human hearing.

[18] Sound levels drop by approximately 6 dB (measured using dBA SPL, or any other decibel measure), which represents a halving of loudness, with every doubling in distance from a point source, and 3 dB with every doubling of distance from a linear source, such as a highway.

of impacts from highway and urban noise do not directly address PTS and TTS, although they may need to be considered in extremely noisy areas.

Other acute impacts of noise, such as masking and behavioral disruption, occur over a much larger area. Masking occurs when the perception of a sound is affected by the presence of background noise, with high levels of background noise decreasing the perception of a sound.[19] One possible consequence of masking is a decrease in the efficacy of acoustic communication. Many animals use acoustic signals to attract and retain mates, settle territorial disputes, promote social bonding, and alert other individuals to predators. Disruption of communication can, therefore, have dramatic impacts on survival and reproduction.[20] In one laboratory study, high environmental noise reduced the strength of the pair bond in monogamous zebra finches, *Taeniopygia guttata*, likely because females either had increased difficulty identifying mates or pair-bond maintenance calls were masked.[21] The broader consequence of this finding is that females in noisy areas may be more likely to copulate with extra-pair partners, and this in turn can change the social and genetic dynamics of a population.

In other research, birds have been found to change their songs and calls in response to noise in urban areas, which may reduce masking of communication.[22] However, the consequences of this vocal adjustment on reproduction in a species remain unclear. One outcome may be that populations using urban dialects have a better chance to thrive in urban areas. But by the same token they may experience a decrease in mate recognition and/or gene flow with populations in non-urban areas.[23]

Beyond interfering with communication, introduced background noise can also mask the sounds of approaching predators or prey, and increase the perception of risk from predation. Studies have yet to compare predation rates or hunting success in noisy and quiet areas while controlling for other confounding factors. The degree to which noise affects predator/prey relations

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[19] Lohr et al., *supra* note 5.

[20] M.A. Bee & E.M. Swanson, *Auditory Masking of Anuran Advertisement Calls by Road Traffic Noise*, 74 ANIMAL BEHAV. 1765–1776 (2007); Henrik Brumm, *The Impact of Environmental Noise on Song Amplitude in a Territorial Bird*, 73 J. ANIMAL ECOLOGY 434–440 (2004); L. Habib et al., *Chronic Industrial Noise Affects Pairing Success and Age Structure of Ovenbirds* Seiurus aurocapilla, 44 J. APPLIED ECOLOGY 176–184 (2007); Frank E. Rheindt, *The Impact of Roads on Birds: Does Song Frequency Play a Role in Determining Susceptibility to Noise Pollution?*, 144 J. ORNITHOLOGIE 295–306 (2003).

[21] J.P. Swaddle & L.C. Page, *Increased Amplitude of Environmental White Noise Erodes Pair Preferences in Zebra Finches: Implications for Noise Pollution*, 74 ANIMAL BEHAV. 363–368 (2007).

[22] Slabbekorn & Ripmeester, *supra* note 10; Brumm, *supra* note 15; Hans Slabbekoorn & Margriet Peet, *Birds Sing at a Higher Pitch in Urban Noise*, 424 NATURE 267 (2003); William E. Wood & Stephen M. Yezerinac, *Song Sparrow (*Melozpiza melodia*) Song Varies with Urban Noise*, 123 THE AUK 650–659 (2006).

[23] Patricelli & Blickley, *supra* note 10; Warren et al. *supra* note 10; Slabbekoorn & Peet, *supra* note 17.

in any species, therefore, remains largely unexplored.[24] One study found that birds nesting near noisy natural gas pads had higher nesting success, likely due to reduced presence of the most common nest predator, the western scrub jay.[25] As suggested by these authors, the higher nesting success of birds in noisy areas provides a mechanism by which noise-tolerant species could become more common in a noisy world. Noise also causes short-term disruptions in behavior, such as startling or frightening animals away from food or other resources.[26]

In addition to the acute effects of noise, animals may suffer chronic effects, including elevated stress levels and associated physiological responses. Over the short term, chronic stress can result in elevated heart rate.[27] Longer-term stress can be associated with the ability to resist disease, survive, and successfully reproduce.[28] Good measures of chronic stress come from elevated stress hormones, like corticosterone, in blood or fecal samples.[29] In noise-stressed laboratory rats, elevated corticosterone was linked with reduced food consumption and decreased weight gain,[30] raising the possibility that for some individuals there may be longer-term welfare and survival consequences from the elevated stress associated with noise introduction.

3.2 Population Level Impacts

The cumulative impacts of noise on individuals can manifest at the population level in various ways that can potentially range from population declines up to

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[24] Quinn found that chaffinchs (*Fringilla coelebs*) perceived an increased risk of predation while feeding in noisy conditions, likely due to a reduced ability to detect auditory cues from potential predators. L. Quinn et al., *Noise, Predation Risk Compensation and Vigilance in the Chaffinch* Fringilla coelebs, 37 J. AVIAN BIOL. 601–608 (2006). Research on greater sage-grouse also highlights the potential for noise to contribute to predation. One of the methods for capturing sage-grouse is to mask the sound of researcher footfalls using a noise source such as a stereo or a chain saw. With such masking, the grouse can be easily approached and netted in their night roosts for banding or blood sampling. Presumably, predators would be equally fortunate in noisy areas, though the ability of predators to use acoustic cues for hunting could be diminished by masking as well.

[25] Clinton D. Francis et al., *Noise Pollution Changes Avian Communities and Species Interactions*, 19 CURRENT BIOL. 1–5 (2009).

[26] Dooling & Popper, *supra* note 1; N. Kempf & O. Huppop, *The Effects of Aircraft Noise on Wildlife: A Review and Comment*, 137 J. ORNITHOLOGIE 101–113 (1996); D.K. Delaney et al., *Effects of Helicopter Noise on Mexican Spotted Owls*, 63 J. WILDLIFE MGMT. 60–76 (1999); L.A. Rabin, R.G. Coss, & D.H. Owings, *The Effects of Wind Turbines on Antipredator Behavior in California Ground Squirrels* (Spermophilus beecheyi), 131 BIOL. CONS. 410–420 (2006).

[27] Weisenberger et al., *supra* note 4.

[28] J.C. Wingfield & R.M. Sapolsky, *Reproduction and Resistance to Stress: When and how*, 15 J. NEUROENDOCRINOL, 711 (2003); A. Opplinger et al., *Environmental Stress Increases the Prevalence and Intensity of Blood Parasite Infection in the Common Lizard* Lacerta vivipara, 1 ECOLOGY LETTERS 129–138 (1998).

[29] Wingfield & Sapolsky, *supra* note 23; S.K. Wasser et al., *Noninvasive Physiological Measures of Disturbance in the Northern Spotted Owl*, 11 CONS. BIOL. 1019–1022 (1997); D.M. Powell et al., *Effects of Construction Noise on Behavior and Cortisol Levels in a Pair of Captive Giant Pandas (*Ailuropoda melanoleuca*)*, 25 ZOO BIOL. 391–408 (2006).

[30] P. Alario et al., *Body Weight Gain, Food Intake, and Adrenal Development in Chronic Noise Stressed Rats*, 40 PHYSIOL. BEHAV. 29–32 (1987).

regional extinction. If species already threatened or endangered due to habitat loss avoid noisy areas and abandon otherwise suitable habitat because of a particular sensitivity to noise, their status becomes even more critical. As discussed below, numerous studies have documented reduced habitat use and lower breeding success in noisy areas by a variety of animals.[31]

4. MEASURING THE IMPACTS OF NOISE ON SPECIES OF CONCERN

Species vary widely in their ability to tolerate introduced noise and can exhibit very different responses to altered acoustic environments. This variability in response to noise makes generalizations about noise impacts among species and among noise sources difficult. Generalizations relevant to a single species can also be hard to make, because the ability to tolerate noise may vary with reproductive status, prior exposure to noise, and the presence of other stressors in the environment. This is why more measurements of noise impacts and associated variables are needed for a wider range of species.

Measuring the effects of noise at the individual and population levels is, however, extremely challenging. As we noted earlier, noise is typically accompanied by other changes in the environment that may also have physiological, behavioral, and population level effects. For example, habitat fragmentation is a side effect of road development, and fragmentation alone has been shown to cause population declines and changes in communication and other behaviors.[32] So, can we measure the impacts of noise on wildlife in ways that will support biologically relevant noise standards?

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[31] Affected animals include birds, mammals, reptiles, and amphibians. Forman et al., *supra* note 6; Rheindt, *supra* note 15; Rien Reijnen et al., *The Effects of Car Traffic on Breeding Bird Populations in Woodland. III. Reduction of Density in Relation to the Proximity of Main Roads*, 32 J. APPLIED ECOLOGY 187–202 (1995); Rien Reijnen et al., *The Effects of Traffic on the Density of Breeding Birds in Dutch Agricultural Grasslands*, 75 BIOL. CONS. 255–260 (1996); S.J. Peris & M. Pescador, *Effects of Traffic Noise on Passerine Populations in Mediterranean Wooded Pastures*, 65 APPLIED ACOUSTICS 357–366 (2004); R.T.T. Forman & L.E. Alexander, *Roads and Their Major Ecological Effects*, 29 ANN. REV. ECOLOGY SYSTEMATICS 207–231 (1998); E. Stone, *Separating the Noise from the Noise: A Finding in Support of the "Niche Hypothesis," That Birds Are Influenced by Human-Induced Noise in Natural Habitats*, 13 ANTHROZOOS 225–231 (2000); Ian Spellerberg, *Ecological Effects of Roads and Traffic: A Literature Review*, 7 GLOBAL ECOLOGY BIOGEOG. LETTERS 317–333 (1998); David Lesbarrères et al., *Inbreeding and Road Effect Zone in a Ranidae: The Case of Agile Frog,* Rana dalmatina *Bonaparte 1840*, 326 COMPTES RENDUS BIOLOGIES 68–72 (2003).

[32] See, *e.g.*, Jeffrey A. Stratford & W. Douglas Robinson, *Gulliver Travels to the Fragmented Tropics: Geographic Variation in Mechanisms of Avian Extinction*, 3 FRONTIERS ECOLOGY & ENV'T 91–98 (2005); P. Laiolo & J. L. Tella, *Erosion of Animal Cultures in Fragmented Landscapes*, 5 FRONTIERS ECOLOGY & ENV'T 68–72 (2007).

4.1 The Observational Approach

4.1.1 Relating wildlife abundance to noise levels

Much of the evidence for noise impacts on animals comes from field observations of animal density, species diversity, and/or reproductive success in relation to noise sources. Most studies focus on the presence or absence of wildlife near roads, finding lower population densities of many birds,[33] lower overall diversity for birds, reptiles, and amphibians,[34] and road avoidance in large mammals.[35] Most of this work does not separate the impacts of noise from other road effects or measure spatial and temporal variations in noise levels along transects where animals were studied.

One influential series of studies in the Netherlands did find, however, a negative relationship between noise exposure along roadways and both bird diversity and breeding densities.[36] Noise exposure better explained decreased density and diversity than either visual or chemical disturbance. These Dutch studies have been criticized for research design and statistical analysis problems,[37] underscoring the fact that researchers in different countries have different assumptions about how to measure noise and evaluate its impacts.[38] On their own, the Dutch studies are an inadequate basis for establishing internationally standardized noise regulations, but they are among the few analyses that set measurements of noise levels beside data on species presence/absence and diversity.

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[33] Forman & Deblinger, *supra* note 3; Rheindt, *supra* note 15; Peris & Pescador, *supra* note 26; M. Kuitunen et al., *Do Highways Influence Density of Land Birds?* 22 Envtl. Mgmt. 297–302 (1998); A.N. van der Zande et al., *The Impact of Roads on the Densities of Four Bird Species in an Open Field Habitat—Evidence of a Long-Distance Effect*, 18 Biol. Cons. 299–321 (1980).

[34] C.S. Findlay & J. Houlahan, *Anthropogenic Correlates of Species Richness in Southeastern Ontario Wetlands*, 11 Cons. Biol. 1000–1009 (1997).

[35] Studies in large mammals typically find road avoidance, but many small mammals are found in higher densities near roads, due to increased dispersal and reduced numbers of predators. Forman & Deblinger, *supra* note 3; F. J. Singer, *Behavior of Mountain Goats in Relation to US Highway 2, Glacier National Park, Montana*, 42 J. Wildlife Mgmt. 591–597 (1978); G.R. Rost & J.A. Bailey, *Distribution of Mule Deer and Elk in Relation to Roads*, 43 J. Wildlife Mgmt. 634–641 (1979); L.W. Adams & A.D. Geis, *Effects of Roads on Small Mammals*, 20 J. Applied Ecology 403–415 (1983).

[36] Reijnen et al., *supra* note 29; R. Foppen & R. Reijnen, *The Effects of Car Traffic on Breeding Bird Populations in Woodland. II. Breeding Dispersal of Male Willow Warblers (*Phylloscopus trochilus*) in Relation to the Proximity of a Highway*, 31 J. Applied Ecology 95–101 (1994).

[37] N. Sarigul-Klign, D.C. Karnoop, & F.A. Bradley, *Environmental Effect of Transportation Noise. A Case Study: Criteria for the Protection of Endangered Passerine Birds, Final Report* (Transportation Noise Control Center (TNCC), Department of Mechanical and Aeronautical Engineering, University of California, Davis, 1977); G. Bieringer & A. Garniel, Straßenalärm und Vögel—eine kurze Übersicht über die Literatur mit einer Kritik einflussreicher Arbeiten. Bundesministerium für Verkehr, Innovation und Technologie. Schriftenreihe Straßenforschung. Unpublished manuscript, Vienna, 2010 (copy on file with the authors).

[38] Noise is commonly measured in dBA SPL, a unit that is measured differently in different countries, making extrapolation difficult. Bieringer & Garniel, *supra* note 32.

The value of observational studies of presence/absence and diversity also needs to be assessed in context. One would not want to use information about reduced occupancy of a noisy area, for example, as the only indication that noise was having population-level impacts. It is conceivable that, if noise results in increased mortality or decreased reproduction, noisy areas could become population sinks,[39] and a detriment to conservation efforts across the range of the species. But this conclusion would be premature unless the presence/absence data are assessed in the context of other measures of impact, such as breeding success, stress response, startling and other behavioral changes.

So, while observational studies can be and have been helpful in identifying noise as a conservation problem, their policy relevance and value is constrained if they are unable to separate the effects of noise from the many other confounding disturbances that can affect animal densities near roads and other human development. When Fahrig et al.[40] documented reduced densities of frogs and toads near high traffic roads compared to low traffic roads, noise was a potential causal factor. After controlling for other variables, however, their evidence suggested that differences in density more likely reflected varying levels of traffic-associated road mortality.

One way to reduce, though not eliminate, the problem of confounding variables is to compare behaviors and other response variables in the presence and absence of noise. Animals can be observed, for example, before and after noise sources are introduced, or when noise is intermittent. This approach has been used to demonstrate the impact (or lack of impact) of noise from aircraft, machinery, and vehicles on animal behavior and reproductive success.[41] Spatial variation in noise may also allow researchers to control for some confounding factors. One study examined ovenbirds (*Seiurus aurocapilla)* along the edges of clearings containing either compressor stations or gas-producing wells.[42] Both clearings had a similar level of surface disturbance and human activity, but compressors produced high-amplitude noise whereas the wells were relatively quiet. Near compressors, the analysis found reduced pairing success and evidence that the habitat was non-preferred.[43]

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[39] Sinks are areas where successful reproduction is insufficient to maintain the population without immigration. H.R. Pulliam, *Sources, Sinks, and Population Regulation*, 132 AM. NATURALIST 652–661 (1988).

[40] L. Fahrig et al., *Effect of Road Traffic on Amphibian Density*, 73 BIOL. CONS. 177–182 (1995).

[41] Delaney et al., *supra* note 24; D. Hunsaker, J. Rice, & J. Kern, *The Effects of Helicopter Noise on the Reproductive Success of the Coastal California Gnatcatcher*, 122 J. ACOUSTICAL SOC. AM. 3058 (2007); Jennifer W. C. Sun & Peter M. Narins, *Anthropogenic Sounds Differentially Affect Amphibian Call Rate*, 121 BIOL. CONS. 419–427 (2005).

[42] L. Habib, E.M. Bayne, & S. Boutin, *Chronic Industrial Noise Affects Pairing Success and Age Structure of Ovenbirds* Seiurus aurocapilla, 44 J. APPLIED ECOLOGY 176–184 (2007).

[43] Habib et al. found an increased proportion of juveniles in noisy areas, suggesting that the area is undesirable for breeding adults. *Id.*

An additional observational approach is to include noise as a factor in habitat-selection models. These spatially explicit models, typically produced in GIS (Geographic Information Systems), relate species distribution data to information about landscape characteristics in order to determine the impact of disturbance or habitat quality on habitat usage by wildlife.[44] Multiple habitat layers can be added to the model to determine what factors best predict habitat usage. While few studies have incorporated noise into these types of models, GIS layers of noise can readily be created using commercially available and freeware programs. These types of models may be the best option for measuring noise impacts on a large scale and can also be useful in predicting future areas of conflict with human activities.

Ideally, future observational studies encompassing a variety of noise sources, habitats, and species will measure noise exposure levels and then relate observed impacts to noise exposure while controlling for confounding variables. When effects cannot properly be controlled for in a single study design, a second-best choice is to use replicated studies and let statistical modeling separate out the impacts of noise. To date, only a handful of studies follow this approach.[45]

4.1.2 Estimating the masking potential of noise

There is a relatively simple technique for addressing possible noise impacts on signal detection. It involves estimating the potential of a noise source to mask communication signals and other important sounds, such as the sounds of predators or prey. Masking occurs when background noise is loud relative to the signal, such that it cannot be detected by the receiver.

The estimation of masking requires knowledge of the physiology and behavior of the organism and the nature of the noise. Masking is frequency-specific, so an acoustic signal will only be masked by the portion of the background noise that is in a similar frequency band as the signal.[46] An

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[44] J.B. Dunning et al., *Spatially Explicit Population Models: Current Forms and Future Uses*, 5 ECOLOGICAL APPLICATIONS 3–11 (1995).

[45] Forman, Reineking, & Hersberger, *supra* note 6; Reijnen et al. (1995), *supra* note 29; Reijnen et al. (1996), *supra* note 29; Foppen & Reijnen, *supra* note 34; R. Reijnen & R. Foppen, *The Effects of Car Traffic on Breeding Bird Populations in Woodland. I. Evidence of Reduced Habitat Quality for Willow Warblers (*Phylloscopus trochilus*) Breeding Close to a Highway*, 31 J. APPLIED ECOLOGY 95–101 (1994).

[46] Lohr et al., *supra* note 8; E.A. Brenowitz, *The Active Space of Red-Winged Blackbird Song*, 147 J. COMP. PHYSIOLOGY 511–522 (1982); R.J. Dooling & B. Lohr, *The Role of Hearing in Avian Avoidance of Wind Turbines, in* PROC. NAT'L AVIAN-WIND PLANNING MEETING IV 115–134 (S.S. Schwartz ed., for the Avian Subcommittee, National Wind Coordinating Committee, 2001).

estimation of masking requires,[47] first, the audiogram of the focal species;[48] second, the absolute amplitude and frequency spectrum of the noise;[49] third, the absolute amplitude and frequency spectrum of the vocalization or sound of interest; and fourth, the critical ratio for the focal species.[50]

With this information, masking is estimated by determining how introduced noise changes the "active space" of the signal, which is the area around the sender where the signal can be detected by receivers.[51] Intuitively, there is less masking when signals have a different frequency profile than noise, when noise is quiet, when signals are loud and/or when animals are close together when communicating. Conversely, masking is most problematic when signal and noise have similar frequency profiles, when noise is loud, when calls are quiet, and/or when calls are used over large distances.[52]

There are, however, limitations to masking estimations. The method described addresses only the potential impacts of masking animal vocalizations or other sounds and cannot estimate other impacts of noise, such as startling or chronic stress. Further, in the absence of specific information about the auditory physiology and behaviors of the focal species, estimates of masking using this method may be either too conservative or too liberal. Estimates can be too conservative, for example, in situations in which the mere detection of a vocalization is an insufficient basis for extracting necessary information from the sound.[53] Estimates can be too liberal if as part of their communication

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[47] For detailed methods on calculating masking potential, *see* R.J. Dooling & J.C. Saunders, *Hearing in the Parakeet (*Melopsittacus undulatus*): Absolute Thresholds, Critical Ratios, Frequency Difference Limens, and Vocalizations*, 88 J. COMP. PHYSIOL. 1–20 (1975).

[48] A measure of how hearing sensitivity varies with the frequency of the sound. In general, birds do not hear as well as mammals in very low or high frequencies, or use them to communicate. Dooling & Popper, *supra* note 1.

[49] A measure of how much energy is present in each frequency band of the sound.

[50] This is the difference in amplitude between signal and noise necessary for detection of the signal. For a generalized bird, the critical threshold ranges from approximately 26 to 28 dB between 2 and 3 kHz, meaning that a typical bird cannot hear a 2–3 kHz vocalization unless the vocalization exceeds the background noise in that frequency range by 26–28 dB. In general, birds have higher critical ratios than mammals, making them worse at discriminating signals in noise. If measurements for these parameters are not available for the focal species, then information from closely related species may be used as a substitute. However, this may be misleading if the species of interest has particularly strong or poor hearing capabilities relative to the substitute species. Dooling & Popper, *supra* note 1; Lohr et al., *supra* note 8; Dooling & Saunders, *supra* note 45.

[51] Lohr et al., *supra* note 5; Brenowitz, *supra* note 39.

[52] Lohr et al., *supra* note 5; Bee & Swanson, *supra* note 15; G. Ehret & H.C. Gerhardt, *Auditory Masking and Effects of Noise on Responses of the Green Treefrog (*Hyla cinerea*) to Synthetic Mating Calls*, 141 J. COMP. PHYSIOL. A 13–18 (1980); T. Aubin & P. Jouventin, *Cocktail-Party Effect in King Penguin Colonies* 265 PROC. R. SOC. B 1665–1673 (1998).

[53] This would happen when humans can detect human voices, but not discriminate the identity of the speaker or the words being said. *See* Lohr et al., *supra* note 5, for a discussion of the difference between detection and discrimination.

animals use spatial cues,[54] co-modulation of frequencies,[55] or adjust their vocalizations to reduce masking.[56]

Because so many factors affect the degree of masking, there is a critical need for additional field studies to validate estimation techniques. The available work relating the potential for masking to observed individual- and population-level impacts[57] is just not a sufficient basis for knowing whether masking potential is a reliable predictor of how noise will impact wildlife. If the predictive power of measuring masking potential can be shown, researchers will then have a low-cost tool for predicting impacts in species about which little is known. Otherwise, masking analysis is most informative when used in concert with field studies that assess actual noise impacts. If a disruption of communication or decreased rates of prey capture in noisy areas can be demonstrated, then an analysis of the masking potential of a new noise source could be used to determine the area over which individuals are likely to be affected by that new source.[58]

4.2 The Experimental Approach

Experimental manipulations of noise in the laboratory and the field are more powerful than observational studies in isolating the effects of noise and identifying the underlying causes of noise impacts because they deal more effectively with the problem of controlling for confounding variables. The following sections discuss their advantages and limitations.

4.2.1. Laboratory experiments

Laboratory studies introduce noise to captive animals and measure the impacts in a controlled environment. Studies using captive animals are the basis for much of what we know about the hearing range and sensitivity of a number of animal taxa[59] and about the ability of animals to detect and

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[54] The ability to hear sounds is improved if they are separated spatially. M. Ebata, T. Sone, & T. Nimura, *Improvement of Hearing Ability by Directional Information,* 43 J. ACOUSTICAL SOC. AM. 289–297 (1968); J.J. Schwartz & H.C. Gerhardt, *Spatially Mediated Release From Auditory Masking in an Anuran Amphibian,* 166 J. COMP. PHYSIOL. A 37–41 (1989).

[55] Masking is reduced when the noise has amplitude modulation patterns that make it distinct from the signal. G.M. Klump & U. Langemann, *Co-Modulation Masking Release in a Songbird,* 87 HEARING RES. 157–164 (1995).

[56] Patricelli & Blickley, *supra* note 10; Rabin & Greene, *supra* note 10; Warren et al., *supra* note 10; Slabbekoorn & Peet, *supra* note 17.

[57] Rheindt, *supra* note 18.

[58] Lohr et al., *supra* note 8.

[59] Dooling & Saunders, *supra* note 45; K. Okanoya & Robert F. Dooling, *Hearing in the Swamp Sparrow,* Melospiza georgiana, *and the Song Sparrow,* Melospiza melodia, 36 ANIMAL BEHAV. 726–732 (1988); H.E. Heffner et al., *Audiogram of the Hooded Norway Rat,* 73 HEARING RES. 244–247 (1994); H.E. Heffner & R.S. Heffner, *Hearing Ranges of Laboratory Animals,* 46 J. AM. ASS'N LABORATORY ANIMAL SCI. 20–22 (2007).

discriminate sounds in the presence of background noise.[60] These psychoacoustic studies are critical for assessing masking potential, and provide a physiological and morphological basis for predicting which species are most likely to be impacted by introduced noise.[61] Laboratory studies also provide insight into the physiological and behavioral impacts of noise, and the potential consequences of masking for breeding individuals.[62] As noted earlier, they demonstrate impacts on pair-bonding[63] and the amplitude at which vocalizations are produced.[64] They do not address, however, the long-term consequences of these behavioral changes, which remain unclear and need further study both in the laboratory and in the field.

Traditionally, psychoacoustic studies use white noise or pure tones to measure hearing ability and noise effects.[65] Recent studies also address the effects of anthropogenic noise directly, increasing their relevance to conservation. Lohr and colleagues, for example, measured the masked thresholds of natural contact calls for budgerigars (*Melopsittacus undulates)* and zebra finches, in the lab using simulated traffic noise, allowing them to predict how traffic noise affects the distance at which vocalizations can be detected by receivers.[66]

The environmental control that gives laboratory studies their analytic power can also be a disadvantage, if there is reason to believe that the response of animals to noise in a laboratory setting will be different from that of animals in the wild, where natural variations in the environment and in animal populations can affect the impact of noise. When increased physiological stress from noise is experienced, for example, in combination with habitat loss, synergistic effects on animals will magnify the overall impact of development.

Laboratory studies also must be careful not to extrapolate findings from animals that thrive in captivity to endangered animals, particularly since the

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[60] Lohr et al., *supra* note 8; Dooling & Saunders, *supra* note 45; Klump & Langemann, *supra* note 53; L. Wollerman, *Acoustic Interference Limits Call Detection in a Neotropical frog* Hyla ebraccata, 57 Animal Behav. 529–536 (1999).

[61] Dooling & Popper, *supra* note 1.

[62] Marler et al., *supra* note 14; Ryals et al., *supra* note 14; J. Syka & N. Rybalko, *Threshold Shifts and Enhancement of Cortical Evoked Responses After Noise Exposure in Rats*, 139 Hearing Res. 59–68 (2000); D. Robertson & B.M. Johnstone, *Acoustic Trauma in the Guinea Pig Cochlea: Early Changes in Ultrastructure and Neural Threshold,* 3 Hearing Res. 167–179 (1980).

[63] Swaddle & Page, *supra* note 19.

[64] J. Cynx, et al., *Amplitude Regulation of Vocalizations in Noise by a Songbird,* Taeniopygia guttata, 56 Animal Behav. 107–113 (1998); Marty L. Leonard & Andrew G. Horn, *Ambient Noise and the Design of Begging Signals,* 272 Proc. R. Soc. B 651–656 (2005). This finding has been corroborated with studies of birds in the field in Brumm, *supra* note 18.

[65] Dooling & Saunders, *supra* note 45; Klump & Langemann, *supra* note 53; Wollerman, *supra* note 53; J.B. Allen & S.T. Neely, *Modeling the Relation between the Intensity Just-Noticeable Difference and Loudness for Pure Tones and Wideband Noise*, 102 J. Acoustical Soc. Am. 3628–3646 (1997).

[66] Lohr et al., *supra* note 8. For other studies that introduce anthropogenic noise, see Weisenberger et al., *supra* note 7; Bee & Swanson, *supra* note 18.

animals chosen for laboratory study are often domesticated or otherwise show tolerance for human disturbance. Endangered animals, by contrast, are often driven to rarity due to their inability to tolerate environmental change, which may include sensitivity to noise.[67] The use of surrogate species would be unnecessary if the species of concern could be tested in the lab for noise response. But small population sizes and narrow tolerances often make it impossible to bring threatened or endangered species into the lab for such tests.

The use of anthropogenic noise in laboratory studies of noise effects, particularly noise that is likely to be affecting wild animals, increases the conservation applicability of such research and should be a future priority. Laboratory experiments must also be supplemented with field studies and other methods to fully understand the impacts of noise on wildlife.

4.2.2. Noise introduction experiments in the field

Field experiments are another method for isolating and quantifying the impacts of noise on animals under natural conditions. The controlled introduction of noise can be accomplished either by creating noise in the field or by playing back the associated noise through speakers. The first approach has been used to investigate the impacts on wildlife of aircraft, machinery, and vehicles.[68] As is the case with observational studies, interpretations of this type of research are complicated by the problem of controlling for confounding variables, such as the visual and other disturbances, in addition to noise, associated with many sorts of environmental change. Compared to observational studies, however, field experiments offer greater opportunities to examine interactions among multiple associated stressors. They are also generally a more efficient use of scarce research resources and provide the ability to control for (or examine) seasonal effects, time-of-day effects, and other factors influencing responses to noise.

The second experimental approach, playing back noise that has been recorded from a source of interest or synthesized to match that source,[69] has the advantage that noise effects can be easily separated from other aspects of disturbance. Because noise introduction on a large spatial and temporal scale is logistically challenging in natural habitats, studies to date have been short-term and relatively small in scale. A short-term experiment may be appropriate

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[67] T. Caro, J. Eadie, & A. Sih, *Use of Substitute Species in Conservation Biology*, 19 CONS. BIOL. 1821–1826 (2005).

[68] Delaney, et al., *supra* note 24; P. R. Krausman, et al., *Effects of Jet Aircraft on Mountain Sheep*, 62 J. WILDLIFE MGMT. 1246–1254 (1998); A. Frid, *Dall's Sheep Responses to Overflights by Helicopter and Fixed-Wing Aircraft*, 110 BIOL. CONS. 387–399 (2003).

[69] Sun & Narins, *supra* note 39; A.L. Brown, *Measuring the Effect of Aircraft Noise on Sea Birds*, 16 ENV'T INT'L 587–592 (1990).

for studying dynamic behaviors, such as call rate, startling, or avoidance,[70] but cannot address the longer-term individual- or population-level consequences of noise.

To illustrate study design for a long-term and large-scale noise introduction experiment, we describe our ongoing experiment in Wyoming, addressing the noise impacts of energy development on greater sage-grouse.

4.2.2.1 Noise impacts on sage-grouse: A long-term field experiment

Populations of this species are declining throughout their range in the interior West of the United States,[71] enough to merit consideration for listing under the federal Endangered Species Act. Coal-bed methane (CBM) and deep natural gas extraction are increasing rapidly in sage-grouse habitats, and recent studies document dramatic declines in sage-grouse populations in areas of energy development.[72] However, incomplete knowledge of the causes of these declines is hampering the creation of effective management strategies.

Among the number of disturbances associated with energy development that impact sage-grouse, noise is particularly problematic in breeding areas downwind of development when it causes declines in male attendance, although attendance was not affected by visual disturbance from development.[73] In addition, the life history of sage-grouse makes them particularly vulnerable to disturbance from noise pollution. In the breeding season, males gather on communal breeding grounds (leks) to perform complex acoustic displays, used by females to locate leks and choose mates. The risk is that anthropogenic noise in sage-grouse habitat masks male vocalizations and interferes with reproduction. While there are rules governing the noise emitted during drilling of natural gas wells, exemptions are often granted and there has been little research demonstrating that stipulated noise levels reduce the impacts of development on sage-grouse, as well as other sensitive species.

Our multi-year, noise-introduction experiment on sage-grouse leks in an otherwise undisturbed area tries to separate the impacts of noise from other potential impacts of energy development. Two types of noise are of

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[70] Weisenberger et al., *supra* note 7; Sun & Narins, *supra* note 39; Leonard & Horn, *supra* note 62; Brown, *supra* note 67.

[71] J.W. Connelly et al., Conservation Assessment of Greater Sage-Grouse and Sagebrush Habitats, Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, Wyoming, 2004. Copy online at http://www.ndow.org/wild/conservation/sg/resources/greate_sg_cons_assessment.pdf

[72] M.J. Holloran, Greater Sage-Grouse (*Centrocercus urophasianus*) Population Response to Natural Gas Field Development in Western Wyoming (2005) (unpublished Ph.D. dissertation, University of Wyoming) (accessible online from http://www.sagebrushsea.org/th_energy_sage_grouse_study2.htm); Brett L. Walker et al., *Greater Sage-Grouse Population Response to Energy Development and Habitat Loss*, 71 J. WILDLIFE MGMT. (2007); Dooling & Popper, *supra* note 1.

[73] Other factors at work include habitat loss, fragmentation, dust, air pollution, and West Nile virus. Connelly et al, *supra* note 64; Holloran, *supra* note 70; D.E. Naugle et al., *West Nile Virus: Pending Crisis for Greater Sage-Grouse*, 7 ECOLOGY LETTERS 704–713 (2004).

primary interest, road noise and drilling noise. Both types are dominated by low frequencies, but drilling noise is high intensity, continuous noise, whereas road noise is intermittent with gradual increases and decreases in amplitude. Monitored leks are divided into pairs of control leks and leks with experimentally introduced noise.[74] Ideally, noise would be introduced at different levels on different leks to determine the noise threshold at which an impact can be observed. However, such a "dose-response" experiment would require a large sample of leks and that is logistically infeasible. The experiment, instead, creates a noise gradient across each lek, so that the effect of noise level on microhabitat use and behavior can be measured and noise-tolerance thresholds estimated.

This experimental approach isolates and makes it possible to assess the impacts of noise on lekking sage-grouse at both the individual and population levels. The individual effects are analyzed from audio and video recordings, to determine whether individuals change the rate, frequency structure, and amplitude of their displays in the presence of noise, as has been found in other species.[75] A non-invasive technique compares the relative stress levels of birds on experimental and control leks through analysis of stress hormones in feces.[76] Population-levels effects of noise derive from comparison of lek attendance patterns on experimental and control leks over multiple seasons. This allows detection of noise impacts while controlling for natural variations in behavior, physiology, and larger-scale fluctuations in the population.

Although introducing noise in the wild is a powerful tool for measuring noise impacts on animals, it is only appropriate in certain circumstances. Noise introduction requires access, for example, to a population of animals residing in a relatively undisturbed area. Such a population may be unavailable in some species of concern, or the species may be too sensitive or rare to risk such an experimental manipulation. In addition, animals must be at fairly high densities in order to collect sufficient data for analysis, because it is difficult to create a noise disturbance over a large area using speakers.[77] During the breeding season, noise introduction can rely on battery-powered speakers, because leks are relatively small and have a high density of birds. This same

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[74] Paired leks have similar size and location and are visited by researchers for counts on the same days. Noise is introduced at 70 dBF SPL (unweighted decibels) at 16 meters using three to four battery-powered outdoor speakers. This is similar to noise levels measured at $\frac{1}{4}$-mile from drilling rigs and main haul roads in Pinedale, Wyoming. Control leks have dummy speakers and are visited for "battery changes" with the same frequency as experimental leks.

[75] Patricelli & Blickley, *supra* note 13; Warren et al., *supra* note 13; Rabin et al., *supra* note 13; Rabin & Greene, *supra* note 13; Slabbekoorn & Peet, *supra* note 20.

[76] *See, e.g.,* Wasser et al., *supra* note 27.

[77] Most anthropogenic noise sources are very large, and it is extremely difficult to replicate loud noise over a large area from small speakers, since amplitude (and thus propagation) is limited by source size. This challenge is even greater when speakers are powered by batteries in remote field locations.

approach is less able, however, to address noise impacts on nesting or overwintering behaviors, when sage-grouse are more dispersed.

In some situations, the use of semi-captive populations reaps some of the benefits of both field and laboratory studies, by increasing animal density in a more natural setting than is afforded by laboratory animal colonies. This approach is outside the scope of our current study. Another limitation of the experimental approach is that it underestimates (or even misses) the impacts of noise that occur in interaction with other forms of disturbance, such as the combination of noise pollution with an increase of raptor perches in energy development areas.[78] The combined effects will be larger than that attributable to either disturbance alone, but they can only be examined in observational studies and noise-source introduction experiments. This highlights, again, the need for multiple research approaches to measuring wildlife noise impacts.

There are very few experimental studies that use either noise-source introductions or noise playbacks, even though these experimental tools, used in a field setting or in naturalistic captive settings, are among the most powerful for understanding noise impacts on wild populations. Large-scale field experiments are expensive and logistically challenging. They do, however, appear to be warranted, particularly when observational studies and measurements of masking potential suggest a likely role for noise in impacting wild animals. Future field research should also focus on validating results and methods from laboratory studies, thus increasing the ability to apply lab studies and estimates of masking potential to the development of effective mitigation measures and predictions about the impacts future development is likely to have on wildlife.

5. FUTURE DIRECTIONS AND POLICY RELEVANCE

Even though the rapid spread of human development and associated anthropogenic noise have impacts on wildlife, it is not always logistically, politically, or economically feasible to eliminate or even minimize noise. The more common policy approach is to set noise standards, in the hope of limiting the levels of noise that development produces. The production of noise can then be reduced structurally[79] or operationally[80] to meet these standards. Road noise, for example, can be reduced through the use of certain types of asphalt, although these road surfaces can also have lower durability, lower traction, and higher cost than noisier varieties. Road noise can also be decreased by noise barriers, but these may cut off migration routes and exacerbate rather than

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[78] Connelly et al., *supra* note 69.

[79] Noise can be reduced structurally by using alternative materials and architecture, such as noise barriers, to reduce sound production and propagation.

[80] Noise can be reduced operationally through limitations on the timing and frequency of noisy activities, for example, by avoiding shift changes that occur at 7:00 a.m., in the peak lekking hours of sage-grouse.

reduce overall road impacts.[81] Regulations necessarily balance the economic and environmental trade-offs involved in allowing development to proceed and as a general rule the more information that can be brought to bear on this balancing process the better.

There can be no doubt that the first priority in the development of most current noise standards is the protection of human welfare. They use human criteria of disturbance, generated primarily in areas where humans are impacted.[82] These standards protect animal species with noise tolerances and distributions similar to those of humans. They are not effective, however, in reducing the impacts of noise on sensitive species of wildlife. So what should be our goal in the development of effective noise standards for the protection of wildlife? Environmental managers typically prefer a single noise standard that covers all situations. But since species differ in their ability to tolerate noise, a single noise standard is bound to be conservative for some species and insufficient for others. [83] Simply erring on the side of more conservative standards could do more harm than good in cases where it diverts money from more appropriate types of mitigation, and when noise mitigation measures introduce other environmental and economic costs, as discussed above. Rather than a single standard, a set of standards is needed, based on the measured sensitivities of indicator species and species of concern in a particular habitat type or location. Recently, a panel of experts developed a set of general and species-specific recommendations for marine mammal noise exposure criteria.[84] The development of such a set of standards for terrestrial species will require information about sensitivity to noise pollution in both abundant and rare species; the research priorities outlined here will help to achieve this goal.

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[81] Forman, Reineking, and Hersberger, *supra* note 6.

[82] Dooling & Popper, *supra* note 1; SINGAL, *supra* note 9.

[83] A single noise standard, for example, might establish a maximum acceptable noise level of 49 dBA at a one quarter mile from a noise source.

[84] B.L. Southall, A.E. Bowles, & W.T. Ellison, *Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations*, 125 J. ACOUSTICAL SOC. AM. 2517 (2009). There is no equivalent set of recommendations for terrestrial animals.

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CHAPTER 3

POTENTIAL ACOUSTIC MASKING OF GREATER SAGE-GROUSE (*CENTROCERCUS UROPHASIANUS*) DISPLAY COMPONENTS BY CHRONIC INDUSTRIAL NOISE

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Abstract.—Anthropogenic noise can limit the ability of birds to communicate by masking their acoustic signals. Masking, which reduces the distance over which the signal can be perceived by a receiver, is frequency dependent, so the different notes of a single song may be masked to different degrees. We analyzed the individual notes of mating vocalizations produced by Greater Sage-Grouse (*Centrocercus urophasianus*) and noise from natural gas infrastructure to quantify the potential for such noise to mask Greater Sage-Grouse vocalizations over both long and short distances. We found that noise produced by natural gas infrastructure was dominated by low frequencies, with substantial overlap in frequency with Greater Sage-Grouse acoustic displays. Such overlap predicted substantial masking, reducing the active space of detection and discrimination of all vocalization components, and particularly affecting low-frequency and low-amplitude notes. Such masking could increase the difficulty of mate assessment for lekking Greater Sage-Grouse. We discuss these results in relation to current stipulations that limit the proximity of natural gas infrastructure to leks of this species on some federal lands in the United States. Significant impacts to Greater Sage-Grouse populations have been measured at noise levels that predict little or no masking. Thus, masking is not likely to be the only mechanism of noise impact on this species, and masking analyses should therefore be used in combination with other methods to evaluate stipulations and predict the effects of noise exposure.

Key words: acoustic masking, *Centrocercus urophasianus*, Greater Sage-Grouse, industrial noise.

Enmascaramiento Acústico Potencial de Mayor Sage-Grouse (*Centrocercus urophasianus*) Mostrar Componentes por Ruido Industrial Crónica

Resumen.— Antropógena ruido puede limitar la capacidad de las aves para comunicarse por enmascarar sus señales acústicas. Enmascaramiento, que reduce la distancia sobre la que se puede percibir la señal por un receptor, es frecuencia dependiente, por lo que las diferentes notas de una canción pueden enmascararse en diferentes grados. Analizamos las notas individuales de apareamiento vocalizaciones producidas por mayor Sage-Grouse (Centrocercus urophasianus) y el ruido de infraestructura de gas natural para cuantificar el potencial de tal ruido a vocalizaciones de mayor Sage-urogallo de máscara en distancias cortas y largas. Hemos encontrado que ruido producido por la infraestructura de gas natural fue dominado por las frecuencias bajas, con considerable superposición en frecuencia con pantallas acústicas de mayor Sage-urogallo. Tal superposición predijo enmascaramiento sustancial, reduciendo el espacio activo de detección y discriminación de todos los componentes de vocalización y que afectan particularmente a notas de baja frecuencia y baja amplitud. Estas máscaras podrían aumentar la dificultad de evaluación de mate para lekking mayor Sage-urogallo. Analizaremos estos resultados en relación con las actuales disposiciones que limitan la proximidad de la infraestructura de gas natural a leks de esta especie en algunas tierras federales en los Estados Unidos. Impactos

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significativos a las poblaciones de mayor Sage-urogallo han sido medidos en los niveles de ruido que predicen el enmascaramiento de poca o ninguna. Así, enmascaramiento no es probable que sea el único mecanismo de impacto de ruido en esta especie, y enmascaramiento análisis debe por lo tanto, utilizarse en combinación con otros métodos para evaluar las estipulaciones y predecir los efectos de la exposición al ruido. Así, enmascaramiento no es probable que sea el único mecanismo de impacto de ruido en esta especie, y enmascaramiento análisis debe por lo tanto, utilizarse en combinación con otros métodos para evaluar las estipulaciones y predecir los efectos de la exposición al ruido.

Birds use acoustic signals to communicate with conspecifics for a host of biologically important functions, including mate attraction, territory defense, parent–offspring communication, and predator avoidance. In order for this communication to be successful, the signal must travel from the signaler to the receiver through the local environment. The local physical and acoustic environment, therefore, plays an important role in determining the active space of a signal, the area in which a receiver can successfully perceive it (Brenowitz 1982, Dooling et al. 2009). Background noise, a conspicuous feature of most natural environments, can result in acoustic masking if this noise is loud in relation to the signal of interest. Animals have numerous acoustic and behavioral adaptations to maximize the active space of their signals in the presence of natural background noise. For example, the structural and temporal properties of many acoustic signals appear to be adapted to maximize the propagation distance and minimize masking from abiotic and biotic noise sources in the environment (Marten and Marler 1977, Wiley and Richards 1982, Ryan and Brenowitz 1985, Brumm 2006). However, the spread of humans into natural landscapes has resulted in the proliferation of anthropogenic noise sources, with the potential to affect many of the animal species that live and communicate in these environments (Barber et al. 2010). Acoustic signals that are adapted to deal with natural noise sources may still be susceptible to masking from anthropogenic noise sources if the anthropogenic noise differs enough from natural noise sources in frequency, duration, or daily or seasonal pattern.

Effective communication requires that a receiver be able to detect a given signal, discriminate that signal from other possible signals, and recognize features that may convey information about the specific signaler. The active space of a signal may be different for each of these receiver tasks (Lohr et al. 2003). Detection provides the receiver with the lowest level of information—simply that a signal is present—and requires the lowest contrast between the signal and background noise. For a signal to be successfully detected in a noisy environment requires that the ratio of the signal to the background noise (i.e., signal-to-noise ratio [SNR], the difference between signal and noise amplitudes measured in decibels) within a frequency band exceed a critical detection threshold (Klump 1996). The critical detection threshold for a "typical bird" ranges from 18 dB to 37 dB across frequency bands. Discrimination of the signal from other signals, as would be required to identify the species of the sender or the functional category of the signal, requires a higher SNR than detection. In a laboratory study of two bird species, Lohr et al. (2003) found that discrimination of conspecific song required an SNR approximately 3 dB higher than the levels required for detection. An even more challenging task for a receiver is signal recognition, discerning variation among signals within a category, such as information about individual identity or reproductive quality. For example, receivers may use the acoustic features of the signal such as frequency structure, relative amplitude of notes, and note duration to recognize the identity of the signaling individual. Signal recognition may require an even higher SNR (Dooling and Popper 2007); however, we do not yet know how much higher the signal must be for recognition to occur.

The fitness consequences of being able to detect a signal versus discriminate or recognize a signal is likely to be signal specific. For example, a predator alert call, which functions to alert a conspecific to danger, may be effective so long as it exceeds the critical ratio for detection. However, a mate-attraction call that is used by females to assess the quality of a potential mate may need to exceed the critical recognition threshold in order to be effective. For example, the ability to recognize individual signals is critical to mate choice in the Swamp Sparrow (*Melospiza georgiana*): females use song features such as trill rate and frequency bandwidth to assess the quality of potential mates (Ballentine et al. 2004). Introduced noise has been demonstrated to weaken pair bonds in captive Zebra Finches (*Taeniopygia guttata*; Swaddle and Page 2007), which suggests that reduced recognition can have fitness consequences.

Active space can vary within a given signal as well as among signals. Many bird vocalizations are highly complex and are composed of multiple acoustic components (bouts, phrases, syllables, or notes). Some multicomponent signals may encode either distinct ("multiple messages hypothesis") or redundant ("redundancy hypothesis") information about the signaler (Møller and Pomiankowski 1993, Hebets and Papaj 2005). For example, the trill note and note complex of White-crowned Sparrow (*Zonotrichia leucophrys*) song each convey distinct information about dialect and individual identity, respectively (Nelson and Poesel 2007). Each component can vary in frequency structure, duration, and relative amplitude; these factors interact with the local physical and acoustic environment to determine the active space of the signal component (Patricelli et al. 2008). The result of this variation is that each component of a complex vocalization may have a different active space and be uniquely susceptible to masking by a given noise source.

Anthropogenic noise is typically dominated by low frequencies, so low-frequency signal components and features are most susceptible to masking (Brumm and Slabbekoorn 2005, Slabbekoorn and Ripmeester 2008). Even if a signal is not completely masked, low-frequency background noise could distort a signal, resulting in a higher-frequency note being perceived as having higher relative amplitude than a masked lower-frequency note. Such distortion could result in increased difficulty in assessment or identification.

Our focal species, the Greater Sage-Grouse (*Centrocercus urophasianus*; hereafter "sage-gouse"), is a medium-bodied gallinaceous bird that has long been used as a model system for studies of sexual selection and communication (Wiley 1973; Gibson 1989, 1996). During the breeding season, males gather on strutting grounds (leks) where they establish small display territories that are visited by females for courtship. Males produce a complex visual and acoustic display. Sound is critical to the breeding system on both large and small spatial scales because females use the acoustic component of the display to locate strutting males and, once on a lek, to select a male (Gibson 1989, 1996; Patricelli and Krakauer 2010).

The sage-grouse vocal display is composed of three major note types: a series of low-frequency "coo" notes, two broadband "pops," and a frequency-modulated "whistle" (Fig. 1). The rate of display (strut rate) is positively correlated with male success in mating (Gibson and Bradbury 1985, Gibson 1996, Patricelli and Krakauer 2010). In addition, the time interval between the two pop notes during which the whistle note occurs, the inter-pop interval (IPI), is positively correlated with mating success (Gibson et al. 1991, Gibson 1996). This suggests that assessment of the two pop notes might be particularly critical in female mating decisions. Whistles may also be important in female choice. Gibson and Bradbury (1985) found that the time interval from the first pop to the whistle peak as well as the maximum frequency of the whistle at the apex are related to male mating success. Female sage-grouse also may assess amplitude of the whistle; unpublished results suggest that whistle amplitude may be positively correlated with mating success (J. W. Bradbury pers. comm.), and males orient during courtship so that the highly directional whistle is beamed toward females (Dantzker et al. 1999). This female preference for male-display quantity

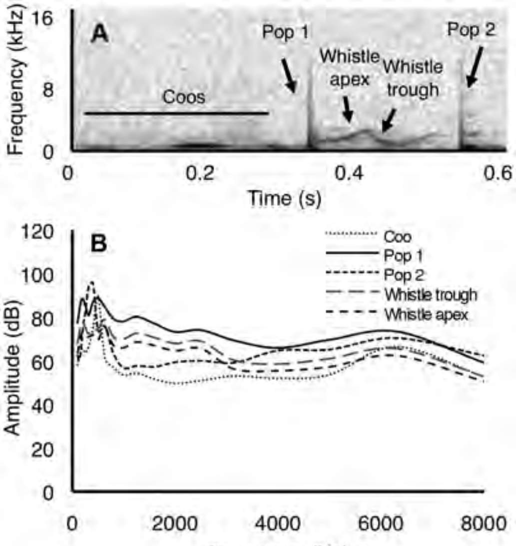

FIG. 1. Spectrogram and (B) power spectra of a male Greater Sage-Grouse strut display with distinct display components labeled. Low-frequency coos are followed by a broadband pop (pop 1), a frequency-modulated whistle with an apex of ~2,500 Hz (whistle apex) and a minimum of ~630 Hz (whistle trough), and another broadband pop (pop 2).

and quality suggests that masking of one or all of these notes by background noise may negatively affect a female's ability to assess males on the lek.

Sage-grouse populations are declining across their range (Connelly et al. 2004, Garton et al. 2011), leading sage-grouse to be listed as endangered under Canada's Species at Risk Act and designated as a candidate species for listing in the United States under the federal Endangered Species Act. Natural gas development has expanded rapidly over the past decade and has been implicated in contributing to population declines (Holloran 2005, Walker et al. 2007, Copeland et al. 2009, Holloran et al. 2010). In particular, noise associated with energy development has been demonstrated to result in reduced attendance on leks (Blickley et al. 2012) and is associated with increased stress hormones in males on noisy leks (J. L. Blickley and G. L. Patricelli unpubl. data). Masked communication has been suggested as a mechanism of this impact, so understanding the potential for introduced noise sources to mask signals used in mating could lead to improved management of vulnerable sage-grouse populations.

The present study addresses the potential for noise pollution from natural gas development to mask or distort acoustic signals that are used in breeding by sage-grouse. We analyzed the individual acoustic components of sage-grouse vocalizations (Fig. 1) and noise from natural gas infrastructure (a compressor station, generator, and drilling rig; Fig. 2) to quantify the potential for such noise to mask sage-grouse vocalizations over both long and short distances. We compared the effect of such noise on the level of both detection and discrimination and discuss the utility of this approach for predicting the impacts of noise on this and other species. For the masking analysis, we focused primarily on noise measurements at 75 m and 400 m (~1/4 mile), which represent a typical distance to the edge of surface disturbance (the pad) from a compressor station or drilling rig and the distance stipulated as the minimum surface-disturbance buffer around leks in our study region, respectively (Bureau of Land Management 2008).

METHODS

Field recordings and measurements.—Between 1 and 5 May 2010, we collected field recordings and vocal amplitude measurements from adult male sage-grouse on Preacher Reservoir lek (42°53.597′N, 108°28.417′W) in Fremont County, Wyoming. Recordings and amplitude measurements were collected simultaneously from a blind on the lek using a handheld Larson Davis 824 sound level meter (software version 3.12) using the logging function with a time-history resolution of 1/32 s and an amplitude resolution of 0.1 dB. A Marantz PMD670 portable solid-state recorder continuously recorded the audio stream from the SPL meter (through the AC/DC output) at 16-bit linear PCM format at 44.1 kHz. Each sound level measurement started prior to the initiation of a display by an individual male. The SPL meter measured and logged the average and peak amplitude in unweighted decibels (dB) at each time interval (0.03 s). Immediately after the vocalization was recorded, the distance between the vocalizing bird and the microphone was measured with a range finder (Leupold RX750). Sage-grouse strut displays are highly directional (Dantzker et al. 1999), so the orientation of the bird and distance to the microphone were also noted for each display measured. We used only high-quality and comparable measurements

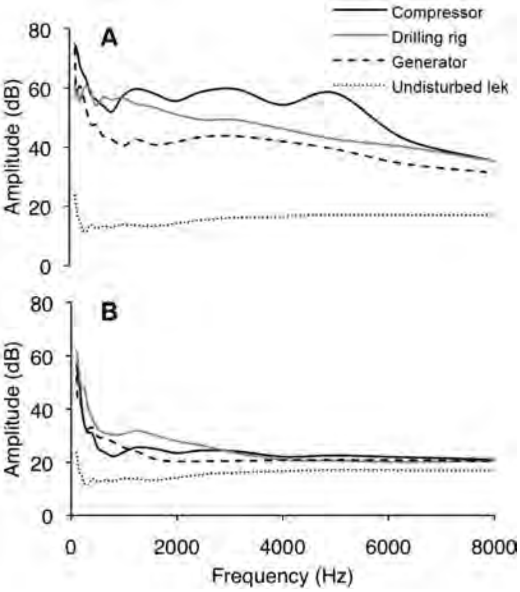

FIG. 2. Power spectra of ambient noise levels at (A) 75 m and (B) 400 m from a natural gas compressor station, natural gas drilling rig, and generator in Sublette County, Wyoming, and on an undisturbed lek (quiet) in Fremont County, Wyoming. Values were interpolated if a measurement for that distance was not available. Noise was dominated by low frequencies at both short and medium distances from the source.

in the analysis, including only vocalizations that we recorded from individuals in a small range of orientations and at similar distances in relation to the microphone. All vocalizations included in the analysis were from individuals with side-facing orientations ranging from 30 to 90 degrees (if zero degrees reflects an orientation with the bird directly facing the observer). We did not use recordings if there was temporal overlap with other strutting males or background noises, such as songbirds. Because of the difficulty of obtaining such recordings, a total of only 6 vocalizations, collected from 2 individuals (2 from one male, 4 from the other), were used in the final analysis.

Ambient noise levels were measured on Chugwater Reservoir lek (42°47.192′N, 108°26.292′W), a lek with little human disturbance in Fremont County, Wyoming. Noise was quantified as a 2-min L_{eq} (equivalent sound pressure level); this is a type of average, defined as the equivalent steady sound level that would produce the energetic equivalent of the actual fluctuating sound levels over the defined 2-min period. The sound level meter calculated an overall L_{eq} for the noise level as well as the 2-min L_{eq} for each 1/3-octave band frequency, which was used for SNR analysis (see below). Ambient measurements were made after lekking in the morning. Ambient noise levels tend to be slightly higher during this time than during the lekking hours (J. L. Blickley and G. L. Patricelli unpubl. data), so this measure is a slight overestimate of ambient levels on an undisturbed lek, leading to a slight underestimate of masking on disturbed leks.

Sound level measurements were made on a large compressor station (Falcon Compressor, which consisted of two Ariel JGC-4 compressors driven by 3,500-HP engines; 42°31.319′N, 109°40.271′W) and a deep natural-gas drilling rig (Questar Drilling Rig no. 232; 42°43.501′N, 109°50.876′W) on the Pinedale Anticline Project Area in Sublette County, Wyoming, and at a generator (East Litton Generator, a 300-kW MQ Power diesel generator powered by a Volvo engine; 43°31.501′N, 105°25.573′W) in the Powder River Basin, Campbell County, Wyoming. These noise sources are all commonly found in areas of natural gas development and typically operate 24 h day–1, year round. Noise was measured along one transect extending from each noise source. Noise measurements were taken at points 75, 200, 300, and 400 m from the Falcon Compressor; at points 8, 16, 32, 64, 128, 256, and 512 m from the East Litton Generator; and at points 75 and 400 m from the Questar Drilling Rig. At each point, distance from the source was measured with a laser range finder (Bushnell Yardage Pro). Noise levels were measured using a Larson Davis 824 sound level meter. During measurements, the sound level meter was held 25 cm from the ground, similar to the height of a grouse. The sound level meter calculated an overall L_{eq} for the noise level as well as the 2-min L_{eq} for each 1/3-octave band frequency. Noise levels are reported in unweighted decibels (reported as dB) re 20 μPa because an unweighted measure of amplitude is required for the estimation of masking potential; A-weighted values (dB[A]) are also presented for comparison. All noise measurements were made in the early morning, before the wind rose to detectable levels. Because of the similarity of noise from each of these sources (see Fig. 2), only noise measurements from the Falcon Compressor were used in the masking analysis; results from other noise sources should be very similar. Noise levels were estimated at distances >400 m from Falcon Compressor using NMSIM software (Wyle Laboratories, Arlington, Virginia). NMSIM generates spatially explicit estimates of noise propagation utilizing input topography, ground impedance, and source spectra. We developed a custom source spectrum for Falcon Compressor using noise measurements from transect data and modeled propagation from the source across flat and open ground using a topographic layer from a location at similar elevation to our study site at 200 rayls ground impedance and –1.1°C air temperature. We used NMSim to estimate the noise spectra at receiver points placed along a transect extending from the source.

Sound analysis.—Individual vocalizations were identified from a spectrogram of the field recording using RAVEN, version 1.3 beta (Cornell Lab of Ornithology, Ithaca, New York; Hann window function, FFT = 512 with 50% overlap). Audio recordings were synchronized with SPL measurements by identifying distinctive high-frequency device noise produced by the SPL meter with the initiation of the measurement; this allowed us to identify the 1/32-s sample(s) in the SPL-meter output that corresponds to each note on the spectrogram and measure the overall amplitude of that note. Each vocalization was then extracted and low-pass filtered at 8.0 KHz to exclude this device noise. For each vocalization, the amplitude of the 1/3-octave band frequencies was measured at intervals of 0.004 s using SPECTRAPLUS (Pioneer Hill Software, Poulsbo, Washington). Call components were identified in the audio recordings in RAVEN and matched with the corresponding overall amplitude measurement from synchronized SPL measurement data. The absolute amplitude of each component was calibrated using the equation

$$\text{Peak dB} = \sum 10^{(aX/10)}$$

where a represents a scaling factor and *X* represents the average amplitude for each 1/3-octave band frequency. By adjusting the value of the scaling factor, we could adjust the overall average amplitude (dB) of the vocalization while maintaining the same relative power at each frequency band. The scaling factor was adjusted to yield different overall average amplitudes (dB) for each vocalization for analysis of masking potential at different source levels. Frequency-specific amplitudes for each call component were averaged across vocalizations.

In order to determine the masking potential of the noise sources at different distances from the vocalizing bird and the noise source, SNRs were calculated for each vocalization by subtracting the average amplitude (dB) for 1/3-octave band frequencies of noise sources (taken from 2-min L_{eq} measurements; see above) from the average amplitude (dB) for 1/3-octave band frequencies of vocalizations as measured in SPECTRAPLUS. Each note of the sage-grouse vocalizations was calibrated to absolute amplitude measures made using the SPL meter (see above). We calculated the expected amplitude of the vocalization at distances 2, 4, 8, 16, 32, 64, and 128 m from the vocalizing bird, based on a 6-dB decrease in amplitude for every doubling of distance due to spherical spreading and frequency-specific rate of excess attenuation. Excess attenuation is attenuation caused by propagation of sound through the environment and is determined by habitat characteristics (e.g., groundcover, temperature) and distance of the vocalizing bird from the ground. To model propagation of vocalizations, we estimated frequency-specific rates of excess attenuation by comparing the overall rate of sound attenuation measured along noise transects with predicted amplitude loss due to spherical spreading alone. These estimated amplitudes were used to scale the vocalizations (see scaling equation above), in order to calculate the SNR for the maximum SNR frequency at different distances from the bird and from the noise source. Vocalizations were defined as "masked" if the SNR of the peak SNR frequency did not exceed the minimum threshold (critical ratio) for detection or discrimination (Dooling 2002, Lohr et al. 2003). Minimum masked distance was used to estimate the maximum detection or discrimination distance (active space). Estimates of sage-grouse critical ratios for detection were drawn from the average critical ratios for detection of 15 bird species, the only ones that have been measured to date (Dooling 2002), and ranged from 22 dB at 400–630 Hz to 27 dB at 2,500 Hz. The critical ratios for discrimination at each frequency band were estimated to be 3 dB higher than the critical ratio for detection in that band (Lohr et al. 2003). The critical ratios for detection and discrimination have not been measured specifically for sage-grouse, but there is relatively little variation in hearing abilities among bird species tested thus far, so estimates of the critical ratio are likely to be accurate to within 5 dB (Dooling 2002). All results are presented ± SE unless otherwise noted.

RESULTS

Noise measurements.—Noise produced by Falcon Compressor was 48.9 dB louder than ambient levels at an undisturbed lek at a distance of 75 m from the source and 34.2 dB louder than ambient at a distance of 400 m (Table 1). Noise produced by the Questar Drilling Rig was 43.5 dB louder than ambient levels at a distance of 75 m from the source and 31.8 dB louder than ambient at a distance of 400 m. Noise produced by East Litton Generator was 24.9 dB louder than ambient levels at a distance of 75 m from the source and 18.4 dB louder than ambient at a distance of 400 m (Table 1). The noise produced by all noise sources was dominated by low frequencies (Fig. 2).

Vocalization measurements.—Individual components of the sage-grouse vocal display varied in amplitude and peak frequency (the frequency at which amplitude was the highest; Table 2). The pop 1 and pop 2 components had the highest peak amplitudes, with measures of 96 ± 2.1 and 98 ± 1.6 dB at 1 m, respectively. The coo components had an overall peak amplitude of 94 ± 1.3 dB at 1 m. The whistle component, by far the quietest component, had a peak amplitude of 84 ± 0.9 dB for the whistle trough (lowest frequency of the whistle component) and 82 ± 1.5 dB for the

Table 1. Overall noise levels (2-min L_{eq} measurements) measured along a transect extending from Falcon Compressor in Sublette County, Wyoming. For comparison, values from an undisturbed lek of Greater Sage-Grouse after the birds departed in late morning are also included (Chugwater Reservoir lek in Fremont County, Wyoming).

Distance	Amplitude (dB[F])	Amplitude (dB[A])
75 m	89.4	70.4
200 m	82.8	58.1
300 m	77.9	52.9
400 m	74.7	47.7
Undisturbed lek (quiet)	40.5	30.5

whistle apex (highest frequency of the whistle component) at 1 m. All vocal components had peak frequencies (400–630 Hz) overlapping with noise produced by natural gas infrastructure, except the apex of the frequency-modulated whistle, which had a peak frequency (2,500 Hz) above most of the noise.

Masking analysis.—We estimated the masking potential of compressor noise for five components of the sage-grouse vocalization: the coos, pop 1, pop 2, whistle trough, and whistle apex. Across all conditions modeled, the maximum detection and discrimination distance (i.e., the active space) for the highest-amplitude frequency band was greatest for the pop 2 component, the loudest note of the display. Overall amplitude of the note was not necessarily an indicator of greater active space—the coo component had a greater maximum detection distance than the pop 1 component (Fig. 3) despite lower overall amplitude, due to the higher amplitude of the maximum frequency. Active space of detection and discrimination for all components was substantially reduced at the noise levels found within 400 m of the compressor station in relation to the ambient conditions on an undisturbed lek (Fig. 3). At 75 m from the noise source, the maximum detection distance and maximum discrimination distance were reduced by 97% and 98%, respectively, for the coo; by 98% and 98% for pop 1; by 97% and 97% for pop 2; by 98% and 98% for the whistle trough; and by 100% and 100% for the whistle apex, in relation to the maximum distances on an undisturbed lek. At 400 m from the noise source, the maximum detection distance and maximum discrimination distance were reduced by 59% and 65%, respectively, for the coo; by 48% and 47% for pop 1; by 59% and 63% for pop 2; by 54% and 57% for the whistle trough; and by 64% and 58% for the whistle apex, in relation to the maximum distances on an undisturbed lek.

The distance from the source at which the active space for detection and discrimination were equal to that in ambient conditions (i.e., the maximum active space) varied for each component. The whistle apex reached maximum active space at 600 m from the noise source. The whistle trough reached maximum active space at 700 m from the source, whereas the coo and pop 1 required a minimum of 700 m from the source before they reached maximum active space. Pop 2 did not reach maximum active space until a minimum of 1,000 m from the noise source.

The SNR varied across frequencies for each component. Peak frequencies for coos, pops, and the whistle trough were relatively low (<1,000 Hz), leading to high overlap with the low-frequency noise produced by the Falcon Compressor and other natural gas infrastructure (Figs. 2 and 4). The SNR was substantially reduced at low frequencies at both short and medium distances to the compressor in relation to quiet lek conditions for all components (Fig. 4). For the whistle, coo, and pop 2 components, the frequency with the peak SNR remained the same under all noise conditions, indicating that no signal distortion would be expected. For the pop 1 component, the frequency with the peak SNR differed under different noise conditions, shifting from 400 Hz under quiet

Table 2. Amplitude and frequency characteristics of Greater Sage-Grouse vocalizations recorded in Fremont County, Wyoming. Measurements are normalized to 1 m from the source.

Note	Peak amplitude (dB)	Peak amplitude range (dB)	Frequency range (Hz)	Peak frequency (Hz, ⅓-octave band)
Coo	94 ± 1.3	89–98	100–800	500
Pop 1	96 ± 2.1	87–99	100–10,500	500
Pop 2	98 ± 1.6	90–100	100–11,500	400
Whistle apex	82 ± 1.3	76–87	2,200–2,600	2,500
Whistle trough	84 ± 0.9	81–87	450–800	630

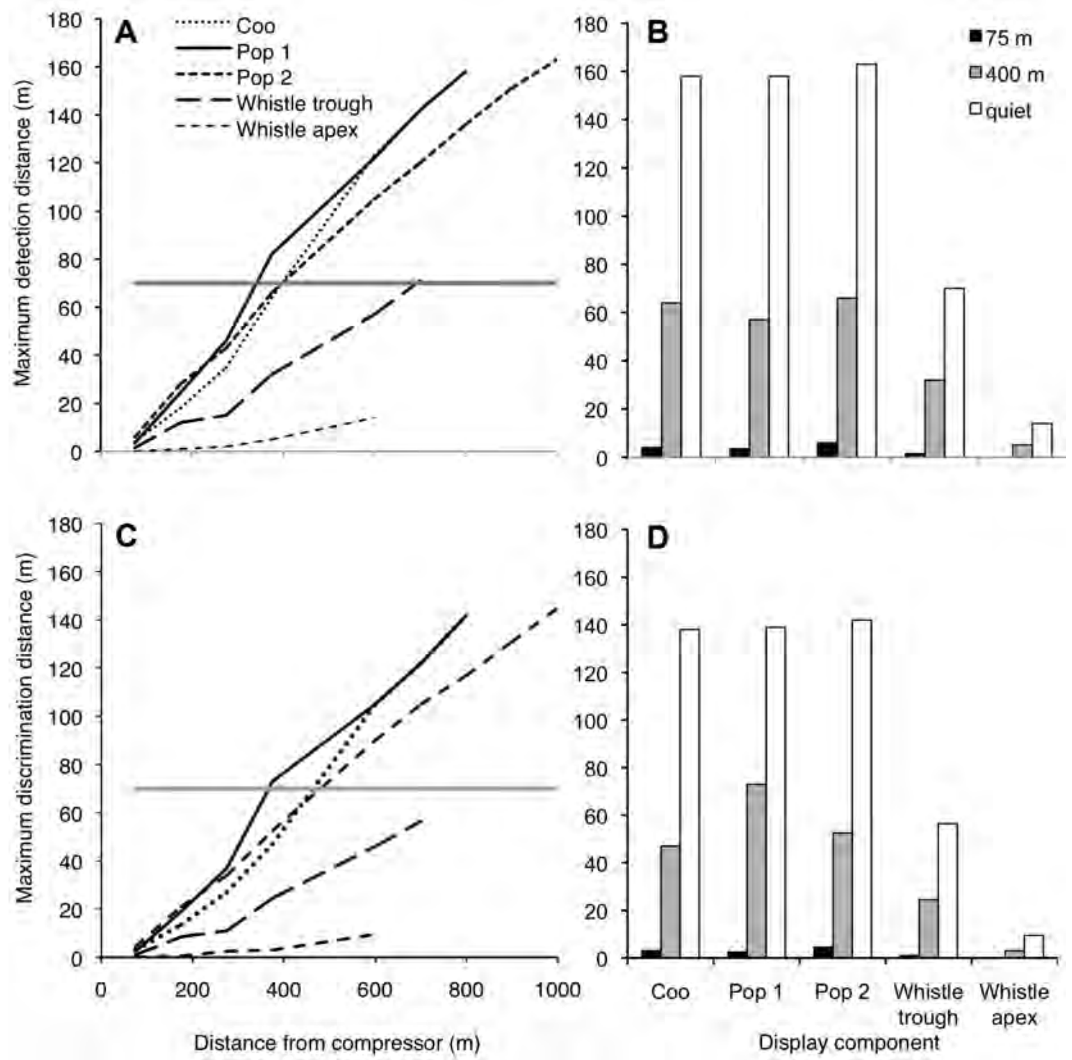

Fig. 3. Maximum (A) detection and (C) discrimination distance of Greater Sage-Grouse strut display components at varying distances from a natural gas compressor station. Gray solid line represents half the length of a typical lek in Fremont County, Wyoming. Lines end at the point where the active space is equal to that under quiet ambient conditions. Maximum (B) detection and (D) discrimination distance of vocalization components at points 75 and 400 m from a natural gas compressor station and under quiet ambient conditions.

conditions to 500 Hz in noisy conditions (Fig. 4B), potentially causing distortion of the signal.

Discussion

We assessed the potential impact of anthropogenic noise on the transmission of sage-grouse vocalizations used for mate attraction (Wiley 1973; Gibson 1989, 1996; Patricelli and Krakauer 2010). Our results indicate that there are marked differences in the active space of individual notes of the sage-grouse acoustic display, both in noisy and quiet conditions. These differences in active space are primarily determined by the frequency structure and amplitude of the different notes of the sage-grouse vocalization, and by differences in the amplitude of the background noise. These factors and their effects on the active space for detection and discrimination are discussed below.

Frequency structure.—The active space of a vocalization is determined, in part, by the frequency structure—including peak frequency and

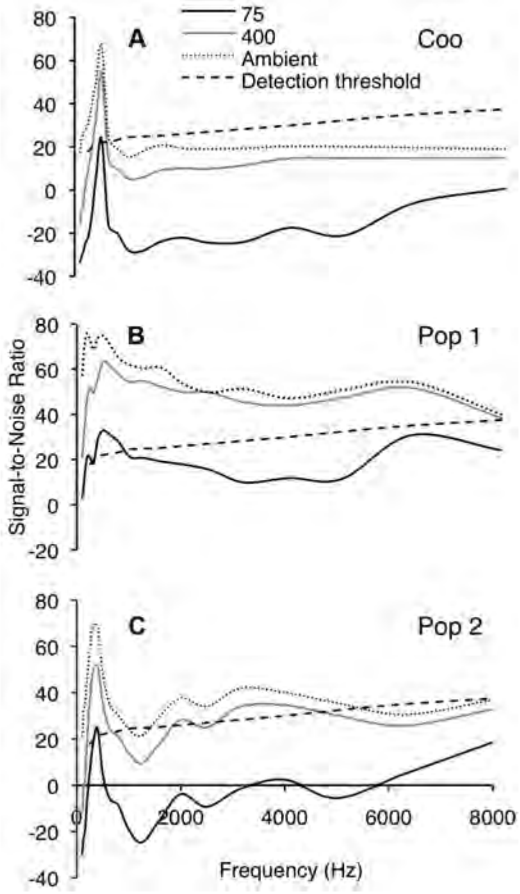

FIG. 4. Signal-to-noise ratio (SNR) of Greater Sage-Grouse acoustic display components (A) coo, (B) pop 1, and (C) pop 2 at a distance of 5 m from the vocalizing male (average close courtship distance) in ambient noise conditions measured 75 and 400 m from a natural gas compressor and on an undisturbed lek. Frequencies with an SNR that exceed the critical ratio for detection (dashed line) can be detected by a receiver. For pop 1, the frequency with the highest SNR is different in noisy and quiet environments, potentially leading to distortion of the vocalization.

frequency range—of both the acoustic signal and the background noise (Lohr et al. 2003). Both of these measures of frequency structure differed among the notes of the sage-grouse display vocalization. Notes with low peak frequencies (the coos, pops, and whistle trough) had high overlap with the noise produced by the Falcon Compressor and other natural gas infrastructure (Figs. 2 and 4), leading to predictions of a substantial reduction in active space of detection and discrimination for these notes in noisy conditions (Fig. 2). The whistle apex had a peak frequency above most of the compressor noise energy, but was still masked because of its lower source amplitude, as discussed below.

The frequency range of a note is also important in determining the degree of overlap with background noise. The coo note of the sage-grouse display is tonal and has a very small frequency range, so the entire note is likely to be masked by low-frequency noise (Fig. 4A). For notes with a broad frequency range, like the broadband pops and the frequency-modulated whistle, some of the higher-frequency energy of the signal is likely to be detectable above background noise that is predominantly low frequency. However, higher frequencies suffer greater attenuation over distance than lower frequencies (Marten and Marler 1977), which reduces the advantage of high-frequency signals in maximizing active space. Because most anthropogenic noise is dominated by low frequencies, species that have low-frequency vocalizations, such as the sage-grouse, will disproportionately experience masking. Indeed, several studies have found that anthropogenic noise more severely affects species with lower-frequency vocalizations (Rheindt 2003; Francis et al. 2009, 2011; Goodwin and Shriver 2011).

Amplitude.—The amplitude of each note is also important in determining the active space, such that quieter notes suffer increased masking at a given distance from the noise source and vocalizing individual. Pops and coos could be detected at greater distances than the whistle apex and whistle trough, despite greater overlap with the background noise, because of greater source amplitudes. The whistle apex, which had the lowest source amplitude, had the smallest active space in noise despite the low overlap with the noise frequencies.

The acoustic directionality of a vocalization may also affect the degree to which masking reduces the overall active space. Many vocalizations radiate from the signaler in a directional pattern, such that the amplitude varies with the orientation of the vocalizing individual. Because of our small sample size, we did not include the effects of directionality on active space in our analysis, but instead assessed the impact of noise on the average active space of the signal across multiple orientations. The whistle is highly directional, with differences of up to 22 dB depending on the relative orientation of the individual (Dantzker et al. 1999). We used values from the loudest orientations of those that we measured;

therefore, masking in the quieter orientations may be much greater than described here. Given that the loudest orientation can vary for different strut components (Dantzker et al. 1999), it is possible that using this small range and averaging across vocalizations may have underestimated the maximum active space for some components. Males that adjust their orientation to beam a highly directional vocalization toward a female may gain an advantage over other males, even under quiet conditions (Brumm 2002, Brumm and Todt 2003, Patricelli and Krakauer 2010); this advantage may be even more pronounced in a noisy environment.

Potential consequences of masking.—Reductions in the active space of detection and discrimination, as predicted by our analysis, could have significant effects on the fitness of individuals in noisy landscapes. Female sage-grouse use acoustic signals to locate lekking males (Bradbury et al. 1989); thus, their ability to find leks could be compromised in noisy environments because of the reduced active space of detection. Once on the lek, females can detect males visually, making detection using acoustic signals less critical. Discrimination and recognition are likely to be more critical on this smaller spatial scale. Female sage-grouse use the acoustic components of the display to select a mate (Gibson et al. 1991, Gibson 1996). In particular, acoustic features such as the IPI, and possibly the whistle, are thought to play a role in attracting females from across the lek (Gibson 1996). Thus, noise that reduces the maximum distance of discrimination to less than half the length of leks in our study population (half average lek length = ~70 m; J. L. Blickley unpubl. data) could negatively affect a male's ability to attract females. Further, background noise could make active comparison of males difficult for females if the maximum discrimination distance is reduced to less than the average distance between males (Forrest and Raspet 1994).

If the interfering noise only overlaps partially with a vocalization, the frequency with the maximum active space may be different under noisy conditions than under normal ambient conditions, leading to the reception of a signal that is distorted. For example, in the pop 1 component of the sage-grouse display, we found that the frequency with the maximum active space was different in noisy compared with quiet conditions. Therefore, a receiver hearing pop 1 under noisy conditions would hear a call dominated by frequencies in the 500 Hz 1/3-octave band; but under quiet conditions, the receiver would hear a call dominated by frequencies in the 200 Hz 1/3-octave band. Depending on which characteristics of the vocalization are assessed by females or competing males, this distortion may lead to difficulty in discrimination or recognition. Previous studies have suggested that female sage-grouse do not assess natural variation among males in peak frequency during mate choice (Gibson et al. 1991), but further behavioral studies would be needed to determine what, if any, effect such distortion might have on female response to male sage-grouse vocalizations. Distortion may have more significant effects on species in which mate choice is based on the frequency of the signal. For example, in species in which females prefer males with low-frequency song (Halfwerk et al. 2011) or assess the fundamental frequency of song as an indicator of male body size, (Ryan and Brenowitz 1985), distortion may lead to increased difficulty in comparing potential mates.

Ultimately, increased difficulty in finding leks or assessing males on the leks may lead to lower female attendance on noisy leks compared with quieter locations. Males may also avoid leks with high levels of noise if they perceive that their vocalizations are masked. Blickley et al. (2012) found lower male and female attendance on leks with experimentally introduced noise from roads and drilling rigs, both of which produce primarily low-frequency sounds similar to the compressor station modeled here. These declines may be due in part to masking, which would be predicted given the substantial overlap in the frequency range of the introduced noise and the sage-grouse strut display. However, the average level of introduced noise across leks in this experiment was relatively low, especially on leks with intermittent road noise, so masking is not likely the only cause of the observed declines. As discussed below, masking is only one possible effect of noise, and other effects may have a larger impact.

Masking in the context of noise regulations.—Are current noise regulations predicted to limit the impact of masking on sage-grouse? Outside of the breeding season, energy development activities are limited within 400 m (1/4 mile) of active sage-grouse leks on federal lands at our study site (Bureau of Land Management 2008). Our analysis indicates that a compressor station, or a similar noise source such as a drilling rig, placed at or inside this stipulated minimum surface-disturbance buffer would have a substantial effect on the ability of sage-grouse to detect a nearby lek and, potentially, to discriminate among individuals on the lek.

Regulations also institute a 2-mile (3.2-km) buffer around leks for permanent infrastructure and lekking-season drilling activities on federal lands in this region (Bureau of Land Management 2008). Our results suggest that the masking footprint of a single compressor station or drilling rig is unlikely to exceed this buffer. Within the range of the peak frequencies for sage-grouse vocalizations (400–2,500 Hz), the noise produced by the compressor station was estimated to drop to ambient levels ≤1,000 m. Even if noise travels farther during temperature inversions common in the early morning, when sage-grouse are actively lekking (Sutherland and Daigle 1998), masking on the lek is likely to be negligible for sources outside the 2-mile (3.2-km) buffer. However, off-lek communication, such as parent–offspring communication, occurs well beyond the boundaries of a lek (Lyon and Anderson 2003) and may still be susceptible to masking. Further, our analysis considered the masking impact of only a single, stationary noise source, but many developed areas contain a network of such sources connected by roads; this will lead to a much greater area of total impact.

Mechanisms to reduce masking.—Features of sound perception and flexibility in signal production may improve the ability of animals to detect signals in noise beyond the active-space predictions calculated by this method. Animals may use directional cues to separate a sound from background noise if the two sound sources are spatially separated (Schwartz and Gerhardt 1989, Dent et al. 1997). Amplitude fluctuations across the spectrum of a sound, or comodulation, may also increase the detectability of the sound against background noise, especially if the noise is relatively constant (Klump and Langemann 1995) like the noise sources investigated here. Animals in noisy areas may adjust their vocalizations to compensate for the increased background noise (Patricelli and Blickley 2006), increasing the amplitude (Brumm 2004) or redundancy (Brumm and Slater 2006) or shifting the peak or minimum frequencies to reduce overlap with background noise frequencies (e.g., Slabbekoorn and Peet 2003, Wood and Yezerinac 2006, Potvin et al. 2011). The potential for these forms of compensation is species specific; the degree to which hearing ability and vocal adjustment affect the active space of sage-grouse vocalizations is unknown.

Noise impacts beyond masking.—Masking is one potential effect of noise on wildlife, but it is certainly not the only one (Barber et al. 2010, Blickley and Patricelli 2010, Kight and Swaddle 2011). Blickley et al. (2012) found strong evidence that sage-grouse leks with experimentally introduced intermittent road noise experienced much greater declines in male attendance than those with more continuous drilling noise, despite the lower masking potential of road noise. Even light vehicular traffic (1–12 vehicles day^{-1}) has been found to substantially reduce nest initiation rates and increase the distance of nests from lek sites in sage-grouse (Lyon and Anderson 2003), despite minimal opportunity for masking. Together, these studies suggest that masking is not the only potential effect of noise or noisy infrastructure on sage-grouse. So, although a masking analysis can be powerful in making predictions about the effects of noise on lek communication in sage-grouse, this type of analysis may not provide sufficient predictive power for estimating the overall impact of the noise on this species.

Noise pollution has been found to induce stress, disrupt physiological processes and behaviors, cause physical trauma to the auditory system, or mask other natural sounds important to survival and reproduction, such as the sound of predator approach, in a variety of species (Marler et al. 1973, Bowles 1995, Kight and Swaddle 2011). For sage-grouse, these effects may extend beyond the area in which masking of the strut display is an issue, particularly for time spent off lek. Wildlife managers that seek to reduce the overall impact of anthropogenic noise on sage-grouse and other species affected by human encroachment must address all the potential effects of noise, including masking potential.

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Conservation Biology

Contributed Paper

Experimental Evidence for the Effects of Chronic Anthropogenic Noise on Abundance of Greater Sage-Grouse at Leks

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Abstract: *Increasing evidence suggests that chronic noise from human activities negatively affects wild animals, but most studies have failed to separate the effects of chronic noise from confounding factors, such as habitat fragmentation. We played back recorded continuous and intermittent anthropogenic sounds associated with natural gas drilling and roads at leks of Greater Sage-Grouse (*Centrocercus urophasianus*). For 3 breeding seasons, we monitored sage grouse abundance at leks with and without noise. Peak male attendance (i.e., abundance) at leks experimentally treated with noise from natural gas drilling and roads decreased 29% and 73%, respectively, relative to paired controls. Decreases in abundance at leks treated with noise occurred in the first year of the study and continued throughout the experiment. Noise playback did not have a cumulative effect over time on peak male attendance. There was limited evidence for an effect of noise playback on peak female attendance at leks or male attendance the year after the experiment ended. Our results suggest that sage-grouse avoid leks with anthropogenic noise and that intermittent noise has a greater effect on attendance than continuous noise. Our results highlight the threat of anthropogenic noise to population viability for this and other sensitive species.*

Keywords: chronic noise, energy development, *Centrocercus urophasianus*, roads

Evidencia Experimental de los Efectos de Ruido Antropogénico Crónico sobre la Abundancia de *Centrocercus urophasianus* en Leks

Resumen: *El incremento de evidencias sugiere que el ruido crónico de actividades humanas afecta negativamente a los animales silvestres, pero la mayoría de los estudios no separan los efectos del ruido crónico de los factores de confusión, como la fragmentación del hábitat. Reprodujimos sonidos antropogénicos intermitentes y continuos asociados con la perforación de pozos de gas natural y caminos en leks de* Centrocercus urophasianus. *Durante 3 épocas reproductivas, monitoreamos la abundancia de* C. urophasianus *e leks con y sin ruido. La abundancia máxima de machos (i.e., abundancia) en leks tratados con ruido de la perforación de pozos de gas natural y caminos decreció 29% y 73% respectivamente en relación con los controles pareados. La disminución en abundancia en leks tratados con ruido ocurrió en el primer año del estudio y continuó a lo largo del experimento. La reproducción de ruido no tuvo efecto acumulativo en el tiempo sobre la abundancia máxima de machos. Hubo evidencia limitada para un efecto de la reproducción de ruido sobre la abundancia máxima de hembras en los leks o sobre la asistencia de machos el año después de que concluyó el experimento. Nuestros resultados sugieren que* C. urophasianus *evita leks con ruido anropogénico y que el ruido intermitente tiene un mayor efecto sobre la asistencia que el ruido continuo. Nuestros*

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resultados resaltan amenaza del ruido antropogénico para la viabilidad poblacional de esta y otras especies sensibles.

Palabras Clave: *Centrocercus urophasianus*, desarrollo energético, ruido crónico, caminos

Introduction

Noise associated with human activity is widespread and expanding rapidly in aquatic and terrestrial environments, even across areas that are otherwise relatively unaffected by humans, but there is still much to learn about its effects on animals (Barber et al. 2009). Effects of noise on behavior of some marine organisms are well-documented (Richardson 1995). In terrestrial systems, the effects of noise have been studied less, but include behavioral change, physiological stress, and the masking of communication signals and predator sounds (Slabbekoorn & Ripmeester 2008; Barber et al. 2009). These effects of noise on individual animals may lead to population decreases if survival and reproduction of individuals in noisy habitats are lower than survival and reproduction of individuals in similar but quiet habitats (Patricelli & Blickley 2006; Warren et al. 2006; Slabbekoorn & Ripmeester 2008). Population declines may also result if animals avoid noisy areas, which may cause a decrease in the area available for foraging and reproduction.

There is evidence of variation among species in their sensitivity to noise. Noise sensitivity may also differ with the type of noise, which varies in amplitude, frequency, temporal pattern, and duration (Barber et al. 2009). Duration may be particularly critical; most anthropogenic noise is chronic and the effects of chronic noise may differ substantially from those of short-term noise in both severity and response type. For example, brief noise exposure may cause elevated heart rate and a startle response, whereas chronic noise may induce physiological stress and alter social interactions. Therefore, when assessing habitat quality for a given species, it is critical to understand the potential effects of the full spectrum of anthropogenic noise present in the species' range.

The effects of noise on wild animals are difficult to study because noise is typically accompanied by other environmental changes. Infrastructure that produces noise may be associated with fragmentation of land cover, visual disturbance, discharge of chemicals, or increased human activity. Each of these factors may affect the physiology, behavior, and spatial distribution of animals, which increases the difficulty of isolating the effects of the noise.

Controlled studies of noise effects on wild animals in terrestrial systems thus far have focused largely on birds. Recent studies have compared avian species richness, occupancy, and nesting success near natural gas wells operating with and without noise-producing compressors. In these studies, spatial variation in noise was used to control for confounding visual changes due to infrastructure (Habib et al. 2007; Bayne et al. 2008; Francis et al. 2009). Results of these studies show that continuous noise affects density and occupancy of a range of bird species and leads to decreases or increases in abundance of some species and has no effect on other species (Bayne et al. 2008; Francis et al. 2009; Francis et al. 2011). Results of these studies also show that noise affects demographic processes, such as reproduction, by reducing the pairing or nesting success of individuals (Habib et al. 2007; Francis et al. 2009).

Although these studies in areas near natural gas wells controlled for the effects of most types of disturbance besides noise, they could not address the effect of noise on naïve individuals in areas without natural gas wells and compressors. Furthermore, there have been no controlled experiments that address the effects of chronic but intermittent noise, such as traffic, which may be more difficult for species to habituate. Road noise may have large negative effects because it is widespread (affecting an estimated 20% of the United States) (Forman 2000) and observational studies indicate that noise may contribute to decreases in abundance of many species near roads (e.g., Forman & Deblinger 2000).

Noise playback experiments offer a way to isolate noise effects on populations from effects of other disturbances and to compare directly the effects of noise from different sources. Playback experiments have been used to study short-term behavioral responses to noise, such as effects of noise on calling rate of amphibians (Sun & Narins 2005; Lengagne 2008), heart rate of ungulates (Weisenberger et al. 1996), diving and foraging behavior of cetaceans (Tyack et al. 2011), and song structure of birds (Leonard & Horn 2008), but have not been used to study effects of chronic noise on wild animals because producing long-term noise over extensive areas is challenging. We conducted a playback experiment intended to isolate and quantify the effects of chronic noise on wild animals. We focused on the effects of noise from natural gas drilling on Greater Sage-Grouse (*Centrocercus urophasianus*).

Greater Sage-Grouse occur in the western United States and Canada and have long been a focus of sexual selection studies (Wiley 1973; Gibson 1989; Gibson 1996). Greater Sage-Grouse populations are decreasing in density and number across the species' range, largely due to extensive habitat loss (Connelly et al. 2004; Garton et al. 2010). The species is listed as endangered under Canada's

Species at Risk Act and is a candidate species for listing under the U.S. Endangered Species Act. Deep natural gas and coal-bed methane development have been expanded rapidly across the species' range since 2000 and substantial evidence suggests that these processes may contribute to observed decreases in the number of Greater Sage-Grouse (Holloran 2005; Walker et al. 2007; Holloran et al. 2010). Many factors associated with deep natural gas and coal-bed methane development are thought to lead to these decreases, including habitat loss, increased occurrence of West Nile Virus, and altered fire regimes due to the expansion of nonnative invasive species (Naugle et al. 2004; Walker et al. 2007; Copeland et al. 2009).

The noise created by energy development may also affect sage grouse by disrupting behavior, causing physiological stress, or masking biologically important sounds. During the breeding season (February–May), male sage grouse gather on communal breeding grounds called leks. Male attendance (number of male birds on the lek) at sage grouse leks downwind of deep natural gas development decreases up to 50% per year compared with attendance at other leks, which suggests noise or aerial spread of chemical pollution as factors contributing to these decreases (Holloran 2005).

We sought to test the hypothesis that lek attendance by male and female sage grouse is negatively affected by both chronic intermittent and continuous noise from energy development. To do so, we conducted a noise playback experiment in a population that is relatively unaffected by human activity. Over 3 breeding seasons (late February to early May), we played noise recorded from natural gas drilling rigs and traffic on gas-field access roads at sage grouse leks and compared attendance patterns on these leks to those on nearby control leks.

We conducted our experiment at leks because lekking sage grouse are highly concentrated in a predictable area, which makes them good subjects for a playback experiment. More importantly, sage grouse may be particularly responsive to noise during the breeding season, when energetic demands and predation risk are high (Vehrencamp et al. 1989; Boyko et al. 2004). Additionally, noise may mask sexual communication on the lek. Lekking males produce a complex visual and acoustic display (Supporting Information) and females use the acoustic component of the display to find lekking males and select a mate (Gibson 1989; Gibson 1996; Patricelli & Krakauer 2010). Furthermore, lek attendance is commonly used as a metric of relative abundance of sage grouse at the local and population level (Connelly et al. 2003; Holloran 2005; Walker et al. 2007). We used counts of lek attendance (lek counts) to assess local abundance relative to noise versus control treatments.

Methods

Study Site and Lek Monitoring

Our study area included 16 leks (Table 1 & Supporting Information) on public land in Fremont County, Wyoming, U.S.A. (42° 50′, 108° 29′). Dominant vegetation in this region is big sagebrush (*Artemisia tridentata wyomingensis*) with a grass and forb understory. The primary land use is cattle ranching, and there are low levels of recreation and natural gas development.

We paired leks on the basis of similarity in previous male attendance and geographic location (Table 2 & Supporting Information). Within a pair, one lek was

Table 1. Pairing, treatment type, location, and baseline attendance for leks used in noise playback experiment.

Lek	*Pair*	*Pair noise type*	*Noise or control*	*Years of playback*	*Baseline attendance**
Gustin	A	drilling	control	3	26
Preacher Reservoir	A	drilling	noise	3	49
North Sand Gulch	B	road	control	3	32
Lander Valley	B	road	noise	3	67
East Twin Creek	C	drilling	control	3	44
Coal Mine Gulch	C	drilling	noise	3	83
East Carr Springs	D	road	control	3	67
Carr Springs	D	road	noise	3	92
Powerline	E	drilling	control	2	49
Conant Creek North	E	drilling	noise	2	44
Monument	F	road	control	2	53
Government Slide Draw	F	road	noise	2	55
Nebo	G	drilling	control	2	18
Arrowhead West	G	drilling	noise	2	24
Onion Flats 1	H	road	control	2	41
Ballenger Draw	H	road	noise	2	38

**Baseline attendance is the average peak male attendance value (annual maximum number of males observed averaged across years) for that lek from 2002 to 2005.*

Table 2. Mixed-effect candidate models used to assess change in peak attendance of male Greater Sage-Grouse at leks from pre-experiment baseline attendance during the natural gas drilling noise playback (2006–2008) and after the experiment (2009).

Model (year)[a]	K[b]	ΔAIC_c[c]	w_i[d]
Male experiment (2006–2008)			
treatment × type + season[e]	9	0	0.64
treatment × type[e]	7	1.8	0.26
treatment + experiment year	6	6.1	0.03
treatment + season	7	6.8	0.02
treatment	5	7.3	0.02
treatment × experiment year	7	8.0	0.01
treatment × type + treatment × season + experiment year	12	8.6	< 0.01
treatment × type + treatment × season	11	9.9	< 0.01
treatment × type + treatment × season + treatment × experiment year	13	10.0	< 0.01
treatment + type	6	10.4	< 0.01
treatment × season	9	16.2	< 0.01
null- random effects only	4	57.0	< 0.01
Male after experiment (2009)			
null, random effects only[e]	3	0.0	0.84
treatment	4	3.3	0.16

[a] *All models contain pair as a random effect, and experiment (2006–2008) models also include year as a random effect. Covariates: treatment, lek treatment (noise or control) assigned to individual leks within a pair; type, pair noise treatment type (road or drilling assigned to pair); season, time of year (early [late February to 1 week prior to peak female attendance for that lek; female peak ranged from 15 March to 6 April], mid [1 week before and after female peak], and late [starting 1 week after female peak]); experiment year, years of experimental noise exposure.*

[b] *Number of parameters in the model.*

[c] *Difference in AIC_c (Akaike's information criterion for small sample size) values from the model with lowest AIC_c.*

[d] *Akaike weight.*

[e] *Model with substantial support ($\Delta AIC_c < 2$).*

randomly assigned to receive experimental noise treatment and the other lek was designated a control. We randomly assigned the experimental leks to receive playback of either drilling or road noise. In 2006, we counted attendance at 8 leks (2 treated with drilling noise, 2 treated with road noise, and 4 control). In both 2007 and 2008, we included an additional 8 leks for a total of 16 leks (4 treated with drilling noise, 4 treated with road noise, and 8 controls).

Throughout the breeding season, we counted males and females on leks with a spotting scope from a nearby point selected to maximize our visibility of the lek. We visited paired leks sequentially on the same days between 05:00 and 09:00, alternating the order in which each member of the pair was visited. We visited lek pairs every day during the breeding season in 2006 and, after expanding our sample size in 2007, every 2–4 days in 2007 and 2008. Peak estimates of male attendance from >4 visits are a highly repeatable measure of abundance at individual leks (Garton et al. 2010), so the lower frequency of visits in 2007 and 2008 was unlikely to have a substantial effect on estimates of peak male attendance. At a minimum, we conducted 2 counts per visit at 10- to 15-min intervals. The annual peak attendance was the highest daily attendance value at each lek for the season for males or females. For males we also calculated the peak attendance in 3 nonoverlapping date ranges: early (late February to 1 week prior to peak female attendance for that lek; female peak ranged from 15 March to 6 April), mid (1 week before and after female peak), and late (starting 1 week after female peak).

Noise Introduction

We recorded noise used for playback near natural gas drilling sites and gas-field access roads in a region of extensive deep natural gas development in Sublette County, Wyoming (Pinedale Anticline Gas Field and Jonah Gas Field). We recorded drilling noise in 2006 within 50 m of the source on a digital recorder (model PMD670, 44.1 kHz/16 bit; Marantz, Mahwah, New Jersey) with a shotgun microphone (model K6 with an ME60 capsule; Sennheiser, Old Lyme, Connecticut). We recorded road noise in 2005 with a handheld computer (iPAQ h5550 Pocket PC, 44.1 KHz/16 bit; Hewlett Packard, Palo Alto, California) and omnidirectional microphone (model K6 with an ME62 capsule; Sennheiser). Drilling noise is relatively continuous and road noise is intermittent (Supporting Information). Both types of noise are predominantly low frequency (<2 kHz).

We played noise on experimental leks from 2 to 4 rock-shaped outdoor speakers (300 W Outdoor Rock Speakers; TIC Corporation, City of Industry, California) hooked to a car amplifier (Xtant1.1; Xtant Technologies, Phoenix, Arizona) and an MP3 player (Sansa m240; SanDisk, Milpitas, California). The playback system was powered with 12 V batteries that we changed every 1–3 days when no birds were present. We placed the speakers

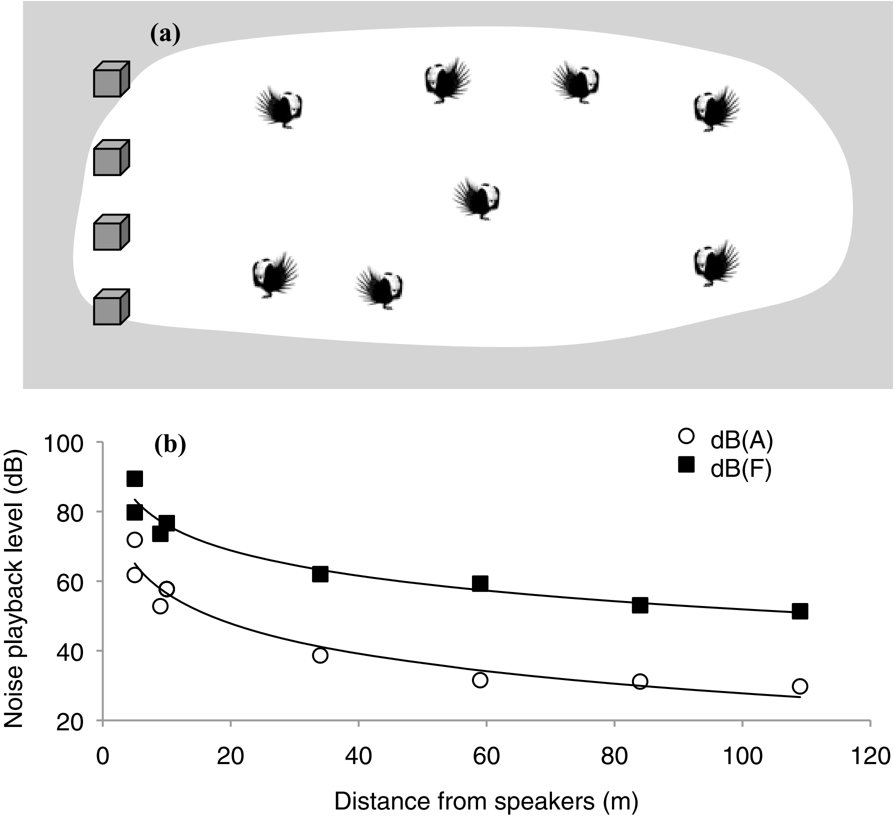

Figure 1. (a) Placement of speakers (on noise-treated leks) or dummy speakers (on control leks) (boxes) at Greater Sage-Grouse leks. (b) Mean maximum noise level (unweighted decibels, dB[F], and A-weighted decibels, dB[A], measured in Lmax [highest root-mean-square sound pressure level within the measurement period]) at Greater Sage-Grouse leks measured on transects at 25-m intervals from the line of speakers on a typical lek treated with road noise. Playback levels of natural gas drilling noise (measured in Leq) followed the same pattern. Ambient levels of noise at control leks ranged from 30 to 35 dB(A).

in a straight line across one end of the lek (Fig. 1a). In 2006 we placed 3 speakers at leks treated with drilling noise and 2 speakers at leks treated with road noise. In 2007 and 2008, we increased the number of speakers, placing 4 at each noise-treated lek to increase the area in which noise was present on the lek. At control leks, we placed dummy speakers of similar size and color to playback speakers (68-L plastic tubs). Within each lek pair, dummy and real speakers were placed in similar configurations. To control for playback-related disturbance, the leks in each pair were visited an equal number of times during the morning for counts of birds and in the afternoon for battery changes.

We played drilling noise and road noise on leks at 70 dB(F) sound pressure level (unweighted decibels) measured 16 m directly in front of the speakers (Fig. 1 & Supporting Information). This is similar to noise levels measured approximately 400 m from drilling rigs and main access roads in Pinedale (J. L. Blickley and G. L. Patricelli, unpublished data). Four hundred meters (0.25 miles) is the minimum surface disturbance buffer around leks at this location (BLM 2008). We calibrated and measured noise playback levels with a hand-held meter that provides sound-pressure levels (System 824; Larson-Davis, Depew, New York) when wind was <9.65 k/h. On drilling-noise-treated leks, where noise was continuous, we calibrated the noise playback level by measuring the average sound level (Leq [equivalent continuous sound level]) over 30 s. On leks treated with road noise, where the amplitude of the noise varied during playback to simulate the passing of vehicles, we calibrated the playback level by measuring the maximum sound level (Lmax [highest root-mean-square sound pressure level within the measurement period]).

For leks treated with drilling noise, recordings from 3 drilling sites were spliced into a 13-min mp3 file that played on continuous repeat. On leks treated with road noise, we randomly interspersed mp3 recordings of 56 semitrailers and 61 light trucks with 170 thirty-second silent files to simulate average levels of traffic on an access road (Holloran 2005). Noise playback on experimental leks continued throughout April in 2006, from mid February or early March through late April in 2007, and from late February through late April in 2008. We played back noise on leks 24 hours/day because noise from deep natural gas drilling and vehicular traffic is present at all times. This experimental protocol was reviewed and approved by the Animal Care and Use Committee at University of California, Davis (protocol 16435).

To measure noise levels across experimental leks, we measured the average amplitude (15 s Leq) of white-noise played at 1–5 points along transects that extended across the lek at 25-m intervals roughly parallel to the line of speakers. We calibrated white-noise measurements by measuring the noise level of both the white noise and either a representative clip of drilling noise or a semitrailer

10 m directly in front of each speaker. To minimize disturbance, we took propagation measurements during the day. Daytime ambient noise levels are typically 5–10 dBA higher than those in the early morning (J. L. Blickley and G. L. Patricelli, unpublished data) and are likely higher than those heard by birds at a lek.

After the experiment, we counted individuals on all leks 2–6 times from 1 March through 30 April 2009. In 2009 we continued to play noise on 2 experimental leks as part of a related experiment, so we did not include these lek pairs in our analysis of postexperiment male attendance at a lek.

Response Variables and Baseline Attendance Levels

Sage grouse leks are highly variable in size and, even within pairs, our leks varied up to 50% in size. To facilitate comparison of changes in attendance on leks of different sizes, we calculated the attendance relative to attendance levels before treatment (i.e., baseline attendance levels). We obtained male baseline abundance from the Wyoming Game and Fish Department. We used the standard lek-count protocol (Connelly et al. 2003) to count birds at leks approximately 3 times/breeding season. Due to the small number of counts in pre-experiment years, we calculated male baseline attendance by averaging the annual peak male attendance at each individual lek over 4 years (2002–2005). We assessed changes in early-, mid-, and late-season peak male attendance from this 4-year baseline attendance. Female attendance was highly variable throughout the season with a short (1–3 day) peak in attendance at each lek. Due to the limited number of annual counts, female counts from 2002 to 2005 were not reliable estimates of peak female attendance and could not be used as baseline attendance levels. Because we introduced noise to experimental leks after the peak in female attendance in 2006, we used maximum female counts from 2006 as a baseline for each of the 8 leks monitored that year. We assessed changes in annual peak female attendance from this 1-year baseline attendance. The 8 leks added to the experiment in 2007 were not included in statistical analyses of female attendance due to the lack of a baseline.

Statistical Analyses

We used an information-theoretic approach to evaluate the support for alternative candidate models (Table 2). All candidate models were linear mixed-effect models that assessed the relation between covariates and the proportional difference in annual and within-season peak attendance and baseline attendance (both males and female) (Tables 2 & 3). We ranked models on the basis of differences in Akaike's information criterion for small sample sizes (ΔAIC_c) (Burnham & Anderson 2002). Akaike weights (w_i) were computed for each model on the basis of ΔAIC_c scores. We calculated model-averaged variable coefficients, unconditional 95% CI, and variable importance (weight across models) for variables contained in models that were strongly supported ($\Delta AIC_c < 2$). All statistical analyses were performed in R (version 2.12.1) (R Development Team 2010).

Table 3. Mixed-effect candidate models used to assess change in peak annual attendance of female Greater Sage-Grouse at leks from pre-experiment baseline attendance in 2006 during noise playback.

Model[a]	K[b]	ΔAIC_c[c]	w_i[d]
Null, random effects only[e]	4	0	0.71
Treatment[e]	5	1.9	0.27
Treatment+experiment year	6	8	0.01
Treatment×experiment year	7	14	<0.001

[a] *All models contained pair and year as random effects. Due to the small sample size (4 pairs), pair type variable (road versus drilling) was not included in the model set. Covariates: treatment, lek treatment (noise or control assigned to individual leks within a pair); experiment year, years of experimental noise exposure.*
[b] *Number of parameters in the model.*
[c] *Difference in AIC_c (Akaike's information criterion for small sample size) values from the most strongly supported (lowest AICc) model.*
[d] *Akaike weight.*
[e] *Model with substantial support ($\Delta AIC_c < 2$).*

The detection probability for males and females is likely to vary across a season and among leks (Walsh et al. 2004). We sought to minimize sources of error and maximize detection by conducting frequent counts from locations with a clear view of the lek and by implementing a paired treatment design (each noise lek is compared with a similar control lek, monitored by the same observer on the same days). To ensure that detection probability did not differ among noise and control leks, we corrected our data for detection probability. First, we used detection error rates, estimated as difference between the maximum count and the count immediately before or after the maximum count within a day (for both males and females), and then we applied the bounded-count method (for males only; Walsh et al. 2004). With the multiple-count estimator, estimates of detection between noise and control leks did not differ (males: $t = 1.02$, $df = 6, p = 0.35$; females: $t = 0.21$, $df = 3, p = 0.84$). We analyzed both corrected and uncorrected counts and found that neither correction qualitatively changed our results; therefore, results are presented for uncorrected counts.

Results

Male Attendance

Peak male attendance at both types of noise leks decreased more than attendance at paired control leks, but the decreases varied by noise type. In the most strongly supported models of the candidate set ($w_i = 0.90$, all

Table 4. Model-averaged parameter direction and effect sizes and variable importance for all variables present in strongly supported models ($\Delta AIC_c < 2$ in Table 2) of changes in peak attendance of male greater sage-grouse at leks from baseline attendance during experimental noise playback.

Variable	*Percent effect size (SE)*	*Variable importance**
Intercept	31 (22)	1.0
Treatment, noise	−29 (7)	0.91
Type, road	33 (22)	0.91
Treatment, noise∗type, road	−40 (10)	0.91
Season, mid	18 (6)	0.66
Season, late	23 (6)	

**Variable importance is the summed weight of all models containing that variable.*

other models $\Delta AIC_c > 6.1$) (Table 2), there was an interaction of the effects of experimental treatment (control versus noise) and noise type (drilling versus road) on annual peak male attendance. At leks treated with road noise, decreases in annual peak male attendance were greater (73%), relative to paired controls, than at drilling noise leks (29%). As indicated by the effect size for the main effect of pair type, attendance at control leks paired with road noise leks was 33% greater relative to the baseline than control leks paired with drilling noise leks (Table 4). However, changes in attendance were compared within a pair to control for such differences. Male attendance increased over the course of a season, with 18% and 23% increases in peak male attendance in mid and late season from the early-season peaks, but seasonal increases were similar across noise and control leks (Table 4 & Fig. 2b).

There was no evidence that the effect of noise on attendance changed as years of exposure to noise increased. The models with substantial support did not contain a main effect of years of exposure or an interaction of years of exposure and treatment type (control versus noise) (Table 2). In spite of decreases in attendance throughout the experiment, peak male attendance exceeded baseline attendance on all leks in 2006, 13 leks in 2007, and 11 leks in 2008 (Table 4 & Fig. 2c). There was an increase in sage grouse abundance regionally in 2006 (Fig. 3).

After the experiment (2009), attendance at leks we experimentally exposed to drilling and road noise was lower relative to paired controls (Table 2). The model that included the treatment variable showed an effect size of −30% (across road and drilling noise leks) but had only moderate support ($\Delta AIC_c = 3.3$) relative to the null model.

Female Attendance

Peak female attendance at leks treated with noise in 2007 and 2008 decreased from the 2006 baseline, relative to control leks (Table 3). The most strongly supported model in the set was the null model; however, the model that included noise treatment was highly supported ($\Delta AIC_c < 2$). The effect size of noise treatment on female attendance was −48% (10% SE), which is similar to the effect of noise on male attendance averaged across both noise types (51%).

Discussion

Results of previous studies show abundance of Greater Sage-Grouse decreases when natural gas and coal-bed methane fields are developed (Holloran 2005; Walker et al. 2007; Doherty et al. 2008). Our results suggest that chronic noise may contribute to these decreases. Peak male attendance relative to the baseline was lower on noise leks than paired control leks, and the decrease was larger at road noise leks (73% decrease in abundance compared with paired controls) than drilling noise leks (29%; Fig. 3). These decreases were immediate and sustained. The effects of noise occurred in the first year of the study and were observed throughout the experiment, although patterns of male attendance within a season were similar at noise and control leks. Differences in male attendance between noise and control leks in the year after the experiment were not supported in the top models, which suggests attendance rebounded after noise ceased. However, the sample size for this analysis was small, and the effect size (30% average decreases in male attendance for both noise types) suggests a residual effect of noise.

There are 2 mechanisms by which noise may reduce male attendance. First, males on noise leks may have had higher mortality than males on control leks. Noise playback was not loud enough to cause direct injury to individuals, but mortality could be increased indirectly by noise playback if the sounds of predators (coyotes [*Canis latrans*] or Golden Eagles [*Aquila chrysaetos*]) were masked by noise. However, on-lek predation events were rare. We observed ≤1 predation event per lek per season during the experiment (observations of sage-grouse carcasses or feathers at a lek [J. L. Blickley, personal observation]). The cumulative effect of rare predation events would lead to a gradual decrease in attendance, rather than the rapid and sustained decrease we observed. Furthermore, experimental noise was likely too localized to substantially affect off-lek predation because noise levels decreased exponentially as distance to the speakers increased (Fig. 1b). To date, increased predation risk of adults due to anthropogenic noise has not been demonstrated in any species, but some species increase vigilance when exposed to noise, leaving less time for feeding, displaying, and other important behaviors (Quinn et al. 2006; Rabin et al. 2006). Noise may also affect off-lek mortality indirectly. For example, noise-stressed males may be more susceptible to disease due to a suppressed

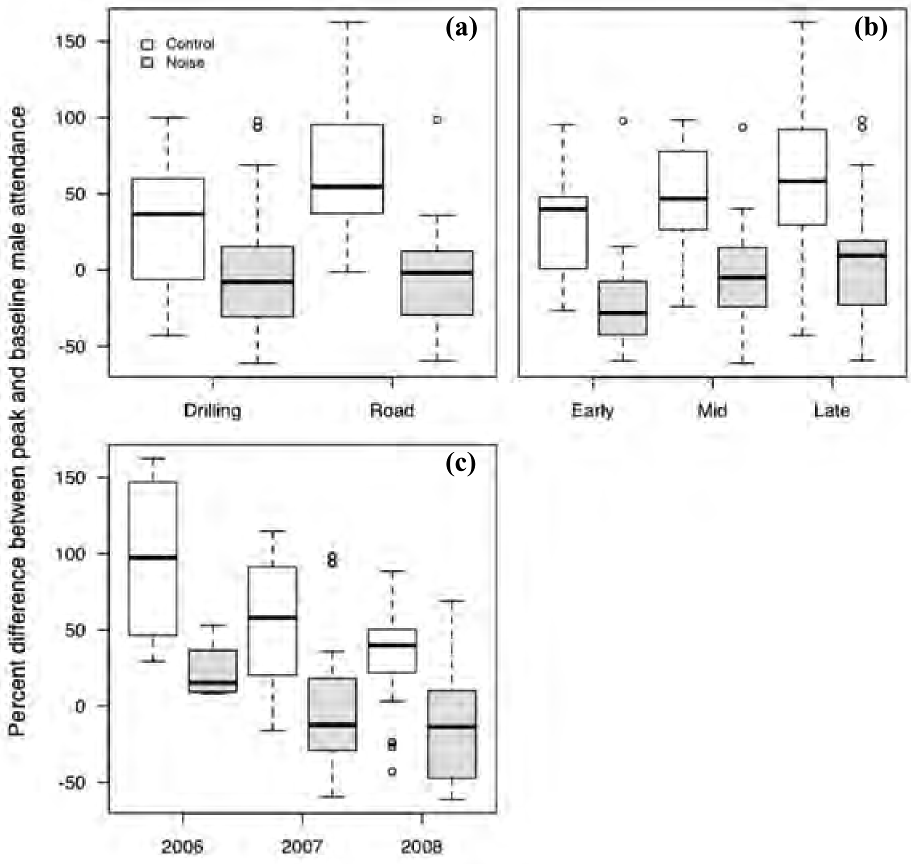

Figure 2. Percent difference between baseline attendance (i.e., abundance before experiments) of male Greater Sage-Grouse and (a) peak male attendance on control leks and leks treated with noise from natural gas drilling and road noise, (b) peak male attendance in the early (late February to 1 week prior to peak female attendance for that lek), mid (1 week before and after female peak [female peak ranged from 15 March to 6 April]), and late (starting 1 week after female peak) breeding season; on control leks and leks treated with noise, and (c) peak male attendance at control leks and leks treated with noise in experimental years 2006, 2007, and 2008 in Fremont County, Wyoming (U.S.A.) (horizontal lines, median value; box ends, upper and lower quartiles, whiskers, maximum and minimum values). Data are observed values, not model output.

immune response (Jankowski et al. 2010). Although long-term stress from noise is unlikely to be the primary cause of the rapid decreases in attendance we observed here, it may have been a contributing factor over the course of the experiment. Furthermore, in areas of dense industrial development, where noise is widespread, noise effects on mortality may be more likely.

Alternatively, noise may lower male attendance through displacement, which would occur if adult or juvenile males avoid leks with anthropogenic noise. Such behavioral shifts are consistent with the rapid decreases in attendance we observed. Adult male sage grouse typically exhibit high lek fidelity (Schroeder & Robb 2003) and visit leks regularly throughout the season, whereas juvenile males visit multiple leks and their attendance peaks late in the season (Kaiser 2006). If juveniles or adults avoid noise by visiting noisy leks less frequently or moving to quieter leks, overall attendance on noisy leks could be reduced. We could not reliably differentiate between juveniles and adults, so we do not know the relative proportion of adults and juveniles observed. Consistent with displacement due to noise avoidance, radio-collared juvenile males avoid leks near deep natural gas developments in Pinedale, Wyoming, which has resulted in decreases in attendance at leks in close proximity to development and increased attendance at nearby leks with less human activity (Kaiser 2006; Holloran et al. 2010). Reduced recruitment of juvenile males is unlikely to be the only driver of the patterns we observed because we did not observe larger decreases in lek attendance on noise-treated leks later in the season, when juvenile attendance peaks. Rather, we found immediate decreases in attendance early in the season when playback began (Fig. 2b), at which time there are few juveniles on the lek. This

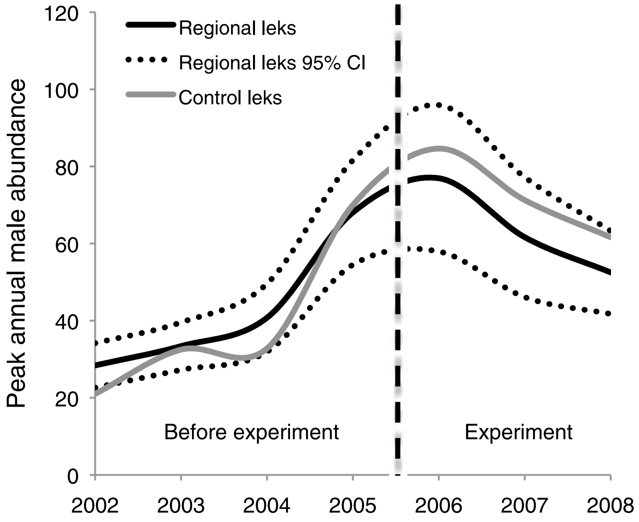

*Figure 3. Maximum abundance of male Greater Sage-Grouse from 2002 to 2008 at control leks (*n = 8*) (no anthropogenic sound played) and other leks in the region that were not part of the experiment (regional leks) (*n = 38*).*

is consistent with both adult and juvenile noise avoidance. We did not find evidence for a cumulative negative effect of noise on lek attendance, although cumulative effects may have been masked by regional population declines after 2006, a year of unusually high abundance (Fig. 3).

Female attendance at leks treated with noise was lower than that on control leks; however, the null model and the model that included noise treatment were both highly supported, providing only moderate support for the effects on noise on attendance. For this model, the overall estimated effect of noise on female attendance (−48%) was similar to that of the effect of noise on male attendance. Due to the high variability of female daily maximum attendance throughout the season and small sample size for this analysis (female attendance data available for only 4 of the 8 lek pairs), our statistical power to detect differences in female attendance was limited and effect sizes may not be representative of actual noise effects.

Our results suggest that males and possibly females avoid leks exposed to anthropogenic noise. A potential cause of avoidance is the masking of communication. Masked communication is hypothesized to cause decreases in abundance of some animal species in urban and other noisy areas. For example, bird species with low-frequency vocalizations are more likely to have low abundance or be absent from natural gas developments, roads, and urban areas than species with high-frequency vocalizations, which suggests that masking is the mechanism associated with differences in abundance (Rheindt 2003; Francis et al. 2009; Hu & Cardoso 2010). Sage-grouse may be particularly vulnerable to masked communication because their low-frequency vocalizations are likely to be masked by most sources of anthropogenic noise, including the noises we played in our experiment (Supporting Information). This may be particularly important for females if they cannot use acoustic cues to find leks or assess displaying males in noisy areas.

Alternatively, individuals may avoid noisy sites if noise is annoying or stressful, particularly if this noise is associated with danger (Wright et al. 2007). Intermittent road noise was associated with lower relative lek attendance than continuous drilling noise, in spite of the overall higher mean noise levels and greater masking potential at leks treated with drilling noise (Supporting Information). Due to the presence of roads in our study area, sage grouse may have associated road noise with potentially dangerous vehicular traffic and thus avoided traffic-noise leks more than drilling-noise leks. Alternatively, the pattern of decrease may indicate that an irregular noise is more disturbing to sage grouse than a relatively continuous noise. Regardless, our results suggest that average noise level alone is not a good predictor of the effects of noise (Slabbekoorn & Ripmeester 2008) and that species can respond differently to different types of noise.

Our results cannot be used to estimate the quantitative contribution of noise alone to observed decreases in Greater Sage-Grouse abundance at energy development sites because our experimental design may have led us to underestimate or overestimate the magnitude of these effects. Decreases in abundance due to noise could be overestimated in our study if adults and juveniles are displaced from noise leks and move to nearby control leks, which would have increased the difference in abundance between paired leks. Similar displacement occurs in areas of energy development, but over a much larger extent than is likely to have occurred in response to localized playbacks in our experiment (Holloran et al. 2010).

In contrast, we could have underestimated noise effects if there were synergistic effects of noise and other disturbances associated with energy development. For example, birds with increased stress levels due to poor forage quality may have lower tolerance for noise-induced stress, or vice versa. Noise in our experiment was localized to the immediate lek area and only played during the breeding season, so we cannot quantify the effects of noise on wintering, nesting, or foraging birds. Noise at energy development sites is less seasonal and more widespread than noise introduced in this study and may thus affect birds at all life stages and have a potentially greater effect on lek attendance. Leks do not represent discrete populations; therefore, local decreases in lek attendance do not necessarily reflect population-level decreases in abundance. However, at large energy development sites, similar displacement of Greater Sage-Grouse away from the ubiquitous noise may result in population-level declines due to spatially extensive changes in land use or increases in dispersal-related and density-dependent sources of mortality (Aldridge & Boyce 2007). Enforcement and refinement of existing seasonal restrictions on human activity could potentially reduce these effects.

We focused on the effect of noise associated with deep natural gas and coal-bed methane development on sage grouse, but our results may increase broader understanding of the effects of noise on animals. Both intermittent and constant noise from energy development affected sage grouse. Other noise sources with similar frequency range and temporal pattern, such as wind turbines, oil-drilling rigs, and mines, may have comparable effects. Similar effects may also be associated with highways, off-road vehicles, and urbanization so that the potential for noise to have an effect is large.

We believe that noise should be investigated as one potential cause of population declines in other lekking North American grouse species that are exposed to similar anthropogenic development. Populations of many bird (van der Zande et al. 1980; Rheindt 2003; Ingelfinger & Anderson 2004) and mammal (Forman & Deblinger 2000; Sawyer et al. 2009) species have been shown to decrease in abundance in response to road, urban, and energy development, and noise produced by these activities may contribute to these decreases. Our results also demonstrate that wild animals may respond differently to chronic intermittent and continuous noise, a comparison that should be expanded to other species. Additionally, we think these results highlight that experimental noise playbacks may be useful in assessing the response of wild animals to chronic noise (Blickley & Patricelli 2010).

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Supporting Information

Spectrograms and power spectrums of drilling noise, road noise and male sage-grouse vocal display (Appendix S1), map of experimental and control leks (Appendix S2), and noise playback levels on experimental leks (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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Experimental Chronic Noise Is Related to Elevated Fecal Corticosteroid Metabolites in Lekking Male Greater Sage-Grouse (*Centrocercus urophasianus*)

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Abstract

There is increasing evidence that individuals in many species avoid areas exposed to chronic anthropogenic noise, but the impact of noise on those who remain in these habitats is unclear. One potential impact is chronic physiological stress, which can affect disease resistance, survival and reproductive success. Previous studies have found evidence of elevated stress-related hormones (glucocorticoids) in wildlife exposed to human activities, but the impacts of noise alone are difficult to separate from confounding factors. Here we used an experimental playback study to isolate the impacts of noise from industrial activity (natural gas drilling and road noise) on glucocorticoid levels in greater sage-grouse (*Centrocercus urophasianus*), a species of conservation concern. We non-invasively measured immunoreactive corticosterone metabolites from fecal samples (FCMs) of males on both noise-treated and control leks (display grounds) in two breeding seasons. We found strong support for an impact of noise playback on stress levels, with 16.7% higher mean FCM levels in samples from noise leks compared with samples from paired control leks. Taken together with results from a previous study finding declines in male lek attendance in response to noise playbacks, these results suggest that chronic noise pollution can cause greater sage-grouse to avoid otherwise suitable habitat, and can cause elevated stress levels in the birds who remain in noisy areas.

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Introduction

Anthropogenic noise is becoming ubiquitous as natural landscapes are increasingly dominated by humans, but we still have much to learn about the impacts of chronic noise exposure on wildlife [1–3]. Recent studies have shown that some species avoid developed areas with high noise levels, reducing available habitat and potentially leading to reduced populations [4–6]. However, there is variation among species and individuals in the tendency to avoid noise [4,5,7], which raises the question of whether animals that remain suffer detrimental effects, or if these individuals are better able to habituate to noise or are less susceptible to its effects. It has been suggested that animals remaining in (or unable to leave) noisy areas may have lower survival and reproductive success [8–10]; indeed, recent studies have demonstrated complex effects of noise on community structure and on breeding and pairing success [4–6,11]. Given the ubiquity of noise in the environment, it is critical that we understand noise impacts on animals whether they remain in or avoid disturbed areas.

One possible impact of introduced noise on animals is the induction of stress, which may be defined broadly as nonspecific adverse effects in vertebrates but is most often characterized by its influence on neuroendocrine physiology. The duration of noise exposure affects the stress response of animals exposed to it [12]. Exposure to a brief but loud noise event, such as a single sonic boom, will result in an acute stress response. An acute stress response is characterized by a rapid release of epinephrine and norepinephrine (the "fight or flight" response) followed by a hypothalamic-pituitary-adrenal (HPA) cascade. The HPA cascade results in increased secretion of glucocorticoid hormones, cortisol or corticosterone, in the blood. Long-term exposure to a chronic noise stressor, such as a high-traffic freeway, can lead to chronic stress, defined as long-term overstimulation of coping mechanisms. This in turn can lead to less predictable changes in the HPA axis. Acclimation or exhaustion may result in reduced glucocorticoid release to the same or novel stressors; facilitation, conversely, can lead to elevated glucocorticoid release in response to novel stressors, and even in cases of reduced peak glucocorticoid response, deficits in negative feedback may develop that result in greater overall exposure to glucocorticoids due to prolonged elevation [12,13].

Glucocorticoid hormones and their metabolites are commonly used to measure a stress response [14–16]. Glucocorticoid hormones can be measured from blood samples or their metabolites may be measured non-invasively from fecal samples as an index of the relative physiological stress of animals [17–19]. Glucocorticoid hormones play a major role in allocating energy, and prolonged exposure due to chronic stress can affect fitness by inhibiting resource allocation to reproductive or immune activities, a condition known as allostatic overload [12,20–24].

Studies in captive animals have found that noise can increase HPA activity and glucocorticoid levels [25,26]; indeed studies of stress physiology often use noise exposure as a method to induce a stress response [27,28]. Previous observational and experimental studies on the impacts of anthropogenic noise on glucocorticoid levels in wild animals have yielded mixed results. Snowmobile and wheeled-vehicle traffic was associated with elevated fecal glucocorticoid metabolites in wolves and elk [14]. Noise is one potential mechanism of this impact, but visual and other types of disturbance may also contribute to these responses; indeed, the quieter activity of Nordic skiing also correlates with FCMs in capercaillie (*Tetrao urogallus*) [29]. Delaney et al. [30] found behavioral responses in spotted owls to loud noise from visually hidden chainsaws and helicopters, but subsequent studies found no evidence of change in FCMs with exposure to quieter chainsaw noise (below behavioral response threshold) or road proximity to nesting sites [31]. Results from chronic noise studies on humans have also been mixed [32]. Studies of children in areas with high road noise have found increased overnight glucocorticoid levels in urine, as well as impaired circadian rhythms, sleep, memory and concentration, [33] and increased heart-rate responsiveness to acute stressors [34]. However, a study in children living in communities near airports found increases in some measures of stress (blood pressure, epinephrine and norepinephrine) but no similar elevation in overnight urinary cortisol [35]. These results indicate that noise may have a significant effect on glucocorticoids and other stress-related variables in many species, but that further study is needed to determine the degree and extent of these effects and how the effects may vary with different types of noise.

In this study, we test the hypothesis that chronic noise causes an increase in stress levels of lekking greater sage-grouse. We used fecal levels of immunoreactive corticosteroid metabolites (FCMs) as an index of physiological stress and compared FCMs for breeding males on display grounds (leks) with and without experimentally introduced noise. The greater sage-grouse, an iconic species once widespread in western North America, is now declining throughout its range, leading to its listing as an endangered species in Canada and its recent designation as "warranted but precluded" for listing under the Endangered Species Act in the USA [36,37]. Over the last decade, natural gas development has expanded rapidly across much of the sage-grouse range and has been implicated in reduced lek attendance and abandonment of long-occupied (often for decades) lek sites by males [e.g. 38,39–41]. Males typically gather on lekking grounds for several hours in the early morning when conditions are quiet and still, a time when they may be particularly vulnerable to disturbance from noise pollution from natural gas development and other sources [42]. To investigate whether noise exposure may have contributed to declines in lek attendance, Blickley et al. [43] experimentally introduced noise from natural gas development activities (drilling and road noise) on leks over three breeding seasons (2006–2008). This noise playback caused immediate and sustained declines in sage-grouse lek attendance. Further, different types of noise had different degrees of impact, with drilling noise and road noise causing an average 29% and 73% decline in lek attendance, respectively, compared to their paired controls. That study provides evidence that anthropogenic noise from energy development causes some males to avoid attending leks with introduced noise, but we do not yet know whether noise also has a negative impact on the individuals that remain on noisy leks. The lekking season is a time of high metabolic demand [44] and stress [45] for males, so exposure to noise during this period may have a greater fitness cost.

Here we compare the FCM levels of male sage-grouse on control leks and leks with experimentally introduced noise in the second and third seasons of experimental noise playback (2007 and 2008) [43]. We predict that if noise exposure leads to chronic stress, male sage-grouse on experimental leks will have higher FCMs than males on control leks. Such differences in observed FCM levels may also be observed if males with low glucocorticoid levels are more likely to disperse from noise-treated leks, so we compared the variance in FCM levels on noise and control leks. We also investigated whether elevated FCM levels were associated with declines in peak male attendance on leks to determine the value of this metric as a tool for predicting lek declines.

Materials and Methods

Study Area & Experimental Design

Study sites were located on federal land relatively undisturbed by human development in Fremont County, Wyoming (42° 50′, 108° 29′30). We monitored a total of 16 leks that were divided into 8 pairs, with the leks of a pair matched according to size and location (6 pairs near the town of Hudson and 2 pairs near the town of Riverton) (Figure 1). Of the 8 lek pairs, 4 pairs were randomly assigned to each noise type, such that there were 4 "drilling pairs", each including one lek exposed to drilling noise and a similar lek as its control, and 4 "road pairs," each with one road noise and a matched control. For 3 of the pairs, one lek within a pair was randomly assigned to the treatment (noise) group and the other assigned as control. For the fourth pair, the treatment and control leks were deliberately assigned due to another study that was in progress. During sample collection periods, both leks in a pair were normally visited on the same day.

Noise and playback methods have been previously described [43] and are summarized here. Noise was played beginning in mid-February to early March and continuing through the end of April of each year. Noise was recorded from drilling and main road sites at the Pinedale Anticline natural gas fields and played back using a commercial car amplifier and 3–4 rock-shaped outdoor speakers placed along one edge of the lek. On leks with road-noise playback, recordings of semi-trailer trucks and pickup trucks were combined with 30- and 60-second files of silence at a ratio reflecting the average number of each truck type found on a main energy field access road; these files were then played using the "random shuffle" feature on an MP3 player. Most shift changes occur at 8 am, so our playback may underestimate actual traffic levels during the lekking time. On leks with drilling noise, a 14-minute recording of a drilling rig was played on continuous loop. Natural gas development activities occur 24 hours a day, so noise was broadcast continuously day and night at playback levels that approximate the noise level at 0.25 mile (402 m) from a typical drilling site (JLB and GLP unpublished data). Drilling-noise recordings were broadcast on experimental leks at an equivalent sound level (L_{eq}) of 71.4±1.7 dBF (unweighted decibels) SPL re 20 μPa (56.1±0.5 dBA [A-weighted decibels]) as measured at 16 meters; on road-noise leks, where the amplitude of the noise varied with the simulated passing of vehicles, noise was broadcast at an L_{max} (maximum RMS amplitude) of 67.6±2.0 dBF SPL (51.7±0.8 dBA) (see Blickley, et al. [43], for detailed noise-exposure measurements). Noise from playback was localized to each lek due to the small size of our speakers. To control for visual disturbance of the speaker system and researcher presence, control

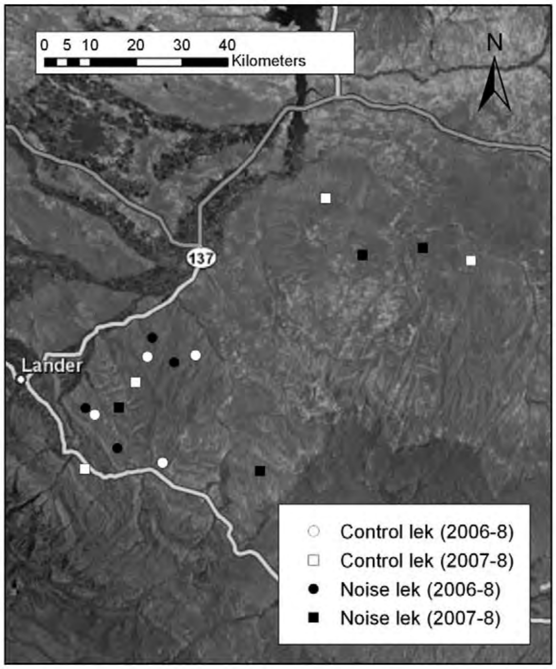

Figure 1. Noise playback study area in Fremont County, Wyoming, USA, 2006–2009. Experimental and control leks were paired on the basis of size and geographic location (the four leks in the upper right are part of the Riverton region, whereas the rest of the leks are in the Lander region).
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leks had dummy speakers placed in the same arrangement and were also visited to simulate the periodic battery changes on noise leks. This experimental protocol was reviewed and approved by the Animal Care and Use Committee at UC Davis (Protocol # 16435) and the Wyoming Game and Fish Department (Permit # 33–405).

In the first year of the experiment (2006), we played noise on only 4 of the 8 lek pairs (2 experimental leks with introduced drilling noise, 2 with introduced road noise). Therefore, some leks had been exposed to noise the breeding season prior to the first year of FCM measurement; however, we detected no significant impact of duration of noise exposure on lek attendance [43], so years of noise exposure was not included as a potential explanatory variable in candidate model sets.

Collection of Fecal Samples

Fecal samples were collected from leks soon after all sage-grouse had left the lek for the morning. Samples were collected twice per year from each lek (once during the mid season [April 4–6 in 2007, April 6–8 in 2008] and once during the late season [April 23–26 in 2007, April 22–24 in 2008]) and were collected from paired leks on the same day. Samples were collected using a sweep-search method in which the entire lek was systematically searched and fresh fecal samples were collected individually in Whirl-Pak bags and labeled with a location on the lek relative to the speakers (or dummy speakers). To minimize the chance of collecting multiple fecal samples from the same individual, we collected samples that were a minimum of 5 meters apart, roughly the minimum territory size of a male sage-grouse. Jankowski [45] found lower FCM levels in female sage-grouse than in breeding male sage-grouse. Therefore to avoid collecting samples from females, we collected samples on dates when female visitation is rare; if there were more than 1–2 females on the lek on a potential collection day, sampling for that lek pair was postponed until the next day. Time to collect samples varied among leks from 20–80 minutes. Samples were frozen at −20°C within a few hours of collection until processing. Jankowski et al. [45] found no difference in FCM levels for greater sage-grouse samples held for variable times up to 16 hours prior to freezing.

Extraction & Radioimmunoassay of Cort

We used extraction and assay procedures, with minor modifications, that were previously validated for application to greater sage-grouse by Jankowski et al. [46]. Individual fecal pellets were kept on ice while uric acid (often present in a discrete cap on the pellet) was removed and discarded. Samples were then lyophilized and returned to storage at −20°C. On the day of extraction, individual fecal pellets were weighed to the nearest 0.0001 g, then manually homogenized, vortexed, and shaken in 5 mL of 80% methanol for at least 30 minutes. Longer incubation in methanol often occurred due to the large number of tubes in each assay, but experimentation with overnight extraction produced no substantial change in detected metabolites. Samples were centrifuged at 5000 rpm for 30 minutes, then 1.5mL of supernatant was drawn off, placed in a separate tube, dried under streaming air in a 70°C water bath and reconstituted in 1.0 mL of steroid diluent provided in the RIA kit (see below). For some very large samples, it was not possible to remove 1.5 mL; in these cases, 500 μL of supernatant was drawn off and reconstitution volume was adjusted accordingly after drying. Extracts were covered with Parafilm and stored at 4°C until assayed.

A pooled sample was made by homogenizing a collection of multiple samples from one control lek (Monument lek) in a blender prior to lyophilization. From this pooled sample, 0.5 g was assayed initially to determine parallelism with the RIA standard curve, and one or more pooled samples were included in each extraction and assay.

Radioimmunoassays were conducted according to the manufacturer's instructions (catalog # 07-120103, MP Biomedicals, Costa Mesa, CA) using 1:16 dilution of reconstituted extract. This RIA kit utilizes a rabbit-produced BSA IgG polyclonal antibody against corticosterone-3-carboxymethyloxime. This antibody has been widely used for fecal assays due to its ability to bind a broad spectrum of corticosteroid metabolites [47]. Samples were randomly distributed among assays with respect to year and treatment to minimize any impacts of inter-assay variation.

FCM measures were adjusted for the mass of the fecal sample (ng ICM/g sample) to account for differences among leks in fecal pellet mass. In dividing ICM by sample mass, we effectively assume that the relationship between sample mass and fecal transit time (during which corticosteroid metabolites are secreted into the lumen of the gut) is positive and linear. To guard against faults in this assumption, we ran the same statistical analyses using "per sample" FCM data and found no difference in the main effects as reported.

Statistical Analysis

Fecal glucocorticoid metabolites levels were natural log-transformed to meet assumptions of normality and homoscedasticity prior to analysis. We used an information theoretic approach to evaluate the support for alternative candidate models using Akaike's Information Criterion for small sample sizes (AIC_c) [48]. Candidate models for the overall effect of noise (Noise effect models) were linear mixed-effect models that assessed the relationship between explanatory variables and the concentration of FCMs collected from experimental and control leks. Potential explanatory variables included pair type (NoiseType, drilling or road noise), control status (Treatment, noise or control), pellet/collection distance from speakers (SpeakerDist), maximum lek size for that year (MaxSize), location (Hudson or Riverton), season (early or late April), and relevant interactions (see Table 1 for full set of candidate models). All models contained lek pair ID, and year (2007 or 2008) as random effects.

We also evaluated a set of candidate models that assessed the relationship between the concentration of FCMs on experimental leks and the declines in peak male attendance from the previous year (attendance models). Models contained lek ID and year (2007 or 2008) as random effects. Models were ranked on the basis of differences in AICc scores (ΔAICc) and were assigned Akaike weights (w_i) corresponding to the degree of support. We calculated model-averaged coefficients and variable importance (sum of variable weights for all models in which the variable was included) for variables contained in all models that received strong support (ΔAICc <2). We also compared the variance in FCM concentrations measured on noise and control leks using a Levene's test. All statistical analyses were performed in R (version 2.12.1, R Development Team 2010).

Results

We measured baseline fecal immunoreactive corticosterone metabolites of 103.2 and 119.9 ng/g for control and treatment groups, respectively (Table 2). These values are lower than baseline measures of approximately 149 ng/g obtained previously for breeding male greater sage-grouse in Nevada, from which fecal samples were collected after capture [45].

Males on leks exposed to noise had higher (16.7% on average) FCM levels compared with controls ($w_i = 0.96$, Table 1, 2; Figure 2). While models that included the effect of Treatment (noise versus control) were highly supported by the data, there was little support for an interaction of Treatment with NoiseType variable ($w_i = 0.01$, Table 1), indicating that while noise exposure was associated with increased cort, there was little difference in FCM levels between leks with drilling versus road-noise playback. Candidate models containing other possible explanatory variables, including distance from the nearest speaker (SpeakerDist), maximum size of the lek (MaxSize), the regional location of the lek in the Hudson area or Riverton area (Location) and time of the season (Season), received little support relative to the null model (Table 1, Figure 2B), indicating that none of these factors had a strong influence on FCM levels.

To determine whether noise-playback leks with a higher stress response were associated with larger declines in lek attendance, we compared candidate models for the relationship between FCM level and change in lek attendance from the previous year. Only the null model received support (Table 3), indicating that fecal FCM level was not associated with the magnitude of changes in lek attendance on noise leks.

Finally, we examined whether there was a difference in variance among samples on noise leks and control leks. We found no significant differences in variance between treatment types in 2007 (variance on noise leks = 7729.94, control leks = 6168.28, Levene's

Table 1. Mixed-effect candidate models for the effect of noise playback on mass-dependent FCM concentrations (natural log-transformed).

Model[a,b]	K[c]	ΔAIC_c [d]	w_i [e]
Treatment[f]	5	0	0.66
Treatment + Location	6	2.4	0.20
Treatment + Location + Treatment:Location	7	4.7	0.06
Null- random effects only	4	5.5	0.04
Treatment + Season	6	6.5	0.03
Treatment + Season + Treatment:Season	7	10.0	<0.01
Treatment + NoiseType + Treatment:NoiseType	7	10.8	<0.01
Treatment + Location + NoiseType + Treatment:Location + Treatment:NoiseType	9	11.2	<0.01
Treatment + NoiseType + Season + Treatment:Season + Treatment:NoiseType	9	20.7	<0.01
Treatment + MaxSize + Treatment:MaxSize	7	25.3	<0.01
Treatment + NoiseType + Season + Treatment:NoiseType + Treatment:Season + Treatment:NoiseType:Season	11	27.3	<0.01
Treatment + SpeakerDistance + Treatment:SpeakerDistance	7	27.5	<0.01
Treatment + NoiseType + MaxSize + Treatment:NoiseType + Treatment:MaxSize	10	35.4	<0.01
Treatment + NoiseType + SpeakerDistance + Treatment:NoiseType + Treatment:SpeakerDistance	9	38.2	<0.01
Treatment + NoiseType + MaxSize + Treatment:NoiseType + Treatment:MaxSize + Treatment:NoiseType:MaxSize	12	45.1	<0.01
Treatment + NoiseType + SpeakerDistance + Treatment:NoiseType + Treatment:SpeakerDistance + Treatment:NoiseType:SpeakerDistance	11	60.4	<0.01

[a] Abbreviations of predictor variables in methods.
[b] All models contain lek pairing and year as a random effect.
[c] Number of parameters in the model.
[d] Difference in AIC_c (Akaike's Information criteria for small sample size) values from the top ranking model.
[e] Akaike weight (Probability that the model is the best fit model giving the data and model candidate set).
[f] Model with substantial support (ΔAIC_c <2).

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Table 2. Parameter estimates (± SE) and relative variable importance for variables in highly supported models ($\Delta AIC_c < 3$).

Variable	Parameter estimates[a]	Parameter estimates (back-transformed)[b]	Relative variable importance[c]
Intercept	4.63 (.06)	103.2[d]	-
Treatment:Noise	.15 (.04)	16.7[d]	0.96
Location: Hudson	0.02(.01)	2.9[d]	0.26

[a] Parameter estimates are natural-log transformed.

[b] SE not included due to back-transformation.

[c] Relative variable importance is the summed total of the model weights for models containing that variable.

[d] Intercept value was added to parameter estimates prior to back-transformation and then subtracted.

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W = 0.6327, p = 0.427). Variance on noise leks was significantly higher than on control leks in 2008 (variance on noise leks = 4462.28, control leks = 2758.69, Levene's W = 6.6064, p = 0.01).

Discussion

We found higher (16.7%) FCM levels on noise-treated leks compared to controls, supporting the hypothesis that chronic noise pollution increases stress levels in male greater sage-grouse. Combined with results from monitoring of lek attendance in the same experiment [43], these results suggest that noise from natural gas development activities can dramatically decrease male attendance on leks and cause physiological impacts on males that remain on noisy leks. The mean level of FCMs in remaining birds was not a good predictor of the degree of decline in peak male attendance on a lek compared with the previous year, indicating that the FCM level measured on a lek is not diagnostic of an effect of noise on peak male attendance (Table 3). Further, we did not find support for an effect of distance from the speakers on FCM levels. Male sage-grouse typically maintain a fixed territory on a lek throughout the season. Within a noise-treated lek, each individual's exposure to noise varied, depending on the location of their territory relative to the speakers. Since noise levels decline exponentially with distance from the speakers, the lack of a distance effect suggests that stress is not exclusively dependent on the noise exposure of individuals. Instead, noise impacted FCM levels on a lek-wide basis.

Blickley et al. [43] found a decline in lek attendance on road-noise leks more than twofold larger than the decline in lek attendance on drilling-noise leks, yet we found no difference in FCM levels between noise-playback types (Table 1, Figure 1). Both noise sources have most of their sound energy ≤2 kHz, but road noise is less predictable than drilling noise and more intermittent,

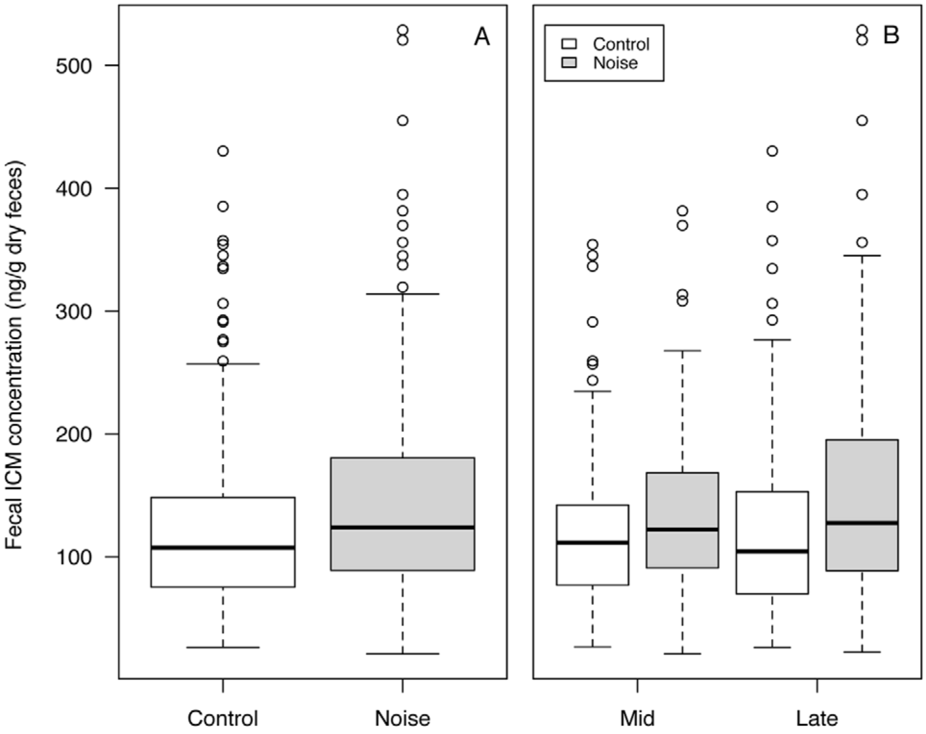

Figure 2. FCM concentrations from control and noise-treated groups. Data shown (A) pooled by season and (B) for mid and late season samples. Horizontal line represents the median value, box ends represent upper and lower quartiles, whiskers represent maximum and minimum values and open circles represent outliers. Plots present measured FCM values, not model output, which is presented in Table 2.

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Table 3. Mixed-effect candidate models assessing the relationship of FCM concentrations and changes in lek attendance from the previous year on noise-playback leks.

Model[a,b]	K^c	$\Delta \mathrm{AIC}_c$ [d]	w_i [e]
Null- random effects only[f]	5	0	0.90
Fecal cort	6	4.6	0.10

[a] Abbreviations of predictor variables in methods.
[b] All models contain lek pairing and year as a random effect.
[c] Number of parameters in the model.
[d] Difference in AIC_c (Akaike's Information criteria for small sample size) values from the top ranking model.
[e] Akaike weight.
[f] Model with substantial support ($\Delta \mathrm{AIC}_c < 3$).
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leading to a lower average noise exposure across road-noise leks (43.2±0.89 dBA L_{eq}) than drilling-noise leks (56.1±0.45 dBA L_{eq}) [43]. Studies on physiological stress in rodents indicate that stressors administered at unpredictable intervals result in greater elevations in plasma corticosterone [49]. Since cort levels may also be implicated in decisions to escape from deleterious conditions [50], we cannot say with certainty that noise type has no differential impact on FCM levels, only that there was no difference observed among males that chose to remain. If road noise did result in a greater cort response in some birds, but the most susceptible birds were also the most likely to disperse, differences would not necessarily be expected among remaining birds. In this scenario, it is likely that variance would be reduced in leks with high losses, reflecting disappearance of individuals with higher FCM levels. Levene's tests did not identify any such difference in variance (indeed, there was a significant difference in one year of the study, but in the opposite direction to predictions). However, the possibility that dispersal is linked to FCM levels cannot be ruled out. Regardless of whether the stress levels of birds on noise leks increased, or whether only high-stress-level individuals remained on noisy leks, these results indicate that chronic noise at leks creates less desirable habitat for greater sage-grouse.

The unknown status of dispersed grouse – and their unknown destinations – leaves several other possible scenarios that should be considered. It is possible that the individuals most likely to disperse could have had different cort profiles at the outset compared with those more prone to remain. If noise playback caused individuals with lower integrated cort to disperse away from noisy leks, that coupled with the possible addition of those birds to control leks could cause trends similar to those observed here. Two possible sources of variation in pre-experiment cort levels among individuals are age and social status [51–53]. Reduced juvenile recruitment may have contributed to the observed declines in lek attendance on noise leks, potentially leading to a difference in age structure on noise and control leks [43]; however, this is unlikely to explain the results of this study. Studies of altricial and semi-altricial birds have found lower stress responsiveness shortly after hatching, but responses resemble those of adults by the age of fledging or first molt [54–57]. Since young male sage-grouse attending leks are likely to be at least 10 months old and after their first molt, it is unlikely that they would have lower stress response than adults. Social status can also be related to corticosteroid levels [58], therefore social upheaval caused by dispersal between noise and control leks may have contributed to observed FCM levels. Further studies are needed determine whether age-class- and social-status-dependent dispersal in response to noise contributed to the observed results.

Unlike noise sources in most energy development sites, our noise introduction in this study was localized to the immediate lek area, so birds were exposed to noise for only a few hours a day, and only during the breeding season. Therefore, we cannot quantify the effects of noise on FCMs for wintering, nesting or foraging males. Noise at energy development sites is less seasonal and more widespread and may thus affect birds at all life stages, with a potentially greater impact on stress levels. In addition, we looked only at male stress levels in this study, but males and females may respond differently to stress. For example, Jankowski et al. [45] measured FCM levels in sage-grouse in habitats with and without cattle grazing; they found no difference in male FCM levels in response to grazing regime, however, breeding females showed elevated stress response in grazed areas. This suggests that females may be more vulnerable to some types of disturbance; further studies are needed to assess whether female stress levels are influenced by noise.

Why might noise be stressful?

Increased adrenocortical activity occurs in response to circumstances perceived as threatening by an animal. Although we cannot determine from this study the extent to which noise itself is a threat to sage-grouse, noise may affect social dynamics and increase the perception of threat. Noise may have social impacts on sage-grouse by masking acoustic communication on the lekking grounds [42]. Masking occurs when the perception of a sound is decreased by the presence of background noise, which may reduce the efficacy of acoustic communication. Acoustic signals play an important role in many social interactions, including mate attraction and assessment, territorial interactions, recognition of conspecifics and alarm calling in response to environmental threats [9,10,59]. Masking of these acoustic signals may alter or interfere with social interactions and mate choice behaviors [60,61].

For prey species such as sage-grouse, noise may also increase stress levels by masking the sounds of approaching predators and increasing the perception of risk from predation [62,63]. The degree to which noise directly affects mortality through changes in predation is largely unknown, as few studies have compared predation rates or hunting success in noisy and quiet areas while controlling for other confounding factors. Francis et al. [4] did so and found that nest predation rates in some songbirds decline in noise-impacted areas, as the dominant nest predator avoided noise. This suggests that noise may cause complicated changes in predator-prey dynamics. Noise may also cause stress due to short-term disruptions in behavior, such as startling or frightening animals away from food or other resources [2,64]. Further, if individuals associate a particular type of noise, such as road noise, with a danger, such as vehicular traffic, this may provoke a stress response [43].

The impacts of chronic stress

Glucocorticoid release under challenging conditions is an adaptation to life in an unpredictable and threatening world [20]; individuals benefit from curtailing reproduction, altering behavioral patterns, and redirecting metabolic substrates to maximize glucose availability for action in response to genuine threats. Glucocorticoid levels alone are not directly or inversely correlated with fitness measures under all conditions [65], however, chronic adrenal activation has many known trade-offs that result in vulnerability to disease and death [22]. Unlike threats from predators, food shortages and inclement weather, noise typically does not directly threaten the survival of an individual or its offspring (though there may be exceptions, as discussed below). Therefore, the cost of chronic adrenal activation in response to noise pollution is unlikely to be outweighed by the benefits in most cases, and thus the net result may be adverse.

One important trade-off is the effect of corticosterone on immune response. Chickens infected with West Nile Virus (WNV) and administered corticosterone had increased oral shedding and lengthened duration of viremia compared to those without elevated cort [66]. For sage-grouse, which are highly susceptible to WNV [67,68], reduced immune response due to elevated glucocorticoid levels could have a significant effect on survival in areas where they are exposed to WNV. Therefore, despite the adaptive nature of the stress response under natural conditions, elevated glucocorticoid levels due to human disturbance may have detrimental long-term impacts on welfare and survival of sage-grouse and other wildlife.

Stress as an indicator of human impacts on sage-grouse

Measurement of FCMs may provide a non-invasive monitoring tool to assess the impact of human development (e.g. oil and gas drilling, wind farms, highways, off-road vehicle traffic) on stress levels of greater sage-grouse and other species. However comparisons between disturbed and undisturbed areas would need to account for differences in age, sex, and breeding condition of individuals sampled as well as for differences in the environmental conditions between sites in order to isolate stress as the likely cause of change [15,18,69]. We controlled for such differences by using an experimental presentation of noise that minimized effect on other habitat variables, limiting our collection to lekking birds, collecting only on days with limited female attendance and collecting samples from all leks within a short 2–3 day window. We did not find support for differences in FCM levels from samples collected in early versus late April within each season (~20 days apart in a 2–3 month breeding season), and only limited evidence for an effect of location (Hudson vs. Riverton, ~32 kilometers apart), suggesting that these temporal and spatial differences did not affect FCM levels in our study. However with a larger sample of leks or in another region or time period, it is possible that such differences might emerge.

Conclusions

Taken together, results from Blickley et al. [43] and this study suggest that noise alone can cause greater sage-grouse to avoid otherwise suitable habitat and increase the stress responses of birds that remain in noisy areas. Thus, noise mitigation may be a fruitful conservation measure for this species of concern. In this study, we focused on the effects of noise from roads and drilling rigs in natural gas development areas; other natural gas development infrastructure, including compressor stations and generators, produces noise similar to drilling rigs, with the potential for similar effects on FCM levels. Likewise, other types of energy development produce noise similar in frequency, timing, and amplitude to the noise sources used here, including shale gas, coal-bed methane, oil, and geothermal development. The noise sources used in this study also share some characteristics with other anthropogenic noise sources that are increasing across the landscape, like wind turbines, off-road vehicles, highways and urban development; this suggests that the impacts on greater sage-grouse observed here may be widespread. More generally, populations of many species of birds [4,70–74] and mammals [75–78] decline with proximity to noisy human activities, such as roads, urban and industrial developments. While further study is needed to determine whether chronic noise exposure contributes to the impacts of these human activities by activating the chronic stress response, this study adds to a growing body of evidence that such noise pollution is a threat to wildlife [1,2], significantly increasing our estimates of the footprint of human development beyond the boundaries of visible disturbance.

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Author Contributions

Conceived and designed the experiments: JLB GLP AHK SNS. Performed the experiments: JLB AHK GLP SNS KRW JLP JCW. Analyzed the data: JLB KRW GLP AHK JLP CCT JCW. Contributed reagents/materials/analysis tools: GLP JCW. Wrote the paper: JLB KRW GLP.

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Effects of Organophosphorus Insecticides on Sage Grouse in Southeastern Idaho
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EFFECTS OF ORGANOPHOSPHORUS INSECTICIDES ON SAGE GROUSE IN SOUTHEASTERN IDAHO

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Abstract: Die-offs of sage grouse (*Centrocercus urophasianus*) were verified in southeastern Idaho in 1981. We captured 82 apparently healthy grouse to quantify the effects of organophosphorus insecticides (OP's) and other pesticides on sage grouse in sagebrush (*Artemisia* spp.) bordering agricultural lands in July 1985 and 1986. Grouse were fitted with radio collars and tracked through part of each summer. At least 18% of 82 radio-tagged grouse in 1985–86 subsequently occupied fields at the time they were sprayed with OP insecticides dimethoate or methamidophos. Cholinesterase (ChE) assays of brains and residue analysis of crop contents indicated that 5 and 16% of the marked sample died from OP's in 1985 and 1986, respectively. Approximately 200 sage grouse were present in a block of alfalfa sprayed with dimethoate; 63 of these were later found dead and ChE activity in 43 brains suitable for assay were depressed >50%. Maximum residues in crop contents of dead grouse were 18 μg/g methamidophos and 30 μg/g dimethoate. Intoxicated or dead grouse were observed in or near 6 fields sprayed with dimethoate or methamidophos in 1985–86. Twenty of 31 intoxicated grouse radiotagged after being found in dimethoate-sprayed (1986) alfalfa died. Our study indicates that certain pesticides have the potential for adversely affecting grouse populations.

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Replacement of organochlorine insecticides (OC's) with shorter-lived chemicals such as organophosphorus (OP), carbamate, and other compounds alleviated many problems with persistence and bioaccumulation of lipid-soluble OC's (Blus 1982, Wiemeyer et al. 1984). Additional research revealed that serious effects, resulting from different modes of action, are also associated with use of the newer compounds, particularly from a short-term perspective where acute or subacute toxicity (Hill and Fleming 1982, Grue et al. 1983, Henny et al. 1985) and reduction in the food base are major concerns (Rands 1985, Potts 1986).

Initial evidence that OP's caused mortality of sage grouse was noted in 1981 when a die-off occurred near a potato field sprayed with methamidophos. Brain ChE activity of 5 sage grouse collected when intoxicated (sick, immobile, and showing signs of OP poisoning) and later sacrificed ranged from normal to 61% inhibition (E. F. Hill, Fish and Wildl. Serv., pers. commun.). Data collected in 1983 indicated depression of 40 to 65% in brain ChE activity of grouse collected in a potato field shortly after spraying with methamidophos. These preliminary findings and previous unverified reports of die-offs suggested a potentially serious situation and led to radio-telemetry studies in southeastern Idaho in 1985–86. The purpose of our study was to determine and quantify effects of OP's on a population of sage grouse.

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STUDY AREA AND METHODS

The study area was located in southeastern Idaho near Mud Lake, Monteview, Hamer, and Camas in Jefferson County and Arco in Butte County (Fig. 1). This area provided summer range for sage grouse (Gates 1983, Connelly et al. 1988). Major agricultural crops included small

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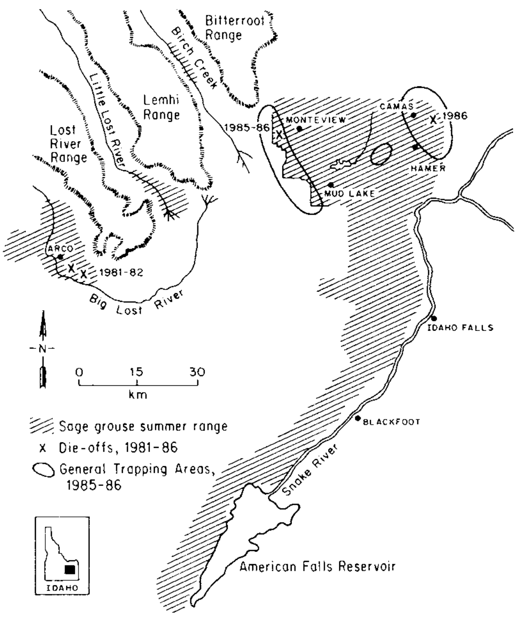

Fig. 1. Area of sage grouse study where die-offs occurred.

grains, potatoes, and alfalfa; many fields were bordered by sagebrush. Field work was conducted from April to August 1985 and from May to early September 1986. Spraying regimes employed by farmers in the study area were those normally used there.

From 9 to 26 July 1985, 39 apparently healthy sage grouse (30 juv and 9 ad F) were captured by night-lighting (Giesen et al. 1982) in sagebrush near alfalfa fields, and fitted with radio collars (Amstrup 1980, Dunn and Braun 1985). An intoxicated grouse captured in a sprayed alfalfa field was also radiotagged.

We captured apparently healthy sage grouse from 7 to 29 July 1986 by night-lighting. Radio collars were attached to 31 sage grouse taken near alfalfa fields and 12 sage grouse taken near potato fields; 31 grouse found intoxicated in sprayed fields were also radiotagged. In 1985 and 1986, individual grouse were located 2–14 times/week until the signal was permanently lost, the bird died or was collected, or the study was terminated (23 Aug 1985 and 3 Sep 1986 with a subsequent collection of 3 birds on 17 Sep 1986). Survival of radio-tagged grouse was recorded in grouse-days (i.e., 1 grouse surviving 1 day). Habitat was recorded each grouse-day that we located a bird; radio locations were verified by triangulation of several readings taken within 0.5 km of each grouse. Most radio tracking was done from trucks equipped with a null-peak system; some tracking was done on foot and from fixed-wing aircraft. Searches for radio-tagged grouse were not random; rather, we concentrated our work in areas where the grouse were last seen and expanded our search area to look for missing grouse.

Grouse found dead and those shot were placed on ice and frozen within 4 hours of collection. For analysis, grouse were thawed at room temperature and their brains were removed after medial bisection. We performed ChE assays on each half of the brain and values were averaged.

Although 2 different spectrophotometers were used, standardized methods for ChE assays (Ellman et al. 1961) with subsequent modifications (Hill and Fleming 1982) were used throughout the study. All assays were performed at 25 C and brains of apparently healthy (control) sage grouse were assayed concurrently with those of grouse exposed to OP's. Controls consisted of hunter-killed grouse and road-killed individuals picked up in non-agricultural areas. Precilip standard (Boehringer Mannheim, Indianapolis, Ind.) with an acceptable range of ChE values for freeze-dried human serum was used for quality assurance. The standard was tested ≥ 1 time/day that grouse brains were assayed to ensure that the spectrophotometer was properly calibrated and that our procedures resulted in accurate readings. In both years, ChE assays of the standard indicated our results were in the acceptable range listed by the manufacturer.

Cholinesterase activity is expressed as micromoles of substrate (acetylthiocholine iodide) hydrolyzed/minute/g of brain tissue. Control ChE activity is expressed as the mean ± 2 standard deviations (SD). Exposure of individual grouse to an anti-ChE compound is indicated when the ChE level is $\leq$ the control $\bar{x} - 2$ SD, and anti-ChE exposure is postulated as the cause of death with inhibition $\geq$50% (Ludke et al. 1975, Hill and Fleming 1982).

Crop or gizzard contents of sage grouse collected in 1985 and 1986 were homogenized, extracted, and analyzed for OP's at the Patuxent Wildlife Research Center or the Environmental Protection Agency, Corvallis Environmental Research Laboratory, with a gas chromatograph equipped with an electron capture detector (White et al. 1982; E. J. Kolbe, Fish and Wildl. Serv., pers. commun.; R. S. Bennett, Environ. Prot. Agency, pers. commun.). Approximately

Table 1. Proportion of time radio-tagged sage grouse were located in various habitats in summer range, southeastern Idaho, 1985–86.

Yr	Grouse-days and individuals located in fields				
Statistics	Alfalfa	Potatoes	Other crops	Non-cropland	Totals
1985	119		31	145	775
n	31		11	35	39
$\bar{x}$	3.9		2.6	4.1	19.9
SD	3.9		1.9	2.7	12.4
Range	1–17		1–6	1–11	1–45
1986	342	96	44	390	1,476
n	27	9	7	41	43
$\bar{x}$	13.3	10.7	3.7	9.5	34.3
SD	9.8	8.1	3.3	10.1	17.6
Range	1–34	1–21	1–10	1–43	1–57

10% of the residue analyses was confirmed with a mass spectrometer. Recovery of dimethoate or methamidophos from spiked samples ranged from 70 to 90%; residues were not corrected for recovery values. The lower limit of quantification ranged from 0.1 to 0.5 μg/g; residues were expressed on a wet weight basis.

Survival functions of radio-collared sage grouse were estimated with the Kaplan-Meier (product limit) non-parametric estimator (Lee 1980). Using this method we estimated the probability of grouse surviving beyond a specified time, to a specific date or number of days since marking. A staggered entry scheme was used in estimating the survival function (Pollock et al. 1989) to preserve the relationship between the survival function and the calendar date. A Chi-square test was used to compare survival of adult and juvenile grouse that were radiotagged when apparently healthy or intoxicated.

RESULTS

General Movements

Each of 39 healthy sage grouse radiocollared near alfalfa fields in 1985 were tracked from 1 to 45 days for 775 grouse-days (Table 1). Thirty-one grouse were observed in cropland; 19 and 15% of the grouse-days were recorded in cropland and alfalfa, respectively.

The 43 healthy sage grouse radiocollared in 1986 were divided into 2 groups: grouse captured near alfalfa ($n = 31$) or potatoes ($n = 12$). All grouse were trapped in sagebrush within 0.5 km of cropland. Each grouse trapped near alfalfa or potato fields was tracked from 1 to 57 days and 12 to 41 days, respectively (Table 1). Grouse captured near alfalfa spent 33% of the total grouse-days in cropland (31% in alfalfa), while those captured near potato fields spent 32% of the grouse-days in cropland (25% in potato fields).

During 1985 and 1986 85% of the 82 radio-tagged grouse were located ≥1 time in cropland, and the other 15% remained near cropland through much of the tracking period. Maximum distances sage grouse moved from sagebrush into cropland were 2.3 and 3.9 km in 1985 and 1986, respectively; these grouse remained in cropland for several weeks. By late August 1986, a few grouse moved back to sagebrush; some were 4 km from the nearest cropland. The daily activity pattern of about 90% of the radio-tagged sage grouse suggested feeding in cropland and roosting and loafing in nearby sagebrush. Because individuals were not located on 62 and 41% of the grouse-days in 1985 and 1986, respectively, their use of cropland and other habitats was much higher than recorded.

Intoxication and Mortality

Six of 39 (15%) grouse radiocollared when apparently healthy in 1985 later occupied a 240-ha alfalfa field (AB alfalfa) sprayed with dimethoate on 5 August; all 6 became intoxicated and 2 birds died with 62 and 73% inhibition of brain ChE activity (Table 2). The 4 intoxicated birds could not walk or fly; they were emaciated, had diarrhea, frequently salivated, and sometimes uttered faint vocalizations. These signs are characteristic of anticholinesterase compounds such as OP's and carbamates. The biochemical lesion is phosphorylation or carbamylation of acetylcholinesterase and resultant accumulation of acetylcholine that induces problems with the nervous system (O'Brien 1960). Four intoxicat-

Table 2. Brain cholinesterase (ChE) activity of sage grouse, controls compared to birds collected or found dead in summer in or near southeastern Idaho cropland, 1985 and 1986.

				Brain ChE			
				% change from control[a]		% of grouse	
Y	*n*	OP[b]	Condition	$\bar{x}$	Range	Exposed[c]	With ≥50% inhibition
1985	2	DI	Dead	−67.3	−72.5−−62.1	100	100
1985	3	—	Dead[d]	+0.6	−9.8–13.7	0	0
1985	5	DI	Shot	−34.2	−36.8−−31.0	100	0
1985	11	—	Shot	+7.1	−61.1–37.9	9	9
1985	2	DI	Sick	−66.5	−66.8−−66.3	100	100
1986	43	DI	Dead	−73.6	−90.3−−50.6	100	100
1986	2	ME	Dead	−40.8	−42.8−−38.7	100	0
1986	8	DI	Shot	−13.9	−30.2–6.2	25	0
1986	1	—	Dead[e]		−7.8	0	0

[a] Results of control ChE assays ($\bar{x}$ micromoles of substrate [acetylthiocholine iodide] hydrolyzed/min/g of brain tissue ± 2 SD) were 12.54 ± 2.18 for 11 birds in 1985 and 15.30 ± 3.34 for 7 birds in 1986.

[b] Known exposure to methamidophos (ME) or dimethoate (DI) listed when known; — = no known exposure to organophosphorus insecticides (OP's).

[c] Less than control $\bar{x}$ − 2 SD.

[d] Includes roadkill, predator kill, and undetermined cause of death.

[e] Roadkill.

ed grouse recovered after approximately 1 week and left the alfalfa field; these birds appeared normal but had 31–35% inhibition of brain ChE activity when shot on 14 or 23 August (Table 2).

Three intoxicated grouse without radio collars were located in 1985 during a field search in AB alfalfa for radio-tagged grouse. Two grouse were captured and sacrificed (8–9 Aug); brain ChE activity was inhibited 66 and 67%. The third intoxicated grouse found on 9 August was fitted with a radio collar. It recovered and seemed healthy when shot on 23 August; however, its brain ChE was still inhibited 37% (Table 2). On 6 August, 2 grouse without radio collars were shot on the ground in sagebrush near AB alfalfa. The brain ChE activity of 1 grouse was normal but the other showed 61% inhibition (Table 2).

In 1985, residue analysis of the gizzard contents of 3 grouse adversely affected by dimethoate sprayed on AB alfalfa (2 found dead and 1 sacrificed 3–4 days post-spray) revealed that only 1 grouse had residues of dimethoate (0.2 μg/g); crops of all 3 were empty. Seven grouse that were shot, including 5 that had recovered from OP intoxication in AB alfalfa and were collected 9 or 18 days post-spray, contained no residues of dimethoate in crop or gizzard contents.

Nine of 43 (21%) grouse radiocollared when healthy in 1986 later occupied fields sprayed with OP's. Eight of the 9 became intoxicated and 7 died from OP's. Five juveniles died after being sprayed with dimethoate in AB alfalfa at 0600 on 1 August; an adult female in the same field left shortly after spraying and showed no signs of intoxication. On 5 August, 2 partially eaten juvenile grouse were found buried in or near a potato field that was sprayed with methamidophos the previous day; these birds were probably eaten by a coyote (*Canis latrans*). A radio-tagged adult male that occupied a small alfalfa field sprayed with dimethoate on 6 August was intoxicated for several days; this was the only sick grouse found in the field adjacent to AB alfalfa.

We observed 100 sick or dead grouse around 3 alfalfa and 2 potato fields that were sprayed with OP's in 1986; the major die-off occurred in the AB alfalfa fields where we noted dead grouse in 1985. A flock of about 200 sage grouse occupied the AB alfalfa sprayed on 1 August; about 30 intoxicated and dead grouse were observed on 2 August with the last verified OP mortality occurring there on 12 August. We found 63 dead sage grouse in the AB alfalfa; these included 5 grouse radiotagged when healthy, 20 radiocollared when intoxicated, and 38 birds without radios (Table 3). In the large block of AB alfalfa sprayed with dimethoate on 1 August, we radiotagged 29 sage grouse found intoxicated; 20 of these apparently died from dimethoate and 10 deaths were verified by brain ChE assays.

Intoxicated sage grouse in the AB fields exhibited the same signs noted in 1985. Most of the sick grouse attempted to move into sagebrush. At least 2 grouse fell to the ground from

Table 3. Incidence of organophosphorus-related mortality of sage grouse by age and sex, southeastern Idaho, 1986.

	No. grouse					
	F		M		Unknown sex	
Marking Physical condition	Ad	Juv	Ad	Juv	Juv	Unknown sex and age
Radiotagged						
Healthy	11 (0)[a]	9 (3)	4 (0)	9 (4)	10 (0)	
Intoxicated	4 (4)	11 (5)	1 (1)	14 (9)		1 (1)
Unmarked	(1)	(7)	(1)	(13)	(3)	(13)

[a] Grouse radiotagged with organophosphorus insecticide-induced mortalities in parentheses.

flight. Most grouse died in or at the edge of the AB alfalfa, but 2 grouse radiotagged when intoxicated died in sagebrush 0.8 and 1 km from the field border. Avian and mammalian predators were attracted to the dead and dying grouse. We found 17 depredated carcasses in or near the AB fields ≤2 weeks after spray.

Assays of brains of 43 sage grouse found dead in AB alfalfa in 1986 revealed 51–90% inhibition of ChE activity (Table 2). Brains of 9 depredated grouse were suitable for ChE assay; activity was depressed from 51 to 86%. Of the 9 grouse that were radiocollared in AB alfalfa when intoxicated and subsequently recovered, 5 shot on 3 September had brain ChE activity inhibited from 9 to 30%; 3 other grouse shot on 17 September had brain ChE activity that ranged from −13 to 6% of control values. Unlike the 2 grouse that died from OP's in 1985, some of the birds in 1986 died soon after spraying; crops of 16 of 18 grouse found on 2 August contained alfalfa. Dimethoate residues in crop contents of 12 grouse found dead the day after spray ranged from 3 to 30 μg/g.

Two depredated radio-collared grouse that were found buried in or near a potato field the day after it was sprayed with methamidophos had brain ChE activity depressed 39 and 43% and crop contents of 1 grouse contained 18 μg/g methamidophos; these were the only 2 suspected OP mortalities during this study that had <50% inhibition of ChE activity.

Survival Analysis

Survival analysis of the 39 sage grouse radiotagged when apparently healthy in 1985 indicated that the probability of these grouse dying during the 45-day tracking period was 0.25 (mortality = 1 − survival); however, only 2 (juv) of 9 documented deaths (1 ad F and 8 juv) were related to OP intoxication (probability of dying from OP's = 0.10). Four radio-tagged grouse were killed by predators, 2 by farm machinery, and 1 died from an unknown cause; ChE activity in brains of 2 of these grouse was similar to control values. Two young killed by farm machinery died the day after they were trapped and were not included in the mortality estimates. Of the 7 deaths unrelated to OP poisoning, 5 occurred from 10 to 27 July and 2 occurred in early August. As a result of the short range of the transmitters (<1.3 km) and related problems, signals from 17 grouse were lost before the study ended; thus, the mortality values are minimal estimates with low precision.

Of the 43 sage grouse radiocollared when healthy in 1986, 10 died (7 from OP's) before the end of the study with an overall mortality rate of 0.32. The probability of a grouse dying during the 72-day study from OP poisoning was 0.25. Aside from the 7 juvenile grouse that died from OP's, 3 additional radio-tagged grouse (2 juv and 1 ad F) were depredated on 15 and 20 August and 17 September. Although these 3 grouse were located in cropland from 3 to 20 days, there is no evidence of their exposure to OP sprays and their brains were not available for ChE assays. Radio collars were removed from apparently healthy grouse on 1 August (1 grouse) and 2 August (4 grouse); these units were then placed on intoxicated grouse.

The probability of mortality for 31 grouse, radiotagged when intoxicated in alfalfa from 25 July to 7 August 1986, was 0.76 to 12 August when the die-off from dimethoate in AB alfalfa apparently ended and 0.78 to 3 September when several of these grouse were collected. Dimethoate apparently accounted for deaths of 20 of these grouse; ChE activity was inhibited >50% in brains of 10 birds. Mortality of grouse instrumented when intoxicated was highest in 8 marked in AB alfalfa on 2 August (1 day postspray) and all died by 5 August; 12 of 21 grouse radiocollared when intoxicated on 3–7 August died from 4 to 12 August and 1 was depredated on 1 September. The grouse that died on 12 August was depredated; however, its brain ChE activity was inhibited 55.3%. The longer range (2.0–2.5 km) of the transmitters used in 1986 resulted in more efficient tracking compared to 1985; nevertheless, signals of 5 grouse were lost before the end of the study.

Age Effects.—Concerning sage grouse radiotagged when healthy in 1986, juveniles were more likely to die from OP poisoning than adults (Table 3); 7 of 28 juveniles died compared with zero of 15 adults ($P < 0.05$). There was no significant difference ($P > 0.05$) in survival of adults and juveniles radiocollared when intoxicated; however, all 5 adults died compared with 14 of 25 juveniles. Two adults were among 38 nonradioed birds that probably died from dimethoate in the AB alfalfa fields; however, sex and age of 13 birds were unknown. Considering the 6 grouse radiotagged when healthy and subsequently sprayed in AB alfalfa, an adult female showed no ill effects but all 5 juveniles died. The first 2 grouse radiocollared when sick were found in several cm of water in an alfalfa field on 25 July; the field was sprayed with dimethoate 2 days previously and was subsequently flood irrigated. One grouse flew from the field the same day it was radiotagged and the other left the field the next day.

DISCUSSION

Generally, sage grouse in southeastern Idaho are migratory (Dalke et al. 1963, Connelly and Ball 1983); movements to summer range, including cropland, begin in June. Maximum movement of adult sage grouse from winter range to summer range was 82 km (Connelly and Markham 1983, Connelly et al. 1988). Distances moved from nests to summer range by 6 females with broods ranged from 3 to 21 km (Gates 1983). Gates (1983) also noted that 82% of 22 sage grouse trapped and marked on leks subsequently moved to irrigated cropland. Based on this study and previous work by Gates (1983), most of the Idaho population uses cropland for summer range; such use increases sharply during extended periods of extremely hot and dry weather (J. W. Connelly, Id. Dep. Fish and Game, pers. commun.). In our study area, spraying crops with pesticides is initiated in late spring, but most applications occur in July and August at the height of cropland use by sage grouse.

The die-offs during our study were apparently the first verified records for wildlife losses that resulted from dimethoate application. There are no toxicity data relating to sage grouse tolerance to OP insecticides. Factors that increased risk of OP's to sage grouse were their use of alfalfa fields for feeding, roosting, and loafing, and their extensive feeding on alfalfa foliage after spraying.

The conditions associated with methamidophos application to potatoes that result in risk to sage grouse were similar to those associated with dimethoate applications to alfalfa. Some sage grouse used potato fields extensively during this study. The crops of grouse shot or found dead in potato fields contained foliage of weeds and small amounts of insect material; sage grouse may occasionally eat potato leaves (J. W. Connelly, Id. Dep. Fish and Game, pers. commun.). We are uncertain whether repellency of dietary methamidophos to experimental birds (Stromborg 1986) is an important factor mediating toxicity to wild sage grouse, especially in view of the 18 μg/g methamidophos detected in crop contents of a sage grouse. Although the acute toxicity of methamidophos is higher than for dimethoate (Hudson et al. 1984), we located only 1 record of a die-off of wild birds (house sparrow [*Passer domesticus*] and killdeer [*Charadrius vociferus*]) from this compound (Smith 1987). On the basis of survival of about 35% of the sage grouse found intoxicated, some of the sick birds may have survived effects of OP's had they not been depredated. In any case, OP exposure was considered the primary cause of death when ChE assay results and residues were available for verification. Although the 2 depredated sage grouse found in or near the potato field sprayed with methamidophos had brain ChE activity depressed <50%, recent experimental evidence supports the probability that their deaths resulted from the spraying. Japanese quail (*Coturnix japonica*) were critically intoxicated when euthanized 1 hour after receiving an oral dose of the OP dicrotophos; however, brain ChE activity was inhibited about 40% (Hill 1989).

In other studies, half-time of dimethoate and methamidophos on plants was <4 days; however, low residues of these systemic insecticides may persist for several weeks (Szeto et al. 1984, Westcott et al. 1987). Thus, intoxicated sage grouse in cropland may be exposed to additional residues of OP's when ChE reversal is initiated and the grouse resume feeding on contaminated foliage. Sublethal depression of ChE activity in the brain did not have lasting physiological effects in experimental birds in earlier studies (Metz 1958, Glow and Rose 1966, Banks and Russell 1967), but more recent studies present evidence that OP's similar to dimethoate and methamidophos are capable of inducing long-term effects (Farage-Elawar and Francis 1987, 1988). There are few data for free-ranging birds (Hill and Fleming 1982). European starling (*Sturnus vulgaris*) nestlings exhibited 19% mortality within 48 hours of receiving a dose of the OP dicrotophos compared with no mortality among controls; thereafter, survival of dosed and control young was similar for 1 month (Stromborg et al. 1988). We found no short-term effects after recovery of locomotive abilities by grouse, but the sample size was small and mortality was the only factor considered. The approximate time for renewal of ChE activity in intoxicated sage grouse in this study was similar to the 26-day recovery period (from 55 to 64% inhibition to within 2 SD of the control $\bar{x}$) measured for 5 avian species given diets containing dicrotophos (Fleming and Grue 1981).

Our findings suggest that OP's may adversely affect sage grouse populations, but this study only involved that segment of the population whose summer range included cropland. The mortality rate and sublethal intoxication of our marked population, induced by OP's and possibly other pesticides used in the area, was probably underestimated because sage grouse were radiotracked only during part of the season when OP's and other pesticides were applied, signals were lost from a number of grouse before the study terminated each year, radio collars were removed from 5 healthy birds in 1986 for use on intoxicated grouse, and some unrecorded exposure of marked grouse may have occurred between radio locations because the birds were not tracked continuously.

MANAGEMENT IMPLICATIONS

In all fields where grouse were affected, the spray pilot reported the maximum allowable rates of dimethoate (0.56 kg active ingredient [ai]/ha) and methamidophos (1.13 kg ai/ha) were applied. Use of the minimal recommended application rates of 0.37 kg ai/ha for dimethoate and 0.85 kg ai/ha for methamidophos may reduce the hazard to grouse. General wildlife repellents are being tested by ≥ 1 chemical company for use with pesticides; successful short-lived repellents may deter sage grouse from ingesting contaminated foliage and may force them to leave sprayed fields. Die-offs of sage grouse and other species of birds including ring-necked pheasants (*Phasianus colchicus*) and gray partridge (*Perdix perdix*) are possible throughout much of their range in Idaho and in other states where cropland is available. The situation may worsen if intensive spraying of OP's on small grains is expanded in efforts to control the newly invading Russian wheat aphid (*Diuraphis noxia*). Our study provides evidence for claims that pesticides are at least partially responsible for declining populations of upland game birds in the United States and Europe; however, additional data are needed for verification.

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CHANGES IN SAGE GROUSE LEK COUNTS WITH ADVENT OF SURFACE COAL MINING

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Abstract: Intensive investigations of sage grouse (*Centrocercus urophasianus*) in North Park, Jackson County, Colorado were initiated in 1973. Three surface coal mines became active for varying periods in northeastern North Park during 1973–83. Numbers of known active sage grouse leks in North Park increased from 1973 through 1979, decreased in 1980, and were stable through 1983. Average number of males counted per lek in North Park was stable from 1973 through 1977, increased in 1978, and remained stable through 1983. Between 1974 and 1983, 9 leks were located in the mining area of which 7 (77.8%) were active in 1983. During this same interval in areas not impacted by mining, 18 new leks were located of which 13 (72.2%) were active in 1983. Average number of males counted per lek within 2 km of mining activity was low from 1974 to 1976 (9–14/lek), variable from 1977 to 1981 (46–60/lek), and decreased in 1982 and 1983 (47–25/lek). Outside the mining area, average numbers of males counted per lek were stable from 1973 to 1977 (29–33/lek), increased in 1978, and remained at the higher level through 1983 (39–44/lek). Number of males counted on leks closest to the 3 active surface coal mines decreased markedly (average = 60/lek in 1981; 25 in 1983) with increased mine preparation and mining activity.

Responses of sage grouse to mining disturbances are poorly understood even though sage grouse occur near or on many coal mines (53% of 51 mines surveyed) in western North America (Scott and Zimmerman 1984). The scientific literature concerning the impacts of surface coal mining on sage grouse is sparse with 2 of the 3 published papers relating to relocating display areas (leks) (Eng et al. 1979, Tate et al. 1979). The other paper develops criteria for reclamation of sage grouse habitats on areas altered by surface coal mining (Colenso et al. 1980). Considerable effort has been expended by energy companies in gathering baseline data on sage grouse on areas to be mined. These data are not available in the published literature and are generally available only from the mining companies that did the original work (Overthrust Industrial Assoc. 1984). Reasons for the lack of understanding of mining impacts on sage grouse relate to the short term approach of most studies, a lack of understanding of what to measure, failure of sage grouse populations to immediately and dramatically respond to small scale habitat alterations, and inadequate resources directed to the question. This paper describes the changes in a subpopulation of sage grouse and possible explanations of the changes in an area where surface coal mining was planned and implemented.

STUDY AREA AND METHODS

Counts of male sage grouse on leks were conducted from 1973 through 1983 in North Park, Jackson County, Colorado. North Park is a large basin at an elevation of about 2,500 m with surrounding mountains to 3,800 m. Topography is irregular with drainage to the north through a series of small streams that flow into the North Platte River. Sagebrush, primarily *Artemisia tridentata wyomingensis* and *A. t. vaseyana*, is the dominant shrub and occurs with native bunchgrasses and forbs. Many stream bottoms have been developed for raising hay; livestock grazing is the dominant land use (Beck 1975).

Coal mining presently occurs east of Walden in northeastern North Park, south of Jackson County Road 10, east of Colorado 125, and north of Colorado 14. That portion of North Park east of Colorado 125, south and west of the Canadian River, and north of Colorado 14 is termed the mining area and encompasses the 3 surface coal mines that were active sometime in the 1973–83 interval (Figure 1).

Counts of males present on all known sage grouse leks throughout North Park were made in April–May each year following procedures described by Braun and Beck (1976). Three to 4 counts of all birds present on each lek were scheduled at 7–10 day intervals from early April through mid-May. The desired schedule of counts was not uniformly attained because of poor access, predator or other disturbance, and inclement weather. Searches for new leks were made every year using ground vehicles and at 2–3 year intervals using fixed-wing aircraft or helicopters.

Sage grouse throughout North Park were located with spotlights where they roosted on leks or along trails and were captured with long-handled nets (Giesen et al. 1982). Captured birds were classified to age and sex (Beck et al. 1975) and marked with individually numbered aluminum leg bands and colored plastic bandettes coded to either area or year of banding. Locations of recaptured or recovered (dead) birds were recorded.

RESULTS

Numbers of known active leks throughout North Park increased from 1973 to 1979 (17 to 35), decreased between 1979 (35) and 1980 (30), and stabilized from 1981 through 1983 (31). No leks were found in northeastern North

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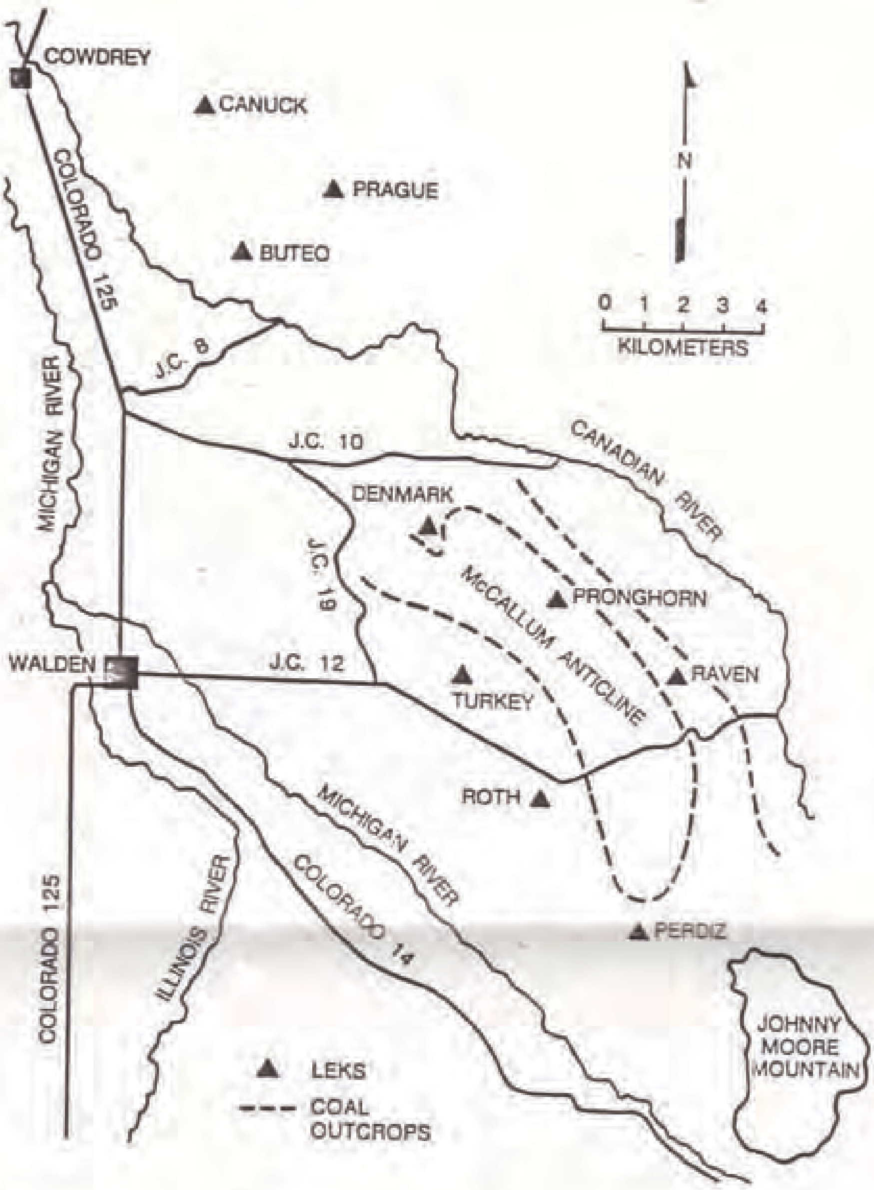

Figure 1. Sage grouse leks and coal outcrops in northeastern North Park, Jackson County, Colorado. Adapted from Schoenberg 1982.

Park in 1973, but 2 were found in 1974. Known numbers of active leks in this area increased from 2 to 7 between 1974 and 1979 and remained stable at 6–7 leks from 1978 through 1983. Male sage grouse were observed displaying at 4 other locations in northeastern North Park in 1981–83. These sites were not included because they were active only sporadically or not at all in 1 or 2 of the years. Numbers of active leks within 2 km of mines that were being developed or were in operation increased from 1 in 1974–76 to 3–4 in 1977–83 (Table 1).

Average numbers of males counted on leks throughout North Park fluctuated little between 1973 and 1977 (28–33), increased in 1978, and stabilized at the higher level through 1983. Numbers of males on leks within the northeastern portion of North Park fluctuated more widely (1977–80) and declined in 1982–83 (Table 1). The same pattern occurred on the 3–4 leks closest to mining activities although the decline in 1983 was far more marked (47 to 25) than elsewhere in North Park.

One small (8–14 males) lek (Roth) became inactive within 3 years of upgrading the haul road to the Wyoming Fuels Mine. This road passed within 50 m of the display site. With opening of the Walden Coal Company Mine in late 1980 and development of a modern haul road, numbers of males on Denmark Lek (0.5 km west of the mine site)

Table 1. Trends in numbers of active leks and average number of males per lek, North Park, Colorado, 1973–83.

	North Park		Outside of mining area		Mining area		Leks ≤ 2 km of mining activity	
Year	N leks	N males/lek	N leks	N males/lek	N leks	N males/lek	N leks	N males/lek
1973	17	33	17	33	0	0	0	0
1974	19	28	17	29	2	19	1	10
1975	19	31	17	32	2	18	1	14
1976	21	32	19	33	2	19	1	9
1977	26	31	21	30	5	36	3	46
1978	34	39	28	39	6	60	3	58
1979	35	43	28	44	7	42	4	54
1980	30	40	24	40	6	83	4	49
1981	31	41	25	41	6	82	3	60
1982	31	41	24	44	7	64	3	47
1983	31	39	24	43	7	56	3	25

decreased 24% in the first year and 83% by the third spring. Numbers of males on 2 other leks (Perdiz, Raven) closest to coal mining activity also decreased (8 and 69%) as the mines were prepared for expansion (Table 2).

DISCUSSION

Numbers of sage grouse in North Park as measured by numbers of active leks and average numbers of males present per lek increased from 1973 to 1983. This increase occurred throughout the area and was pronounced within the area where coal mines were developed in the late 1970s and early 1980s. Reasons for the increase are not clearly known, but are probably related to improvement in habitat conditions following cessation of large-scale sagebrush manipulation projects that occurred throughout North Park in the late 1960's (Braun and Beck 1976).

Coal mining has occurred sporadically near Coalmont and northeast of Walden for many years (Beekly 1915). Expansion of coal mining activities in northeastern North Park in the late 1970s and early 1980s occurred at the same time that the sage grouse population was expanding. However, as haul roads were improved (3 mines), site preparation increased (2 mines), and one mine became fully operational (Walden Coal Company Mine) numbers of sage grouse counted on leks closest to the mining activity began to decrease and one lek became inactive. The declines at 2 leks were precipitous (69% in 5 years, 83% in 3 years). Both of these leks are expected to be inactive by 1986.

Why have numbers of males decreased on the leks closest to mine development? Why did one lek become inactive with prospects for two more leks to become inactive in the near future? Numbers of sage grouse present on leks in spring are largely controlled by recruitment of yearlings. The average annual mortality rate of adult male sage grouse approximates 50% (C. E. Braun, unpubl. data). Thus, to maintain stability, numbers of yearlings recruited must equal the number of adults that died. If no yearlings are recruited, the number of males present on leks will decrease 50% each year. Trapping data for the two leks (Denmark, Raven) experiencing the largest declines indicated that no yearling males were recruited to one (Denmark) in 1982 and 1983 and the other (Raven) in 1983. Failure to recruit yearlings was also the problem at the lek (Roth) that became inactive as the last 1–2 birds present at this lek had been banded prior to full development of the adjacent haul road.

Why do yearling males fail to recruit to a lek? Failure to recruit may be related to dispersal, poor nesting success of hens, and/or decreased survival of young. It may also be related to acoustical or physical factors that deter yearling males from becoming established. It is well documented that adult males tend to return to the same lek year after year once they become established (Braun and Beck 1976; C. E. Braun, unpubl. data). If young are produced and survive to

Table 2. Numbers of male sage grouse per lek on leks ≤ 2 km of surface coal mining activity, North Park, Colorado, 1974–83.

Year	Lek				Average
	Denmark	Perdiz	Raven	Roth	
1974				10	10
1975				14	14
1976				9	9
1977	58		73	8	46
1978	80		94	1	58
1979	136	16	63	2	54
1980	144	8	43	1	49
1981	109	23	49	0	60
1982	71	27	44	0	47
1983	24	21	29	0	25

recruit to established leks, but fail to do so, they should either establish new leks or recruit to other, more favorable established leks. One new lek (Turkey) has become established 4 km south of the lek (Denmark) experiencing the greatest decline. Since establishment, this new lek has increased from 22 to 59 males. This is less than the number of males "lost" from the declining lek. Numbers of males on other leks in northeastern North Park have not increased. Thus, the evidence suggests that the overall sage grouse population in the area impacted by mining has decreased without a concomitant increase elsewhere in North Park. This decrease is attributed to decreased recruitment of yearling males.

Analysis of banding, recapture, and recovery data indicate that few sage grouse (only 4 recoveries from 4,491 bandings) migrate from North Park. Recaptures of adult males during the display period further than 5 km from where captured previously on leks have not occurred. Also, no movements of banded males from leks with decreasing number of males to other leks within the area have been documented. Thus, declines in numbers of males on leks over a several year period cannot be attributed to emigration. The declines documented fit the hypothesis that adult males return to leks where they are established until they die and that no or few yearlings are recruited to replace those adults dying. Thus, a lek can go to extinction in 4–6 years. Research should now focus on the factors that make established leks unattractive to yearling males in areas affected by mining disturbance.

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Fall Population Structure of Sage-grouse in Colorado and Oregon

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OREGON DEPARTMENT OF FISH AND WILDLIFE
In cooperation with Grouse Inc., Colorado Parks and Wildlife, and Washington Department of Fish and Wildlife

Frontispiece: George Keister (left) of ODFW and Dr. Clait Braun of Grouse Inc. examine a greater sage-grouse wing.

Fall Population Structure of Sage-grouse in Colorado and Oregon

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ABSTRACT We studied the population structure of sage-grouse (*Centrocercus* spp.) based on collection and analysis of 67,679 wings from hunter-harvested birds in 10 areas in Colorado and 12 areas in Oregon during 1973–1998 and 1993–2013, respectively. The harvest age structure for greater sage-grouse (*C. urophasianus*) varied from 42 to 63% juveniles in Colorado and 27 to 58% in Oregon. Approximately 59% of the Gunnison sage-grouse (*C. minimus*) harvest was juvenile. The overall adult male:female sex ratio was 28:72 for greater sage-grouse in Colorado, 41:59 (this includes an unknown proportion of yearlings) for greater sage-grouse in Oregon, and 34:66 for Gunnison sage-grouse in Colorado. Proportions of females increased in all fall populations from juvenile to yearling to adult age classes. Estimated breeding success was similar for greater sage-grouse in Colorado (47%) and Oregon (49%), but Gunnison sage-grouse appeared to have higher (60%) breeding success. The average number of juveniles in the harvest per breeding-age female varied from 1.2 to 2.4. There was high annual variation within and among areas. Composite estimated annual survival varied from 46 to 48% for adult males and 56 to 59% for adult females.

KEY WORDS age and sex composition, *Centrocercus minimus, C. urophasianus*, chicks per hen, Colorado, harvest, nest success, Oregon, sage-grouse, survival, turnover

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Sage-grouse (*Centrocercus* spp.) are charismatic large grouse of the sagebrush (*Artemisia* spp.) steppe in western North America (Schroeder et al. 1999). They historically occurred in at least 16 states and 3 provinces of Canada. Greater sage-grouse (*C. urophasianus*) are currently considered an endangered species in Canada but are hunted in 8 states (as of 2014). The distribution of sage-grouse has markedly declined from their apparent historical distribution (Schroeder et al. 2004) as have apparent numbers (Braun 1998). The reasons for the declines are related to degradation, loss, and fragmentation of sagebrush-dominated habitats (Braun 1987, Connelly and Braun 1997, Braun 1998). This has led to concern about their status and both species have been repeatedly petitioned for listing under the Endangered Species Act (Knick and Connelly 2011). The U.S. Fish and Wildlife Service has filed a ruling to list Gunnison sage-grouse (*C. minimus*) as threatened (USDI 2014) and the greater sage-grouse is presently listed as warranted but precluded because of higher priorities (USDI 2010).

Data on the structure of sage-grouse populations are not readily available as individuals may occur seasonally in widely-spaced sex-specific flocks in winter (Beck 1977) and also in summer and fall. All individuals cannot be counted, even on leks where males congregate in spring, because all locations of active leks are not known, not all males attend leks, and hen presence on leks is not simultaneous (Beck and Braun 1980). Our objectives were to (1) describe the fall structure of sage-grouse populations, and (2) test hypotheses that the fall structure of sage-grouse populations does not differ among populations of greater sage-grouse within a State, between states, and between greater and Gunnison sage-grouse. This analysis is based on examination and classification of the age and sex of over 67,000 individual sage-grouse harvested in Colorado and Oregon over the periods, 1973–1998, and 1993–2013, respectively. These data have not been examined or published across the range of sage-grouse and are important in understanding the population dynamics of both species. Some harvest data are present in unpublished reports of State wildlife agencies.

METHODS

We collected sage-grouse wings from hunters in Colorado at check stations on highways and roads leading from hunting areas as well as from voluntary wing collection stations placed along access roads (Hoffman and Braun 1975). A wing was clipped from each sage-grouse examined at check stations, the gonads were checked (primarily juveniles) when possible to ascertain sex, and the wings were labeled, and stored cold or frozen until analysis. Hunters in Oregon were requested to return one wing of each sage-grouse harvested in mail-in envelopes that were sent to, or dropped off at a central location for frozen storage.

Wings were thawed prior to analysis and were grouped into young of the year (juveniles), yearlings (young from the previous year), and adults following standardized procedures (Beck et al. 1975, Braun and Schroeder 2015). Sex of juveniles was ascertained based on measurements of primaries (from birds for which gonads were examined at check stations) and appearance of primaries, secondaries, wing coverts, and tertial feathers as described by Braun and Schroeder (2015). The adult category included some yearlings that had progressed enough in the molt, that characteristic yearling feathers (Braun and Schroeder 2015) were no longer present. Breeding success was estimated based on old (prior year) primaries retained at time of harvest. The primary molt of successful hens starts later than for hens losing their clutch during egg laying and or incubation based on recapture data in Colorado (Braun 1984). Annual turnover was estimated based on either the proportion of yearlings (Colorado) or juveniles (Oregon) compared to the proportion of adults (including yearlings) of each sex in the fall harvest. This assumes a population is stable. A population can be stable, increasing, or decreasing and the proportion of yearlings and or juveniles is a measure of overwinter survival (yearlings) or first summer survival to September (juveniles). We present raw data and averages by specific harvest area (Colorado) and by Management Unit (Oregon).

STUDY AREAS

Colorado

Sage-grouse were historically widely distributed in Colorado (Rogers 1964, Schroeder et al. 2004). Their distribution in the state has been greatly reduced (Braun 1995, Schroeder et al. 2004) (Fig. 1). Small Game Management Units historically followed the distribution of sage-grouse in Colorado and were first numbered in 1968, which continued through 1973; they were renumbered continuing through 1986. Numbering of all Big and Small Game Management units in Colorado was standardized in 1987. The distribution of sage-grouse in Colorado is within range-wide sage-grouse management zones II and VII (Stiver et al. 2006). Colorado shares sage-grouse populations with Utah and Wyoming. Sage-grouse in Colorado occur in three Environmental Protection Agency Level III ecoregions: Colorado Plateau, Southern Rockies, and

Wyoming Basin.

North Park - This area is within Jackson County and includes portions of Game Management Units 6, 7, 16, 17, 161, and 171. This area was formerly Small Game Management Unit 4 (1968–1973) and 12 (1974–1986). The area used by greater sage-grouse in North Park is at elevations of 2315–2745 m within a broad basin with numerous streams flowing to the north. Wet meadows and seasonally irrigated hay meadows are abundant. The area is rolling with numerous low and several higher ridges. There are no agricultural crops other than native hay as the growing season is short. Timing of sage-grouse breeding activities can be delayed in some years following severe winters.

Middle Park - This area includes portions of Game Management Units 18, 27, 28, 37, 171, and 181 in Grand and Summit counties. This area was formerly Small Game Unit 11 (1968–1973) and 28 (1974–1986). Middle Park is an open basin at ~2100–2300 m surrounded mostly by higher mountains. It has numerous streams flowing from the south and north, and then west. There is no agriculture other than native hay, and wet meadows are common. The length of the growing season is similar to that in North Park and greater sage-grouse breeding seasons can be late depending upon winter severity.

Eagle - This area includes portions of Game Management Units 25, 35, and 36 in Eagle (north of the Eagle River) and extreme northeastern Garfield counties. This area was formerly part of Small Game Management Units 9 and 10 (1968–1973) and Small Game Management Unit 54 (1974–1986). The Eagle area ranges from mid elevation (< 2000 m) sagebrush meadows to areas sloping sharply to the Eagle and Colorado rivers. Greater sage-grouse use the available sagebrush areas that are disjunct within a larger mosaic of pinyon-juniper (*Pinus*-*Juniperus*) shrubs and trees. Agriculture is limited to small hay meadows. Overall, the area is narrow, linear, and highly dissected by non-sagebrush habitat.

Yampa - This area includes parts of Game Management Units 15, 26, 131, and 231 in southern Routt County. This area was formerly Small Game Management Units 9 and 10 (1968–1973) and parts of Units 26 and 54 (1974–1986). The Yampa area supports greater sage-grouse from mid elevation (~ 2000 m) rolling sagebrush hills to irrigated hay meadows. Overall, the area is dissected by non-sagebrush habitat and hay meadows with more open areas near Yampa.

Piceance Basin - This area is primarily in Rio Blanco County and northern Garfield County in Game Management Unit 22 (1974 to present). It was formerly Small Game Management Unit 8 (1968–1973). This area is highly dissected by drainages and narrow ridges at elevations ranging from 1830 to 2285 m. Wider stream bottoms have been developed for hay production including some non-native species (primarily alfalfa). The population of greater sage-grouse is disjunct and occurs primarily along ridgetops dominated by sagebrush. The growing season is longer and warmer than in higher elevation areas, but little of the area is suitable for agriculture. Development for the extraction of oil, gas, and soda is common throughout the area.

Blue Mountain - This area includes part of Game Management Unit 10 (1987 to present) in far western Moffat County east of the Utah State Line and north of U.S. Highway 40 and west

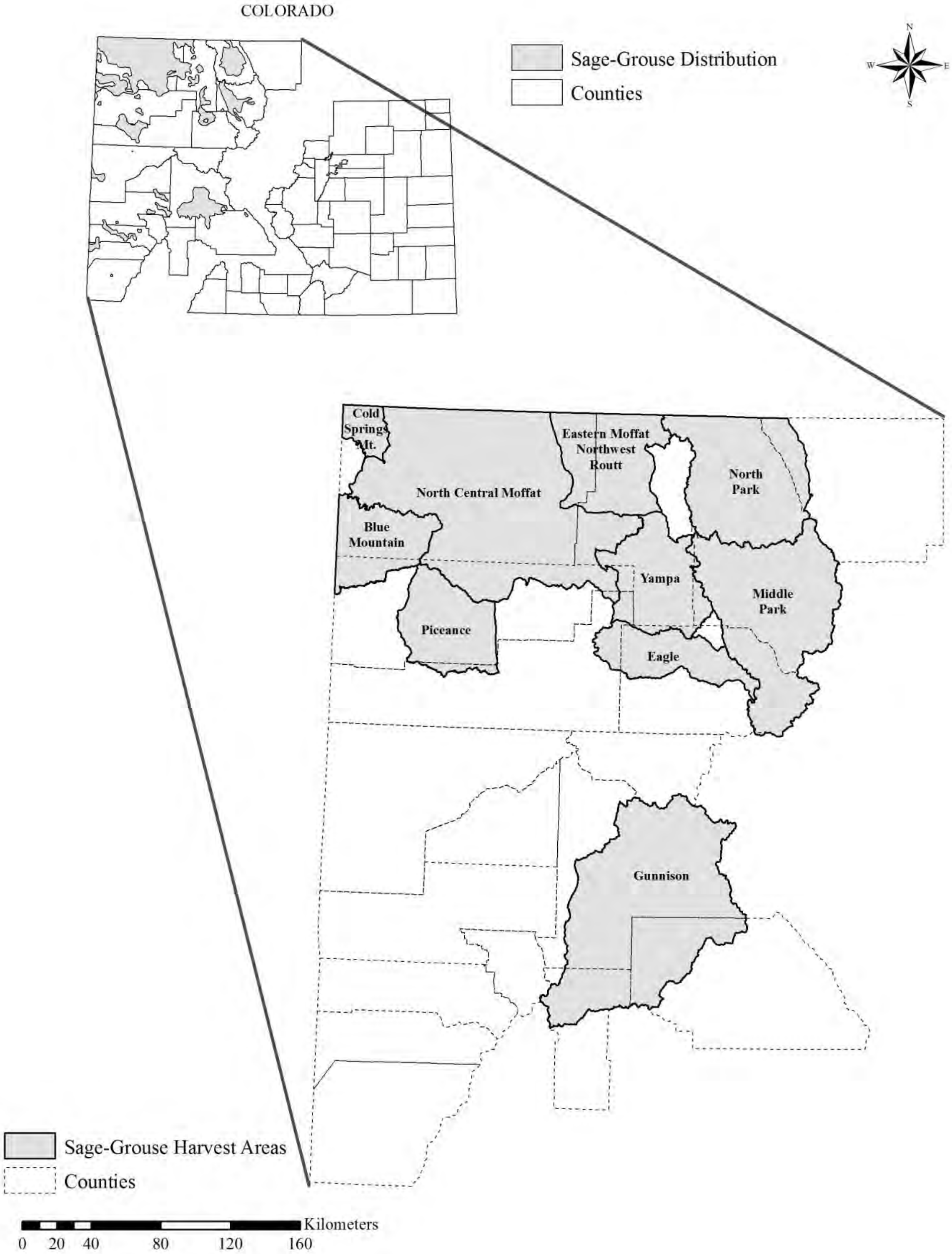

Figure 1. Sage-grouse harvest areas, county boundaries, and current distribution of sage-grouse in Colorado.

of Moffat County Road 16 north to the Yampa River. This was formerly part of Small Game Management Unit 7 (1968–1973) and parts of Units 18 and 20 (1974–1986). Blue Mountain is a higher elevation (~ 2785 m) area with rolling topography and intermittent springs and wet meadows. Greater sage-grouse breeding activity is later than in low elevations to the east and south.

Cold Springs Mountain - This area is in Game Management Unit 201 (1987 to present). It was formerly in Small Game Management Unit 18 (1974–1986) and in Unit 7 from 1968 to 1973. It is in the northwest corner of Moffat County bordered by Utah on the west, Wyoming on the north, Moffat County Road 10 on the east, and Colorado Highway 318 on the south. Cold Springs Mountain is a higher elevation (up to 2785 m) area with rolling topography and an abundance of intermittent springs and wet meadows. Greater sage-grouse breeding activity is later than in low elevations to the east and south. There is no agriculture including production of hay, except on one ranch, in the Unit.

Eastern Moffat County and Northwestern Routt County - This area includes Game Management Units 4, 5, 214, and 441 (1987 to present) and formerly Small Game Management Unit 5 (1968–1973) and Unit 14 (1974–1986) and is primarily east of Colorado Highway 13, north of U.S. Highway 40, and east and northeast of Craig. The topography of this area varies from rolling wheat fields at an elevation slightly over 1525 m along the west side near Craig to elevations of about 2875 m south of the Little Snake River which flows to the west and the Elkhead River that flows south to the Yampa River. Higher precipitation occurs to the northeast. Greater sage-grouse breeding is later at the higher elevations. Most suitable areas at low elevations have been developed for hay or wheat production, particularly along the Little Snake River. Overall, agricultural development is minimal.

Northcentral Moffat County - This large area includes Game Management Units 2, 3, 11, 12, 13, 211, and 301 and is west, northwest, southwest, and southeast of Craig. It formerly included all or parts of Small Game Management Units 6, 7, 8, 9, and 10 (1968–1973) and 16, 18, 20, and 26 (1974–1986). The Northcentral Moffat County area is diverse with extensive areas of small grain production as well as coal mining and oil and gas development. Most of the area supporting greater sage-grouse is at an elevation of 1525 to 1830 m and has a longer growing season. The remaining sagebrush habitats are highly fragmented and used by domestic livestock including both sheep and cattle. Hay production occurs along the Yampa River and other streams.

Gunnison Basin - This was the area supporting most Gunnison sage-grouse. It lies primarily in Gunnison and Saguache counties and marginally south into Hinsdale County west of the Continental Divide within Game Management Units 54, 55, 66, 67, and 551.This area was formerly Small Game Management Unit 20 (1968–1973) and then 66 (1974–1986). The Gunnison area is a large open basin dissected by streams that flow from the north, south, and east to form the west-flowing Gunnison River. The topography is irregular and slopes uphill to the north, east, and south. It lies at an elevation ranging from 2315 to 2745 m with cold winters and a short growing season. Agriculture, other than production of mostly native hay, is not common.

Oregon

Hunting of greater sage-grouse in Oregon is permitted in 12 of 21 state-defined wildlife management units in which sage-grouse are known to occur (Fig. 2). Habitat within each of the units is highly variable ranging from high elevation conifer forests to low elevation arid landscapes dominated by Wyoming big sagebrush (*A. tridentata wyomingensis*). The distribution of sage-grouse in Oregon is within range-wide sage-grouse management zones IV and V (Stiver et al. 2006). Oregon shares sage-grouse populations with California, Idaho, and Nevada. Sage-grouse in Oregon occur in the following four Environmental Protection Agency Level III ecoregions: Blue Mountains, Snake River Plain, Central Basin and Range, and Eastern Cascade Slopes and Foothills. Cattle ranching is the primary agricultural activity in all of the hunted management units.

Sumpter (Management Unit 51) - The Sumpter Wildlife Management Unit (51) occurs mostly within Baker and a small part of northern Malheur counties. The western portion is forested and within the Wallowa-Whitman National Forest of the Blue Mountains of Oregon. Much of this unit is drained by the Burnt River, a tributary of the Snake River. Most of the sage-grouse habitat is below 1000 m in elevation. Most (55%) of the land is in private ownership.

Lookout Mountain (Management Unit 64) - The Lookout Mountain Wildlife Management Unit (64) occurs entirely within Baker County. It is bordered on east by the Snake River and on the west by Interstate 84. Most of the unit is low to mid elevation sagebrush habitat with the highest point being Lookout Mountain at 3,048 m. Ranching was the primary agricultural activity, but hay production in lower elevation areas is also significant. This unit contains the smallest portion of public land (38%) of any Oregon unit open to sage-grouse hunting.

Beulah (Management Unit 65) - Most of the Beulah Wildlife Management Unit (65) is in the north part of Malheur County, but also includes the extreme northeast part of Harney, southwest extreme of Baker, and eastern part of Grant counties. The Baker and Grant county portions are primarily conifer forests and non-habitat for sage-grouse. This is a large unit with the Snake River forming the eastern border and the Malheur River forming the southern border. The eastern portion is characterized by higher human density and intensive row crop agriculture, but the principal agricultural activity throughout the unit is cattle ranching. The unit contains large contiguous expanses of sagebrush-steppe bisected by riparian areas and associated meadows which are often used for hay production. Most of the sage-grouse habitat is below 1000 m in elevation, but some buttes approach 2000 m. The Beulah unit consists of 57% public lands.

Malheur River (Management Unit 66) - The Malheur River Wildlife Management Unit (66) includes most of northeast Harney County, but also portions of Grant and Malheur counties. The Grant County portion is primarily conifer forest in the Malheur National Forest with little habitat for sage-grouse. The Malheur River, a tributary of the Snake River, drains most of the unit. The western portion includes the Malheur Basin with large portions dedicated to pivot irrigation and hay production. In modern history, western juniper (*Juniperus occidentalis*) has expanded into much of the large contiguous expanses of sagebrush-steppe, particularly at higher elevations. The unit is about 69% public lands.

Figure 2. Sage-grouse management units, county boundaries, and current distribution of greater sage-grouse in Oregon.

Owyhee (Management Unit 67) - The Owyhee Wildlife Management Unit (67) is entirely within Malheur County. The Owyhee River, a tributary of the Snake River, bisects the unit from south to north and Idaho forms the eastern border. Historically, this unit contained large expanses of sagebrush-steppe, but large areas were converted to crested wheatgrass (*Agropyron cristatum*) seedings in the 1960s as part of Bureau of Land Management's Vale Project. Sagebrush-steppe has also been lost from frequent lightning-caused wildfires. The relatively low elevation of this unit makes it highly vulnerable to invasive annual grasses. Juniper and conifers only exist on some of the highest points such as Mahogany Mountain (~1988 m). The BLM is the principal land manager with 82% of the area in the public domain.

Whitehorse (Management Unit 68) - The Whitehorse Wildlife Management Unit (68) encompasses the extreme southeast portion of Oregon and includes southern Malheur and southeast Harney counties. This is a large diverse unit and the Owyhee River and associated tributaries drain the northeast portion. The Trout Creek Mountains in the southwest part of the unit are generally below 2000 m and consist of large expanses of low (*A. arbuscula*) and mountain big (*A. t. vaseyana*) sagebrush with stands of aspen (*Populus tremuloides*). The Trout Creek Mountains have consistently had some of the highest densities of sage-grouse in Oregon. The north part of the unit experiences frequent lightning-caused wildfires, but the entire unit is susceptible. Fires of unprecedented scale in modern history impacted approximately 323,760 ha of this unit in 2012, including the Trout Creek Mountains. The unit is largely under the management of the BLM as 90% is public lands.

Steens Mountain (Management Unit 69) - The Steens Mountain Wildlife Management Unit (69) is in Harney County. The north part of the unit includes low elevations dominated by wet meadows and marsh and includes Malheur National Wildlife Refuge (NWR). The southern part of the unit is dominated by Steens Mountain. Steens Mountain is approximately 80 km in length and is a large fault-block mountain. The east side of the mountain drops precipitously by more than a 1000 m, but gradually slopes to the west. The western slopes are bisected by several large glacially-formed valleys. Encroachment by western juniper is an issue at lower elevations, but at higher elevations the juniper transitions to stands of aspen interspersed with meadows and mountain big sagebrush. Areas of low sage dominate some of the higher elevations or ridges with shallow soils. About 64% of the unit is in public ownership.

Beatys Butte (Management Unit 70) - The Beatys Butte Wildlife Management Unit (70) is in the southwest portion of Harney and southeast portion of Lake counties. Most of Hart Mountain National Antelope Refuge (NAR) occupies the northwest part of the unit. This area contains large contiguous expanses of low and big sagebrush with large areas of gentle topography. The western portion of the unit includes the Warner Wetlands and has some areas of western juniper encroachment. The Pueblo Mountains (~2659 m) are on the eastern border, while Hart Mountain (2347 m) is to the northwest and Beatys Butte (~2400 m) is near the middle of the unit. The Beatys Butte unit is 82% public lands.

Juniper (Management Unit 71) - The Juniper Wildlife Management Unit (71) lies mostly within Harney County but includes a portion of eastern Lake County. The southwest portion of the unit includes the Warner Basin and a portion of Hart Mountain NAR while the northeast part of the unit contains Harney Lake on Malheur NWR. Large contiguous expanses of intact sagebrush-steppe with numerous playas dominate this arid unit. Lightning-caused wildfires are periodic and sometimes exceed 40,470 ha. There is little cultivated agriculture with most of the land use influenced by cattle ranching. The Juniper Unit is 89% public lands.

Silvies (Management Unit 72) - The Silvies Wildlife Management Unit (72) is primarily in Harney County but also includes portions of Lake, Deschutes, Crook, and Grant counties. Much of the unit is conifer forest in the Ochoco National Forest. The south and west portions are sagebrush-dominated landscapes, but western juniper distribution has expanded rapidly in this region. Cultivated agriculture occupies a small part of the unit. About 67% of the unit is in public ownership.

Wagontire (Management Unit 73) - The Wagontire Wildlife Management Unit (73) is primarily in Lake County but also includes portions of Harney and eastern Deschutes counties. This arid unit is dominated by large expanses of lower elevation Wyoming big sagebrush with numerous playas and two large closed basins (Summer Lake and Abert) in the south. Post-settlement encroachment of western juniper is compromising sage-grouse habitat quality in the western and northern areas of this unit. Cultivated agriculture is limited to a few irrigated pivots used for hay production. The unit is 85% public lands with the BLM being the principal land management agency.

Warner (Management Unit 74) - The Warner Wildlife Management Unit (74) is entirely within Lake County and is comparatively small. The western portion is bordered by U.S. Highway 395 at the base of Abert Rim and the Warner Mountains to the south. The Warner Mountains are dominated by conifer forest and are part of the Fremont National Forest. The western portion is higher in elevation (1800–2500 m) and receives more precipitation than the eastern area of the unit. The higher elevations with numerous wet meadows are attractive summer and late brood-rearing habitat. Western juniper encroachment is a serious threat to the sagebrush-steppe habitat and thousands of hectares of juniper have been cut in this unit in recent years. The unit is 70% public lands with the U.S. Forest Service and BLM the largest land managers.

HUNTING SEASON REGULATIONS

In general, the length of sage-grouse hunting seasons in Colorado was progressively lengthened from 3 days in 1974 to 16–34 days in the 1983–1994 period, depending upon the area (Table 1). Between 1994 and 1998 the seasons were generally reduced to 7–16 days in most areas, and in some cases closed (Eagle, Yampa, Piceance Basin, and Eastern Moffat and Northwestern Routt management units). Daily bag and possession limits were much more consistent throughout 1974–1998, varying from a bag limit of 1 to 3 and a possession limit of 2 to 9 (Table 2). The largest bag and possession limits (3 and 9 respectively) were in place in 1992–1994.

The sage-grouse season length in Oregon varied from 2 (1993–1994), to 5 (1995–2004), and to 9 days (2005–2013). The daily bag and season limits were 2 and 2, respectively. Permits specific to a particular Management Unit were required in all years and allocated based on the estimated fall population for each unit. Hunting was closed or permit numbers were reduced in several Management Units in some years because of West Nile virus or large wildfires.

RESULTS

Sex and age were ascertained for 48,599 greater sage-grouse and 7,547 Gunnison sage-grouse wings in Colorado and 11,533 greater sage-grouse wings in Oregon. Sex and age ratios in the harvest were calculated for each year and area for greater sage-grouse in Colorado (Appendix A1–A9), for greater sage-grouse in all Colorado hunting areas combined (Table 3), for Gunnison sage-grouse in Colorado (Table 4), for greater sage-grouse for each year and management area in Oregon (Appendix A10–A21), and for greater sage-grouse in management areas in Oregon combined (Table 5). The male:female sex ratio among juveniles varied from 41:59 to 52:48 for the 22 areas examined (Table 6). The harvest age structure for greater sage-grouse varied by year from 42 to 63% juveniles (Table 3) in Colorado (mean = 53.9%) and 27 to 58% (Table 5) in Oregon (mean = 48.0%); the Gunnison sage-grouse harvest that was juvenile ranged from 43 to 69% (Table 4) (mean = 59.5%).

The sex ratio changed with age as the male:female sex ratio for adult greater sage-grouse varied from 22:78 in Colorado to 41:59 (including an unknown proportion of yearlings) in Oregon (not counting the 2 areas with sample sizes < 100, Table 6), and 34:66 for Gunnison sage-grouse in Colorado (Table 6). The annual proportion of juveniles in the harvest for greater sage-grouse in Colorado (1974–1998) and Oregon (1993-2013) appeared to decline less than the proportion of juvenile Gunnison sage-grouse in Colorado (1977–1998) (Fig. 3).

Productivity was estimated for each year and area for greater sage-grouse in Colorado (Appendix B1–B9), for greater sage-grouse in all Colorado areas combined (Table 7), for Gunnison sage-grouse in Colorado (Table 8), for greater sage-grouse in Oregon (Appendix B10–B21), and for greater sage-grouse in all Oregon areas combined (Table 9). Estimated breeding success was similar for greater sage-grouse in Colorado (46.9%) and Oregon (48.8%), but was higher (60.0%) for Gunnison sage-grouse (Table 6). There was variability, 35.9–63.2%, in rates of breeding success among units (Table 6, not counting the 2 samples < 100). The average number of juveniles in the harvest per breeding-age female varied from 1.2 to 2.4 and the average number of juveniles per successful female varied from 2.2 to 4.8 (Table 6, excluding the samples <100). Generally, percent breeding success tracked the percent juveniles in the harvest (Table 6). Also notable was that breeding success of yearling females of both species in Colorado (Tables 8 and 9) was lower than for adult females. This comparison had no validity in Oregon (Table 9) as most unsuccessful females (both age classes) had completed replacement of primary flight feathers because of earlier timing of breeding.

Annual turnover of the sage-grouse populations in Colorado was based on the percent of yearlings in the fall harvest. This assumes the population was stable over time. Thus, the proportion of yearlings in the harvest should equal the proportion of adults that died. The survival estimate for greater sage-grouse in Colorado was 48.1% for males and 59.0% for females (Table 6). The survival estimate for Gunnison sage-grouse was 46.3% for males and 56.1% for females. A similar procedure was used for greater sage-grouse in Oregon, except that percent of juveniles was used because it was assumed many yearlings had completed their wing molt by time of harvest. The survival estimate in Oregon was 46.7% for males and 55.8% for females (Table 6). Gunnison sage-grouse generally were more productive (higher percent of juveniles in the harvest, higher estimated breeding success, more juveniles per hen) but had lower survival than greater sage-grouse.

Table 1. Sage-grouse hunting season length by year and area in Colorado, 1974–1998. Only years for which harvest data are available are shown.

Year	North Park	Middle Park	Eagle	Yampa	Piceance Basin	Blue Mountain	Cold Spring Mountain	E Moffat and NW Routt	N-central Moffat	Gunnison Basin
1974	3									
1975	9	3								
1976	9	3				3	3	3	3	
1977	16	7	7	7	7	7	7	7	7	3
1978	16	9	9	9[a]	9	9	9	9[a]	9	7
1979	16	9	9	9	9	16	16	9	16	9
1980	16	16	16	9	16	25	25	25	25	16
1981	23	16	16	16	16	16	16	16	16	16
1982	30	16	16	16	16	16	7	16	16	16
1983	30	16	16	16	16	16	16	16	16	16
1984	30	16	16	16	16	16	16	16	16	16
1985	23	16	16	16	16	16	16	16	16	16
1986	23	23	23	23	23	23	23	23	23	16
1987	23	23	23	23	23	23	23	23	23	16
1988	23	23	23	23	23	23	23	23	23	16
1989	30	30	30	30	30	30	30	30	30	30
1990	30	30	30	30	30	30	30	30	30	30
1991	30	30	30	30	30	30	30	30	30	30
1992	34	34	34	34	34	34	34	34	34	34
1993	33	33	33	33	33	33	33	33	33	33
1994	32	32	32	32	32	32	32	32	32	16
1995	17	17	Closed	17[b]	Closed	17	17	17	17	17
1996	22	22	Closed	22	Closed	22	22	22	22	16
1997	16	16	Closed	16	Closed	16	16	16	16	16
1998	16	16	Closed	Closed	Closed	7	7	Closed	7	16

[a] Season was only 7 days in Yampa area east of Colorado Highway 131 and in the Elk River drainage, and east of Colorado Highway 131 in the Eastern Moffat and Northwestern Routt area.
[b] Unit 26 was closed in the Yampa area in 1995.

Table 2. Sage-grouse hunting season bag and possession limits (in parentheses) by year and area in Colorado, 1974–1998. Only years for which harvest data are available are shown.

Year	North Park	Middle Park	Eagle	Yampa	Piceance Basin	Blue Mountain	Cold Spring Mountain	E Moffat and NW Routt	N-central Moffat	Gunnison Basin
1974	2 (4)									
1975	2 (4)	2 (2)								
1976	3 (6)	2 (4)				2 (4)	2 (4)	2 (4)	2 (4)	
1977	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	2 (2)
1978	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)
1979	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)
1980	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)
1981	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)
1982	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)
1983	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)
1984	3 (6)	2 (4)	2 (4)	2 (4)	2 (4)	2 (4)	1 (2)	2 (4)	2 (4)	2 (4)
1985	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)
1986	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	1 (2)	3 (6)	3 (6)	3 (6)
1987	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	1 (2)	3 (6)	3 (6)	3 (6)
1988	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	1 (2)	3 (6)	3 (6)	3 (6)
1989	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)
1990	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)
1991	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)	3 (6)
1992	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)
1993	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)
1994	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	3 (9)	1 (2)
1995	2 (4)	1 (2)	Closed	1 (2)	Closed	2 (4)	1 (2)	1 (2)	1 (2)	2 (4)
1996	2 (4)	1 (2)	Closed	1 (2)	Closed	2 (4)	1 (2)	1 (2)	1 (2)	2 (4)
1997	2 (4)	1 (2)	Closed	1 (2)	Closed	2 (4)	1 (2)	1 (2)	1 (2)	2 (4)
1998	2 (4)	2 (4)	Closed	Closed	Closed	2 (4)	2 (4)	Closed	2 (4)	2 (4)

Table 3. Age and gender composition of the greater sage-grouse harvest in Colorado, 1974–1998.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1974	171	179	350	48.9:51.1	50.1	49	89	138	35.5:64.5	19.8	45	165	210	21.4:78.6	30.1
1975	124	142	266	46.6:53.4	45.4	56	67	123	45.5:54.5	21.0	56	141	197	28.4:71.6	33.6
1976	341	415	756	45.1:54.9	55.9	96	159	255	37.6:62.4	18.8	76	266	342	22.2:77.8	25.3
1977	343	431	774	44.3:55.7	46.9	144	216	360	40.0:60.0	21.8	148	367	515	28.7:71.3	31.2
1978	1008	1060	2068	48.7:51.3	63.5	154	265	419	36.8:63.2	12.9	224	546	770	29.1:70.9	23.6
1979	1113	1247	2360	47.2:52.8	54.9	523	662	1185	44.1:55.9	27.6	242	511	753	32.1:67.9	17.5
1980	871	1070	1941	44.9:55.1	53.6	265	444	709	37.4:62.6	19.6	351	618	969	36.2:63.8	26.8
1981	709	883	1592	44.5:55.5	50.3	222	441	663	33.5:66.5	20.9	248	664	912	27.2:72.8	28.8
1982	569	647	1216	46.8:53.2	58.0	128	222	350	36.6:63.4	16.7	140	391	531	26.4:73.6	25.3
1983	874	983	1857	47.1:52.9	57.6	254	399	653	38.9:61.1	20.2	168	547	715	23.5:76.5	22.2
1984	542	608	1150	47.1:52.9	56.9	155	280	435	35.6:64.4	21.5	106	331	437	24.3:75.7	21.6
1985	633	737	1370	46.2:53.8	60.0	146	293	439	33.3:66.7	19.2	123	353	476	25.8:74.2	20.8
1986	720	828	1548	46.5:53.5	60.0	185	352	537	34.5:65.5	20.8	132	362	494	26.7:73.3	19.2
1987	793	929	1722	46.1:53.9	57.8	222	414	636	34.9:65.1	21.4	158	461	619	25.5:74.5	20.8
1988	510	628	1138	44.8:55.2	49.4	220	346	566	38.9:61.1	24.6	182	417	599	30.4:69.6	26.0
1989	678	801	1479	45.8:54.2	50.8	265	342	607	43.7:56.3	20.9	293	531	824	35.6:64.4	28.3
1990	588	711	1299	45.3:54.7	46.0	224	416	640	35.0:65.0	22.7	270	614	884	30.5:69.5	31.3
1991	365	505	870	42.0:58.0	46.3	124	227	351	35.3:64.7	18.7	174	484	658	26.4:73.6	35.0
1992	236	331	567	41.6:58.4	42.3	130	176	306	42.5:57.5	22.8	101	368	469	21.5:78.5	34.9
1993	273	308	581	47.0:53.0	53.1	43	99	142	30.3:69.7	13.0	87	285	372	23.4:76.6	34.0
1994	207	267	474	43.7:56.3	53.0	63	95	158	39.9:60.1	17.7	52	210	262	19.8:80.2	29.3
1995	90	89	179	50.3:49.7	59.7	12	40	52	23.1:76.9	17.3	18	51	69	26.1:73.9	23.0
1996	127	166	293	43.3:56.7	56.8	29	60	89	32.6:67.4	17.2	34	100	134	25.4:74.6	26.0
1997	99	90	189	52.4:47.6	52.6	29	46	75	38.7:61.3	20.9	28	67	95	29.5:70.5	26.5
1998	77	90	167	46.1:53.9	45.6	24	64	88	27.3:72.7	24.0	27	84	111	24.3:75.7	30.3
Average	482	566	1048	46.0:54.0	53.9	150	249	399	37.6:62.4	20.5	139	357	497	28.0:72.0	25.6

Table 4. Age and gender composition of the Gunnison sage-grouse harvest, Gunnison Basin, Colorado, 1977–1998.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1977	67	75	142	47.2:52.8	60.4	18	35	53	34.0:66.0	22.6	15	25	40	37.5:62.5	17.0
1978	151	168	319	47.3:52.7	61.7	16	38	54	29.6:70.4	10.4	56	88	144	38.9:61.1	27.9
1979	216	219	435	49.7:50.3	62.9	63	66	129	48.8:51.2	18.6	41	87	128	32.0:68.0	18.5
1980	127	144	271	46.9:53.1	64.5	41	43	84	48.8:51.2	20.0	25	40	65	38.5:61.5	15.5
1981	56	33	89	62.9:37.1	42.6	43	34	77	55.8:44.2	36.8	19	24	43	44.2:55.8	20.6
1982	94	79	173	54.3:45.7	64.6	14	13	27	51.9:48.1	10.1	22	46	68	32.4:67.6	25.4
1983	205	231	436	47.0:53.0	64.5	55	81	136	40.4:59.6	20.1	33	71	104	31.7:68.3	15.4
1984	130	197	327	39.8:60.2	66.3	32	46	78	41.0:59.0	15.8	32	56	88	36.4:63.6	17.8
1985	137	107	244	56.1:43.9	62.9	24	45	69	34.8:65.2	17.8	38	37	75	50.7:49.3	19.3
1986	165	139	304	54.3:45.7	54.8	74	60	134	55.2:44.8	24.1	33	84	117	28.2:71.8	21.1
1987	159	184	343	46.4:53.6	69.0	28	47	75	37.3:62.7	15.1	33	46	79	41.8:58.2	15.9
1988	99	119	218	45.4:54.6	60.1	36	35	71	50.7:49.3	19.6	25	49	74	33.8:66.2	20.4
1989	126	133	259	48.6:51.4	50.0	57	70	127	44.9:55.1	24.5	37	95	132	28.0:72.0	25.5
1990	69	98	167	41.3:58.7	45.6	41	65	106	38.7:61.3	29.0	21	72	93	22.6:77.4	25.4
1991	75	107	182	41.2:58.8	58.9	14	25	39	35.9:64.1	12.6	29	59	88	33.0:67.0	28.5
1992	68	67	135	50.4:49.6	50.6	29	31	60	48.3:51.7	22.5	27	45	72	37.5:62.5	27.0
1993	63	80	143	44.1:55.9	69.4	8	15	23	34.8:65.2	11.2	13	27	40	32.5:67.5	19.4
1994	12	13	25	48.0:52.0	65.8	5	2	7	71.4:28.6	18.4	3	3	6	50.0:50.0	15.8
1995	40	40	80	50.0:50.0	54.4	16	16	32	50.0:50.0	21.8	9	26	35	25.7:74.3	23.8
1996	32	42	74	43.2:56.8	51.0	11	24	35	31.4:68.6	24.1	15	21	36	41.7:58.3	24.8
1997	33	38	71	46.5:53.5	53.8	9	17	26	34.6:65.4	19.7	12	23	35	34.3:65.7	26.5
1998	24	26	50	48.0:52.0	47.2	2	16	18	11.1:88.9	17.0	11	27	38	28.9:71.1	35.8
Average	98	106	204	48.0:52.0	59.5	29	37	66	43.9:56.1	19.2	25	48	73	34.2:65.8	21.3

Table 5. Age and gender composition of the greater sage-grouse harvest in Oregon, 1993–2013.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	103	99	202	51.0:49.0	47.4	5	14	19	26.3:73.7	4.5	80	125	205	39.0:61.0	48.1
1994	145	168	313	46.3:53.7	42.7	6	45	51	11.8:88.2	7.0	116	253	369	31.4:68.6	50.3
1995	68	93	161	42.2:57.8	35.5	1	20	21	4.8:95.2	4.6	86	185	271	31.7:68.3	59.8
1996	105	148	253	41.5:58.5	51.3	1	23	24	4.2:95.8	4.9	68	148	216	31.5:68.5	43.8
1997	147	169	316	46.5:53.5	53.9	7	37	44	15.9:84.1	7.5	88	138	226	38.9:61.1	38.6
1998	110	119	229	48.0:52.0	49.1	1	17	18	5.6:94.4	3.9	86	133	219	39.3:60.7	47.0
1999	173	201	374	46.3:53.7	55.7	5	31	36	13.9:86.1	5.4	108	153	261	41.4:58.6	38.9
2000	120	139	259	46.3:53.7	44.3	11	38	49	22.4:77.6	8.4	131	145	276	47.5:52.5	47.3
2001	181	179	360	50.3:49.7	54.0	5	45	50	10.0:90.0	7.5	113	144	257	44.0:56.0	38.5
2002	192	181	373	51.5:48.5	57.6	4	39	43	9.3:90.7	6.6	106	126	232	45.7:54.3	35.8
2003	145	171	316	45.9:54.1	48.3	4	30	34	11.8:88.2	5.2	142	162	304	46.7:53.3	46.5
2004	178	222	400	44.5:55.5	51.5	4	43	47	8.5:91.5	6.1	130	199	329	39.5:60.5	42.4
2005	171	201	372	46.0:54.0	44.9	2	38	40	5.0:95.0	4.8	189	227	416	45.4:54.6	50.2
2006	147	169	316	46.5:53.5	47.4	9	20	29	31.0:69.0	4.3	157	165	322	48.8:51.2	48.3
2007	58	74	132	43.9:56.1	27.4	3	28	31	9.7:90.3	6.4	121	198	319	37.9:62.1	66.2
2008	117	124	241	48.5:51.5	54.4	0	17	17	0.0:100.0	3.8	56	129	185	30.3:69.7	41.8
2009	131	148	279	47.0:53.0	56.7	0	24	24	0.0:100.0	4.9	92	97	189	48.7:51.3	38.4
2010	96	125	221	43.4:56.6	47.7	1	22	23	4.3:95.7	5.0	79	140	219	36.1:63.9	47.3
2011	78	102	180	43.3:56.7	42.7	2	20	22	9.1:90.9	5.2	105	115	220	47.7:52.3	52.1
2012	39	56	95	41.1:58.9	29.2	14	33	47	29.8:70.2	14.5	89	94	183	48.6:51.4	56.3
2013	74	73	147	50.3:49.7	57.9	2	16	18	11.1:88.9	7.1	32	57	89	36.0:64.0	35.0
Average	123	141	264	46.5:53.5	48.0	4	29	33	12.7:87.3	6.0	104	149	253	41.0:59.0	46.0

Table 6. Summary of sample size, sex ratio, breeding success, and survival for greater and Gunnison sage-grouse in Colorado and Oregon.

Species and area	Wings (*n*)	Male:female sex ratio			Survival (%)[a]		Female success (%)	Juveniles		
		Juveniles	Yearlings	Adults	Male	Female		In harvest (%)	Per female	Per successful female
Greater sage-grouse in Colorado	48599	46:54	38:62	28:72	48.1	59.0	46.9	53.9	1.7	3.7
North Park	13424	47:53	35:65	25:75	46.9	58.4	49.1	50.7	1.5	3.0
Middle Park	1903	50:50	39:61	26:74	41.4	57.7	55.9	52.6	1.6	2.9
Eagle	694	50:50	40:60	33:67	46.5	58.2	63.2	59.3	2.3	3.6
Yampa	920	50:50	46:54	36:64	42.1	54.4	47.9	43.2	1.2	2.6
Piceance Basin	817	47:53	43:57	30:70	41.3	54.8	57.1	57.6	2.1	3.7
Blue Mountain	5408	47:53	41:59	29:71	40.4	53.2	45.0	58.3	2.2	4.8
Cold Spring Mountain	2520	45:55	35:65	21:79	47.1	63.0	53.9	59.4	1.8	3.4
E Moffat and NW Routt counties	3539	48:52	33:67	25:75	42.6	53.5	39.6	53.5	1.6	4.1
Northcentral Moffat County	19374	44:56	39:61	31:69	53.3	62.1	44.2	54.6	1.8	4.1
Gunnison sage-grouse in Colorado	7547	48:52	44:56	34:66	46.3	56.1	60.0	59.5	2.4	4.0
Greater sage-grouse in Oregon	11533	47:53	12:88	41:59	46.7	55.8	48.8	48.0	1.5	3.0
Sumpter, Hunt Unit 51	47	41:59	0:100	43:57	63.2	64.3	33.3	36.2	0.9	2.8
Lookout Mountain, Hunt Unit 64	92	51:49	0:100	60:40	64.0	59.5	20.0	38.0	1.4	7.0
Beulah, Hunt Unit 65	990	52:48	4:96	36:64	40.0	58.4	39.6	49.4	1.5	3.7
Malheur River, Hunt Unit 66	780	45:55	16:84	41:59	45.8	53.8	43.1	49.5	1.6	3.6
Owyhee, Hunt Unit 67	693	51:49	7:93	40:60	50.7	63.1	35.9	42.3	1.2	3.3
Whitehorse, Hunt Unit 68	2721	47:53	7:93	41:59	43.3	53.2	48.5	51.0	1.7	3.4
Steens Mountain, Hunt Unit 69	1193	47:53	17:83	52:48	61.4	59.4	50.5	39.6	1.3	2.5
Beatys Butte, Hunt Unit 70	1999	46:54	19:81	43:57	48.5	54.7	54.8	48.0	1.5	2.8
Juniper, Hunt Unit 71	868	44:56	9:91	36:64	49.7	59.7	54.2	44.1	1.2	2.2
Silvies, Hunt Unit 72	202	43:57	10:90	26:74	35.3	56.0	49.3	51.0	1.4	2.8
Wagontire, Hunt Unit 73	546	46:54	19:81	31:69	40.8	58.2	53.0	48.4	1.3	2.5
Warner, Hunt Unit 74	1402	44:56	6:94	37:63	38.9	51.3	53.3	53.5	1.7	3.2

[a] Survival for greater sage-grouse in Oregon was estimated using annual turnover of juveniles and survival for sage-grouse in Colorado was estimated using annual turnover of yearlings.

Table 7. Greater sage-grouse productivity data, Colorado, 1974–1998.

Year	**Estimated annual reproductive success**						**Juveniles**		
	Adult		**Yearling**		**All females**		**In harvest (%)**	**Per hen**	**Per successful hen**
	%	***n***	**%**	***n***	**%**	***n***			
1974	64.8	165	46.1	89	58.3	254	50.1	1.4	2.4
1975	56.0	141	38.8	67	50.5	208	45.4	1.3	2.5
1976	54.9	266	34.0	159	47.1	425	55.9	1.8	3.8
1977	51.5	367	25.9	216	42.0	583	46.9	1.3	3.2
1978	65.2	546	46.4	265	59.1	811	63.5	2.5	4.3
1979	62.6	511	47.7	662	54.2	1173	54.9	2.0	3.7
1980	50.3	618	34.0	444	43.5	1062	53.6	1.8	4.2
1981	41.4	665	28.2	440	36.1	1105	50.3	1.4	4.0
1982	53.5	391	31.5	222	45.5	613	58.0	2.0	4.4
1983	62.7	547	45.3	408	55.3	955	57.6	2.0	3.5
1984	67.2	326	50.5	285	59.4	611	56.9	1.9	3.2
1985	62.0	353	41.3	293	52.6	646	60.0	2.1	4.0
1986	57.5	362	40.9	352	49.3	714	60.0	2.2	4.4
1987	50.9	462	36.1	413	43.9	875	57.8	2.0	4.5
1988	50.2	416	30.3	347	41.2	763	49.4	1.5	3.6
1989	48.0	531	29.2	342	40.7	873	50.8	1.7	4.2
1990	44.8	614	19.2	416	34.5	1030	46.0	1.3	3.7
1991	49.8	484	32.2	227	44.2	711	46.3	1.2	2.8
1992	40.5	368	23.3	176	34.9	544	42.3	1.0	3.0
1993	66.7	285	43.4	99	60.7	384	53.1	1.5	2.5
1994	61.0	210	38.9	95	54.1	305	53.0	1.6	2.9
1995	66.7	51	57.5	40	62.6	91	59.7	2.0	3.1
1996	64.0	100	36.7	60	53.8	160	56.8	1.8	3.4
1997	56.7	67	48.9	47	53.5	114	52.6	1.7	3.1
1998	50.6	85	23.4	64	38.9	149	45.6	1.1	2.9
Totals	54.2	8931	36.4	6228	46.9	15159	53.9	1.7	3.7

Table 8. Gunnison sage-grouse productivity data, Gunnison Basin, Colorado, 1977–1998.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1977	92.0	25	68.6	35	78.3	60	60.4	2.4	3.0
1978	76.1	88	60.5	38	71.4	126	61.7	2.5	3.5
1979	67.8	87	72.7	66	69.9	153	62.9	2.8	4.1
1980	67.5	40	69.8	43	68.7	83	64.5	3.3	4.8
1981	50.0	24	29.4	34	37.9	58	42.6	1.5	4.0
1982	65.2	46	46.2	13	61.0	59	64.6	2.9	4.8
1983	74.6	71	49.4	81	61.2	152	64.5	2.9	4.7
1984	69.6	56	69.6	46	69.6	102	66.3	3.2	4.6
1985	62.2	37	73.3	45	68.3	82	62.9	3.0	4.4
1986	66.7	84	51.7	60	60.4	144	54.8	2.1	3.5
1987	71.7	46	40.4	47	55.9	93	69.0	3.7	6.6
1988	77.6	49	62.9	35	71.4	84	60.1	2.6	3.6
1989	58.9	95	38.6	70	50.3	165	50.0	1.6	3.1
1990	48.6	72	15.4	65	32.8	137	45.6	1.2	3.7
1991	66.1	59	36.0	25	57.1	84	58.9	2.2	3.8
1992	55.6	45	25.8	31	43.4	76	50.6	1.8	4.1
1993	81.5	27	66.7	15	76.2	42	69.4	3.4	4.5
1994	100.0	3	0.0	2	60.0	5	65.8	5.0	8.3
1995	65.4	26	87.5	16	73.8	42	54.4	1.9	2.6
1996	61.9	21	45.8	24	53.3	45	51.0	1.6	3.1
1997	65.2	23	58.8	17	62.5	40	53.8	1.8	2.8
1998	66.7	27	31.3	16	53.5	43	47.2	1.2	2.2
Totals	66.9	1051	51.2	824	60.0	1875	59.5	2.4	4.0

Table 9. Greater sage-grouse productivity data, Oregon, 1993–2013. Successful yearling females were more likely to be detected because those that were unsuccessful had likely completed replacement of all primaries from the previous year.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1993	55.2	125	100.0	14	59.7	139	47.4	1.5	2.4
1994	40.3	253	37.8	45	39.9	298	42.7	1.1	2.6
1995	35.7	185	30.0	20	35.1	205	35.5	0.8	2.2
1996	51.4	148	47.8	23	50.9	171	51.3	1.5	2.9
1997	54.3	138	81.1	37	60.0	175	53.9	1.8	3.0
1998	45.1	133	100.0	17	51.3	150	49.1	1.5	3.0
1999	66.0	153	100.0	31	71.7	184	55.7	2.0	2.8
2000	42.1	145	55.3	38	44.8	183	44.3	1.4	3.2
2001	42.0	144	64.4	45	47.3	189	54.0	1.9	4.0
2002	57.1	126	100.0	39	67.3	165	57.6	2.3	3.4
2003	52.5	162	63.3	30	54.2	192	48.3	1.6	3.0
2004	42.7	199	100.0	43	52.9	242	51.5	1.7	3.1
2005	45.4	227	100.0	38	53.2	265	44.9	1.4	2.6
2006	49.1	165	55.0	20	49.7	185	47.4	1.7	3.4
2007	32.3	198	53.6	28	35.0	226	27.4	0.6	1.7
2008	47.3	129	76.5	17	50.7	146	54.4	1.7	3.3
2009	44.3	97	66.7	24	48.8	121	56.7	2.3	4.7
2010	35.0	140	50.0	22	37.0	162	47.7	1.4	3.7
2011	40.0	115	60.0	20	43.0	135	42.7	1.3	3.1
2012	31.9	94	15.2	33	27.6	127	29.2	0.7	2.7
2013	45.6	57	56.3	16	47.9	73	57.9	2.0	4.2
Totals	45.2	3133	67.8	600	48.8	3733	47.6	1.5	3.0

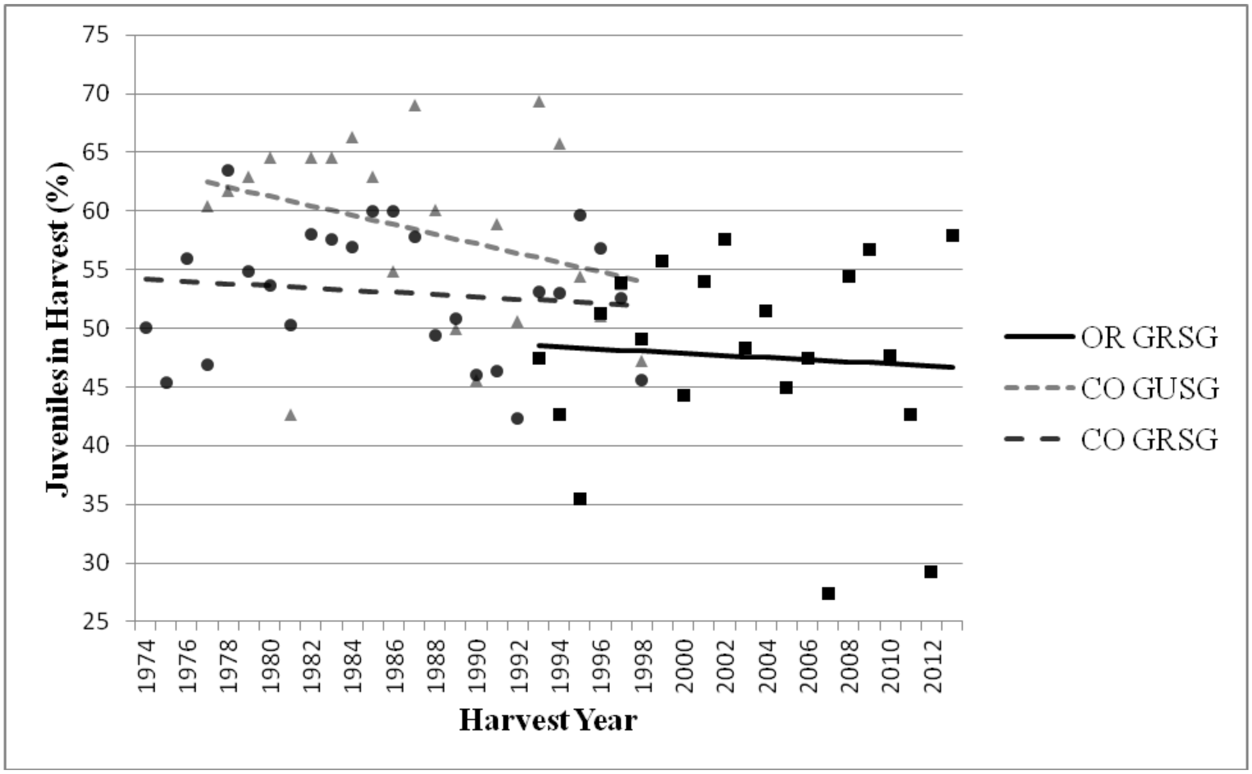

Figure 3. Trends (%) in juvenile sage-grouse as a proportion of harvest for Colorado (1974–1998) and Oregon (1993–2013) (OR GRSG = Oregon greater sage-grouse [squares], CO GUSG = Colorado Gunnison sage-grouse [triangles], CO GRSG = Colorado greater sage-grouse [circles]).

DISCUSSION

The structure of sage-grouse populations has been of interest for many years starting with the work of Patterson (1952). Wings from hunter-harvested sage-grouse were collected in Montana (Eng 1955) and Colorado starting in the 1950s (Rogers 1964) and later in other states (even though understanding the usefulness of wing analysis was rudimentary) (Dalke et al. 1963). Collection and classification of wings (Beck et al. 1975) were not standardized until the early 1970s in Colorado (Braun 1984) when sage-grouse wing collection was instituted in all areas open to sage-grouse hunting. This effort led other states (such as Idaho [Autenrieth 1981]) to follow standard procedures promoted by the Western States Sage Grouse Committee (Autenrieth et al. 1982; reviewed by Connelly and Schroeder 2007). This led to the first compilations of sage-grouse harvest data based on large samples (e.g., Braun 1984).

Several concerns arose from these data sets (Braun 1984) including the high percentage of females in the adult and yearling segments of the harvested sample and the apparent increase in females in the harvest from the juvenile (young of the year = 52%), to yearling (64%), to adult (72%) segments of the fall population. Sex ratios of juveniles in the harvest were approximately 1:1 (10-year average from 1974 to 1983 = 48:52, *n* = 4060 juveniles). This led Braun (1984:153) to indicate that survival favored females in all age classes. He also used progression of the molt of primary flight feathers to estimate nest success of adult and yearling females (page 154) and reported a difference between yearlings (10-year average = 51%) and adults (10-year average = 68%). Braun's (1984) assumption of even sex ratios at hatch is consistent with the findings of Atamian and Sedinger (2010) and Guttery et al. (2013). Recent research indicates differences in juvenile to adult ratios and juveniles per hen may be related to moisture as Blomberg et al. (2014a) documented that clutch size was larger in years with more moisture (generally at higher elevations). These authors suggest that resource availability affects clutch size. A companion paper (Blomberg et al. 2014b) found that postfledging survival of juveniles was higher during cooler and wetter growing seasons compared to hot and dry growing seasons. Thus, those sites in Colorado with adequate sample sizes such as in the higher elevation areas of the Gunnison Basin (59%), Blue Mountain (58%), and Cold Spring Mountain (60%) would be expected to have higher proportions of juveniles in the harvest than in the lower elevation area of northcentral Moffat County (55%). This did not hold for the high elevation area of North Park (51% juveniles in the harvest).

Knowledge of the structure of sage-grouse populations is thus important for understanding the dynamics of changes over time. Most previous projections dating to Patterson's (1952) work have focused on male attendance at leks (Emmons and Braun 1984), even though the proportion of males in the population that attend leks is poorly understood. Females congregate in sex-specific flocks in winter and Beck's (1977) work in North Park, Colorado indicated there were 2 hens per male in winter flocks. Our work has supported that finding using harvest data. All populations studied had about 62–70% adult and yearling females in the adult and yearling segment of the fall harvest. These findings are not surprising as the mating system of sage-grouse is one where a few males do most of the breeding (Wiley 1973, 1978). Thus, even sex ratios are neither necessary nor desirable. The shift from an expected sex ratio of 50:50 at hatch to a ratio favoring females starts at a young age, probably because of the need for large amounts of high protein foods to meet the growth demands of the larger juvenile males (Swenson 1986). This shift continues as adult males especially have low annual survival (37% vs. adult females = 59%) (Zablan et al. 2003), possibly because of higher rates of predation during the breeding season (Connelly et al. 2000, Hagen 2011). Thus, based on the above discussion of the data, we were unable to detect differences using the available techniques to indicate that the fall structure of sage-grouse populations based on harvest differed among populations of greater sage-grouse within a State, between states, and between greater and Gunnison sage-grouse.

Estimates of breeding success of sage-grouse have primarily been based on studies of radio-marked hens (Schroeder 1997, Hagen et al. 2007). Ours is the first to derive breeding success (which includes nesting effort, nesting success, and chick survival to the hunting season) estimates from examination of hunter-harvested sage-grouse. This provides a less expensive way to estimate this important parameter even if it is not precise. More recently, Hagen and Loughin (2008) devised a method to estimate variance in sample sizes needed to provide estimates of productivity based on sage-grouse wing collections from hunters.

Estimated annual turnover (mortality) based on examination of wings varied slightly among areas (and years depending upon sample sizes) and was lower than rates for adult males

(63%), but similar for adult females (41%) published for banded and recovered sage-grouse in North Park, Colorado based on 6,000+ bandings over the period 1973–1990 and recovered in 1973–1993 (Zablan et al. 2003). These data suggest that estimating annual turnover of adult males and females from hunter-harvested sage-grouse has merit in both Colorado and Oregon.

Differential vulnerability to hunting is unknown for sage-grouse but juveniles may be more vulnerable than older age classes (Caudill et al. 2014). Anecdotal comments from hunters suggest there is selection for smaller birds (females and young). However, this is not supported by return of bands from marked sage-grouse of all age classes in Moffat County (unpubl. data) or of birds banded in spring as yearlings and adults in North Park. The data from North Park (Zablan et al. 2003) indicate that adult males had the highest harvest rates. This can be understood as males are larger (Beck and Braun 1978) and appear to flush later than females or juveniles.

MANAGEMENT IMPLICATIONS

The data on population composition of sage-grouse provided in this report span a 40-year period from small to large populations in a variety of habitats from high mountain valleys, which have substantial wet meadows, to low elevations that approach semi-deserts, all within a matrix of live sagebrush and mostly native herbaceous plants. Thus, data can be compared for the 1973–1998 period with that from 1993–2013. Of importance is the overlap from 1993 through 1998 between Colorado and Oregon. Data from small populations (Eagle = 695 wings [1977–1998], Piceance = 817 wings [1977–1994], and Yampa = 920 wings [1977–1998]) in Colorado have value as none of these populations is now hunted and none is likely to be hunted again. The same is true for some Harvest Management Units in Oregon. Even in situations where harvest is continuing, the long-term trend is declining samples of hunter-harvested wings. Consequently, it is unlikely that this quantity of data will ever be replicated.

These small populations have characteristics similar to the larger populations, but with larger variances in parameter estimates. Both species of sage-grouse are candidates for threatened or endangered listing and it is certain that at least one species will be subject to development of a recovery plan in the near future. Thus, it is important to know the characteristics of the populations prior to cessation of hunting and possible ESA listing.

The Gunnison sage-grouse population studied had the highest proportion of young in the fall harvest, the highest young per hen ratio, and was among those with the highest estimated breeding success. Despite these attributes, it still had estimated annual turnover that was quite similar (but somewhat higher) to other populations (Oregon; and especially North Park, Colorado which has similar habitat associations) that had adequate samples of wing receipts. Of interest is the similarity of most parameters measured including age and sex ratios with females comprising larger segments of fall populations in all older age classes. Clearly, the data indicate the mating system of sage-grouse which focuses on large, showy males and nondescript females is negative for male survival. It is also clear that all populations studied did not differ over time periods or geographical regions in their core attributes.

The data represented long periods from two states and indicates the need for population monitoring over time as recommended by Nichols and Williams (2006). Unfortunately, the opportunity to collect large samples may not exist but we show that even small samples collected over time can provide reasonable estimates of the structure of the fall population of sage-grouse.

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Appendix A1. Age and gender composition of the greater sage-grouse harvest, North Park, Colorado, 1974–1998.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1974	171	179	350	48.9:51.1	50.1	49	89	138	35.5:64.5	19.8	45	165	210	21.4:78.6	30.1
1975	101	111	212	47.6:52.4	42.0	52	59	111	46.8:53.2	22.0	55	127	182	30.2:69.8	36.0
1976	104	106	210	49.5:50.5	42.3	46	71	117	39.3:60.7	23.5	49	121	170	28.8:71.2	34.2
1977	136	154	290	46.9:53.1	45.9	47	76	123	38.2:61.8	19.5	48	171	219	21.9:78.1	34.7
1978	184	201	385	47.8:52.2	53.2	62	81	143	43.4:56.6	19.8	67	129	196	34.2:65.8	27.1
1979	306	318	624	49.0:51.0	57.7	102	154	256	39.8:60.2	23.7	72	129	201	35.8:64.2	18.6
1980	207	254	461	44.9:55.1	49.1	80	170	250	32.0:68.0	26.6	70	158	228	30.7:69.3	24.3
1981	234	255	489	47.9:52.1	47.4	78	151	229	34.1:65.9	22.2	87	227	314	27.7:72.3	30.4
1982	197	196	393	50.1:49.9	50.6	53	80	133	39.8:60.2	17.1	81	170	251	32.3:67.7	32.3
1983	295	352	647	45.6:54.4	57.4	90	155	245	36.7:63.3	21.7	53	183	236	22.5:77.5	20.9
1984	236	251	487	48.5:51.5	57.0	68	132	200	34.0:66.0	23.4	37	131	168	22.0:78.0	19.6
1985	163	190	353	46.2:53.8	53.6	47	112	159	29.6:70.4	24.2	33	113	146	22.6:77.4	22.2
1986	168	236	404	41.6:58.4	61.8	27	93	120	22.5:77.5	18.3	25	105	130	19.2:80.8	19.9
1987	153	216	369	41.5:58.5	54.2	54	114	168	32.1:67.9	24.7	29	115	144	20.1:79.9	21.1
1988	80	101	181	44.2:55.8	42.9	52	81	133	39.1:60.9	31.5	18	90	108	16.7:83.3	25.6
1989	89	98	187	47.6:52.4	46.1	25	92	117	21.4:78.6	28.8	17	85	102	16.7:83.3	25.1
1990	69	66	135	51.1:48.9	38.7	21	59	80	26.3:73.8	22.9	25	109	134	18.7:81.3	38.4
1991	47	64	111	42.3:57.7	43.0	18	28	46	39.1:60.9	17.8	18	83	101	17.8:82.2	39.1
1992	37	35	72	51.4:48.6	36.7	26	20	46	56.5:43.5	23.5	15	63	78	19.2:80.8	39.8
1993	53	53	106	50.0:50.0	45.1	6	20	26	23.1:76.9	11.1	25	78	103	24.3:75.7	43.8
1994	65	68	133	48.9:51.1	56.1	15	16	31	48.4:51.6	13.1	15	58	73	20.5:79.5	30.8
1995	10	13	23	43.5:56.5	36.5	4	15	19	21.1:78.9	30.2	10	11	21	47.6:52.4	33.3
1996	38	32	70	54.3:45.7	54.7	5	15	20	25.0:75.0	15.6	7	31	38	18.4:81.6	29.7
1997	31	41	72	43.1:56.9	51.4	12	18	30	40.0:60.0	21.4	10	28	38	26.3:73.7	27.1
1998	22	26	48	45.8:54.2	37.2	4	34	38	10.5:89.5	29.5	9	34	43	20.9:79.1	33.3
Average	128	145	272	46.9:53.1	50.7	42	77	119	35.3:64.7	22.2	37	109	145	25.3:74.7	27.0

Appendix A2. Age and gender composition of the greater sage-grouse harvest, Middle Park, Colorado, 1975–1998.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1975	23	31	54	42.6:57.4	66.7	4	8	12	33.3:66.7	14.8	1	14	15	6.7:93.3	18.5
1976	34	35	69	49.3:50.7	63.9	9	14	23	39.1:60.9	21.3	2	14	16	12.5:87.5	14.8
1977	49	40	89	55.1:44.9	57.1	11	20	31	35.5:64.5	19.9	9	27	36	25.0:75.0	23.1
1978	52	37	89	58.4:41.6	45.9	24	27	51	47.1:52.9	26.3	16	38	54	29.6:70.4	27.8
1979	41	43	84	48.8:51.2	50.0	20	21	41	48.8:51.2	24.4	13	30	43	30.2:69.8	25.6
1980	22	27	49	44.9:55.1	51.6	7	17	24	29.2:70.8	25.3	7	15	22	31.8:68.2	23.2
1981	5	4	9	55.6:44.4	22.0	11	9	20	55.0:45.0	48.8	3	9	12	25.0:75.0	29.3
1982	23	24	47	48.9:51.1	75.8	1	4	5	20.0:80.0	8.1	1	9	10	10.0:90.0	16.1
1983	28	37	65	43.1:56.9	51.6	10	18	28	35.7:64.3	22.2	12	21	33	36.4:63.6	26.2
1984	31	30	61	50.8:49.2	56.0	10	15	25	40.0:60.0	22.9	10	13	23	43.5:56.5	21.1
1985	13	11	24	54.2:45.8	38.7	6	14	20	30.0:70.0	32.3	4	14	18	22.2:77.8	29.0
1986	29	36	65	44.6:55.4	58.6	4	16	20	20.0:80.0	18.0	3	23	26	11.5:88.5	23.4
1987	26	49	75	34.7:65.3	66.4	6	10	16	37.5:62.5	14.2	4	18	22	18.2:81.8	19.5
1988	29	21	50	58.0:42.0	54.3	11	10	21	52.4:47.6	22.8	5	16	21	23.8:76.2	22.8
1989	14	12	26	53.8:46.2	38.2	10	7	17	58.8:41.2	25.0	10	15	25	40.0:60.0	36.8
1990	14	13	27	51.9:48.1	38.6	14	9	23	60.9:39.1	32.9	10	10	20	50.0:50.0	28.6
1991	19	16	35	54.3:45.7	47.9	9	7	16	56.3:43.8	21.9	4	18	22	18.2:81.8	30.1
1992	16	18	34	47.1:52.9	45.3	7	7	14	50.0:50.0	18.7	6	21	27	22.2:77.8	36.0
1993	12	17	29	41.4:58.6	54.7	1	12	13	7.7:92.3	24.5	1	10	11	9.1:90.9	20.8
1994	1	1	2	50.0:50.0	100.0	0	0	0		0.0	0	0	0		0.0
1995	2	2	4	50.0:50.0	30.8	2	1	3	66.7:33.3	23.1	2	4	6	33.3:66.7	46.2
1996	7	6	13	53.8:46.2	68.4	0	3	3	0.0:100.0	15.8	1	2	3	33.3:66.7	15.8
1997	2	1	3	66.7:33.3	30.0	0	3	3	0.0:100.0	30.0	1	3	4	25.0:75.0	40.0
1998	0	0	0		0.0	0	1	1	0.0:100.0	50.0	0	1	1	0.0:100.0	50.0
Average	21	21	42	50.0:50.0	52.5	7	11	18	38.9:61.1	22.5	5	14	20	26.3:73.7	25.0

Appendix A3. Age and gender composition of the greater sage-grouse harvest, Eagle, Colorado, 1977–1998.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1977	7	16	23	30.4:69.6	65.7	0	8	8	0.0:100.0	22.9	0	4	4	0.0:100.0	11.4
1978	27	20	47	57.4:42.6	59.5	5	3	8	62.5:37.5	10.1	5	19	24	20.8:79.2	30.4
1979	19	17	36	52.8:47.2	48.6	15	6	21	71.4:28.6	28.4	9	8	17	52.9:47.1	23.0
1980	22	25	47	46.8:53.2	69.1	0	7	7	0.0:100.0	10.3	4	10	14	28.6:71.4	20.6
1981	5	5	10	50.0:50.0	76.9	1	1	2	50.0:50.0	15.4	0	1	1	0.0:100.0	7.7
1982	8	6	14	57.1:42.9	100.0	0	0	0		0.0	0	0	0		0.0
1983	26	25	51	51.0:49.0	56.7	8	16	24	33.3:66.7	26.7	3	12	15	20.0:80.0	16.7
1984	8	3	11	72.7:27.3	42.3	4	6	10	40.0:60.0	38.5	2	3	5	40.0:60.0	19.2
1985	13	7	20	65.0:35.0	58.8	0	2	2	0.0:100.0	5.9	5	7	12	41.7:58.3	35.3
1986	11	16	27	40.7:59.3	69.2	0	4	4	0.0:100.0	10.3	0	8	8	0.0:100.0	20.5
1987	18	17	35	51.4:48.6	55.6	6	10	16	37.5:62.5	25.4	4	8	12	33.3:66.7	19.0
1988	8	12	20	40.0:60.0	54.1	1	5	6	16.7:83.3	16.2	4	7	11	36.4:63.6	29.7
1989	4	2	6	66.7:33.3	75.0	0	1	1	0.0:100.0	12.5	0	1	1	0.0:100.0	12.5
1990	9	7	16	56.3:43.8	61.5	1	0	1	100.0:0.0	3.8	1	8	9	11.1:88.9	34.6
1991	11	17	28	39.3:60.7	63.6	7	5	12	58.3:41.7	27.3	2	2	4	50.0:50.0	9.1
1992	3	7	10	30.0:70.0	45.5	5	1	6	83.3:16.7	27.3	3	3	6	50.0:50.0	27.3
1993	0	1	1	0.0:100.0	25.0	0	0	0		0.0	1	2	3	33.3:66.7	75.0
1994	3	1	4	75.0:25.0	36.4	1	0	1	100.0:0.0	9.1	4	2	6	66.7:33.3	54.5
1995	0	0	0			0	0	0			0	0	0		
1996	0	0	0			0	0	0			0	0	0		
1997	0	1	1	0.0:100.0	50.0	0	1	1	0.0:100.0	50.0	0	0	0		0.0
1998	2	2	4	50.0:50.0	80.0	0	0	0		0.0	0	1	1	0.0:100.0	20.0
Average	9	9	19	50.0:50.0	59.4	2	3	6	40.0:60.0	18.8	2	5	7	33.3:66.7	21.9

Appendix A4. Age and gender composition of the greater sage-grouse harvest, Yampa, Colorado, 1977–1998.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1977	30	28	58	51.7:48.3	58.6	9	16	25	36.0:64.0	25.3	5	11	16	31.3:68.8	16.2
1978	28	28	56	50.0:50.0	45.5	5	14	19	26.3:73.7	15.4	16	32	48	33.3:66.7	39.0
1979	20	31	51	39.2:60.8	37.0	23	28	51	45.1:54.9	37.0	17	19	36	47.2:52.8	26.1
1980	31	30	61	50.8:49.2	42.4	21	19	40	52.5:47.5	27.8	16	27	43	37.2:62.8	29.9
1981	7	10	17	41.2:58.8	21.3	17	26	43	39.5:60.5	53.8	3	17	20	15.0:85.0	25.0
1982	8	11	19	42.1:57.9	57.6	5	4	9	55.6:44.4	27.3	0	5	5	0.0:100.0	15.2
1983	16	8	24	66.7:33.3	57.1	4	7	11	36.4:63.6	26.2	1	6	7	14.3:85.7	16.7
1984	7	7	14	50.0:50.0	51.9	5	3	8	62.5:37.5	29.6	2	3	5	40.0:60.0	18.5
1985	2	6	8	25.0:75.0	34.8	2	3	5	40.0:60.0	21.7	3	7	10	30.0:70.0	43.5
1986	4	3	7	57.1:42.9	63.6	0	2	2	0.0:100.0	18.2	0	2	2	0.0:100.0	18.2
1987	3	1	4	75.0:25.0	33.3	2	4	6	33.3:66.7	50.0	0	2	2	0.0:100.0	16.7
1988	3	2	5	60.0:40.0	16.7	11	2	13	84.6:15.4	43.3	8	4	12	66.7:33.3	40.0
1989	7	9	16	43.8:56.3	43.2	10	3	13	76.9:23.1	35.1	6	2	8	75.0:25.0	21.6
1990	2	6	8	25.0:75.0	47.1	1	2	3	33.3:66.7	17.6	2	4	6	33.3:66.7	35.3
1991	7	6	13	53.8:46.2	48.1	1	5	6	16.7:83.3	22.2	3	5	8	37.5:62.5	29.6
1992	1	2	3	33.3:66.7	25.0	5	0	5	100.0:0.0	41.7	1	3	4	25.0:75.0	33.3
1993	12	11	23	52.2:47.8	54.8	0	2	2	0.0:100.0	4.8	3	14	17	17.6:82.4	40.5
1994	1	1	2	50.0:50.0	18.2	3	1	4	75.0:25.0	36.4	4	1	5	80.0:20.0	45.5
1995	1	3	4	25.0:75.0	50.0	0	0	0		0.0	0	4	4	0.0:100.0	50.0
1996	1	1	2	50.0:50.0	100.0	0	0	0		0.0	0	0	0		0.0
1997	0	0	0			0	0	0			0	0	0		
1998	2	0	2	100.0:0.0	100.0	0	0	0		0.0	0	0	0		0.0
Average	9	9	18	50.0:50.0	42.9	6	6	12	45.5:54.5	28.6	4	8	12	36.4:63.6	28.6

Appendix A5. Age and gender composition of the greater sage-grouse harvest, Piceance Basin, Colorado, 1977–1994.

	Juveniles					Yearlings					Adults				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1977	13	19	32	40.6:59.4	49.2	6	9	15	40.0:60.0	23.1	3	15	18	16.7:83.3	27.7
1978	33	42	75	44.0:56.0	65.8	4	12	16	25.0:75.0	14.0	6	17	23	26.1:73.9	20.2
1979	23	16	39	59.0:41.0	54.9	10	4	14	71.4:28.6	19.7	8	10	18	44.4:55.6	25.4
1980	22	31	53	41.5:58.5	67.9	8	6	14	57.1:42.9	17.9	5	6	11	45.5:54.5	14.1
1981	9	11	20	45.0:55.0	83.3	1	1	2	50.0:50.0	8.3	0	2	2	0.0:100.0	8.3
1982	24	17	41	58.5:41.5	69.5	2	6	8	25.0:75.0	13.6	1	9	10	10.0:90.0	16.9
1983	17	15	32	53.1:46.9	62.7	5	9	14	35.7:64.3	27.5	1	4	5	20.0:80.0	9.8
1984	15	11	26	57.7:42.3	61.9	1	5	6	16.7:83.3	14.3	3	7	10	30.0:70.0	23.8
1985	12	13	25	48.0:52.0	69.4	2	2	4	50.0:50.0	11.1	1	6	7	14.3:85.7	19.4
1986	9	16	25	36.0:64.0	37.9	10	12	22	45.5:54.5	33.3	8	11	19	42.1:57.9	28.8
1987	17	17	34	50.0:50.0	63.0	3	10	13	23.1:76.9	24.1	3	4	7	42.9:57.1	13.0
1988	8	7	15	53.3:46.7	55.6	2	5	7	28.6:71.4	25.9	0	5	5	0.0:100.0	18.5
1989	7	11	18	38.9:61.1	36.7	12	8	20	60.0:40.0	40.8	6	5	11	54.5:45.5	22.4
1990	5	4	9	55.6:44.4	37.5	4	2	6	66.7:33.3	25.0	6	3	9	66.7:33.3	37.5
1991	0	1	1	0.0:100.0	14.3	1	1	2	50.0:50.0	28.6	1	3	4	25.0:75.0	57.1
1992	3	6	9	33.3:66.7	47.4	1	5	6	16.7:83.3	31.6	0	4	4	0.0:100.0	21.1
1993	6	2	8	75.0:25.0	57.1	1	1	2	50.0:50.0	14.3	0	4	4	0.0:100.0	28.6
1994	9	3	12	75.0:25.0	70.6	1	0	1	100.0:0.0	5.9	0	4	4	0.0:100.0	23.5
Average	13	13	26	47.4:52.6	56.5	4	5	10	42.9:57.1	21.7	3	7	10	30.0:70.0	21.7

Appendix A6. Age and gender composition of the greater sage-grouse harvest, Blue Mountain, Colorado, 1976–1998.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1976	32	37	69	46.4:53.6	61.6	7	10	17	41.2:58.8	15.2	4	22	26	15.4:84.6	23.2
1977	26	38	64	40.6:59.4	60.4	10	7	17	58.8:41.2	16.0	11	14	25	44.0:56.0	23.6
1978	166	164	330	50.3:49.7	62.1	28	68	96	29.2:70.8	18.1	31	74	105	29.5:70.5	19.8
1979	97	107	204	47.5:52.5	45.0	76	74	150	50.7:49.3	33.1	29	70	99	29.3:70.7	21.9
1980	102	136	238	42.9:57.1	68.8	11	31	42	26.2:73.8	12.1	13	53	66	19.7:80.3	19.1
1981	27	40	67	40.3:59.7	54.9	13	19	32	40.6:59.4	26.2	11	12	23	47.8:52.2	18.9
1982	58	100	158	36.7:63.3	70.5	23	21	44	52.3:47.7	19.6	4	18	22	18.2:81.8	9.8
1983	41	50	91	45.1:54.9	63.2	6	17	23	26.1:73.9	16.0	4	26	30	13.3:86.7	20.8
1984	78	81	159	49.1:50.9	63.1	28	28	56	50.0:50.0	22.2	9	28	37	24.3:75.7	14.7
1985	125	98	223	56.1:43.9	67.4	25	36	61	41.0:59.0	18.4	18	29	47	38.3:61.7	14.2
1986	116	115	231	50.2:49.8	59.5	41	50	91	45.1:54.9	23.5	17	49	66	25.8:74.2	17.0
1987	150	151	301	49.8:50.2	66.3	35	41	76	46.1:53.9	16.7	21	56	77	27.3:72.7	17.0
1988	69	79	148	46.6:53.4	50.0	32	48	80	40.0:60.0	27.0	32	36	68	47.1:52.9	23.0
1989	74	75	149	49.7:50.3	41.3	51	58	109	46.8:53.2	30.2	42	61	103	40.8:59.2	28.5
1990	70	89	159	44.0:56.0	55.4	27	38	65	41.5:58.5	22.6	10	53	63	15.9:84.1	22.0
1991	40	81	121	33.1:66.9	54.0	15	35	50	30.0:70.0	22.3	15	38	53	28.3:71.7	23.7
1992	32	41	73	43.8:56.2	45.9	16	23	39	41.0:59.0	24.5	14	33	47	29.8:70.2	29.6
1993	43	60	103	41.7:58.3	65.2	3	11	14	21.4:78.6	8.9	8	33	41	19.5:80.5	25.9
1994	17	38	55	30.9:69.1	48.7	11	22	33	33.3:66.7	29.2	7	18	25	28.0:72.0	22.1
1995	41	29	70	58.6:41.4	74.5	1	13	14	7.1:92.9	14.9	1	9	10	10.0:90.0	10.6
1996	39	43	82	47.6:52.4	56.6	11	16	27	40.7:59.3	18.6	10	26	36	27.8:72.2	24.8
1997	20	14	34	58.8:41.2	50.0	9	9	18	50.0:50.0	26.5	8	8	16	50.0:50.0	23.5
1998	10	10	20	50.0:50.0	50.0	1	6	7	14.3:85.7	17.5	6	7	13	46.2:53.8	32.5
Average	64	73	137	46.7:53.3	58.3	21	30	50	41.2:58.8	21.3	14	34	48	29.2:70.8	20.4

Appendix A7. Age and gender composition of the greater sage-grouse harvest, Cold Spring Mountain, Colorado, 1976–1998. Wings were not identifiable to specific hunting area in 1978 and 1979.

	Juveniles					Yearlings					Adults				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1976	18	20	38	47.4:52.6	73.1	2	2	4	50.0:50.0	7.7	0	10	10	0.0:100.0	19.2
1977	18	43	61	29.5:70.5	59.8	6	12	18	33.3:66.7	17.6	3	20	23	13.0:87.0	22.5
1978	0	0	0			0	0	0			0	0	0		
1979	0	0	0			0	0	0			0	0	0		
1980	25	22	47	53.2:46.8	60.3	2	4	6	33.3:66.7	7.7	4	21	25	16.0:84.0	32.1
1981	75	81	156	48.1:51.9	61.7	8	28	36	22.2:77.8	14.2	19	42	61	31.1:68.9	24.1
1982	25	26	51	49.0:51.0	64.6	5	8	13	38.5:61.5	16.5	2	13	15	13.3:86.7	19.0
1983	97	79	176	55.1:44.9	68.0	15	24	39	38.5:61.5	15.1	3	41	44	6.8:93.2	17.0
1984	4	14	18	22.2:77.8	39.1	3	8	11	27.3:72.7	23.9	4	13	17	23.5:76.5	37.0
1985	50	73	123	40.7:59.3	62.1	12	22	34	35.3:64.7	17.2	3	38	41	7.3:92.7	20.7
1986	39	31	70	55.7:44.3	61.4	8	12	20	40.0:60.0	17.5	2	22	24	8.3:91.7	21.1
1987	15	20	35	42.9:57.1	49.3	9	12	21	42.9:57.1	29.6	4	11	15	26.7:73.3	21.1
1988	23	23	46	50.0:50.0	54.1	6	13	19	31.6:68.4	22.4	6	14	20	30.0:70.0	23.5
1989	46	52	98	46.9:53.1	51.3	12	24	36	33.3:66.7	18.8	24	33	57	42.1:57.9	29.8
1990	42	63	105	40.0:60.0	52.5	11	24	35	31.4:68.6	17.5	8	52	60	13.3:86.7	30.0
1991	56	74	130	43.1:56.9	68.1	1	13	14	7.1:92.9	7.3	8	39	47	17.0:83.0	24.6
1992	27	57	84	32.1:67.9	51.9	13	23	36	36.1:63.9	22.2	10	32	42	23.8:76.2	25.9
1993	40	51	91	44.0:56.0	62.3	6	17	23	26.1:73.9	15.8	6	26	32	18.8:81.3	21.9
1994	22	25	47	46.8:53.2	72.3	4	8	12	33.3:66.7	18.5	2	4	6	33.3:66.7	9.2
1995	6	9	15	40.0:60.0	60.0	0	3	3	0.0:100.0	12.0	1	6	7	14.3:85.7	28.0
1996	14	20	34	41.2:58.8	63.0	5	3	8	62.5:37.5	14.8	5	7	12	41.7:58.3	22.2
1997	21	15	36	58.3:41.7	65.5	1	6	7	14.3:85.7	12.7	2	10	12	16.7:83.3	21.8
1998	17	26	43	39.5:60.5	45.7	9	13	22	40.9:59.1	23.4	7	22	29	24.1:75.9	30.9
Average	32	39	65	45.1:54.9	59.6	7	13	18	35.0:65.0	16.5	6	23	26	20.7:79.3	23.9

Appendix A8. Age and gender composition of the greater sage-grouse harvest, Eastern Moffat and Northwestern Routt counties, Colorado, 1976–1998. The season was closed in 1998 but some wings were received. There were no wings received in 1995.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1976	10	15	25	40.0:60.0	46.3	11	7	18	61.1:38.9	33.3	3	8	11	27.3:72.7	20.4
1977	14	22	36	38.9:61.1	39.6	4	14	18	22.2:77.8	19.8	13	24	37	35.1:64.9	40.7
1978	99	108	207	47.8:52.2	77.8	8	17	25	32.0:68.0	9.4	10	24	34	29.4:70.6	12.8
1979	112	103	215	52.1:47.9	57.5	27	84	111	24.3:75.7	29.7	3	45	48	6.3:93.8	12.8
1980	69	81	150	46.0:54.0	50.8	18	48	66	27.3:72.7	22.4	26	53	79	32.9:67.1	26.8
1981	83	107	190	43.7:56.3	42.7	43	85	128	33.6:66.4	28.8	28	99	127	22.0:78.0	28.5
1982	52	35	87	59.8:40.2	46.3	14	36	50	28.0:72.0	26.6	17	34	51	33.3:66.7	27.1
1983	42	54	96	43.8:56.3	47.5	21	23	44	47.7:52.3	21.8	18	44	62	29.0:71.0	30.7
1984	15	21	36	41.7:58.3	62.1	1	9	10	10.0:90.0	17.2	4	8	12	33.3:66.7	20.7
1985	34	50	84	40.5:59.5	65.1	6	22	28	21.4:78.6	21.7	3	14	17	17.6:82.4	13.2
1986	52	58	110	47.3:52.7	70.1	15	14	29	51.7:48.3	18.5	5	13	18	27.8:72.2	11.5
1987	53	44	97	54.6:45.4	65.1	6	22	28	21.4:78.6	18.8	4	20	24	16.7:83.3	16.1
1988	36	40	76	47.4:52.6	50.7	12	24	36	33.3:66.7	24.0	8	30	38	21.1:78.9	25.3
1989	79	68	147	53.7:46.3	59.8	19	30	49	38.8:61.2	19.9	4	46	50	8.0:92.0	20.3
1990	82	81	163	50.3:49.7	49.8	40	49	89	44.9:55.1	27.2	26	49	75	34.7:65.3	22.9
1991	28	33	61	45.9:54.1	42.1	15	24	39	38.5:61.5	26.9	14	31	45	31.1:68.9	31.0
1992	12	15	27	44.4:55.6	34.2	9	9	18	50.0:50.0	22.8	7	27	34	20.6:79.4	43.0
1993	11	13	24	45.8:54.2	32.4	3	7	10	30.0:70.0	13.5	8	32	40	20.0:80.0	54.1
1994	20	24	44	45.5:54.5	62.0	1	13	14	7.1:92.9	19.7	1	12	13	7.7:92.3	18.3
1995	0	0	0			0	0	0			0	0	0		
1996	5	6	11	45.5:54.5	47.8	0	5	5	0.0:100.0	21.7	1	6	7	14.3:85.7	30.4
1997	2	0	2	100.0:0.0	100.0	0	0	0		0.0	0	0	0		0.0
1998	0	2	2	0.0:100.0	14.3	0	4	4	0.0:100.0	28.6	0	8	8	0.0:100.0	57.1
Average	40	43	82	48.2:51.8	53.2	12	24	36	33.3:66.7	23.4	9	27	36	25.0:75.0	23.4

Appendix A9. Age and gender composition of the greater sage-grouse harvest, Northcentral Moffat County, Colorado, 1976–1998.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1976	143	202	345	41.4:58.6	65.1	21	55	76	27.6:72.4	14.3	18	91	109	16.5:83.5	20.6
1977	50	71	121	41.3:58.7	33.3	51	54	105	48.6:51.4	28.9	56	81	137	40.9:59.1	37.7
1978	419	460	879	47.7:52.3	71.7	18	43	61	29.5:70.5	5.0	73	213	286	25.5:74.5	23.3
1979	495	612	1107	44.7:55.3	57.1	250	291	541	46.2:53.8	27.9	91	200	291	31.3:68.7	15.0
1980	371	464	835	44.4:55.6	53.0	118	142	260	45.4:54.6	16.5	206	275	481	42.8:57.2	30.5
1981	264	370	634	41.6:58.4	54.8	50	121	171	29.2:70.8	14.8	97	255	352	27.6:72.4	30.4
1982	174	232	406	42.9:57.1	61.4	25	63	88	28.4:71.6	13.3	34	133	167	20.4:79.6	25.3
1983	312	363	675	46.2:53.8	57.1	95	130	225	42.2:57.8	19.0	73	210	283	25.8:74.2	23.9
1984	148	190	338	43.8:56.2	55.7	35	74	109	32.1:67.9	18.0	35	125	160	21.9:78.1	26.4
1985	221	289	510	43.3:56.7	62.7	46	80	126	36.5:63.5	15.5	53	125	178	29.8:70.2	21.9
1986	292	317	609	47.9:52.1	58.6	80	149	229	34.9:65.1	22.0	72	129	201	35.8:64.2	19.3
1987	358	414	772	46.4:53.6	55.9	101	191	292	34.6:65.4	21.2	89	227	316	28.2:71.8	22.9
1988	254	343	597	42.5:57.5	51.3	93	158	251	37.1:62.9	21.6	101	215	316	32.0:68.0	27.1
1989	358	474	832	43.0:57.0	53.9	126	119	245	51.4:48.6	15.9	184	283	467	39.4:60.6	30.2
1990	295	382	677	43.6:56.4	44.5	105	233	338	31.1:68.9	22.2	182	326	508	35.8:64.2	33.4
1991	157	213	370	42.4:57.6	40.7	57	109	166	34.3:65.7	18.2	109	265	374	29.1:70.9	41.1
1992	105	150	255	41.2:58.8	41.3	48	88	136	35.3:64.7	22.0	45	182	227	19.8:80.2	36.7
1993	96	100	196	49.0:51.0	53.1	23	29	52	44.2:55.8	14.1	35	86	121	28.9:71.1	32.8
1994	69	106	175	39.4:60.6	47.7	27	35	62	43.5:56.5	16.9	19	111	130	14.6:85.4	35.4
1995	30	33	63	47.6:52.4	64.9	5	8	13	38.5:61.5	13.4	4	17	21	19.0:81.0	21.6
1996	23	58	81	28.4:71.6	55.9	8	18	26	30.8:69.2	17.9	10	28	38	26.3:73.7	26.2
1997	23	18	41	56.1:43.9	50.0	7	9	16	43.8:56.3	19.5	7	18	25	28.0:72.0	30.5
1998	24	24	48	50.0:50.0	60.0	10	6	16	62.5:37.5	20.0	5	11	16	31.3:68.8	20.0
Average	204	256	459	44.3:55.7	54.5	61	96	157	38.9:61.1	18.6	69	157	226	30.8:69.2	26.8

Appendix A10. Age and gender composition of the greater sage-grouse harvest, Sumpter, Hunt Unit 51, Oregon, 1993–2013.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	3	2	5	60.0:40.0	83.3	0	0	0		0.0	0	1	1	0.0:100.0	16.7
1994	1	4	5	20.0:80.0	50.0	0	1	1	0.0:100.0	10.0	0	4	4	0.0:100.0	40.0
1995	0	0	0		0.0	0	0	0		0.0	2	1	3	66.7:33.3	100.0
1996	0	2	2	0.0:100.0	33.3	0	0	0		0.0	3	1	4	75.0:25.0	66.7
1997	1	0	1	100.0:0.0	25.0	0	0	0		0.0	2	1	3	66.7:33.3	75.0
1998	0	0	0			0	0	0			0	0	0		
1999	0	0	0		0.0	0	0	0		0.0	1	1	2	50.0:50.0	100.0
2000	0	1	1	0.0:100.0	33.3	0	1	1	0.0:100.0	33.3	0	1	1	0.0:100.0	33.3
2001	0	0	0		0.0	0	0	0		0.0	0	2	2	0.0:100.0	100.0
2002	0	0	0			0	0	0			0	0	0		
2003	0	0	0		0.0	0	0	0		0.0	2	2	4	50.0:50.0	100.0
2004	1	0	1	100.0:0.0	100.0	0	0	0		0.0	0	0	0		0.0
2005	1	1	2	50.0:50.0	100.0	0	0	0		0.0	0	0	0		0.0
2006	0	0	0			0	0	0			0	0	0		
2007	0	0	0			0	0	0			0	0	0		
2008	0	0	0		0.0	0	0	0		0.0	0	2	2	0.0:100.0	100.0
2009	0	0	0		0.0	0	0	0		0.0	2	0	2	100.0:0.0	100.0
2010	0	0	0			0	0	0			0	0	0		
2011	0	0	0			0	0	0			0	0	0		
2012	0	0	0			0	0	0			0	0	0		
2013	0	0	0			0	0	0			0	0	0		
Average	0	1	1	41.2:58.8	36.2	0	0	0	0.0:100.0	4.3	1	1	1	42.9:57.1	59.6

Appendix A11. Age and gender composition of the greater sage-grouse harvest, Lookout Mountain, Hunt Unit 64, Oregon, 1993–2013.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	2	3	5	40.0:60.0	62.5	0	0	0		0.0	1	2	3	33.3:66.7	37.5
1994	0	1	1	0.0:100.0	25.0	0	0	0		0.0	1	2	3	33.3:66.7	75.0
1995	3	1	4	75.0:25.0	50.0	0	2	2	0.0:100.0	25.0	1	1	2	50.0:50.0	25.0
1996	0	3	3	0.0:100.0	100.0	0	0	0		0.0	0	0	0		0.0
1997	0	0	0		0.0	0	0	0		0.0	3	0	3	100.0:0.0	100.0
1998	0	0	0		0.0	0	0	0		0.0	4	0	4	100.0:0.0	100.0
1999	3	0	3	100.0:0.0	25.0	0	0	0		0.0	5	4	9	55.6:44.4	75.0
2000	0	0	0		0.0	0	0	0		0.0	2	0	2	100.0:0.0	100.0
2001	1	2	3	33.3:66.7	60.0	0	0	0		0.0	1	1	2	50.0:50.0	40.0
2002	1	1	2	50.0:50.0	66.7	0	0	0		0.0	1	0	1	100.0:0.0	33.3
2003	3	3	6	50.0:50.0	66.7	0	1	1	0.0:100.0	11.1	0	2	2	0.0:100.0	22.2
2004	0	0	0		0.0	0	0	0		0.0	2	1	3	66.7:33.3	100.0
2005	2	2	4	50.0:50.0	50.0	0	0	0		0.0	2	2	4	50.0:50.0	50.0
2006	2	1	3	66.7:33.3	33.3	0	0	0		0.0	5	1	6	83.3:16.7	66.7
2007	0	0	0		0.0	0	0	0		0.0	3	1	4	75.0:25.0	100.0
2008	0	0	0		0.0	0	0	0		0.0	0	2	2	0.0:100.0	100.0
2009	0	0	0			0	0	0			0	0	0		
2010	0	0	0			0	0	0			0	0	0		
2011	0	0	0		0.0	0	0	0		0.0	0	1	1	0.0:100.0	100.0
2012	1	0	1	100.0:0.0	25.0	0	1	1	0.0:100.0	25.0	1	1	2	50.0:50.0	50.0
2013	0	0	0			0	0	0			0	0	0		
Average	1	1	2	51.4:48.6	38.0	0	0	0	0.0:100.0	4.3	2	1	3	60.4:39.6	60.0

Appendix A12. Age and gender composition of the greater sage-grouse harvest, Beulah, Hunt Unit 65, Oregon, 1993–2013.

	Juveniles					Yearlings					Adults				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	6	1	7	85.7:14.3	38.9	0	1	1	0.0:100.0	5.6	3	7	10	30.0:70.0	55.6
1994	21	6	27	77.8:22.2	52.9	0	4	4	0.0:100.0	7.8	7	13	20	35.0:65.0	39.2
1995	3	6	9	33.3:66.7	31.0	0	1	1	0.0:100.0	3.4	11	8	19	57.9:42.1	65.5
1996	9	5	14	64.3:35.7	50.0	0	1	1	0.0:100.0	3.6	5	8	13	38.5:61.5	46.4
1997	14	17	31	45.2:54.8	45.6	1	5	6	16.7:83.3	8.8	10	21	31	32.3:67.7	45.6
1998	17	8	25	68.0:32.0	47.2	0	2	2	0.0:100.0	3.8	10	16	26	38.5:61.5	49.1
1999	13	21	34	38.2:61.8	47.9	0	3	3	0.0:100.0	4.2	19	15	34	55.9:44.1	47.9
2000	19	12	31	61.3:38.7	47.0	0	1	1	0.0:100.0	1.5	15	19	34	44.1:55.9	51.5
2001	14	15	29	48.3:51.7	55.8	0	3	3	0.0:100.0	5.8	5	15	20	25.0:75.0	38.5
2002	18	11	29	62.1:37.9	49.2	0	2	2	0.0:100.0	3.4	8	20	28	28.6:71.4	47.5
2003	12	11	23	52.2:47.8	39.7	0	4	4	0.0:100.0	6.9	15	16	31	48.4:51.6	53.4
2004	17	21	38	44.7:55.3	62.3	0	3	3	0.0:100.0	4.9	1	19	20	5.0:95.0	32.8
2005	19	28	47	40.4:59.6	51.1	0	2	2	0.0:100.0	2.2	18	25	43	41.9:58.1	46.7
2006	19	19	38	50.0:50.0	63.3	0	0	0		0.0	5	17	22	22.7:77.3	36.7
2007	4	2	6	66.7:33.3	25.0	0	1	1	0.0:100.0	4.2	3	14	17	17.6:82.4	70.8
2008	6	8	14	42.9:57.1	60.9	0	1	1	0.0:100.0	4.3	0	8	8	0.0:100.0	34.8
2009	18	15	33	54.5:45.5	57.9	0	0	0		0.0	8	16	24	33.3:66.7	42.1
2010	11	17	28	39.3:60.7	49.1	0	4	4	0.0:100.0	7.0	8	17	25	32.0:68.0	43.9
2011	2	8	10	20.0:80.0	37.0	1	2	3	33.3:66.7	11.1	8	6	14	57.1:42.9	51.9
2012	7	5	12	58.3:41.7	38.7	0	4	4	0.0:100.0	12.9	6	9	15	40.0:60.0	48.4
2013	3	1	4	75.0:25:0	80.0	0	0	0		0	1	0	1	100.0:0.0	20.0
Average	12	11	23	51.5:48.5	49.4	0	2	2	0.0:100.0	4.3	8	14	22	36.5:63.5	46.0

Appendix A13. Age and gender composition of the greater sage-grouse harvest, Malheur River, Hunt Unit 66, Oregon, 1993–2013.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	9	14	23	39.1:60.9	71.9	0	1	1	0.0:100.0	3.1	2	6	8	25.0:75.0	25.0
1994	17	23	40	42.5:57.5	46.0	3	3	6	50.0:50.0	6.9	13	28	41	31.7:68.3	47.1
1995	5	9	14	35.7:64.3	50.0	0	2	2	0.0:100.0	7.1	6	6	12	50.0:50.0	42.9
1996	7	13	20	35.0:65.0	60.6	0	1	1	0.0:100.0	3.0	2	10	12	16.7:83.3	36.4
1997	2	10	12	16.7:83.3	52.2	0	1	1	0.0:100.0	4.3	5	5	10	50.0:50.0	43.5
1998	5	7	12	41.7:58.3	36.4	0	3	3	0.0:100.0	9.1	8	10	18	44.4:55.6	54.5
1999	13	16	29	44.8:55.2	56.9	0	3	3	0.0:100.0	5.9	7	12	19	36.8:63.2	37.3
2000	8	12	20	40.0:60.0	41.7	1	3	4	25.0:75.0	8.3	10	14	24	41.7:58.3	50.0
2001	13	16	29	44.8:55.2	45.3	2	7	9	22.2:77.8	14.1	17	9	26	65.4:34.6	40.6
2002	16	10	26	61.5:38.5	56.5	0	3	3	0.0:100.0	6.5	6	11	17	35.3:64.7	37.0
2003	10	19	29	34.5:65.5	54.7	1	4	5	20.0:80.0	9.4	5	14	19	26.3:73.7	35.8
2004	14	20	34	41.2:58.8	59.6	1	1	2	50.0:50.0	3.5	8	13	21	38.1:61.9	36.8
2005	17	10	27	63.0:37.0	37.0	0	3	3	0.0:100.0	4.1	24	19	43	55.8:44.2	58.9
2006	13	5	18	72.2:27.8	46.2	0	2	2	0.0:100.0	5.1	7	12	19	36.8:63.2	48.7
2007	2	5	7	28.6:71.4	31.8	1	4	5	20.0:80.0	22.7	4	6	10	40.0:60.0	45.5
2008	7	10	17	41.2:58.8	50.0	0	2	2	0.0:100.0	5.9	6	9	15	40.0:60.0	44.1
2009	5	2	7	71.4:28.6	43.8	0	2	2	0.0:100.0	12.5	3	4	7	42.9:57.1	43.8
2010	9	11	20	45.0:55.0	66.7	0	1	1	0.0:100.0	3.3	2	7	9	22.2:77.8	30.0
2011	0	0	0		0.0	0	0	0		0.0	0	5	5	0.0:100.0	100.0
2012	1	0	1	100.0:0.0	33.3	0	0	0		0.0	2	0	2	100.0:0.0	66.7
2013	0	1	1	0.0:100.0	33.3	0	1	1	0.0:100.0	33.3	0	1	1	0.0:100.0	33.3
Average	8	10	18	44.8.0:55.2	49.5	0	2	3	16.1:83.9	7.2	7	10	17	40.5:59.5	43.3

Appendix A14. Age and gender composition of the greater sage-grouse harvest, Owyhee, Hunt Unit 67, Oregon, 1993–2013.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	1	3	4	25.0:75.0	25.0	0	0	0		0.0	0	12	12	0.0:100.0	75.0
1994	7	5	12	58.3:41.7	40.0	0	0	0		0.0	2	16	18	11.1:88.9	60.0
1995	1	5	6	16.7:83.3	37.5	0	1	1	0.0:100.0	6.3	3	6	9	33.3:66.7	56.3
1996	8	12	20	40.0:60.0	62.5	0	3	3	0.0:100.0	9.4	2	7	9	22.2:77.8	28.1
1997	3	4	7	42.9:57.1	36.8	0	0	0		0.0	5	7	12	41.7:58.3	63.2
1998	4	2	6	66.7:33.3	18.8	0	1	1	0.0:100.0	3.1	14	11	25	56.0:44.0	78.1
1999	12	11	23	52.2:47.8	47.9	0	3	3	0.0:100.0	6.3	9	13	22	40.9:59.1	45.8
2000	15	13	28	53.6:46.4	53.8	0	2	2	0.0:100.0	3.8	12	10	22	54.5:45.5	42.3
2001	24	21	45	53.3:46.7	66.2	1	3	4	25.0:75.0	5.9	7	12	19	36.8:63.2	27.9
2002	6	13	19	31.6:68.4	47.5	0	3	3	0.0:100.0	7.5	6	12	18	33.3:66.7	45.0
2003	6	4	10	60.0:40.0	25.6	0	2	2	0.0:100.0	5.1	12	15	27	44.4:55.6	69.2
2004	13	15	28	46.4:53.6	52.8	0	1	1	0.0:100.0	1.9	8	16	24	33.3:66.7	45.3
2005	10	8	18	55.6:44.4	32.1	0	3	3	0.0:100.0	5.4	14	21	35	40.0:60.0	62.5
2006	5	5	10	50.0:50.0	22.2	0	1	1	0.0:100.0	2.2	21	13	34	61.8:38.2	75.6
2007	4	1	5	80.0:20.0	20.8	1	1	2	50.0:50.0	8.3	5	12	17	29.4:70.6	70.8
2008	5	3	8	62.5:37.5	50.0	0	0	0		0.0	2	6	8	25.0:75.0	50.0
2009	9	3	12	75.0:25.0	54.5	0	0	0		0.0	1	9	10	10.0:90.0	45.5
2010	4	2	6	66.7:33.3	37.5	0	1	1	0.0:100.0	6.3	6	3	9	66.7:33.3	56.3
2011	1	1	2	50.0:50.0	13.3	0	0	0		0.0	7	6	13	53.8:46.2	86.7
2012	7	11	18	38.9:61.1	43.9	0	2	2	0.0:100.0	4.9	10	11	21	47.6:52.4	51.2
2013	3	3	6	50.0:50.0	46.2	0	0	0		0	4	3	7	57.1:42.9	53.8
Average	7	7	14	50.5:49.5	42.3	0	1	1	6.9:93.1	4.2	7	11	18	40.4:59.6	53.5

Appendix A15. Age and gender composition of the greater sage-grouse harvest, Whitehorse, Hunt Unit 68, Oregon, 1993–2013. The season was closed in 2012.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	27	30	57	47.4:52.6	44.9	0	3	3	0.0:100.0	2.4	29	38	67	43.3:56.7	52.8
1994	38	53	91	41.8:58.2	54.5	0	8	8	0.0:100.0	4.8	23	45	68	33.8:66.2	40.7
1995	25	33	58	43.1:56.9	48.7	1	7	8	12.5:87.5	6.7	13	40	53	24.5:75.5	44.5
1996	32	37	69	46.4:53.6	51.1	0	8	8	0.0:100.0	5.9	18	40	58	31.0:69.0	43.0
1997	39	36	75	52.0:48.0	58.1	1	15	16	6.3:93.8	12.4	16	22	38	42.1:57.9	29.5
1998	23	32	55	41.8:58.2	56.7	0	2	2	0.0:100.0	2.1	14	26	40	35.0:65.0	41.2
1999	43	46	89	48.3:51.7	64.5	0	6	6	0.0:100.0	4.3	14	29	43	32.6:67.4	31.2
2000	18	31	49	36.7:63.3	35.8	7	15	22	31.8:68.2	16.1	34	32	66	51.5:48.5	48.2
2001	44	39	83	53.0:47.0	55.3	0	9	9	0.0:100.0	6.0	25	33	58	43.1:56.9	38.7
2002	58	42	100	58.0:42.0	63.3	1	11	12	8.3:91.7	7.6	22	24	46	47.8:52.2	29.1
2003	37	37	74	50.0:50.0	51.4	0	6	6	0.0:100.0	4.2	34	30	64	53.1:46.9	44.4
2004	52	61	113	46.0:54.0	52.8	0	11	11	0.0:100.0	5.1	44	46	90	48.9:51.1	42.1
2005	47	52	99	47.5:52.5	44.4	0	14	14	0.0:100.0	6.3	43	67	110	39.1:60.9	49.3
2006	42	44	86	48.8:51.2	48.0	1	7	8	12.5:87.5	4.5	49	36	85	57.6:42.4	47.5
2007	12	9	21	57.1:42.9	18.8	0	3	3	0.0:100.0	2.7	36	52	88	40.9:59.1	78.6
2008	27	38	65	41.5:58.5	63.7	0	3	3	0.0:100.0	2.9	7	27	34	20.6:79.4	33.3
2009	28	35	63	44.4:55.6	56.8	0	5	5	0.0:100.0	4.5	25	18	43	58.1:41.9	38.7
2010	28	41	69	40.6:59.4	52.7	0	7	7	0.0:100.0	5.3	14	41	55	25.5:74.5	42.0
2011	24	37	61	39.3:60.7	48.0	0	10	10	0.0:100.0	7.9	22	34	56	39.3:60.7	44.1
2012	0	0	0			0	0	0			0	0	0		
2013	7	3	10	70.0:30.0	47.6	0	1	1	0.0:100.0	4.8	5	5	10	50.0:50.0	47.6
Average	33	37	69	46.9:53.1	51.0	1	8	8	6.8:93.2	6.0	24	34	59	41.6:58.4	43.1

Appendix A16. Age and gender composition of the greater sage-grouse harvest, Steens Mountain, Hunt Unit 69, Oregon, 1993–2013.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	13	11	24	54.2:45.8	29.3	4	4	8	50.0:50.0	9.8	23	27	50	46.0:54.0	61.0
1994	28	23	51	54.9:45.1	45.5	0	5	5	0.0:100.0	4.5	17	39	56	30.4:69.6	50.0
1995	7	8	15	46.7:53.3	23.4	0	2	2	0.0:100.0	3.1	24	23	47	51.1:48.9	73.4
1996	9	20	29	31.0:69.0	42.0	1	4	5	20.0:80.0	7.2	14	21	35	40.0:60.0	50.7
1997	16	18	34	47.1:52.9	51.5	4	3	7	57.1:42.9	10.6	12	13	25	48.0:52.0	37.9
1998	6	5	11	54.5:45.5	24.4	1	1	2	50.0:50.0	4.4	14	18	32	43.8:56.3	71.1
1999	12	12	24	50.0:50.0	50.0	1	3	4	25.0:75.0	8.3	6	14	20	30.0:70.0	41.7
2000	11	11	22	50.0:50.0	57.9	0	3	3	0.0:100.0	7.9	8	5	13	61.5:38.5	34.2
2001	12	10	22	54.5:45.5	52.4	1	2	3	33.3:66.7	7.1	11	6	17	64.7:35.3	40.5
2002	17	13	30	56.7:43.3	43.5	1	12	13	7.7:92.3	18.8	14	12	26	53.8:46.2	37.7
2003	11	19	30	36.7:63.3	53.6	1	3	4	25.0:75.0	7.1	12	10	22	54.5:45.5	39.3
2004	9	16	25	36.0:64.0	31.6	1	5	6	16.7:83.3	7.6	21	27	48	43.8:56.3	60.8
2005	14	22	36	38.9:61.1	50.7	0	1	1	0.0:100.0	1.4	25	9	34	73.5:26.5	47.9
2006	10	18	28	35.7:64.3	41.2	3	1	4	75.0:25.0	5.9	22	14	36	61.1:38.9	52.9
2007	6	14	20	30.0:70.0	26.0	1	5	6	16.7:83.3	7.8	24	27	51	47.1:52.9	66.2
2008	13	4	17	76.5:23.5	56.7	0	1	1	0.0:100.0	3.3	7	5	12	58.3:41.7	40.0
2009	3	12	15	20.0:80.0	46.9	0	1	1	0.0:100.0	3.1	13	3	16	81.3:18.8	50.0
2010	5	1	6	83.3:16.7	17.6	0	2	2	0.0:100.0	5.9	19	7	26	73.1:26.9	76.5
2011	5	3	8	62.5:37.5	25.8	0	0	0		0.0	15	8	23	65.2:34.8	74.2
2012	6	6	12	50.0:50.0	25.0	2	1	3	66.7:33.3	6.3	23	10	33	69.7:30.3	68.8
2013	7	7	14	50.0:50.0	43.8	0	4	4	0.0:100.0	12.5	5	9	14	35.7:64.3	43.8
Average	10	12	23	46.5:53.5	39.6	1	3	4	17.0:83.0	7.0	16	15	30	51.7:48.3	53.3

Appendix A17. Age and gender composition of the greater sage-grouse harvest, Beatys Butte, Hunt Unit 70, Oregon, 1993–2013.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	23	23	46	50.0:50.0	59.7	1	2	3	33.3:66.7	3.9	13	15	28	46.4:53.6	36.4
1994	13	21	34	38.2:61.8	30.1	2	14	16	12.5:87.5	14.2	26	37	63	41.3:58.7	55.8
1995	14	18	32	43.8:56.3	31.7	0	1	1	0.0:100.0	1.0	16	52	68	23.5:76.5	67.3
1996	14	16	30	46.7:53.3	43.5	0	3	3	0.0:100.0	4.3	11	25	36	30.6:69.4	52.2
1997	42	32	74	56.8:43.2	56.1	1	9	10	10.0:90.0	7.6	18	30	48	37.5:62.5	36.4
1998	22	27	49	44.9:55.1	67.1	0	2	2	0.0:100.0	2.7	6	16	22	27.3:72.7	30.1
1999	28	37	65	43.1:56.9	55.1	3	4	7	42.9:57.1	5.9	21	25	46	45.7:54.3	39.0
2000	16	25	41	39.0:61.0	43.2	2	9	11	18.2:81.8	11.6	18	25	43	41.9:58.1	45.3
2001	18	20	38	47.4:52.6	45.2	1	3	4	25.0:75.0	4.8	23	19	42	54.8:45.2	50.0
2002	29	26	55	52.7:47.3	58.5	0	2	2	0.0:100.0	2.1	21	16	37	56.8:43.2	39.4
2003	27	30	57	47.4:52.6	52.8	0	3	3	0.0:100.0	2.8	31	17	48	64.6:35.4	44.4
2004	32	38	70	45.7:54.3	52.2	0	9	9	0.0:100.0	6.7	17	38	55	30.9:69.1	41.0
2005	27	29	56	48.2:51.8	44.1	0	8	8	0.0:100.0	6.3	37	26	63	58.7:41.3	49.6
2006	21	33	54	38.9:61.1	51.9	3	5	8	37.5:62.5	7.7	19	23	42	45.2:54.8	40.4
2007	6	10	16	37.5:62.5	21.9	0	6	6	0.0:100.0	8.2	20	31	51	39.2:60.8	69.9
2008	18	21	39	46.2:53.8	60.0	0	2	2	0.0:100.0	3.1	8	16	24	33.3:66.7	36.9
2009	31	27	58	53.4:46.6	58.0	0	9	9	0.0:100.0	9.0	14	19	33	42.4:57.6	33.0
2010	12	13	25	48.0:52.0	45.5	0	1	1	0.0:100.0	1.8	8	21	29	27.6:72.4	52.7
2011	24	27	51	47.1:52.9	51.5	0	3	3	0.0:100.0	3.0	30	15	45	66.7:33.3	45.5
2012	3	12	15	20.0:80.0	17.6	12	12	24	50.0:50.0	28.2	20	26	46	43.5:56.5	54.1
2013	23	31	54	42.6:57.4	58.1	2	5	7	28.6:71.4	7.5	14	18	32	43.8:56.2	34.4
Average	21	25	46	46.2:53.8	48.0	1	5	7	19.4:80.6	7.0	19	24	43	43.4:56.6	45.1

Appendix A18. Age and gender composition of the greater sage-grouse harvest, Juniper, Hunt Unit 71, Oregon, 1993–2013.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	9	6	15	60.0:40.0	53.6	0	0	0		0.0	7	6	13	53.8:46.2	46.4
1994	2	8	10	20.0:80.0	18.5	1	6	7	14.3:85.7	13.0	6	31	37	16.2:83.8	68.5
1995	3	4	7	42.9:57.1	23.3	0	0	0		0.0	5	18	23	21.7:78.3	76.7
1996	10	12	22	45.5:54.5	47.8	0	3	3	0.0:100.0	6.5	4	17	21	19.0:81.0	45.7
1997	12	20	32	37.5:62.5	61.5	0	1	1	0.0:100.0	1.9	7	12	19	36.8:63.2	36.5
1998	5	9	14	35.7:64.3	50.0	0	0	0		0.0	3	11	14	21.4:78.6	50.0
1999	16	14	30	53.3:46.7	47.6	0	2	2	0.0:100.0	3.2	12	19	31	38.7:61.3	49.2
2000	13	11	24	54.2:45.8	47.1	1	0	1	100.0:0.0	2.0	13	13	26	50.0:50.0	51.0
2001	14	22	36	38.9:61.1	59.0	0	2	2	0.0:100.0	3.3	6	17	23	26.1:73.9	37.7
2002	14	22	36	38.9:61.1	60.0	1	3	4	25.0:75.0	6.7	11	9	20	55.0:45.0	33.3
2003	7	13	20	35.0:65.0	39.2	0	2	2	0.0:100.0	3.9	10	19	29	34.5:65.5	56.9
2004	11	11	22	50.0:50.0	48.9	0	1	1	0.0:100.0	2.2	10	12	22	45.5:54.5	48.9
2005	10	13	23	43.5:56.5	39.0	0	3	3	0.0:100.0	5.1	13	20	33	39.4:60.6	55.9
2006	5	11	16	31.3:68.8	32.0	0	0	0		0.0	14	20	34	41.2:58.8	68.0
2007	0	4	4	0.0:100.0	13.8	0	1	1	0.0:100.0	3.4	8	16	24	33.3:66.7	82.8
2008	13	7	20	65.0:35.0	51.3	0	0	0		0.0	6	13	19	31.6:68.4	48.7
2009	10	12	22	45.5:54.5	56.4	0	1	1	0.0:100.0	2.6	6	10	16	37.5:62.5	41.0
2010	4	9	13	30.8:69.2	44.8	0	2	2	0.0:100.0	6.9	8	6	14	57.1:42.9	48.3
2011	8	4	12	66.7:33.3	48.0	0	0	0		0.0	6	7	13	46.2:53.8	52.0
2012	0	1	1	0.0:100.0	4.8	0	3	3	0.0:100.0	14.3	8	9	17	47.1:52.9	81.0
2013	2	2	4	50.0:50.0	50	0	2	2	0.0:100.0	25	0	2	2	0.0:100.0	25
Average	8	10	18	43.9:56.1	44.1	0	2	2	8.6:91.4	4.0	8	14	21	36.2:63.8	51.8

Appendix A19. Age and gender composition of the greater sage-grouse harvest, Silvies, Hunt Unit 72, Oregon, 1993–2013.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	8	4	12	66.7:33.3	85.7	0	1	1	0.0:100.0	7.1	0	1	1	0.0:100.0	7.1
1994	3	6	9	33.3:66.7	47.4	0	1	1	0.0:100.0	5.3	0	9	9	0.0:100.0	47.4
1995	3	0	3	100.0:0.0	75.0	0	0	0		0.0	0	1	1	0.0:100.0	25.0
1996	0	4	4	0.0:100.0	50.0	0	0	0		0.0	0	4	4	0.0:100.0	50.0
1997	0	7	7	0.0:100.0	63.6	0	0	0		0.0	0	4	4	0.0:100.0	36.4
1998	0	3	3	0.0:100.0	27.3	0	0	0		0.0	0	8	8	0.0:100.0	72.7
1999	9	2	11	81.8:18.2	91.7	0	0	0		0.0	0	1	1	0.0:100.0	8.3
2000	0	1	1	0.0:100.0	20.0	0	0	0		0.0	4	0	4	100.0:0.0	80.0
2001	2	1	3	66.7:33.3	33.3	0	1	1	0.0:100.0	11.1	2	3	5	40.0:60.0	55.6
2002	3	5	8	37.5:62.5	80.0	0	1	1	0.0:100.0	10.0	0	1	1	0.0:100.0	10.0
2003	2	1	3	66.7:33.3	25.0	0	0	0		0.0	1	8	9	11.1:88.9	75.0
2004	0	0	0			0	0	0			0	0	0		
2005	0	3	3	0.0:100.0	37.5	1	0	1	100.0:0.0	12.5	2	2	4	50.0:50.0	50.0
2006	2	6	8	25.0:75.0	61.5	0	1	1	0.0:100.0	7.7	1	3	4	25.0:75.0	30.8
2007	4	4	8	50.0:50.0	50.0	0	1	1	0.0:100.0	6.3	3	4	7	42.9:57.1	43.8
2008	2	1	3	66.7:33.3	21.4	0	0	0		0.0	4	7	11	36.4:63.6	78.6
2009	1	3	4	25.0:75.0	36.4	0	1	1	0.0:100.0	9.1	3	3	6	50.0:50.0	54.5
2010	0	2	2	0.0:100.0	25.0	0	0	0		0.0	1	5	6	16.7:83.3	75.0
2011	0	3	3	0.0:100.0	50.0	0	0	0		0.0	2	1	3	66.7:33.3	50.0
2012	2	1	3	66.7:33.3	75.0	0	1	1	0.0:100.0	25.0	0	0	0		0.0
2013	3	2	5	60.0:40.0	71.4	0	1	1	0.0:100.0	14.3	0	1	1	0.0:100.0	14.3
Average	2	3	5	42.7:57.3	51.0	0	0	0	10.0:90.0	5.0	1	3	4	25.8:74.2	44.1

Appendix A20. Age and gender composition of the greater sage-grouse harvest, Wagontire, Hunt Unit 73, Oregon, 1993–2013.

	Juveniles					Yearlings					Adults				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	0	0	0		0.0	0	0	0		0.0	1	4	5	20.0:80.0	100.0
1994	6	4	10	60.0:40.0	35.7	0	1	1	0.0:100.0	3.6	7	10	17	41.2:58.8	60.7
1995	1	3	4	25.0:75.0	23.5	0	2	2	0.0:100.0	11.8	2	9	11	18.2:81.8	64.7
1996	5	11	16	31.3:68.8	64.0	0	0	0		0.0	1	8	9	11.1:88.9	36.0
1997	8	7	15	53.3:46.7	53.6	0	1	1	0.0:100.0	3.6	3	9	12	25.0:75.0	42.9
1998	12	14	26	46.2:53.8	57.8	0	2	2	0.0:100.0	4.4	7	10	17	41.2:58.8	37.8
1999	4	3	7	57.1:42.9	33.3	0	1	1	0.0:100.0	4.8	5	8	13	38.5:61.5	61.9
2000	10	10	20	50.0:50.0	41.7	0	3	3	0.0:100.0	6.3	9	16	25	36.0:64.0	52.1
2001	14	18	32	43.8:56.3	60.4	0	5	5	0.0:100.0	9.4	7	9	16	43.8:56.3	30.2
2002	3	13	16	18.8:81.3	55.2	1	1	2	50.0:50.0	6.9	3	8	11	27.3:72.7	37.9
2003	4	6	10	40.0:60.0	34.5	1	2	3	33.3:66.7	10.3	6	10	16	37.5:62.5	55.2
2004	6	5	11	54.5:45.5	55.0	1	1	2	50.0:50.0	10.0	1	6	7	14.3:85.7	35.0
2005	6	8	14	42.9:57.1	60.9	1	2	3	33.3:66.7	13.0	1	5	6	16.7:83.3	26.1
2006	10	4	14	71.4:28.6	53.8	2	1	3	66.7:33.3	11.5	4	5	9	44.4:55.6	34.6
2007	5	7	12	41.7:58.3	40.0	0	0	0		0.0	4	14	18	22.2:77.8	60.0
2008	2	2	4	50.0:50.0	25.0	0	0	0		0.0	6	6	12	50.0:50.0	75.0
2009	7	10	17	41.2:58.8	73.9	0	0	0		0.0	2	4	6	33.3:66.7	26.1
2010	3	4	7	42.9:57.1	35.0	0	0	0		0.0	2	11	13	15.4:84.6	65.0
2011	5	4	9	55.6:44.4	56.3	0	2	2	0.0:100.0	12.5	1	4	5	20.0:80.0	31.3
2012	4	4	8	50.0:50.0	32.0	0	1	1	0.0:100.0	4.0	6	10	16	37.5:62.5	64.0
2013	7	5	12	58.3:41.7	63.2	0	0	0		0	0	7	7	0.0:100.0	36.8
Average	6	7	13	46.2:53.8	48.4	0	1	1	19.4:80.6	5.7	4	8	12	31.1:68.9	46.0

Appendix A21. Age and gender composition of the greater sage-grouse harvest, Warner, Hunt Unit 74, Oregon, 1993–2013.

	Juveniles					**Yearlings**					**Adults**				
Year	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**	**Males (*n*)**	**Females (*n*)**	**Total (*n*)**	**Male:female sex ratio**	**% in harvest**
1993	2	2	4	50.0:50.0	30.8	0	2	2	0.0:100.0	15.4	1	6	7	14.3:85.7	53.8
1994	9	14	23	39.1:60.9	39.7	0	2	2	0.0:100.0	3.4	14	19	33	42.4:57.6	56.9
1995	3	6	9	33.3:66.7	26.5	0	2	2	0.0:100.0	5.9	3	20	23	13.0:87.0	67.6
1996	11	13	24	45.8:54.2	61.5	0	0	0		0.0	8	7	15	53.3:46.7	38.5
1997	10	18	28	35.7:64.3	54.9	0	2	2	0.0:100.0	3.9	7	14	21	33.3:66.7	41.2
1998	16	12	28	57.1:42.9	62.2	0	4	4	0.0:100.0	8.9	6	7	13	46.2:53.8	28.9
1999	20	39	59	33.9:66.1	67.8	1	6	7	14.3:85.7	8.0	9	12	21	42.9:57.1	24.1
2000	10	12	22	45.5:54.5	56.4	0	1	1	0.0:100.0	2.6	6	10	16	37.5:62.5	41.0
2001	25	15	40	62.5:37.5	51.9	0	10	10	0.0:100.0	13.0	9	18	27	33.3:66.7	35.1
2002	27	25	52	51.9:48.1	65.0	0	1	1	0.0:100.0	1.3	14	13	27	51.9:48.1	33.8
2003	26	28	54	48.1:51.9	59.3	1	3	4	25.0:75.0	4.4	14	19	33	42.4:57.6	36.3
2004	23	35	58	39.7:60.3	53.2	1	11	12	8.3:91.7	11.0	18	21	39	46.2:53.8	35.8
2005	18	25	43	41.9:58.1	50.0	0	2	2	0.0:100.0	2.3	10	31	41	24.4:75.6	47.7
2006	18	23	41	43.9:56.1	55.4	0	2	2	0.0:100.0	2.7	10	21	31	32.3:67.7	41.9
2007	15	18	33	45.5:54.5	46.5	0	6	6	0.0:100.0	8.5	11	21	32	34.4:65.6	45.1
2008	24	30	54	44.4:55.6	54.0	0	8	8	0.0:100.0	8.0	10	28	38	26.3:73.7	38.0
2009	19	29	48	39.6:60.4	60.8	0	5	5	0.0:100.0	6.3	15	11	26	57.7:42.3	32.9
2010	20	25	45	44.4:55.6	54.2	1	4	5	20.0:80.0	6.0	11	22	33	33.3:66.7	39.8
2011	9	15	24	37.5:62.5	34.3	1	3	4	25.0:75.0	5.7	14	28	42	33.3:66.7	60.0
2012	8	16	24	33.3:66.7	38.1	0	8	8	0.0:100.0	12.7	13	18	31	41.9:58.1	49.2
2013	19	18	37	51.4:48.6	69.8	0	2	2	0.0:100.0	3.8	3	11	14	21.4:78.6	26.4
Average	16	20	36	44.3:55.7	53.5	0	4	4	5.6:94.4	6.3	10	17	27	36.6:63.4	40.2

Appendix B1. Greater sage-grouse productivity data, North Park, Colorado, 1974–1998.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1974	64.8	165	46.1	89	58.3	254	50.1	1.4	2.4
1975	52.8	127	39.0	59	48.4	186	42.0	1.1	2.4
1976	52.9	121	26.8	71	43.2	192	42.3	1.1	2.5
1977	59.1	171	32.9	76	51.0	247	45.9	1.2	2.3
1978	59.7	129	38.3	81	51.4	210	53.2	1.8	3.6
1979	65.1	129	55.8	154	60.1	283	57.7	2.2	3.7
1980	55.7	158	30.6	170	42.7	328	49.1	1.4	3.3
1981	37.4	227	21.9	151	31.2	378	47.4	1.3	4.1
1982	58.8	170	37.5	80	52.0	250	50.6	1.6	3.0
1983	65.6	183	50.6	164	58.5	347	57.4	1.9	3.3
1984	74.6	126	53.3	137	63.5	263	57.0	1.9	2.9
1985	54.9	113	43.8	112	49.3	225	53.6	1.6	3.2
1986	61.0	105	47.3	93	54.5	198	61.8	2.0	3.7
1987	50.4	115	36.0	114	43.2	229	54.2	1.6	3.7
1988	61.1	90	38.3	81	50.3	171	42.9	1.1	2.1
1989	49.4	85	19.6	92	33.9	177	46.1	1.1	3.1
1990	45.9	109	32.2	59	41.1	168	38.7	0.8	2.0
1991	53.0	83	28.6	28	46.8	111	43.0	1.0	2.1
1992	33.3	63	35.0	20	33.7	83	36.7	0.9	2.6
1993	69.2	78	40.0	20	63.3	98	45.1	1.1	1.7
1994	62.1	58	43.8	16	58.1	74	56.1	1.8	3.1
1995	63.6	11	60.0	15	61.5	26	36.5	0.9	1.4
1996	67.7	31	40.0	15	58.7	46	54.7	1.5	2.6
1997	53.6	28	44.4	18	50.0	46	51.4	1.6	3.1
1998	47.1	34	17.6	34	32.4	68	37.2	0.7	2.2
Totals	56.6	2709	38.8	1949	49.1	4658	50.7	1.5	3.0

Appendix B2. Greater sage-grouse productivity data, Middle Park, Colorado, 1975–1998.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1975	85.7	14	37.5	8	68.2	22	66.7	2.5	3.6
1976	64.3	14	64.3	14	64.3	28	63.9	2.5	3.8
1977	51.9	27	25.0	20	40.4	47	57.1	1.9	4.7
1978	68.4	38	44.4	27	58.5	65	45.9	1.4	2.3
1979	80.0	30	42.9	21	64.7	51	50.0	1.6	2.5
1980	53.3	15	70.6	17	62.5	32	51.6	1.5	2.5
1981	33.3	9	33.3	9	33.3	18	22.0	0.5	1.5
1982	77.8	9	25.0	4	61.5	13	75.8	3.6	5.9
1983	71.4	21	27.8	18	51.3	39	51.6	1.7	3.2
1984	92.3	13	40.0	15	64.3	28	56.0	2.2	3.4
1985	71.4	14	50.0	14	60.7	28	38.7	0.9	1.4
1986	65.2	23	37.5	16	53.8	39	58.6	1.7	3.1
1987	83.3	18	20.0	10	60.7	28	66.4	2.7	4.4
1988	75.0	16	50.0	10	65.4	26	54.3	1.9	2.9
1989	66.7	15	71.4	7	68.2	22	38.2	1.2	1.7
1990	60.0	10	33.3	9	47.4	19	38.6	1.4	3.0
1991	66.7	18	71.4	7	68.0	25	47.9	1.4	2.1
1992	23.8	21	28.6	7	25.0	28	45.3	1.2	4.9
1993	40.0	10	33.3	12	36.4	22	54.7	1.3	3.6
1994		0		0		0	100.0		
1995	75.0	4	100.0	1	80.0	5	30.8	0.8	1.0
1996	50.0	2	66.7	3	60.0	5	68.4	2.6	4.3
1997	100.0	3	33.3	3	66.7	6	30.0	0.5	0.7
1998	0.0	1	0.0	1	0.0	2	0.0	0.0	
Totals	65.5	345	42.7	253	55.9	598	52.6	1.6	2.9

Appendix B3. Greater sage-grouse productivity data, Eagle, Colorado, 1977–1998. Wings of only juveniles were reported in 1982 and no wings were received in 1995 and 1996.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1977	50.0	4	50.0	8	50.0	12	65.7	1.9	3.8
1978	57.9	19	100.0	3	63.6	22	59.5	2.1	3.4
1979	62.5	8	83.3	6	71.4	14	48.6	2.6	3.6
1980	60.0	10	42.9	7	52.9	17	69.1	2.8	5.2
1981	100.0	1	0.0	1	50.0	2	76.9	5.0	10.0
1982		0		0		0	100.0		
1983	75.0	12	50.0	16	60.7	28	56.7	1.8	3.0
1984	100.0	3	83.3	6	88.9	9	42.3	1.2	1.4
1985	71.4	7	50.0	2	66.7	9	58.8	2.2	3.3
1986	50.0	8	50.0	4	50.0	12	69.2	2.3	4.5
1987	75.0	8	40.0	10	55.6	18	55.6	1.9	3.5
1988	83.3	6	33.3	6	58.3	12	54.1	1.7	2.9
1989	100.0	1	100.0	1	100.0	2	75.0	3.0	3.0
1990	75.0	8		0	75.0	8	61.5	2.0	2.7
1991	100.0	2	80.0	5	85.7	7	63.6	4.0	4.7
1992	33.3	3	0.0	1	25.0	4	45.5	2.5	10.0
1993	100.0	2		0	100.0	2	25.0	0.5	0.5
1994	100.0	2		0	100.0	2	36.4	2.0	2.0
1995		0		0		0	0.0		
1996		0		0		0	0.0		
1997		0	100.0	1	100.0	1	50.0	1.0	1.0
1998	100.0	1		0	100.0	1	80.0	4.0	4.0
Totals	68.6	105	55.8	77	63.2	182	59.3	2.3	3.6

Appendix B4. Greater sage-grouse productivity data, Yampa, Colorado, 1977–1998.

	Estimated annual reproductive success						**Juveniles**		
Year	**Adult**		**Yearling**		**All females**		**In harvest (%)**	**Per hen**	**Per successful hen**
	%	***n***	**%**	***n***	**%**	***n***			
1977	45.5	11	25.0	16	33.3	27	58.6	2.1	6.5
1978	50.0	32	50.0	14	50.0	46	45.5	1.2	2.4
1979	68.4	19	39.3	28	51.1	47	37.0	1.1	2.1
1980	48.1	27	52.6	19	50.0	46	42.4	1.3	2.7
1981	50.0	18	20.0	25	32.6	43	21.3	0.4	1.2
1982	60.0	5	25.0	4	44.4	9	57.6	2.1	4.8
1983	83.3	6	57.1	7	69.2	13	57.1	1.8	2.7
1984	100.0	3	33.3	3	66.7	6	51.9	2.3	3.5
1985	42.9	7	0.0	3	30.0	10	34.8	0.8	2.7
1986	100.0	2	0.0	2	50.0	4	63.6	1.8	3.5
1987	0.0	3	66.7	3	33.3	6	33.3	0.7	2.0
1988	75.0	4	50.0	2	66.7	6	16.7	0.8	1.2
1989	0.0	2	33.3	3	20.0	5	43.2	3.2	16.0
1990	50.0	4	50.0	2	50.0	6	47.1	1.3	2.7
1991	60.0	5	80.0	5	70.0	10	48.1	1.3	1.9
1992	66.7	3		0	66.7	3	25.0	1.0	1.5
1993	42.9	14	100.0	2	50.0	16	54.8	1.4	2.9
1994	100.0	1	0.0	1	50.0	2	18.2	1.0	2.0
1995	100.0	4		0	100.0	4	50.0	1.0	1.0
1996		0		0		0	100.0		
1997		0	100.0	1	100.0	1	0.0		
1998	100.0	1		0	100.0	1	100.0		
Totals	55.0	171	39.3	140	47.9	311	43.2	1.2	2.6

Appendix B5. Greater sage-grouse productivity data, Piceance Basin, Colorado, 1977–1994.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1977	73.3	15	55.6	9	66.7	24	49.2	1.3	2.0
1978	76.5	17	50.0	12	65.5	29	65.8	2.6	3.9
1979	100.0	10	100.0	4	100.0	14	54.9	2.8	2.8
1980	66.7	6	33.3	6	50.0	12	67.9	4.4	8.8
1981	0.0	2	100.0	1	33.3	3	83.3	6.7	20.0
1982	66.7	9	50.0	6	60.0	15	69.5	2.7	4.6
1983	50.0	4	77.8	9	69.2	13	62.7	2.5	3.6
1984	71.4	7	60.0	5	66.7	12	61.9	2.2	3.2
1985	50.0	6	50.0	2	50.0	8	69.4	3.1	6.3
1986	45.5	11	41.7	12	43.5	23	37.9	1.1	2.5
1987	50.0	4	40.0	10	42.9	14	63.0	2.4	5.7
1988	60.0	5	80.0	5	70.0	10	55.6	1.5	2.1
1989	20.0	5	37.5	8	30.8	13	36.7	1.4	4.5
1990	33.3	3	0.0	2	20.0	5	37.5	1.8	9.0
1991	0.0	3	0.0	1	0.0	4	14.3	0.3	
1992	50.0	4	20.0	5	33.3	9	47.4	1.0	3.0
1993	75.0	4	0.0	1	60.0	5	57.1	1.6	2.7
1994	100.0	4		0	100.0	4	70.6	3.0	3.0
Totals	63.0	119	50.0	98	57.1	217	57.6	2.1	3.7

Appendix B6. Greater sage-grouse productivity data, Blue Mountain, Colorado, 1976–1998.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1976	50.0	22	20.0	10	40.6	32	61.6	2.2	5.3
1977	35.7	14	28.6	7	33.3	21	60.4	3.0	9.2
1978	51.4	74	36.8	68	44.4	142	62.1	2.3	5.2
1979	54.3	70	36.5	74	45.1	144	45.0	1.4	3.1
1980	56.6	53	25.8	31	45.2	84	68.8	2.8	6.3
1981	41.7	12	52.6	19	48.4	31	54.9	2.2	4.5
1982	55.6	18	33.3	21	43.6	39	70.5	4.1	9.3
1983	69.2	26	29.4	17	53.5	43	63.2	2.1	4.0
1984	60.7	28	46.4	28	53.6	56	63.1	2.8	5.3
1985	86.2	29	41.7	36	61.5	65	67.4	3.4	5.6
1986	55.1	49	36.0	50	45.5	99	59.5	2.3	5.1
1987	48.2	56	41.5	41	45.4	97	66.3	3.1	6.8
1988	61.1	36	20.8	48	38.1	84	50.0	1.8	4.6
1989	49.2	61	29.3	58	39.5	119	41.3	1.3	3.2
1990	41.5	53	15.8	38	30.8	91	55.4	1.7	5.7
1991	55.3	38	31.4	35	43.8	73	54.0	1.7	3.8
1992	36.4	33	13.0	23	26.8	56	45.9	1.3	4.9
1993	75.8	33	54.5	11	70.5	44	65.2	2.3	3.3
1994	66.7	18	45.5	22	55.0	40	48.7	1.4	2.5
1995	77.8	9	46.2	13	59.1	22	74.5	3.2	5.4
1996	61.5	26	31.3	16	50.0	42	56.6	2.0	3.9
1997	50.0	8	55.6	9	52.9	17	50.0	2.0	3.8
1998	57.1	7	16.7	6	38.5	13	50.0	1.5	4.0
Totals	55.1	773	33.6	681	45.0	1454	58.3	2.2	4.8

Appendix B7. Greater sage-grouse productivity data, Cold Spring Mountain, Colorado, 1976–1998. Wings were not identifiable to specific hunting area in 1978–1979.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1976	80.0	10	0.0	2	66.7	12	73.1	3.2	4.7
1977	80.0	20	25.0	12	59.4	32	59.8	1.9	3.2
1978		0		0		0	0.0		
1979		0		0		0	0.0		
1980	61.9	21	50.0	4	60.0	25	60.3	1.9	3.1
1981	47.6	42	21.4	28	37.1	70	61.7	2.2	6.0
1982	53.8	13	12.5	8	38.1	21	64.6	2.4	6.4
1983	73.2	41	54.2	24	66.2	65	68.0	2.7	4.1
1984	61.5	13	37.5	8	52.4	21	39.1	0.9	1.6
1985	63.2	38	31.8	22	51.7	60	62.1	2.1	4.0
1986	77.3	22	33.3	12	61.8	34	61.4	2.1	3.3
1987	63.6	11	33.3	12	47.8	23	49.3	1.5	3.2
1988	64.3	14	15.4	13	40.7	27	54.1	1.7	4.2
1989	60.6	33	20.8	24	43.9	57	51.3	1.7	3.9
1990	57.7	52	16.7	24	44.7	76	52.5	1.4	3.1
1991	59.0	39	53.8	13	57.7	52	68.1	2.5	4.3
1992	62.5	32	56.5	23	60.0	55	51.9	1.5	2.5
1993	88.5	26	70.6	17	81.4	43	62.3	2.1	2.6
1994	100.0	4	87.5	8	91.7	12	72.3	3.9	4.3
1995	83.3	6	33.3	3	66.7	9	60.0	1.7	2.5
1996	71.4	7	66.7	3	70.0	10	63.0	3.4	4.9
1997	60.0	10	33.3	6	50.0	16	65.5	2.3	4.5
1998	54.5	22	15.4	13	40.0	35	45.7	1.2	3.1
Totals	64.5	476	35.8	279	53.9	755	59.4	1.8	3.4

Appendix B8. Greater sage-grouse productivity data, Eastern Moffat and Northwestern Routt counties, Colorado, 1976–1998. Season closed in 1998 but some wings were received. No wings were received in 1995.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1976	50.0	8	28.6	7	40.0	15	46.3	1.7	4.2
1977	58.3	24	28.6	14	47.4	38	39.6	0.9	2.0
1978	70.8	24	76.5	17	73.2	41	77.8	5.0	6.9
1979	48.9	45	35.7	84	40.3	129	57.5	1.7	4.1
1980	47.2	53	29.2	48	38.6	101	50.8	1.5	3.8
1981	31.3	99	18.8	85	25.5	184	42.7	1.0	4.0
1982	52.9	34	27.8	36	40.0	70	46.3	1.2	3.1
1983	59.1	44	34.8	23	50.7	67	47.5	1.4	2.8
1984	62.5	8	77.8	9	70.6	17	62.1	2.1	3.0
1985	64.3	14	31.8	22	44.4	36	65.1	2.3	5.3
1986	69.2	13	57.1	14	63.0	27	70.1	4.1	6.5
1987	55.0	20	27.3	22	40.5	42	65.1	2.3	5.7
1988	50.0	30	12.5	24	33.3	54	50.7	1.4	4.2
1989	50.0	46	16.7	30	36.8	76	59.8	1.9	5.3
1990	49.0	49	16.3	49	32.7	98	49.8	1.7	5.1
1991	38.7	31	33.3	24	36.4	55	42.1	1.1	3.0
1992	33.3	27	33.3	9	33.3	36	34.2	0.8	2.3
1993	53.1	32	0.0	7	43.6	39	32.4	0.6	1.4
1994	75.0	12	30.8	13	52.0	25	62.0	1.8	3.4
1995		0		0		0	0.0		
1996	66.7	6	20.0	5	45.5	11	47.8	1.0	2.2
1997		0		0		0	100.0		
1998	25.0	8	50.0	4	33.3	12	14.3	0.2	0.5
Totals	48.8	627	29.1	546	39.6	1173	53.5	1.6	4.1

Appendix B9. Greater sage-grouse productivity data, Northcentral Moffat County, Colorado, 1976–1998.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1976	54.9	91	40.0	55	49.3	146	65.1	2.4	4.8
1977	25.9	81	7.4	54	18.5	135	33.3	0.9	4.8
1978	74.2	213	60.5	43	71.9	256	71.7	3.4	4.8
1979	62.0	200	49.5	291	54.6	491	57.1	2.3	4.1
1980	45.1	275	33.8	142	41.2	417	53.0	2.0	4.9
1981	47.5	255	41.3	121	45.5	376	54.8	1.7	3.7
1982	43.6	133	27.0	63	38.3	196	61.4	2.1	5.4
1983	56.2	210	40.0	130	50.0	340	57.1	2.0	4.0
1984	57.6	125	44.6	74	52.8	199	55.7	1.7	3.2
1985	62.4	125	42.5	80	54.6	205	62.7	2.5	4.6
1986	50.4	129	38.3	149	43.9	278	58.6	2.2	5.0
1987	48.0	227	36.1	191	42.6	418	55.9	1.8	4.3
1988	39.5	215	29.7	158	35.4	373	51.3	1.6	4.5
1989	45.2	283	37.8	119	43.0	402	53.9	2.1	4.8
1990	41.1	326	16.7	233	30.9	559	44.5	1.2	3.9
1991	46.8	265	23.9	109	40.1	374	40.7	1.0	2.5
1992	42.3	182	13.6	88	33.0	270	41.3	0.9	2.9
1993	65.1	86	37.9	29	58.3	115	53.1	1.7	2.9
1994	54.1	111	25.7	35	47.3	146	47.7	1.2	2.5
1995	47.1	17	75.0	8	56.0	25	64.9	2.5	4.5
1996	60.7	28	33.3	18	50.0	46	55.9	1.8	3.5
1997	55.6	18	55.6	9	55.6	27	50.0	1.5	2.7
1998	63.6	11	66.7	6	64.7	17	60.0	2.8	4.4
Totals	50.0	3606	34.7	2205	44.2	5811	54.6	1.8	4.1

Appendix B10. Greater sage-grouse productivity data, Sumpter, Hunt Unit 51, Oregon, 1993–2013.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1993	100.0	1		0	100.0	1	83.3	5.0	5.0
1994	25.0	4	100.0	1	40.0	5	50.0	1.0	2.5
1995	100.0	1		0	100.0	1	0.0	0.0	0.0
1996	100.0	1		0	100.0	1	33.3	2.0	2.0
1997	0.0	1		0	0.0	1	25.0	1.0	
1998		0		0		0	0.0		
1999	100.0	1		0	100.0	1	0.0	0.0	0.0
2000	0.0	1	0.0	1	0.0	2	33.3	0.5	
2001	0.0	2		0	0.0	2	0.0	0.0	
2002		0		0		0	0.0		
2003	0.0	2		0	0.0	2	0.0	0.0	
2004		0		0		0	100.0		
2005		0		0		0	100.0		
2006		0		0		0	0.0		
2007		0		0		0	0.0		
2008	0.0	2		0	0.0	2	0.0	0.0	
2009		0		0		0	0.0		
2010		0		0		0	0.0		
2011		0		0		0	0.0		
2012		0		0		0	0.0		
2013		0		0		0	0.0		
Totals	31.3	16	50.0	2	33.3	18	50.0	0.9	2.8

Appendix B11. Greater sage-grouse productivity data, Lookout Mountain, Hunt Unit 64, Oregon, 1993–2013.

Year	**Estimated annual reproductive success**						**Juveniles**		
	Adult		**Yearling**		**All females**		**In harvest (%)**	**Per hen**	**Per successful hen**
	%	***n***	**%**	***n***	**%**	***n***			
1993	0.0	2		0	0.0	2	62.5	2.5	
1994	0.0	2		0	0.0	2	25.0	0.5	
1995	0.0	1	50.0	2	33.3	3	50.0	1.3	4.0
1996		0		0		0	100.0		
1997		0		0		0	0.0		
1998		0		0		0	0.0		
1999	0.0	4		0	0.0	4	25.0	0.8	
2000		0		0		0	0.0		
2001	0.0	1		0	0.0	1	60.0	3.0	
2002		0		0		0	66.7		
2003	100.0	2	100.0	1	100.0	3	66.7	2.0	2.0
2004	0.0	1		0	0.0	1	0.0	0.0	
2005	0.0	2		0	0.0	2	50.0	2.0	
2006	0.0	1		0	0.0	1	33.3	3.0	
2007	0.0	1		0	0.0	1	0.0	0.0	
2008	50.0	2		0	50.0	2	0.0	0.0	0.0
2009		0		0		0	0.0		
2010		0		0		0	0.0		
2011	0.0	1		0	0.0	1	0.0	0.0	
2012	0.0	1	0.0	1	0.0	2	25.0	0.5	
2013		0		0		0	0.0		
Totals	14.3	21	50.0	4	20.0	25	40.0	1.4	7.0

Appendix B12. Greater sage-grouse productivity data, Beulah, Hunt Unit 65, Oregon, 1993–2013.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1993	71.4	7	100.0	1	75.0	8	38.9	0.9	1.2
1994	30.8	13	50.0	4	35.3	17	52.9	1.6	4.5
1995	12.5	8	100.0	1	22.2	9	31.0	1.0	4.5
1996	25.0	8	0.0	1	22.2	9	50.0	1.6	7.0
1997	28.6	21	40.0	5	30.8	26	45.6	1.2	3.9
1998	50.0	16	100.0	2	55.6	18	47.2	1.4	2.5
1999	60.0	15	100.0	3	66.7	18	47.9	1.9	2.8
2000	31.6	19	100.0	1	35.0	20	47.0	1.6	4.4
2001	53.3	15	33.3	3	50.0	18	55.8	1.6	3.2
2002	60.0	20	100.0	2	63.6	22	49.2	1.3	2.1
2003	25.0	16	0.0	4	20.0	20	39.7	1.2	5.8
2004	31.6	19	100.0	3	40.9	22	62.3	1.7	4.2
2005	56.0	25	100.0	2	59.3	27	51.1	1.7	2.9
2006	23.5	17		0	23.5	17	63.3	2.2	9.5
2007	14.3	14	100.0	1	20.0	15	25.0	0.4	2.0
2008	37.5	8	100.0	1	44.4	9	60.9	1.6	3.5
2009	25.0	16		0	25.0	16	57.9	2.1	8.3
2010	47.1	17	0.0	4	38.1	21	49.1	1.3	3.5
2011	33.3	6	50.0	2	37.5	8	37.0	1.3	3.3
2012	11.1	9	0.0	4	7.7	13	38.7	0.9	12.0
2013		0		0		0	80.0	-	-
Totals	37.7	289	52.3	44	39.6	333	49.0	1.5	3.7

Appendix B13. Greater sage-grouse productivity data, Malheur River, Hunt Unit 66, Oregon, 1993–2013.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1993	66.7	6	100.0	1	71.4	7	71.9	3.3	4.6
1994	42.9	28	33.3	3	41.9	31	46.0	1.3	3.1
1995	16.7	6	0.0	2	12.5	8	50.0	1.8	14.0
1996	20.0	10	100.0	1	27.3	11	60.6	1.8	6.7
1997	0.0	5	0.0	1	0.0	6	52.2	2.0	
1998	40.0	10	100.0	3	53.8	13	36.4	0.9	1.7
1999	50.0	12	100.0	3	60.0	15	56.9	1.9	3.2
2000	42.9	14	66.7	3	47.1	17	41.7	1.2	2.5
2001	44.4	9	42.9	7	43.8	16	45.3	1.8	4.1
2002	36.4	11	100.0	3	50.0	14	56.5	1.9	3.7
2003	35.7	14	25.0	4	33.3	18	54.7	1.6	4.8
2004	76.9	13	100.0	1	78.6	14	59.6	2.4	3.1
2005	42.1	19	100.0	3	50.0	22	37.0	1.2	2.5
2006	25.0	12	50.0	2	28.6	14	46.2	1.3	4.5
2007	16.7	6	50.0	4	30.0	10	31.8	0.7	2.3
2008	22.2	9	50.0	2	27.3	11	50.0	1.5	5.7
2009	25.0	4	50.0	2	33.3	6	43.8	1.2	3.5
2010	57.1	7	0.0	1	50.0	8	66.7	2.5	5.0
2011	20.0	5		0	20.0	5	0.0	0.0	0.0
2012		0		0		0	33.3		
2013	100	1	100	1	100	2	33.3	0.5	0.5
Totals	39.3	201	59.6	47	43.1	248	46.4	1.6	3.6

Appendix B14. Greater sage-grouse productivity data, Owyhee, Hunt Unit 67, Oregon, 1993–2013.

Year	**Estimated annual reproductive success**						**Juveniles**		
	Adult		**Yearling**		**All females**		**In harvest (%)**	**Per hen**	**Per successful hen**
	%	***n***	**%**	***n***	**%**	***n***			
1993	50.0	12		0	50.0	12	25.0	0.3	0.7
1994	18.8	16		0	18.8	16	40.0	0.8	4.0
1995	50.0	6	0.0	1	42.9	7	37.5	0.9	2.0
1996	42.9	7	66.7	3	50.0	10	62.5	2.0	4.0
1997	28.6	7		0	28.6	7	36.8	1.0	3.5
1998	36.4	11	100.0	1	41.7	12	18.8	0.5	1.2
1999	38.5	13	100.0	3	50.0	16	47.9	1.4	2.9
2000	20.0	10	0.0	2	16.7	12	53.8	2.3	14.0
2001	33.3	12	66.7	3	40.0	15	66.2	3.0	7.5
2002	66.7	12	100.0	3	73.3	15	47.5	1.3	1.7
2003	26.7	15	50.0	2	29.4	17	25.6	0.6	2.0
2004	37.5	16	100.0	1	41.2	17	52.8	1.6	4.0
2005	38.1	21	100.0	3	45.8	24	32.1	0.8	1.6
2006	23.1	13	100.0	1	28.6	14	22.2	0.7	2.5
2007	16.7	12	0.0	1	15.4	13	20.8	0.4	2.5
2008	16.7	6		0	16.7	6	50.0	1.3	8.0
2009	33.3	9		0	33.3	9	54.5	1.3	4.0
2010	0.0	3	0.0	1	0.0	4	37.5	1.5	
2011	0.0	6		0	0.0	6	13.3	0.3	
2012	36.4	11	0.0	2	30.8	13	43.9	1.4	4.5
2013	33	3	0	0	33.3	3	46.2	1.7	5
Totals	32.6	221	63.0	27	35.9	248	42.3	1.2	3.3

Appendix B15. Greater sage-grouse productivity data, Whitehorse, Hunt Unit 68, Oregon, 1993–2013. The Whitehorse Unit was closed to hunting in 2012.

Year	**Estimated annual reproductive success**						**Juveniles**		
	Adult		**Yearling**		**All females**		**In harvest (%)**	**Per hen**	**Per successful hen**
	%	***n***	**%**	***n***	**%**	***n***			
1993	42.1	38	100.0	3	46.3	41	44.9	1.4	3.0
1994	35.6	45	50.0	8	37.7	53	54.5	1.7	4.6
1995	50.0	40	42.9	7	48.9	47	48.7	1.2	2.5
1996	62.5	40	37.5	8	58.3	48	51.1	1.4	2.5
1997	54.5	22	86.7	15	67.6	37	58.1	2.0	3.0
1998	30.8	26	100.0	2	35.7	28	56.7	2.0	5.5
1999	75.9	29	100.0	6	80.0	35	64.5	2.5	3.2
2000	28.1	32	53.3	15	36.2	47	35.8	1.0	2.9
2001	34.4	32	77.8	9	43.9	41	55.3	2.0	4.5
2002	45.8	24	100.0	11	62.9	35	63.3	2.9	4.5
2003	60.0	30	83.3	6	63.9	36	51.4	2.1	3.2
2004	41.3	46	100.0	11	52.6	57	52.8	2.0	3.8
2005	46.3	67	100.0	14	55.6	81	44.4	1.2	2.2
2006	52.8	36	57.1	7	53.5	43	48.0	2.0	3.7
2007	21.2	52	33.3	3	21.8	55	18.8	0.4	1.8
2008	51.9	27	100.0	3	56.7	30	63.7	2.2	3.8
2009	38.9	18	60.0	5	43.5	23	56.8	2.7	6.3
2010	26.8	41	57.1	7	31.3	48	52.7	1.4	4.6
2011	29.4	34	70.0	10	38.6	44	48.0	1.4	3.6
2012		0		0		0			
2013	60	5	0	1	50.0	6	47.6	1.7	3.3
Totals	42.8	684	74.2	151	48.5	835	51.1	1.7	3.4

Appendix B16. Greater sage-grouse productivity data, Steens Mountain, Hunt Unit 69, Oregon, 1993–2013.

	Estimated annual reproductive success						**Juveniles**		
Year	**Adult**		**Yearling**		**All females**		**In harvest (%)**	**Per hen**	**Per successful hen**
	%	***n***	**%**	***n***	**%**	***n***			
1993	66.7	27	100.0	4	71.0	31	29.3	0.8	1.1
1994	33.3	39	20.0	5	31.8	44	45.5	1.2	3.6
1995	34.8	23	0.0	2	32.0	25	23.4	0.6	1.9
1996	33.3	21	100.0	4	44.0	25	42.0	1.2	2.6
1997	61.5	13	100.0	3	68.8	16	51.5	2.1	3.1
1998	44.4	18	100.0	1	47.4	19	24.4	0.6	1.2
1999	71.4	14	100.0	3	76.5	17	50.0	1.4	1.8
2000	20.0	5	66.7	3	37.5	8	57.9	2.8	7.3
2001	16.7	6	0.0	2	12.5	8	52.4	2.8	22.0
2002	50.0	12	100.0	12	75.0	24	43.5	1.3	1.7
2003	70.0	10	100.0	3	76.9	13	53.6	2.3	3.0
2004	29.6	27	100.0	5	40.6	32	31.6	0.8	1.9
2005	33.3	9	100.0	1	40.0	10	50.7	3.6	9.0
2006	57.1	14	0.0	1	53.3	15	41.2	1.9	3.5
2007	44.4	27	100.0	5	53.1	32	26.0	0.6	1.2
2008	80.0	5	100.0	1	83.3	6	56.7	2.8	3.4
2009	33.3	3	100.0	1	50.0	4	46.9	3.8	7.5
2010	57.1	7	100.0	2	66.7	9	17.6	0.7	1.0
2011	37.5	8		0	37.5	8	25.8	1.0	2.7
2012	20.0	10	0.0	1	18.2	11	25.0	1.1	6.0
2013	55.6	9	50.0	4	53.8	13	43.8	1.1	2.0
Totals	44.6	307	79.4	63	50.5	370	39.6	1.3	2.5

Appendix B17. Greater sage-grouse productivity data, Beatys Butte, Hunt Unit 70, Oregon, 1993–2013.

Year	**Estimated annual reproductive success**						**Juveniles**		
	Adult		**Yearling**		**All females**		**In harvest (%)**	**Per hen**	**Per successful hen**
	%	***n***	**%**	***n***	**%**	***n***			
1993	66.7	15	100.0	2	70.6	17	59.7	2.7	3.8
1994	59.5	37	35.7	14	52.9	51	30.1	0.7	1.3
1995	42.3	52	0.0	1	41.5	53	31.7	0.6	1.5
1996	44.0	25	0.0	3	39.3	28	43.5	1.1	2.7
1997	70.0	30	100.0	9	76.9	39	56.1	1.9	2.5
1998	50.0	16	100.0	2	55.6	18	67.1	2.7	4.9
1999	68.0	25	100.0	4	72.4	29	55.1	2.2	3.1
2000	64.0	25	44.4	9	58.8	34	43.2	1.2	2.1
2001	47.4	19	100.0	3	54.5	22	45.2	1.7	3.2
2002	68.8	16	100.0	2	72.2	18	58.5	3.1	4.2
2003	76.5	17	100.0	3	80.0	20	52.8	2.9	3.6
2004	47.4	38	100.0	9	57.4	47	52.2	1.5	2.6
2005	34.6	26	100.0	8	50.0	34	44.1	1.6	3.3
2006	52.2	23	60.0	5	53.6	28	51.9	1.9	3.6
2007	45.2	31	33.3	6	43.2	37	21.9	0.4	1.0
2008	56.3	16	100.0	2	61.1	18	60.0	2.2	3.5
2009	52.6	19	66.7	9	57.1	28	58.0	2.1	3.6
2010	42.9	21	100.0	1	45.5	22	45.5	1.1	2.5
2011	60.0	15	33.3	3	55.6	18	51.5	2.8	5.1
2012	46.2	26	41.7	12	44.7	38	17.6	0.4	0.9
2013	27.8	18	60	5	34.8	23	58.1	2.4	6.8
Totals	52.4	510	66.1	112	54.8	622	48.0	1.5	2.8

Appendix B18. Greater sage-grouse productivity data, Juniper, Hunt Unit 71, Oregon, 1993–2013.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1993	33.3	6		0	33.3	6	53.6	2.5	7.5
1994	58.1	31	50.0	6	56.8	37	18.5	0.3	0.5
1995	11.1	18		0	11.1	18	23.3	0.4	3.5
1996	64.7	17	33.3	3	60.0	20	47.8	1.1	1.8
1997	75.0	12	100.0	1	76.9	13	61.5	2.5	3.2
1998	45.5	11		0	45.5	11	50.0	1.3	2.8
1999	68.4	19	100.0	2	71.4	21	47.6	1.4	2.0
2000	46.2	13		0	46.2	13	47.1	1.8	4.0
2001	29.4	17	100.0	2	36.8	19	59.0	1.9	5.1
2002	66.7	9	100.0	3	75.0	12	60.0	3.0	4.0
2003	73.7	19	50.0	2	71.4	21	39.2	1.0	1.3
2004	33.3	12	100.0	1	38.5	13	48.9	1.7	4.4
2005	65.0	20	100.0	3	69.6	23	39.0	1.0	1.4
2006	80.0	20		0	80.0	20	32.0	0.8	1.0
2007	31.3	16	0.0	1	29.4	17	13.8	0.2	0.8
2008	46.2	13		0	46.2	13	51.3	1.5	3.3
2009	80.0	10	100.0	1	81.8	11	56.4	2.0	2.4
2010	33.3	6	100.0	2	50.0	8	44.8	1.6	3.3
2011	42.9	7		0	42.9	7	48.0	1.7	4.0
2012	33.3	9	0.0	3	25.0	12	4.8	0.1	0.3
2013	0	2	100	2	50	4	50	1	2
Totals	52.6	287	68.7	32	54.2	319	44.1	1.2	2.2

Appendix B19. Greater sage-grouse productivity data, Silvies, Hunt Unit 72, Oregon, 1993–2013.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1993	100.0	1	100.0	1	100.0	2	85.7	6.0	6.0
1994	22.2	9	0.0	1	20.0	10	47.4	0.9	4.5
1995	0.0	1		0	0.0	1	75.0	3.0	
1996	75.0	4		0	75.0	4	50.0	1.0	1.3
1997	75.0	4		0	75.0	4	63.6	1.8	2.3
1998	87.5	8		0	87.5	8	27.3	0.4	0.4
1999	100.0	1		0	100.0	1	91.7	11.0	11.0
2000		0		0		0	20.0		
2001	66.7	3	100.0	1	75.0	4	33.3	0.8	1.0
2002	100.0	1	100.0	1	100.0	2	80.0	4.0	4.0
2003	12.5	8		0	12.5	8	25.0	0.4	3.0
2004		0		0		0	0.0		
2005	100.0	2		0	100.0	2	37.5	1.5	1.5
2006	66.7	3	100.0	1	75.0	4	61.5	2.0	2.7
2007	0.0	4	100.0	1	20.0	5	50.0	1.6	8.0
2008	28.6	7		0	28.6	7	21.4	0.4	1.5
2009	33.3	3	0.0	1	25.0	4	36.4	1.0	4.0
2010	60.0	5		0	60.0	5	25.0	0.4	0.7
2011	0.0	1		0	0.0	1	50.0	3.0	
2012		0	0.0	1	0.0	1	75.0	3.0	
2013	100	1	0	1	50	2	71.4	2.5	5
Totals	48.5	66	55.6	9	49.3	75	51	1.4	2.8

Appendix B20. Greater sage-grouse productivity data, Wagontire, Hunt Unit 73, Oregon, 1993–2013.

Year	**Estimated annual reproductive success**						**Juveniles**		
	Adult		**Yearling**		**All females**		**In harvest (%)**	**Per hen**	**Per successful hen**
	%	***n***	**%**	***n***	**%**	***n***			
1993	50.0	4		0	50.0	4	0.0	0.0	0.0
1994	30.0	10	0.0	1	27.3	11	35.7	0.9	3.3
1995	33.3	9	0.0	2	27.3	11	23.5	0.4	1.3
1996	62.5	8		0	62.5	8	64.0	2.0	3.2
1997	44.4	9	100.0	1	50.0	10	53.6	1.5	3.0
1998	70.0	10	100.0	2	75.0	12	57.8	2.2	2.9
1999	87.5	8	100.0	1	88.9	9	33.3	0.8	0.9
2000	62.5	16	100.0	3	68.4	19	41.7	1.1	1.5
2001	44.4	9	60.0	5	50.0	14	60.4	2.3	4.6
2002	50.0	8	100.0	1	55.6	9	55.2	1.8	3.2
2003	10.0	10	100.0	2	25.0	12	34.5	0.8	3.3
2004	66.7	6	100.0	1	71.4	7	55.0	1.6	2.2
2005	80.0	5	100.0	2	85.7	7	60.9	2.0	2.3
2006	40.0	5	0.0	1	33.3	6	53.8	2.3	7.0
2007	42.9	14		0	42.9	14	40.0	0.9	2.0
2008	33.3	6		0	33.3	6	25.0	0.7	2.0
2009	50.0	4		0	50.0	4	73.9	4.3	8.5
2010	45.5	11		0	45.5	11	35.0	0.6	1.4
2011	75.0	4	100.0	2	83.3	6	56.3	1.5	1.8
2012	50.0	10	0.0	1	45.5	11	32.0	0.7	1.6
2013	57.1	7		0	57.1	7	63.2	1.7	3
Totals	50.3	173	72.0	25	53.0	198	48.4	1.3	2.5

Appendix B21. Greater sage-grouse productivity data, Warner, Hunt Unit 74, Oregon, 1993–2013.

Year	Estimated annual reproductive success						Juveniles		
	Adult		Yearling		All females		In harvest (%)	Per hen	Per successful hen
	%	*n*	%	*n*	%	*n*			
1993	66.7	6	100.0	2	75.0	8	30.8	0.5	0.7
1994	42.1	19	0.0	2	38.1	21	39.7	1.1	2.9
1995	25.0	20	50.0	2	27.3	22	26.5	0.4	1.5
1996	85.7	7		0	85.7	7	61.5	3.4	4.0
1997	71.4	14	50.0	2	68.8	16	54.9	1.8	2.5
1998	14.3	7	100.0	4	45.5	11	62.2	2.5	5.6
1999	83.3	12	100.0	6	88.9	18	67.8	3.3	3.7
2000	50.0	10	100.0	1	54.5	11	56.4	2.0	3.7
2001	66.7	18	70.0	10	67.9	28	51.9	1.4	2.1
2002	69.2	13	100.0	1	71.4	14	65.0	3.7	5.2
2003	84.2	19	66.7	3	81.8	22	59.3	2.5	3.0
2004	47.6	21	100.0	11	65.6	32	53.2	1.8	2.8
2005	35.5	31	100.0	2	39.4	33	50.0	1.3	3.3
2006	57.1	21	50.0	2	56.5	23	55.4	1.8	3.2
2007	52.4	21	50.0	6	51.9	27	46.5	1.2	2.4
2008	60.7	28	62.5	8	61.1	36	54.0	1.5	2.5
2009	54.5	11	80.0	5	62.5	16	60.8	3.0	4.8
2010	13.6	22	50.0	4	19.2	26	54.2	1.7	9.0
2011	53.6	28	33.3	3	51.6	31	34.3	0.8	1.5
2012	16.7	18	0.0	8	11.5	26	38.1	0.9	8.0
2013	54.5	11	50	2	53.8	13	69.8	2.9	5.3
Totals	50.4	357	65.5	84	53.3	441	53.5	1.7	3.2

Bureau of Land Management and Oregon Dept. of Fish and Wildlife biologists examine greater sage-grouse wings mailed in by hunters in 2004, Hines, Oregon.

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OREGON DEPARTMENT OF FISH AND WILDLIFE

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Management and Conservation Article

Sage-Grouse Habitat Selection During Winter in Alberta

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ABSTRACT Greater sage-grouse (*Centrocercus urophasianus*) are dependent on sagebrush (*Artemisia* spp.) for food and shelter during winter, yet few studies have assessed winter habitat selection, particularly at scales applicable to conservation planning. Small changes to availability of winter habitats have caused drastic reductions in some sage-grouse populations. We modeled winter habitat selection by sage-grouse in Alberta, Canada, by using a resource selection function. Our purpose was to 1) generate a robust winter habitat-selection model for Alberta sage-grouse; 2) spatially depict habitat suitability in a Geographic Information System to identify areas with a high probability of selection and thus, conservation importance; and 3) assess the relative influence of human development, including oil and gas wells, in landscape models of winter habitat selection. Terrain and vegetation characteristics, sagebrush cover, anthropogenic landscape features, and energy development were important in top Akaike's Information Criterion–selected models. During winter, sage-grouse selected dense sagebrush cover and homogenous less rugged areas, and avoided energy development and 2-track truck trails. Sage-grouse avoidance of energy development highlights the need for comprehensive management strategies that maintain suitable habitats across all seasons.

KEY WORDS *Centrocercus urophasianus*, critical habitat, energy development, greater sage-grouse, resource selection functions, winter habitats.

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) is an endangered species in Canada (Committee on the Status of Endangered Wildlife in Canada 2004). Range-wide sage-grouse have lost approximately 44% of their presettlement range (Schroeder et al. 2004), and populations have continued to decline by 2% per year since 1965 (Connelly and Braun 1997, Connelly et al. 2004), with local declines as high as 92% (Connelly et al. 2000, Aldridge and Brigham 2003). As a result, sage-grouse are the focus of intensive research and management efforts across their range. Population declines are thought to be driven by reductions in habitat quality during 3 critical life stages: nesting, brood rearing, and wintering (Connelly et al. 2000, 2004; Moynahan et al. 2006; Aldridge and Boyce 2007; Hagen et al. 2007). Aldridge and Boyce (2007) identified and mapped critical habitats for sage-grouse nesting and brood rearing in Alberta, Canada, but Doherty et al. (2008) noted the lack information on landscape-level winter habitat needs for sage-grouse. Winter habitats are generally not considered a research priority because winter survival of sage-grouse is typically high (Connelly et al. 2004), but winter habitats may be of greater importance in declining populations. For example, in northern Colorado, USA, 80% of winter sites used by sage-grouse occurred in <7% of the total area of sagebrush (*Artemisia* spp.; Beck 1977), and small changes to the quality and availability of winter habitats have resulted in severe reductions in sage-grouse populations (Swenson et al. 1987). Furthermore, severe winters can contribute to reduced annual survival (Moynahan et al. 2006).

Most studies of sage-grouse winter habitats focused on site-specific features such as height, canopy cover, or crude protein levels in sagebrush and clearly identified the importance of moderate-to-dense sagebrush cover during winter (e.g., Eng and Schladweiler 1972, Beck 1977, Connelly et al. 2000, Crawford et al. 2004, Sauls 2006). Although important in understanding habitat use, such local studies do not present managers an understanding of habitat selection at a scale useful to identify and prioritize landscapes for conservation. An exception is in the Powder River Basin of Wyoming and Montana, USA, where a landscape approach was successfully used to determine that landscape factors, including vegetation, topography, and oil and gas development, affected sage-grouse winter habitat selection (Doherty et al. 2008).

Modeling habitat selection using resource selection functions (RSF) offers the ability to rank areas by their relative probability of selection (Manly et al. 2002). Mapping these relative probabilities in a Geographic Information System (GIS) can identify regions with high-quality habitats and can provide managers with a meaningful tool for prioritizing areas of conservation importance (Aldridge and Boyce 2007). Testing a habitat-selection model with independent data ensures inferences regarding habitat selection are robust and a competing-models framework can be used to evaluate alternative models of habitat selection (Burnham and Anderson 2002, Manly et al. 2002).

We investigated winter habitat selection by sage-grouse in southeastern Alberta. Our objectives were to 1) generate a robust winter habitat selection model for sage-grouse; 2) spatially depict habitat suitability to identify areas with a high probability of selection and thus, conservation importance; and 3) assess the relative influence of human development in landscape models, including intensive

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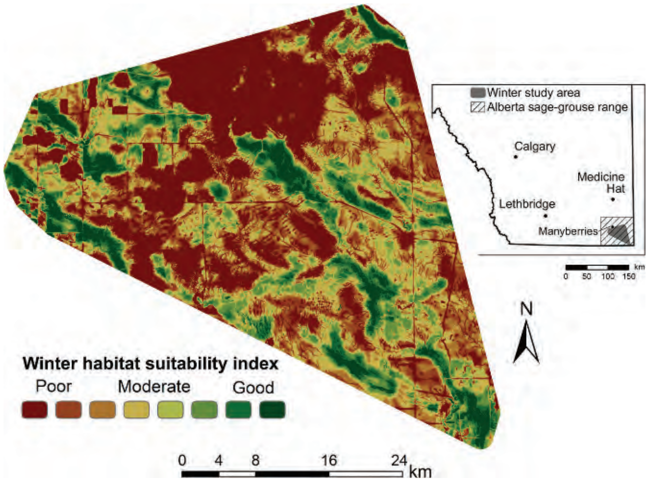

Figure 1. Winter habitat suitability for greater sage-grouse as determined by a resource selection function that incorporated terrain and vegetation, sagebrush, energy development, and anthropogenic feature variables. Good index values indicate increased probability of habitat selection by sage-grouse during winter. Inset depicts range of greater sage-grouse and location of study area within southeastern Alberta, Canada, 2002–2004.

energy development, on winter habitat selection. We hypothesized that sage-grouse select habitats containing greater abundance of sagebrush in landscapes that are free of snow throughout winter and that sage-grouse avoid landscapes with anthropogenic disturbances, such as those associated with energy development (i.e., well sites).

STUDY AREA

In the dry mixed grass prairie of southern Alberta, sage-grouse are found within an approximately 4,000-km^2 area. Cattle graze most of this area and approximately 30% of this area is influenced by oil and gas development (Aldridge and Boyce 2007). Our study area (49°24′N, 110°42′W, ~900-m elevation) encompassed the core of the winter range (1,400 km^2; Fig. 1, inset). Snowfall between November and March averaged 73 cm, and approximately 30 days per year were $<-20°$ C (Environment Canada 2009). Silver sagebrush (*Artemisia cana*) was the predominant shrub and no other species grows in this area. Grass was dominated by native grasses such as needle-and-thread grass (*Stipa comata*), June grass (*Koeleria macrantha*), and western wheatgrass (*Agropyron smithii*; Coupland 1961, Aldridge and Brigham 2003).

METHODS

We captured female sage-grouse on 5 of 8 active leks (breeding sites) in southeastern Alberta from 1999 to 2003 by using walk-in traps (Schroeder and Braun 1991). In August and September 2003, we captured additional juvenile females by on foot nightlighting of flocks containing adult females with radiocollars (Connelly et al. 2003). We fit females with 14-g necklace-style radio-transmitters (RI-2BM transmitters; Holohil Systems Ltd., Carp, ON, Canada). We located birds with a 3-element Yagi antenna and an R-1000 scanning telemetry receiver (Communications Specialists, Inc., Orange, CA). When we could not locate signals from the ground, we searched for signals from a fixed-wing aircraft. We located and flushed females approximately once per week during winter from 1 November to 15 March in 2002–2003 and 2003–2004 (hereafter winter 1 and winter 2, respectively). If a flock of birds flushed and we could not determine the exact location of the radiocollared bird, we recorded the approximate center of the flock as the use location. In this case, if we flushed multiple marked birds from the same flock, we considered a location for each bird in model development.

Geographic Information System Predictor Variables

Following Aldridge and Boyce (2007), we developed a suite of variables in a GIS that are probably important predictors of sage-grouse winter habitat selection. Following our hypotheses that sage-grouse select habitats with sagebrush and avoid landscapes with anthropogenic disturbances, we grouped variables into 4 classes: 1) terrain and vegetation; 2) sagebrush; 3) energy development; and 4) anthropogenic features, encompassing 86 variables (Table 1).

To analyze terrain and vegetation variables, we used Landsat Thematic Mapper satellite images from July 2000 to generate brightness (*brit_30*), greenness (*gren_30*), and normalized difference vegetation index (*ndvi*) by using a tasselled-cap transformation (Crist and Cicone 1984, Sellers 1985) in the program PCI Geomatica Prime 8.2 (PCI Geomatics, Richmond Hill, ON, Canada). We used a soil moisture index, referred to as compound topographic index (*cti*), that is correlated with soil moisture and nutrients and derived from a digital elevation model (Evans 2004). We also used a terrain ruggedness index (*tri*) derived from the amount of elevation difference between adjacent cells of a digital elevation model (Riley et al. 1999). We also estimated the mean of *ndvi*, *cti*, and *tri* and standard deviation of *ndvi* and *cti* values within a 1-km^2 moving window (*av_ndvi*, *sd_ndvi*, *cti_mean*, *cti_sd*, *tri_km*^{2}). We interpreted higher standard deviation values as representative of increasingly variable (heterogeneous) patches. Finally, we used a dry mixed grass plant community guide primarily based on soil types (Adams et al. 2005) to assign plant communities to ecosite categories (B. W. Adams, Alberta Sustainable Resource Development, personal communication) and estimated the proportion of each ecosite within a 1-km^2 moving window (*pec1*…*pec7*).

Sagebrush is an important habitat component for sage-grouse across all life stages at local scales (Beck 1977, Connelly et al. 2000, Crawford et al. 2004, Sauls 2006, Hagen et al. 2007) and also across landscapes (Aldridge and Boyce 2007, Doherty et al. 2008). Following Aldridge and Boyce (2007), we estimated sagebrush cover at both the pixel (*sbcov*) and 1-km^2 moving-window (*sbmean*) by using the results of Jones et al. (2005). Because sage-grouse seem to select intermediate sagebrush cover (Aldridge and Boyce 2007), we assessed quadratic functions for all sagebrush-cover metrics to identify potential nonlinearities in selection. We developed 2 measures (*sb_patch1*, *sb_patch2*) of patchy or heterogeneous sagebrush distribution (Aldridge and Boyce 2007) based on sagebrush distribution patterns described by

Table 1. Explanatory Geographic Information System (GIS) variables used within an information-theoretic approach to model winter habitat of sage-grouse in Alberta, Canada, 2002–2004. Data are 10-m resolution except where indicated. Decay function is in the form of (−exp[dist]/decay distance), where dist is the distance to the variable and decay distance is the specified decay distance value that shapes the function.

Variable name	Description
Landscape features	
crop_dst	Distance to nearest cultivated lands in km
crop_den	Proportion of land that is cultivated within a 1-km^2 moving window
crop_dst1000/500/250/50	Decay function for distance to *crop*
urban_dst	Distance to nearest urban development in km
urban_den	Proportion of land that is urban within a 1-km^2 moving window
urban_dst1000/500/250/50	Decay function for distance to *urban*
human_dst	Distance to any human habitat (roads, wells, urban) in km
human_den	Proportion of land that is human habitats within a 1-km^2 moving window
human_dst1000/500/250/50	Decay function for distance to *human*
edge_dst	Distance to habitat that creates an anthropogenic edge (*human* and *crop*) in km
edge_den	Proportion of land that is edge habitat within 1-km^2 moving window
edge_dst1000/500/250/50	Decay function for distance to *edge*
water_dst	Distance to nearest natural water body in km
water_dst1000/500/250/50	Decay function for distance to *water*
imped_dst	Distance to nearest water impoundment (dam, dugout, canal) in km
imped_den	Count of number of water impoundments within a 1-km^2 moving window
imped_dst1000/500/250/50	Decay function for distance to water impoundment
trail_dst	Distance to nearest *trail* (non-paved or graveled 2-track truck road) in km
trail_den	Linear km per km^2 of *trail* (non-paved or graveled 2-track truck road)
trail_dst1000/500/250/50	Decay function for distance to *trail* (non-paved or graveled 2-track truck road)
road_dst	Distance to nearest *road* (paved or graveled) in km
road_den	Linear km per km^2 of *roads* (paved or graveled)
road_dst1000/500/250/50	Decay function for distance to *road*
Energy development	
well_dst	Distance to nearest standing energy well site in km
well_den	Count of energy well sites within a 1-km^2 moving window
well_dst1000/500/250/50	Decay function for distance to energy well site
Terrain and vegetation	
brit_30	Brightness generated from Landsat 7 TM satellite imagery[a]
gren_30[b]	Greenness generated from Landsat 7 TM imagery[a]
wet_30m	Wetness generated from Landsat 7 TM imagery[a]
ndvi	Normalized difference vegetation index calculated from TM[c] imagery[a]
av_ndvi[b]	Mean NDVI[d] value within a 1-km^2 moving window[a]
sd_ndvi	Standard deviation of NDVI within a 1-km^2 moving window[a]
cti[b]	Compound topographic index (CTI; high values = increased moisture)[a]
cti_mean[b]	Mean CTI values within a 1-km^2 moving window[a]
cti_sd	Standard deviation of CTI values within a 1-km^2 moving window[a]
tri_alb[b]	Terrain ruggedness index (TRI; high values = increased ruggedness)[a]
tri_km^2	Mean TRI within a 1-km^2 moving window[a]
eco1	Thin break range sites, soils vary, characterized by greater shrub cover (1,0; categorical)
eco2	Loamy upland sites with medium texture soils and needle-and-thread grass, wheatgrass (*Agropyron* spp.), and June grass (1,0; categorical)
eco3	Blowout and overflow sites, solonetzic soils; varies, but higher density of sagebrush (1,0; categorical)
eco4	Saline lowlands, swales and depression, sparse low sagebrush (1,0; categorical)
eco5	Broad, wetland, and shrubby (willow [*Salix* spp.], rose [*Rosa* spp.], snowberry [*Symphoricarpos occidentalis*]) riparian habitats (1,0; categorical)
eco6	Loamy range site with well drained soils, low sagebrush cover (1,0; categorical)
eco7	Badlands type habitats with juniper (*Juniperus horizontalis*), needle-and-thread grass, and blue grama (*Bouteloua gracilis*; 1,0; categorical)
eco8	All anthropogenic altered habitats (urban, crop, wells, roads; 1,0; categorical)
pec1, pec2, … pec7[b]	Proportion of class within a 1-km^2 moving window that is eco1, eco2, …, eco7
Sagebrush	
sbcov	Sagebrush cover (%) as identified from air photo interpretation
sbcovsq	Squared term for *sbcov*
sbmean	Mean sagebrush cover (%) within a 1-km^2 moving window
sbmeansq	Squared term for *sbmean*
sb_patch1,sb_patch2	Patchy sagebrush distribution 1 (codes 7, 8, 9) or 2 (codes 7, 8, 9, 11) from Jones et al. (2005)
sb_prop_patch1, 2	Proportion of habitat within a 1-km^2 moving window that fits within patchy sagebrush distribution 1 or 2

[a] 30-m resolution.

[b] Variables removed from model development due to correlations.

[c] Thematic Mapper.

[d] Normalized difference vegetation index.

Jones et al. (2005). We assessed the proportion of each patch class within a 1-km^2 moving-window across the landscape (*sb_prop_patch1*, *sb_prop_patch2*).

Energy developments included distance to the nearest energy well site and the number of well sites within a 1-km^2 moving window (*well_dst*, *well_den*). Anthropogenic features included distance to the nearest road (*road_dst*); 2-track truck trail (*trail_dst*); cultivated (crop) land (*crop_dst*); and urban development, including a town, farmstead, or building not at a well site (*urban_dst*). Because anthropogenic variables can change between years, we fixed these variables at their 2003 condition and incorporated them into the landscape for the sagebrush and ecosite variables by replacement where an anthropogenic feature, such as a road or well, existed in 2003. We calculated density metrics for roads and 2-track truck trails as their linear km per km^2 or as the proportion of area that was crop or urban within a 1-km^2 moving window (*road_den*, *trail_den*, *crop_den*, *urban_den*). We generated additive estimates of human (roads, energy wells, urban) and anthropogenic edge (roads, oil wells, urban, crop) metrics as both distance and density (proportion of area within a 1-km^2 moving window) variables (*human_dst*, *human_den*, *edge_dst*, *edge_den*). In addition, we included metrics measuring the distance to nearest water source (*water_dst*) and water impoundment (*imped_dst*, *imped_den*).

For all distance variables, we calculated decay variables (Nielsen et al. 2009) because the response of birds to a given landscape factor typically declines as the distance between them increases. Accordingly, we created 4 decay variables for each distance variable by using the form $e^{-\alpha/d}$, where d was the distance in meters from each pixel to a landscape feature, and we set α at 50, 250, 500, and 1,000. This scaled each distance variable between 0 and 1, with highest values close to the feature of interest.

Model Development

We used logistic regression contrasting used versus available pixels to estimate an exponential RSF to identify the relative probability of selection as a function of landscape covariates (Boyce et al. 2002, Manly et al. 2002, Johnson et al. 2006). We generated 5,000 random locations across a 1-km buffer around a 100% minimum convex polygon surrounding 296 winter locations of 23 sage-grouse females. Annual variation can be of vital importance to understanding habitat selection if resource use varies between years (Schooley 1994). However, there was no indication of behavioral differences between winter 1 and winter 2 so to increase sample size, we included bird locations from both years in the same model. To reduce bias associated with the larger sample of available (0) resource units, we used an importance weight that gave full weighting to used resource units, but available resource units received a weighting (down) proportional to the ratio of sampled use (1) points to available points (StataCorp 2007; see Aldridge and Boyce 2007).

With limited large-scale studies on which to base a priori models (Burnham and Anderson 2002), we used a hierarchical information-theoretic method. First, we compared models or metrics and determined a best model to represent each of 4 variable classes (terrain and vegetation, sagebrush, energy developments, and anthropogenic features). Second, we allowed all combinations of the top models from each variable class to compete in an Akaike's Information Criterion (AIC) framework. At all stages, we accepted only models with a change in AIC (ΔAIC) score of <2, relative to the best model.

In the terrain and vegetation class, a priori models included variables for ecosite and measures of terrain. In cases of correlated predictors ($|r| > 0.7$), we chose to keep the most explanatory variable based on a univariate comparison. After removing correlated terrain variables, all models included *brit_30*, *wet_30m*, *ndvi*, *sd_ndvi*, and *cti*. We included a measure of landscape ruggedness (*tri_km*^{2}) in 2 of the models based on the importance of gentle topography in winter habitat selection by sage-grouse in Montana and Wyoming (Doherty et al. 2008). Because sagebrush and other shrubs might be important for both food and cover, we created 4 combinations of ecosite classes associated with shrub cover: higher density sagebrush (*pec1*), low sparse sagebrush (*pec4*), riparian shrubs (*pec5*), and low sagebrush cover (*pec6*).

In the sagebrush variable class, a priori models included both univariate and quadratic measures of sagebrush cover and patchiness. Based on Aldridge and Boyce (2007), we also included multi-variable models for sagebrush cover and patchiness (*sbcov*, *sbmean*, *sb_patch1*, *sb_patch2*, *sb_prop_patch1*, *sb_prop_patch2*). For the energy developments variable class, we evaluated univariate metrics for the density and distance to energy well sites by using AIC, and we selected only the best-performing metric to represent the energy variable class. We removed variables for well density and the smallest distance decay because there was no use of habitats within these buffers, causing models with the variables *well_dst50* and *well_den* to not converge. In the anthropogenic features variable class, we selected the best metric or scale for each of *road*, *trail*, *edge*, *urban*, *crop*, *water*, *imped*, and *human*. After removing correlated variables, we combined the best metrics for each of these to represent the anthropogenic variable class because we suspect these metrics all influence sage-grouse habitat selection.

After identifying a final model within each of the 4 variable classes, we allowed all 15 combinations of these top models to compete and accepted only models with a ΔAIC score <2 relative to the best model to represent winter sage-grouse habitat selection. At all levels of model selection, we did not allow correlated predictors ($|r| > 0.7$) in the same model. After estimating the final model, we assessed the effect size of anthropogenic features by predicting the relative probability of selection at increasing distances from the feature while holding each other variable at its mean value from the use locations.

We evaluated our top AIC-selected model by predicting it to an independent sample of 54 winter tracking locations made on birds captured between 1998 and 2001. During winters 1998–1999 and 2001–2002, 7 male (1.9 ± 0.34 locations/bird) and 25 female (1.6 ± 0.11 locations/bird)

Table 2. Akaike's Information Criterion (AIC)–selected models representing terrain and vegetation in winter habitat selection by greater sage-grouse in Alberta, Canada, from 2002 to 2004. We report model log likelihood (LL), number of model parameters (K), AIC, change in AIC from lowest model (ΔAIC), and Akaike weights (w_i) for 4 a priori candidate models.

Model[a]	LL	K	AIC	ΔAIC	w_i
brit_30, *wet_30m*, *sd_ndvi*, *cti_sd*, *tri_km*^{2}, *pec1*, *pec2*, *pec3*, *pec4*, *pec5*, *pec6*[b]	−202.5	12	429	0	1.00
brit_30, *wet_30m*, *sd_ndvi*, *cti_sd*, *tri_km*^{2}, *pec3*, *pec4*, *pec5*	−234.8	9	488	59	0.00
brit_30, *wet_30m*, *sd_ndvi*, *cti_sd*, *tri_km*^{2}, *pec3*, *pec4*, *pec5*, *pec6*	−234.8	10	490	61	0.00
brit_30, *wet_30m*, *sd_ndvi*, *cti_sd*, *pec1*, *pec2*, *pec3*, *pec4*, *pec5*, *pec6*	−265.4	11	553	124	0.00

[a] Refer to Table 1 for variable descriptions.

[b] Accepted model for the terrain and vegetation class (ΔAIC < 2).

sage-grouse were flushed or located from a fixed wing aircraft. Although we used data from 9 of these females in subsequent years in model development, we believe that locations from separate years are sufficiently independent for inclusion in the evaluation of model predictive capacity. To evaluate the top AIC-selected model, we grouped the landscape by geometric means into 10 bins. Because some bins contained no data points for evaluation, we combined bins to avoid null cells, resulting in a total of 8 bins. Following Johnson et al. (2006), we converted expected and observed locations within each RSF bin into proportions and assessed the relationship between expected and observed frequencies by using linear regression testing the slope relative to 1 and evaluated overall fit using a chi-square goodness-of-fit test.

RESULTS

During the 2 winters, we obtained 296 locations for 23 females. We tracked 7 females only during winter 1, 10 only during winter 2, and 6 during both winters. There were 3 mortalities, all in February of either 2003 or 2004. Both years had close to average mean monthly temperatures. Snowfall during winter 1 (74 cm) was typical compared to the Canadian Climate Normal of 73 cm (1971–2000; Environment Canada 2009), but snowfall was greater (104 cm) during winter 2. Flock size of relocated birds was 13.5 ± 0.72 (SE; range 1–100), with many mixed sex flocks. On several occasions, radiomarked birds made long-distance movements of approximately 50 km in <2 days during winter.

Table 3. Akaike's Information Criterion (AIC)–selected models representing sagebrush in winter habitat selection by greater sage-grouse in Alberta, Canada, from 2002 to 2004. We report model log likelihood (LL), number of model parameters (K), AIC, change in AIC from lowest model (ΔAIC), and Akaike weights (w_i) for all 10 candidate models.

Model[a]	LL	K	AIC	ΔAIC	w_i
sbmean, *sbmeansq*, *sb_prop_patch2*[b]	−213	4	434	0	0.99
sbmean, *sbmeansq*	−219	3	444	10	0.01
sbmean	−235	2	474	40	0.00
sbcov, *sbcovsq*, *sb_prop_patch2*	−256	4	520	86	0.00
sbcov, *sbcovsq*	−274	3	554	120	0.00
sbcov	−284	2	572	138	0.00
sb_prop_patch2	−342	2	688	254	0.00
sb_patch2	−370	2	744	310	0.00
sb_prop_patch1	−408	2	820	386	0.00
sb_patch1	−410	2	824	390	0.00

[a] Refer to Table 1 for variable descriptions.

[b] Accepted model representing sagebrush (ΔAIC < 2).

Evaluation of the terrain and vegetation variable class model indicated the model combination of brightness; wetness; standard deviation of *ndvi*, *cti*; mean *tri*; and the remaining ecosite classes (*brit_30*, *wet_30m*, *sd_ndvi*, *cti_sd*, *tri_km*^{2}, *pec1 pec2*, *pec3*, *pec4*, *pec5*, *pec6*; Table 1) was the top model with greatest support, and no other models had moderate support (ΔAIC < 2.0; Table 2). The most supported model for the sagebrush variable class (ΔAIC $<$ 2.0; Table 3) included the quadratic form of mean sagebrush cover and patchy distribution 2 (*sbmean*, *sb_prop_patch2*). Among 5 energy feature variable models, the most supported model (ΔAIC < 2.0; Table 4) was distance to well with a decay function of 250 m (*well_dst250*). For the anthropogenic features class, we removed variables for roads, urban, crop, and human (*road*, *urban*, *crop*, *human*) due to correlations with other variables. The most supported models among the impediment, water, edge, and 2-track truck trail variable groups (ΔAIC ≤ 2.0; Table 5) included impediment density (*imped_den*), distance to water (*water_dst50*), distance to edge (*edge_dst50*), and distance to 2-track truck trail (*trail_dst500*), respectively.

Combined evaluation of the best models from all 4 variable classes (Table 6) indicated the most supported model (ΔAIC < 2.0; Table 7) included the terrain and vegetation, sagebrush, energy development, and anthropogenic features. After applying this RSF model spatially to the landscape (Fig. 1), we used validation points to predict a linear regression model of the proportion of expected and observed validation location points. Model fit was high ($r^2 = 0.94$), with a slope different from zero ($P < 0.01$) and an intercept not different from zero ($\beta_0 = 0.02$, $P = 0.29$). A chi-square goodness-of-fit test ($\chi^2_8 = 5.05$, $P > 0.5$) and Spearman rank

Table 4. Akaike's Information Criterion (AIC)–selected models representing energy development in winter habitat selection by greater sage-grouse in Alberta, Canada, from 2002 to 2004. We report model log likelihood (LL), number of model parameters (K), AIC, change in AIC from lowest model (ΔAIC), and Akaike weights (w_i) for all 4 candidate models.

Model[a]	LL	K	AIC	ΔAIC	w_i
well_dst250[b]	−386	2	776	0	0.95
well_dst500	−389	2	782	6	0.05
well_dst1000	−398	2	800	24	0
well_dst	−407	2	818	42	0

[a] Refer to Table 1 for variable descriptions.

[b] Accepted model representing energy development (ΔAIC < 2).

Table 5. Akaike's Information Criterion (AIC)–selected models of anthropogenic feature variables for winter habitat selection by greater sage-grouse in Alberta, Canada, from 2002 to 2004. We report model log likelihood (LL), number of model parameters (K), AIC, change in AIC from lowest model (ΔAIC), and Akaike weights (w_i) for each variable relative to similar variables at different scales. We combined the 4 accepted variables to represent the anthropogenic features variable class.

Variable[a]	LL	K	AIC	ΔAIC	w_i
water_dst50[b]	−408.0	2	820	0	0.61
water_dst250	−409.5	2	823	3	0.14
water_dst500	−409.9	2	824	4	0.09
water_dst1000	−410.0	2	824	4	0.08
water_dst	−410.0	2	824	4	0.08
trail_dst500[b]	−391.0	2	786	0	0.54
trail_den	−392.0	2	788	2	0.20
trail_dst1000	−392.0	2	788	2	0.20
trail_dst	−394.0	2	792	6	0.03
trail_dst250	−394.0	2	792	6	0.03
trail_dst50	−405.0	2	814	28	0.00
imped_den[b]	−386.0	2	776	0	0.97
imped_dst1000	−390.0	2	784	8	0.02
imped_dst500	−391.0	2	786	10	0.01
imped_dst	−392.0	2	788	12	0.00
imped_dst250	−395.0	2	794	18	0.00
imped_dst50	−408.0	2	820	44	0.00
edge_dst50[b]	−397.0	2	798	0	0.88
edge_dst	−399.0	2	802	4	0.12
edge_dst250	−407.0	2	818	20	0.00
edge_den	−409.0	2	822	24	0.00
edge_dst1000	−409.0	2	822	24	0.00
edge_dst500	−410.0	2	824	26	0.00

[a] Refer to Table 1 for variable descriptions.

[b] Accepted variables (ΔAIC < 2) included in the anthropogenic features variable class.

correlation ($r_s = 0.83$) corroborated the ability of our model to predict independent winter sage-grouse locations.

After estimating the final model, we assessed the effect size of the energy development, trail, and edge variables (*well_dst250*, *trail_dst500*, *edge_dst50*) by predicting relative probability of selection at increasing distances from the landscape feature while holding all other variables constant at their mean values (Table 8). We also added or subtracted one standard error from the coefficient of the variable of interest and held all other model variables constant at their mean, to estimate standard errors around predictions. The predicted probability of selection dropped sharply at approximately 1,900 m from energy wells and at 200 m from anthropogenic edges but for trails, the effect was less pronounced (Fig. 2).

DISCUSSION

Our habitat model was highly predictive and is useful in identifying important winter habitats for wintering sage-grouse. Consistent with findings in Wyoming and Montana (Doherty et al. 2008), and as we hypothesized, the abundance and patchy distribution of sagebrush on the landscape influenced sage-grouse winter habitat selection. Topographic metrics and measures of productivity calculated from satellite imagery also contributed to the model. Again consistent with findings of Doherty et al. (2008), sage-grouse selected less rugged areas at lower elevations. During breeding season, sage-grouse in this population showed avoidance of anthropogenic edge (Aldridge and Boyce 2007). Human impacts also were important predictors of winter habitats. During winter, sage-grouse avoided all anthropogenic edges, regardless of type, although the smallest scale we tested provided the best model fit (*edge_dst50*), and edge was pronounced in our model with no habitats selected within 100 m of edge and limited selection from 100 m to 300 m (Fig. 2).

Models that included energy development (well metrics) performed better in AIC selection than the identical competing model without wells. Furthermore, the response to energy wells was at a large scale in our model, with no habitats selected within 1,200 m and limited selection between 1,200 m and 1,900 m. Doherty et al. (2008) found that density of coal bed natural gas wells was a better measure of sage-grouse avoidance at a large scale than a more local scale. Similarly, our model for sage-grouse in Alberta

Table 6. Mean, standard deviation, and range (min. and max. values) for all covariates included in final candidate Akaike's Information Criterion models to predict greater sage-grouse winter habitat selection in Alberta, Canada, from 2002 to 2004.

Variable category	Variable name[a]	$\bar{x}$	SD	Min.	Max.
Energy	*well_dst250*	0.020	0.086	0	0.95
Sagebrush	*sbmean*	14.91	13.70	0	86.78
	sbmeansq	409.96	795.52	0	7530
	sb_prop_patch2	0.19	0.27	0	1
Terrain and vegetation	*brit_30*	217.52	20.58	54.99	360.61
	wet_30m	18.22	8.84	−8.98	86.62
	sd_ndvi	0.038	0.027	0.0091	0.19
	tri_km^2	2.37	2.63	0	18.16
	pec1	0.130	0.2630	0	1
	pec2	0.0963	0.2542	0	1
	pec3	0.355	0.4002	0	1
	pec4	0.0898	0.2412	0	1
	pec5	0.144	0.2840	0	1
	pec6	0.0834	0.1970	0	1
Anthropogenic	*imped_den*	0.42	0.66	0	5
	water_dst50	0.21	0.28	0	1
	edge_dst50	0.064	0.21	0	1
	trail_dst500	0.0032	0.048	0	1

[a] Refer to Table 1 for variable descriptions.

Table 7. Akaike's Information Criterion (AIC)–selected models for winter habitat selection by greater sage-grouse in Alberta, Canada, from 2002 to 2004. We report model log likelihood (LL), number of model parameters (*K*), AIC, change in AIC from lowest model (ΔAIC), and Akaike weights (w_i) for all candidate models. Variable classes include energy development (E), sagebrush (S), anthropogenic features (A), and terrain and vegetation (T).

Model[a]	LL	*K*	AIC	ΔAIC	w_i
E, S, A, T[b]	−108	20	256	0	0.98
S, A, T	−113	19	264	8	0.02
E, S, T	−119	16	270	14	<0.01
S, T	−126	15	282	26	<0.01
E, S, A	−172	9	362	106	<0.01
S, A	−182	8	380	124	<0.01
E, A, T	−180	17	393	137	<0.01
T, A	−184	16	400	144	<0.01
E, S	−202	5	414	158	<0.01
T, E	−197	13	420	164	<0.01
T	−202	12	428	172	<0.01
S	−214	4	436	180	<0.01
E, A	−337	6	686	430	<0.01
A	−354	5	718	462	<0.01
E	−386	2	776	520	<0.01

[a] Refer to Table 6 for covariates included in each variable class.

[b] Accepted model for sage-grouse winter habitat selection.

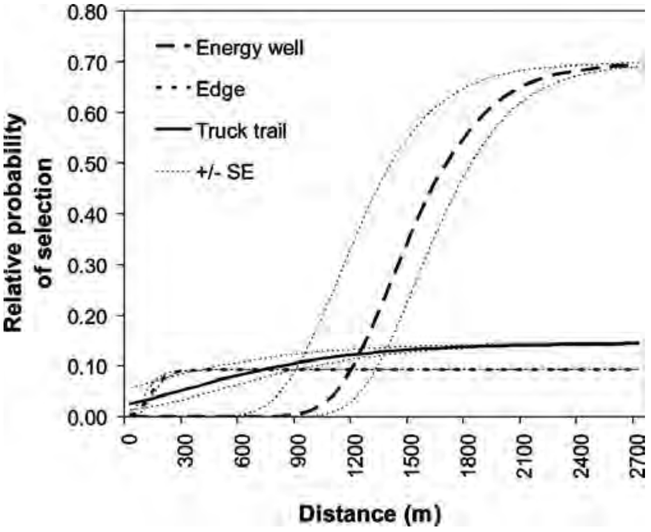

Figure 2. Predicted probability of selection by greater sage-grouse in Alberta, Canada, 2002–2004, as determined by a resource selection function. We calculated relative probabilities at different distances for 2-track truck trail, energy well, and edge (*trail_dst500*, *well_dst250*, *edge_dst50*, respectively) while holding all other model variables constant at their mean values. Faint dashed lines represent relative probabilities calculated using plus or minus a standard error to the coefficient of the variable of interest (one of *trail_dst500*, *well_dst250*, or *edge_dst50*) and recalculating the predictions.

predicted that the relative probability of selection drops sharply when habitat is within 1,900 m of an energy well (Fig. 2) and not surprisingly, the closest distance any sage-grouse was located to a well during the study was 1,293 m. Although mean distance from a well was 8,802 m (95% CI, $8{,}589 \leq \bar{x} \leq 9{,}016$), in the third of the winter study area with the highest oil and gas activity (460 km^2), mean distance to a well was 1,034 m (95% CI, $1{,}008 \leq \bar{x} \leq 1{,}060$). Thus, avoidance of energy development by sage-grouse in Alberta resulted in substantial loss of functional habitat surrounding wells, similar to other life stages (Aldridge and Boyce 2007).

Aldridge and Boyce (2007) identify the potential importance of habitat connectivity between winter and other life stages (i.e., nest and brood). Despite year-round tracking efforts, the importance of habitat connectivity was difficult to assess. Although summer and winter habitats of some birds were adjacent or overlapping, other birds made seasonal movements of 40–50 km (C. L. Aldridge, Colorado State University, unpublished data). A limited number of tracking locations suggest birds make these long movements following the topography of large valleys, potentially tracking the distribution of sagebrush. However, data collected at more frequent intervals than we obtained during

Table 8. Estimated coefficients (β), standard errors, and 95% confidence intervals of covariates included in the accepted model for winter habitat selection by greater sage-grouse in Alberta, Canada, from 2002 to 2004. To characterize habitat availability, we weighted 5,000 random points by using importance weights such that the available sample was effectively 296 points.

Variable class	Variable[a]	β	SE	95% CI	
				Lower	Upper
Energy development	*well_dst250*	−173.96	119.69	−408.54	60.62
Sagebrush	*sbmean*	0.24	0.041	0.16	0.32
	sbmeansq	−0.0019	0.0005	−0.0029	−0.0009
	sb_prop_patch2	1.74	0.82	0.14	3.34
Anthropogenic features	*edge_dst50*	−5.86	2.43	−10.62	−1.099
	water_dst50	−2.039	0.73	−3.48	−0.60
	imped_den	0.70	0.28	0.15	1.26
	trail_dst500	−1.65	0.77	−3.16	−0.14
Terrain and vegetation	*brit_30*	−0.026	0.0082	−0.042	−0.0097
	wet_30m	0.10	0.022	0.059	0.15
	sd_ndvi	15.84	7.90	0.35	31.32
	cti_sd	1.034	0.49	0.079	1.99
	tri_km^2	−1.63	0.30	−2.21	−1.035
	pec1	4.39	2.58	−0.67	9.45
	pec2	−0.72	2.69	−6.00	4.56
	pec3	−1.9664	2.4341	−6.7371	2.8043
	pec4	−2.3040	2.4912	−7.1867	2.5786
	pec5	−1.2870	2.5303	−6.2463	3.6723
	pec6	−3.9847	2.7289	−9.3332	1.3637

[a] Refer to Table 1 for variable descriptions.

our study, possibly with Global Positioning System technologies, are needed to confirm these movements and to assess how birds travel through disturbed landscapes to reach suitable winter habitats. Threats such as oil and gas development or cultivation of native habitats could reduce connectivity and disrupt migratory patterns, possibly causing bottlenecks between seasonal ranges or populations.

Sage-grouse congregate into groups of varying size during winter. We located a flock estimated at 100 birds on one occasion in 2004. This flock represented a substantial proportion of the population in one location, because the Alberta population was estimated at between 288 and 427 birds during spring 2003 (Lungle and Pruss 2008). Of the validation locations, 72% occurred in the 2 highest RSF bins, which represents just 13% of our study area. Beck (1977) also found winter habitat was limited in northern Colorado where 80% of winter sites used by sage-grouse occurred in <7% of the total area of sagebrush. Because winter habitats are limited in Alberta, comprehensive management strategies to maintain suitable habitats across all seasons are required, particularly because sage-grouse avoid energy development in otherwise suitable winter habitats.

MANAGEMENT IMPLICATIONS

Sound management planning requires an understanding of habitat selection at large scales, identifying where priority habitats are located and determining how species respond to relevant disturbances. Our model for sage-grouse winter habitats in Alberta provides one step toward meeting this management challenge. Given the endangered status of sage-grouse in Canada, any loss of crucial winter habitats could be detrimental to population persistence (Beck 1977, Swenson et al. 1987). We recommend that areas identified as crucial to meeting winter habitat needs of sage-grouse be protected from disturbance and degradation and designated as Critical Habitat under the Canadian Species at Risk Act (Species at Risk Act 2002). Moreover, we recommend a setback distance of ≥1,900 m for any energy development from all winter habitats identified as Critical Habitat based on our model. Mitigation of disturbances that negatively affect sage-grouse winter habitat quality (energy and anthropogenic development) could be applied in key sagebrush habitats to enhance critical winter habitats for sage-grouse.

Although much past management for prairie grouse has focused around lek sites (Aldridge and Boyce 2007), modeling approaches such as applied here permit more comprehensive conservation planning. Considering spatially explicit models for sage-grouse nest, brood, and wintering habitats, combined with knowledge of lek locations, bird movements, and habitat connectivity, provide a biological foundation for development of an effective conservation strategy for sage-grouse.

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Estimating sightability of greater sage-grouse at leks using an aerial infrared system and *N*-mixture models

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Counts of grouse present at leks (breeding grounds) during spring are widely used to monitor population numbers and assess trends. However, only a proportion of birds available to count are detected resulting in a biased population index. We designed a study using an aerial integrated infrared imaging system (AIRIS) and experimental pseudo-leks to quantify sightability (proportion of birds detected) of conventional ground-based visual (GBV) surveys for greater sage-grouse *Centrocercus urophasianus*. Specifically, we calibrated AIRIS at pseudo-leks composed of known numbers of captively-raised birds, primarily ring-necked pheasant *Phasianus colchicus*. We then carried out AIRIS and GBV surveys, simultaneously, on nearby sage-grouse leks, allowing us to model AIRIS and GBV sightability. AIRIS detected ~93% of birds on pseudo-leks while GBV detected ~86% of sage-grouse on leks. Thus, the ground count observation error was −14% from the 'true' number of male sage-grouse attending the leks. We also found sagebrush cover decreased sightability for GBV counts but did not influence sightability by AIRIS. Because standard GBV protocols typically make repeated counts of sage-grouse in a single morning, we also modeled repeated GBV counts using *N*-mixture models and found an 88% sightability, which was nearly the same as GBV sightability from the AIRIS analysis. This suggests that the use of repeated morning counts can potentially account for imperfect detection in the standard GBV surveys currently implemented. We also provide generalized correction values that could be employed by resource managers using either GBV or AIRIS to better estimate 'true' numbers of sage-grouse attending leks within similar environments to this study. The findings and interpretation presented can help guide effective monitoring protocols that account for observation error and improve accuracy of data used for population trend and abundance estimation.

Keywords: aerial survey, *Centrocercus urophasianus*, detection, greater sage-grouse, infrared, lek counts, *N*-mixture model, observation error, sightability

A primary goal in designing wildlife monitoring surveys is to develop data collection protocols capable of informing managers of changes in population abundance over time (Nichols 1991, Williams et al. 2002). Count data obtained from leks (traditional breeding grounds) of greater sage-grouse *Centrocercus urophasianus* (hereafter sage-grouse) have been a primary source of information used to assess population trends since the 1940s when lek monitoring first began (Patterson 1952, Connelly and Schroeder 2007). Sage-grouse numbers have declined throughout their range since the 1950s averaging an annual decrease of approximately 0.85% per year (Garton et al. 2015, WAFWA 2015). The species currently occupies roughly one half of its historic distribution (Schroeder et al. 2004), and with further habitat losses in the sagebrush biome likely in coming decades (Coates et al. 2016, Smith et al. 2016, Green et al. 2017) and upcoming consideration for protection under the Endangered Species Act, improved information on populations from lek count data will be central to sage-grouse conservation.

Accordingly, accounting for intrinsic biases in count data due to observation error would improve estimation of true demographic patterns resulting from environmental change. Like many types of survey data used as population indices, lek-count data is often scrutinized as a biased representation of true population numbers (Beck and Braun 1980, Applegate 2000). Part of the uncertainty in lek-count data results from imperfect observation rates of individual grouse during conventional ground-based visual (GBV) surveys lead-

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ing to variable and biased estimates. This long-recognized problem has led to several evaluations of lek counts and the factors that affect their accuracy (Fremgen et al. 2016, Baumgardt et al. 2017). Nichols et al. (2009) described four distinct components to detectability in count surveys. The first component is the probability (p) that an individual's home range overlaps the sampling unit (p_s). Because the sampling unit for sage-grouse is the lek site, home ranges of all sage-grouse within those populations are assumed to intersect the lek. However, not all leks on the landscape are known and counted (Shyvers et al. 2018), so individuals associated with those leks will not be counted. A second component is the probability an individual is present at the sampling unit during the time of survey (p_p). For example, individual attendance on leks can vary within mornings (Monroe et al. 2016), throughout the breeding season, and among years (Blomberg et al. 2013, Fremgen et al. 2019, Wann et al. 2019). Given the individual is present at the sampling unit, the third and fourth components are the probability of being available for detection during the count (p_a, e.g. not obscured by vegetation) and probability of detection conditional on availability (p_d; e.g. accurate count of unobscured individuals), respectively, and are collectively referred to as sightability ($p_a p_d$; Fremgen et al. 2016, Baumgardt et al. 2017). Thus, sightability can also be interpreted as the proportion of available individuals which are observed.

Infrared video-surveying is an emerging technology that is particularly useful for sensing endothermic animals (Havens and Sharp 1998) and shows promise as a tool for monitoring upland gamebird populations. The spectral signatures of these animals in the infrared wavelength (i.e. heat) is generally distinct from their environment. Infrared technology has been applied in wildlife studies for decades but has been limited primarily to uncooled infrared sensors (Gillette et al. 2013). Current systems include a single, gyroscopically-stabilized unit (to reduce motion blur in a moving aircraft) which contains both an infrared camera that is cryogenically-cooled (to improve measurement precision of spectral intensity) and a high-resolution camera in the visible spectra allowing for high-magnification zooming (e.g. to distinguish between male and female sage-grouse). We refer to this combination of technologies into one device operated from fixed-wing aircraft as an aerial integrated infrared imaging system (AIRIS).

Several state agencies have initiated lek surveys using a combination of AIRIS and GBV counts within their monitoring programs. However, without accounting for differences in sightability among survey types, population trend estimates can be confounded by mixed survey methodology which may misinform population performance and ultimately management actions. Rigorous measurement of sightability differences between AIRIS and GBV surveys may provide appropriate adjustment to lek counts and improve accuracy of trend estimates. Furthermore, AIRIS can also be used to assess the accuracy of GBV counts, as we demonstrate in this study. Although past studies have compared similarities between counts recorded with infrared cameras to those collected on the ground for sharp-tailed grouse *Tympanuchus phasianellus* and sage-grouse (Gillette et al. 2013, 2015), sightability of newer AIRIS has not been formally estimated.

Conversely, AIRIS surveys can be relatively expensive and may not be feasible for extensive surveying (Gillette et al. 2015). Therefore, agencies charged with monitoring sage-grouse populations over large areas may be interested in cost-effective alternatives to AIRIS to account for imperfect detection in lek counts. The *N*-mixture model developed by Royle (2004) offers one promising alternative because it only requires repeated counts during a period of population closure (i.e. no movement in and out of survey site during time counts occur), which is a crucial assumption. *N*-mixture models estimate sightability and true population abundance (N; i.e. animals available at the survey site for observation). The *N*-mixture model has been used to estimate the male population of sage-grouse at leks using repeated surveys conducted throughout the breeding season (McCaffery and Lukacs 2016). However, those estimates may be difficult to interpret given that the closure assumption is likely violated due to variation in attendance rates across survey days (Fremgen et al. 2019, Wann et al. 2019, Monroe et al. 2019). In contrast, repeated counts that occur across a relatively short period in morning hours should satisfy the closure assumption, although the estimated lek abundance will be specific to the day the counts occurred and will change by survey day given the variability in lek attendance. Nonetheless, estimating the day-specific abundance is analogous to the conventional survey estimate of using the maximum daily count and is precisely of interest in our study.

Sightability can vary considerably among lek surveys (Fremgen et al. 2016, Baumgardt et al. 2017), meaning the error in raw lek counts (i.e. the proportion of the true number of birds missed) may include substantial bias, and there is a lack of consensus on how to account for these errors. In this study, we quantify sightability error through an experimental approach that combined emerging technology with traditional methods, and then offer multiple options to account for error to managers assessing and collecting lek data. Our first objective was to estimate AIRIS sightability by quantifying the proportion of a known number of captively-raised galliform birds serving as proxies for sage-grouse on pseudo-leks. Our second objective was to estimate overall GBV error by combining the sightability of GBV counts relative to simultaneous AIRIS counts with the AIRIS sightability from objective one. We also assessed the effects of environmental factors such as sagebrush cover (serving as an index visual obstruction) and the time since sunrise (serving as an index of degree of daylight) on sightability for GBV and AIRIS counts. We were particularly interested in differences in the effects of environmental predictors and how sightability varied between the two types of survey counts. Our third objective was to derive an alternative estimate of sightability using *N*-mixture models from repeated within-morning GBV counts. We compared the *N*-mixture estimate to the result of objective two and discuss the practical potential of all three methods (i.e. GBV, AIRIS, *N*-mixture GBV) for integrated sage-grouse monitoring designs.

Methods

Study area

We surveyed sage-grouse leks and pseudo-leks located in northeastern California (Lassen County; lattitude: 40°58′ N, 120°27′W), eastern Idaho (Clark, Fremont and Jefferson Counties; 43°99′N, 111°96′W), southwestern Idaho (Owyhee County; 42°98'N, 116°50'W), northeastern Nevada (Elko County; 41°38′N, 115°68′W), and north-central Nevada (Eureka and Lander counties; 40°08′N, −116°36′W) over three breeding seasons during April and May, 2015–2017 (Fig. 1). Vegetation communities in our study areas were typical of the sagebrush ecosystem of the northern Great Basin. Dominant shrubs included several species of sagebrush (primarily *Artemisia arbuscula*, *A. nova* and *A. tridentata*), rabbitbrush *Ericameria nauseosa* and *Chrysothamnus viscidiflorus*, snowberry *Symphoricarpos* spp., western serviceberry *Amelanchier alnifolia*, and antelope bitterbrush *Purshia tridentata*. Forbs and grasses were largely dormant when our surveys occurred, but leks were generally snow free.

Study design

We surveyed birds at two different location types: 1) active leks consisting of wild sage-grouse and 2) pseudo-leks consisting of captively-raised ring-necked pheasant *Phasianus colchicus* (hereafter, pheasant) or chukar partridges *Alectoris chukar* (hereafter, chukar) which were tethered to the ground. Pseudo-leks contained known numbers of birds which provided a true population size for deriving AIRIS sightability. Pseudo-lek locations were randomly generated (given the following constraints) between 500 and 600 m from a real sage-grouse lek. We chose 500 m as a minimum because leks were clearly distinct from the aircraft at this distance. We chose 600 m as a maximum so general habitat characteristics were similar and flight time for the aircraft between locations was minimized, allowing for similar levels of ambient infrared radiation between both survey types. We targeted areas with percent shrub cover ≤20% within the boundaries of the pseudo-lek, which was similar to our real sage-grouse leks. Additionally, pseudo-leks had to be relatively close to an unimproved or two-track road (≤100 m) to facilitate transportation and placement of pheasant and chukar.

We placed a known number of captively-raised pheasant or chukar at pseudo-leks as a proxy for sage-grouse to estimate a proportion of birds observed by AIRIS. We chose these morphologically different galliform species to create size variation and to avoid unknown idiosyncrasies of a single species. We rationalized that lack of difference in AIRIS sightability between pheasant and chukar would indicate that sage-grouse share similarities in sightability. AIRIS at sage-grouse leks and their paired pseudo-leks occurred on the same mornings so weather and visibility conditions

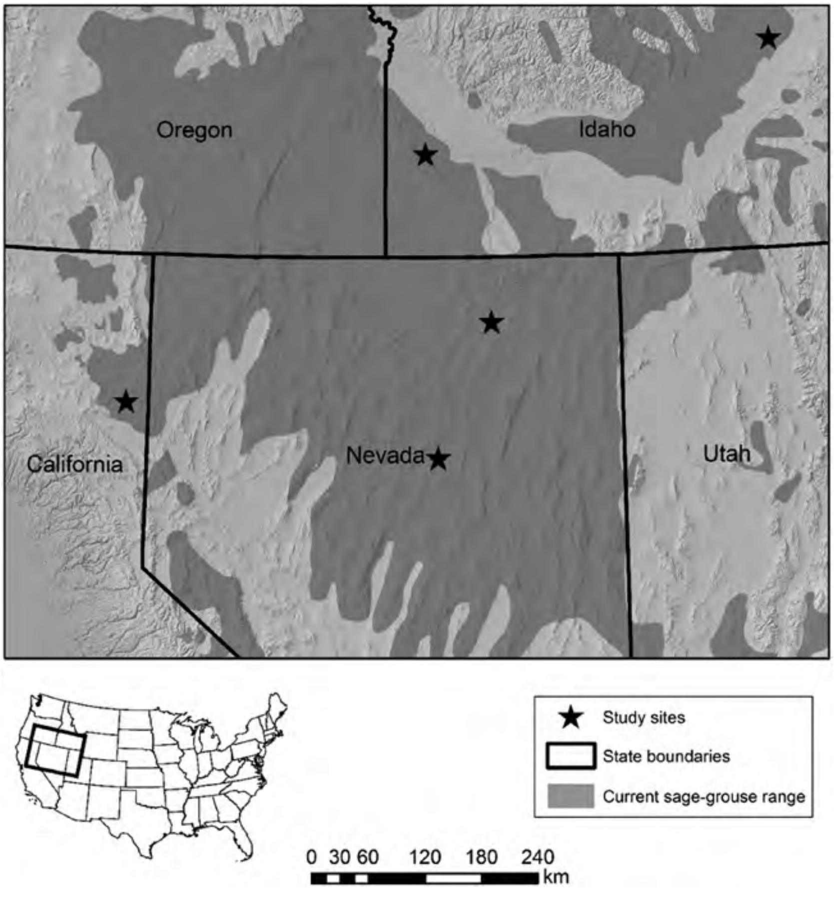

Figure 1. Greater sage-grouse *Centrocercus urophasianus* study areas where aerial integrated infrared imaging system (AIRIS) and ground-based visual (GBV) surveys were assessed for sightability at real and pseudo-leks in California, Nevada and Idaho from 2015 to 2017.

were similar. Chukar and pheasant were not mixed on the same pseudo-lek (i.e. only one species occurred on a given pseudo-lek).

Placement of individual pheasant and chukar on pseudo-leks (i.e. distance from center point) followed observed patterns of sage-grouse locations on real leks digitized in a geographic information system (GIS) from infrared images recorded in Nevada and Idaho. We then measured distances of each individual sage-grouse to the geometric mean of all sage-grouse present in the image (mean = 16.3 m; standard deviation = 9.4 m) using Euclidian distance tool in ArcMap 10.3. We used these measured distances to estimate Gamma distribution parameters (shape $\alpha = 2.4$; rate $\theta = 0.038$) using the 'MASS' package (Venables and Ripley 2002) in program R (<www.r-project.org>). We chose Gamma distribution because sage-grouse locations were clustered on leks and this distribution was skewed (Kéry 2010). We determined the pseudo-lek size by sampling from a normal distribution based on sage-grouse lek counts from across Nevada reported to the Nevada Dept of Wildlife in 2015. To determine bird placement relative to the pseudo-lek center, we sampled a distance from the Gamma distribution and randomly selected a directional azimuth for each bird. Each psuedo-lek bird was tethered to a stake at the pre-determined location prior to the surveys using paracord attached to its tibiotarsus (see Supplementary material Appendix 1 more information).

Lek counts

AIRIS counts were recorded at pseudo-leks and nearby real sage-grouse leks sequentially during the morning on survey days. A detailed description of the AIRIS technology and methods used in this study is provided in Supplementary material Appendix 2. We carried out double-blind GBV counts at real leks using two independent observers on the ground simultaneous with AIRIS surveys (Supplementary material Appendix 3).

GBV counts were conducted over two periods: 1) before the AIRIS plane arrived, and 2) during the plane visit. Within each of these primary periods, observers counted and recorded the number of male, female and unknown (i.e. sex could not be determined) grouse three times over a period of 10–15 min. Conducting three successive counts is consistent with most state agency lek count protocols (Connelly et al. 2003). For all double-blind ground counts, we randomly selected either the first or second observer's maximum count of males recorded simultaneous to the AIRIS survey with two exceptions. First, if grouse were visibly disturbed by the plane (e.g. stopped displaying and hid behind or under shrubs), we used the count that occurred prior to the AIRIS survey. Counts obtained before and during the AIRIS survey were highly correlated (r = 0.97), indicating the choice was likely to have minimal bias. In addition, we checked the influence of plane activity on our estimates by re-running models using only the GBV count data recoded prior to the AIRIS survey. Second, at Idaho sites in 2016, we used the total number of grouse from our GBV survey, because the AIRIS survey did not distinguish between males and females. We accounted for this difference in count type in the model.

Sightability modeling using AIRIS and GBV

We used a Bayesian modeling framework to simultaneously estimate AIRIS and GBV sightability from 1) true numbers of birds deployed to pseudo-leks, 2) AIRIS counts of pseudo-leks, 3) AIRIS counts of sage-grouse leks, and 4) GBV counts of sage-grouse leks. This framework allowed for parameter-sharing across multiple models, which provided a unique opportunity to estimate GBV sightability. The first two equations of our model formulated a calibration for AIRIS surveys using pseudo-leks (*P*). A Poisson distribution was specified to model counts as:

$$n_{AP,i} \sim \text{Poisson}\left(\lambda_{P,i}\right) \tag{1}$$

$$\lambda_{P,i} = \omega_{P,i} n_{TP,i} \tag{2}$$

Here, $n_{AP,i}$ is the number of birds on pseudo-lek i counted from the plane, and the rate $\lambda_{P,i}$ is a function of the product of the true number of birds located on each pseudo-lek ($n_{TP,i}$) and a proportional variable ($\omega_{P,i}$). The proportional variable allowed for proportions >1 (overcounting). Thus, ω_P represented the AIRIS sightability parameter and was modeled as a deterministic function of lek-level covariates (J) using a log-link function as:

$$\log\left(\omega_{P,i}\right) = \alpha_P + \sum_{j=1}^{J} \beta_{P,j} X_{P,ij} \tag{3}$$

Therefore, ω_P represented the proportion of birds on pseudo-lek i recorded by AIRIS cameras (e.g. an estimate <1 suggests AIRIS cameras on average undercounted the true number of birds), and this proportion was determined by covariates and associated model parameters including the intercept (α_P) and slope coefficients ($\beta_{P,j}$).

The fourth and fifth equations established the relationship between GBV counts of sage-grouse on real leks and predicted 'true' numbers of sage-grouse. We derived separate posterior distributions of ω_P based on the conditions observed at real leks (R), which we refer to as $\hat{\omega}_{P,i}$ and divided that value into the number of sage-grouse observed from the air for each real lek ($n_{AR,i}$). We added a constant (C) of 0.01 to $n_{AR,i}$ to avoid taking the log of 0 when AIRIS counts failed to observe any birds. We assigned a Poisson distribution to the number of sage-grouse observed on the ground $n_{GR,i}$ as:

$$n_{GR,i} \sim \text{Poisson}\left(\lambda_{R,i}\right) \tag{4}$$

$$\lambda_{R,i} = \omega_{R,i}\left(\frac{n_{AR,i} + C}{\hat{\omega}_{P,i}}\right) \tag{5}$$

Thus, $\omega_{R,i}$ represented the proportion of sage-grouse recorded on the ground relative to the predicted 'true' number, providing a GBV sightability parameter. In parallel, we modeled $\omega_{R,i}$ as a deterministic function of lek-level covariates (J) using a log link function as:

$$\log\left(\omega_{R,i}\right) = \alpha_R + \sum_{j=1}^{J} \beta_{R,j} X_{R,ij} \tag{6}$$

We specified vague priors in terms of mean and precision (i.e. inverse-variance) for all model coefficients (intercepts and slopes) including $\alpha_T \sim \text{normal}(0, 0.0001)$ and $\beta_T \sim \text{normal}(0, 0.0001)$, and subscripts denote coefficients estimated for real or pseudo-leks ($T = \{R, P\}$).

Covariates

We considered several covariates as potentially influencing the accuracy of AIRIS and GBV counts. However, prior to fitting all covariates, we tested the assumption that captively-raised pheasant and chukar were equally detectable by AIRIS using a model that included only an intercept and coefficient for the two-level species effect (1 = pheasant, 0 = chukar). An estimated coefficient for the species effect with 95% credible interval (CI) overlapping 0 supported similar detectability between the species by AIRIS.

A covariate for count type (i.e. males only or both males and females) was considered for the GBV sightability model. Additionally, we considered temporal effects (minutes before or after sunrise at which count occurred, i.e. 'time since sunrise'), and concealment effects (topographic roughness and shrub canopy cover) for both the GBV sightability and AIRIS sightability models. We calculated time since sunrise for each lek location and date that a count occurred using the spatial package 'sp' (Bivand et al. 2013) in program R. We also calculated average shrub canopy cover from 30-m resolution National Land Cover Database Shrubland Products (NLCD; Xian et al. 2015) and topographic roughness as the variance in elevation from a 30-m digital elevation model (Riley et al. 1999) within 100 m of leks using the zonal statistics tool in ArcMap 10.3.

We first estimated AIRIS and GBV sightability without environmental effects but accounting for count type (see above) and reported estimates of GBV sightability of males attending leks. We then estimated sightability accounting for covariate effects and predicted the average sightability while holding the habitat characteristics at the mean values for real leks. Sightability was not constrained between 0 and 1 because, although rare, overcounting sometimes occurred in AIRIS surveys at pseudo-leks.

Our full AIRIS sightability model included an intercept and four covariates (species, time since sunrise, shrub cover and topographic roughness), and our full GBV sightability model included an intercept and four covariates (count type, time since sunrise, shrub cover and topographic roughness). Covariates were considered supported by data if 95% CI of estimated coefficient (β) did not overlap 0. We also evaluated support based on the posterior probability of nonzeroness derived from a stochastic search variable selection (SSVS) method (George and McCulloch 1996). Specifically, we assigned a Bernoulli prior with probability of inclusion of 0.5 and derived a posterior probability of β being included in the model. This value represents how likely $\beta \neq 0$ given the data. We considered evidence substantial for values >0.6, marginal for 0.5–0.6, and deficient for <0.5.

Sightability *N*-mixture modeling

In addition to the sightability model using AIRIS data in conjunction with GBV data, we analyzed repeated counts from GBV data only collected at real leks as an alternative approach using a basic binomial *N*-mixture model (Royle 2004). The purpose of this analysis was to compare sightability estimates between the two approaches and provide wildlife managers with alternative methods in accounting for observation error using repeated count designs. As previously described, during sage-grouse lek surveys, GBV observers recorded three repeated ground counts simultaneously with the AIRIS counts. *N*-mixture models were fit to the repeated GBV counts during single morning surveys. Thus, unlike the GBV-AIRIS sightability analysis which used the maximum GBV count, the *N*-mixture model analysis used all three GBV counts recorded during a survey.

For each real lek, we randomly selected one of the two observers and used their repeated GBV counts. We modeled counts at real lek i during count period j as arising from a binomial distribution as $y_{ij} \sim \text{binomial}(N_i, p)$, where N_i is abundance at lek i, which is a latent state estimated from the repeated counts. The parameter p in the *N*-mixture model can also be thought of as the probability of detecting an individual conditional on availability ($p_a p_d$; i.e. sightability) on a given count. Because these surveys were conducted in a single morning over a relatively short period of time, the component p_p (i.e. probability of presence) was not included because bird movement into and out of leks was not expected. Thus, sightability and abundance were conditional on the set of birds on lek during this time frame (Nichols et al. 2009). We fit simple intercept structures for both N and p using a log and logit link, respectively, and specified vague priors for both intercepts as $\beta_0 \sim \text{normal}(0, 0.0001)$. Because state agencies generally report the maximum count when multiple counts occur in a morning, and p by itself is not informative for datasets which only report the maximum from repeated counts, we also calculated a derived maximum sightability, p_D, as:

$$\frac{\sum_{i=1}^{I} \max\left(y_{ij}\right) N_i^{-1}}{I}$$

In this equation, every lek has the maximum of its repeated counts divided by its estimated abundance, and the total summation of this value is divided by the total number of leks (I) to obtain an average, represented as p_D. Only lek counts with >1 displaying male were used in the *N*-mixture analysis (i.e. the maximum of repeated counts had to have 2 or more males recorded).

Model implementation

All models were fit using the package 'R2jags' (Su and Yajima 2015) in Program R, which interfaced with the MCMC sampler program JAGS (ver. 4.2.0; Plummer 2003). We monitored three posterior chains over 20 000 MCMC iterations, the first 5000 of which were discarded as burn-in. Convergence of the marginal posterior distributions were assessed using the Brooks–Gelman statistic, $\hat{R}$ (Brooks and Gelman 1998). Values of $\hat{R} > 1.1$ suggest lack of convergence. We ran the AIRIS and GBV sightability models simultaneously and saved output from the three MCMC chains for parameter inference. We summarized statistics (i.e. median and 95% CI) from the posterior marginal

Table 1. Number of pseudo-leks (ring-necked pheasant *Phasianus colchicus* and chukar *Alectoris chukar*) and real leks (greater sage-grouse *Centrocercus urophasianus*) surveyed by site and year to quantify sightability using ground visual surveys and aerial infrared surveys within 6 field sites in the Great Basin during 2015–2017. Pseudo-lek counts were not conducted in 2015.

			Pseudo-lek counts		Real lek counts		
Site	No. of psuedo-leks	No. of real leks	2016	2017	2015	2016	2017
Northeastern California	10	5	0	20	0	0	9
Eastern Idaho	9	13	9	0	0	13	0
Southwestern Idaho	5	8	5	0	0	8	0
Northeastern Nevada	24	18	20	15	0	17	10
Northcentral Nevada	0	11	0	0	11	0	0
Total	48	55	34	35	11	38	19

distributions for parameters monitored in our models. Derived parameters were calculated from the saved MCMC output from both the pseudo-lek and real lek models.

Results

We conducted surveys at 48 pseudo-leks and 55 real leks (Table 1) and used 69 maximum counts at pseudo-leks and 68 maximum counts at real leks in our analysis (Table 1). Thus, some leks consisted of >1 maximum count based on sampling across years. Pheasant were used during 62 pseudo-lek counts and chukar were used during 7. Most field data were collected in Nevada and Idaho. Sampling effort varied by year and site and we did not conduct pseudo-lek counts in 2015 at any sites (Table 1). On rare occasions sage-grouse were observed to stop displaying or crouch low to the ground during aerial counts.

All parameter estimates from our models converged ($\hat{R} < 1.1$). Based on model parameters, the AIRIS sightability model produced an average sightability (ω_P) of 0.93 (95% CI: 0.87, 0.99), the GBV sightability model produced an average sightability (ω_R) of 0.86 (95% CI: 0.78, 0.95). Thus, the estimated ground count observation error was −14% from the 'true' number of male sage-grouse attending the lek (Fig. 2). Replacing GBV counts with those recorded before the plane arrived also produced an average GBV sightability of 0.86 (95% CI: 0.77, 0.95). Overall, the average counts were similar between paired AIRIS (19.3; SE = 2.1) and GBV (17.9; SE = 2.1). The strong correlation between AIRIS counts and pseudo-lek numbers (i.e. truth; r = 0.94) was similar to the correlation between AIRIS and GBV counts (r = 0.94; Fig. 3a–b). We also found no differences in sightability between pheasant and chukar at pseudo-leks based on counts collected in AIRIS surveys ($\beta_{\text{species}} = 0.02$, 95% CI: −0.20, 0.23; Supplementary material Appendix 3 Fig. A1). Correlations between the double-blind GBV counts at sage-grouse leks were high (r = 0.99, indicating agreement in counts obtained between observers. However, residuals between the paired counts increased with lek size, suggesting decreasing precision as a function of lek size (Fig. 3c).

Shrub cover reduced sightability for GBV surveys but did not affect AIRIS surveys (Fig. 4) based on non-overlap of 95% CI for β and SSVS analysis (Table 2). We found marginal evidence that sightability increased as time elapsed from sunrise (linear) for GBV surveys (Fig. 4c) but not for AIRIS (Table 2, Fig. 4d). Although weaker, evidence suggests differences in sightability associated with topographic roughness (Table 2). The type of count (males only versus combined males and females) showed some evidence of influencing AIRIS sightability, but 95% CIs overlapped 0. Using a model that included count type and covariates fixed at their median values for sagebrush, roughness, and time since sunrise, we estimated average GBV sightability ($\bar{\omega}_R$) to be 0.85 (95% CI: 0.76, 0.95).

The binomial *N*-mixture model was fit to repeated GBV counts recorded at 31 leks. All parameters converged (all $\hat{R} < 1.1$). The estimated sightability using repeated counts for any given GBV count was 0.82 (95% CI: 0.78, 0.86), whereas maximum sightability derived from the maximum count (p_D) among these counts was 0.88 (95% CI: 0.83, 0.93).

Discussion

Our empirical calibration of AIRIS allowed a novel and robust assessment of effectiveness of GBV counts for sage-grouse population monitoring. Our findings corroborate

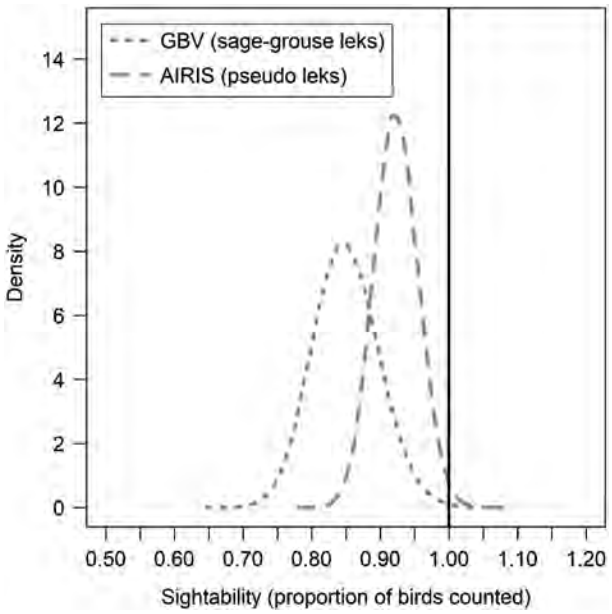

Figure 2. Posterior distributions of the proportion of birds detected at multiple sites in the Great Basin during 2015–2017 using ground-based visual (GBV) surveys and aerial integrated infrared imaging system (AIRIS). Estimates of GBV were derived from real-leks attended by unknown numbers of greater sage-grouse *Centrocercus urophasianus*. Estimates of AIRIS were derived from pseudo-leks with known numbers of ring-necked pheasant *Phasianus colchicus* and chukar *Alectoris chukar*. Perfect detection is denoted by the solid black line.

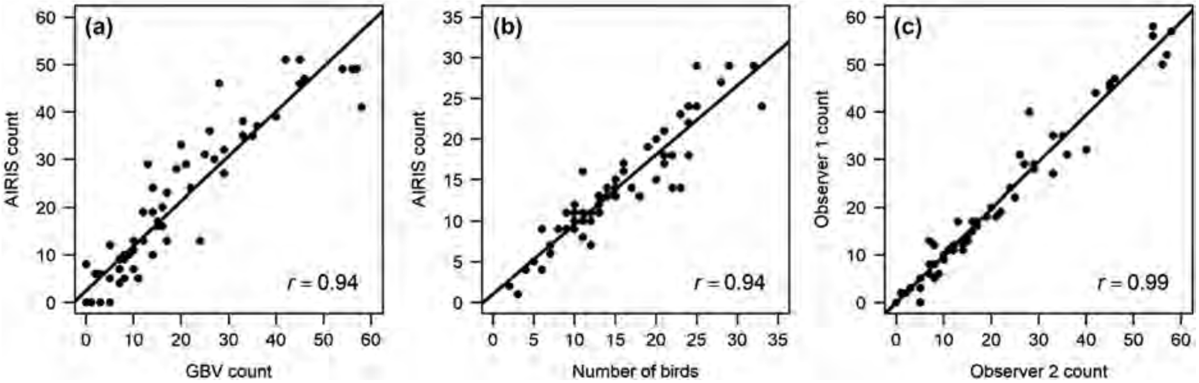

Figure 3. Correlation between counts obtained from (a) aerial infrared imaging system (AIRIS) and ground-based visual (GBV) surveys at real leks with unknown numbers of greater sage-grouse, (b) AIRIS obtained counts of pseudo-leks with known numbers of ring-necked pheasant *Phasianus colchicus* and chukar *Alectoris chukar*, and (c) paired counts of real leks obtained by double-blind observers. Data were collected from multiple sites in the Great Basin from 2015 to 2017.

previous aerial infrared studies of lekking grouse that also reported correlations between infrared cameras and ground counts (Gillette et al. 2013, 2015). However, we extend this study to provide robust estimates based on actual proportion of grouse counted from the aircraft relative to a 'true' number on the ground. Although GBV and AIRIS counts were highly correlated, AIRIS sightability was greater on sage-grouse leks than GBV sightability. Additionally, calibrating AIRIS with known numbers at pseudo-leks and calibrating GBV surveys with AIRIS at sage-grouse leks provided an experimental approach to robustly estimate that GBV surveys observed ~86% of male sage-grouse attending a lek during the survey period. Because our double-blind surveys indicated agreement between observers, especially for smaller leks, failure to detect all males by GBV was not driven intrinsically by individual observer effects.

Aerial infrared technology for wildlife surveys has advanced rapidly and use on sage-grouse lek counts has increased substantially across the western US (J. Romero, Owyhee Air Research, pers. comm.), largely because more leks can be counted per morning especially in remote areas (Gillette et al. 2013, 2015). Because AIRIS and GBV surveys can vary across years at individual leks, population trend estimates may be confounded without appropriately adjusting count data based on methodology.

One option to improve precision and decrease bias of population estimates, is for managers to apply a published estimate of sightability, such as ours, to their maximum lek count data. While this may be a coarse correction for different regions, it can readily be applied to existing lek databases. We therefore provide sightability estimates that may serve as adjustment factors for single maximum lek count data from GBV and AIRIS. These adjustment factors are intended to better approximate true numbers of sage-grouse attending leks and reduce confounding effects of survey type. For example, simply dividing observed counts by the median GBV sightability value reported here, as well as upper and lower 95% credible limits, will provide more accurate estimates of the numbers of males attending a lek during the survey. Additionally, counts obtained with AIRIS can be divided by AIRIS sightability to be comparable with adjusted GBV counts. Adjusted values can then be used to improve accuracy in estimates of population trends and factors influencing population changes by accounting for detection.

A second option to improve population estimates is for managers to develop their own detection probabilities and or corrected population sizes specific to their leks, regions, and survey times. Our use of an *N*-mixture model provided a relatively simple modeling framework to estimate sightability and lek abundance that can be carried out readily by wildlife managers. Most state agency lek databases currently consist only of maximum counts derived from a series of repeated counts conducted in one morning, while the lower counts are discarded. Applying *N*-mixture models to estimate sightability would only require recording and retaining all the repeated count data within each morning in the lek database rather than just the daily or annual maximum count. Single morning successive repeated counts also allow the closure assumption to be met (Royle 2004). The correspondence between our GBV–AIRIS and *N*-mixture results increased our confidence in the reliability of this method for lek counts, and the reduced cost compared to AIRIS surveys makes it an attractive alternative. Future research that critically evaluates the use of *N*-mixture models on repeated counts during single morning lek surveys would be highly beneficial.

We found that the effects of environmental factors on sightability varied among GBV and AIRIS surveys. The most influential factor that decreased sightability for GBV surveys was increased shrub cover at the lek, which was consistent with findings elsewhere (Fremgen et al. 2016). Fremgen et al. (2016) observed a negative effect of shrub height, and both height and cover likely affect visual obstruction. Thus, GBV observers are seemingly limited by visual screening from shrubs when counting sage-grouse from the ground. AIRIS methods overcome this issue to some extent owing to the plane's ability to circle sage-grouse and observe them from multiple angles, as well as infrared camera's ability to detect partially obstructed birds. We found some evidence that time since sunrise influenced sightability of birds using GBV but not AIRIS, which may be explained by increased ambient lighting. However, another recent sightability study (Baumgardt et al. 2017) observed a negative relationship with time since sunrise, which they

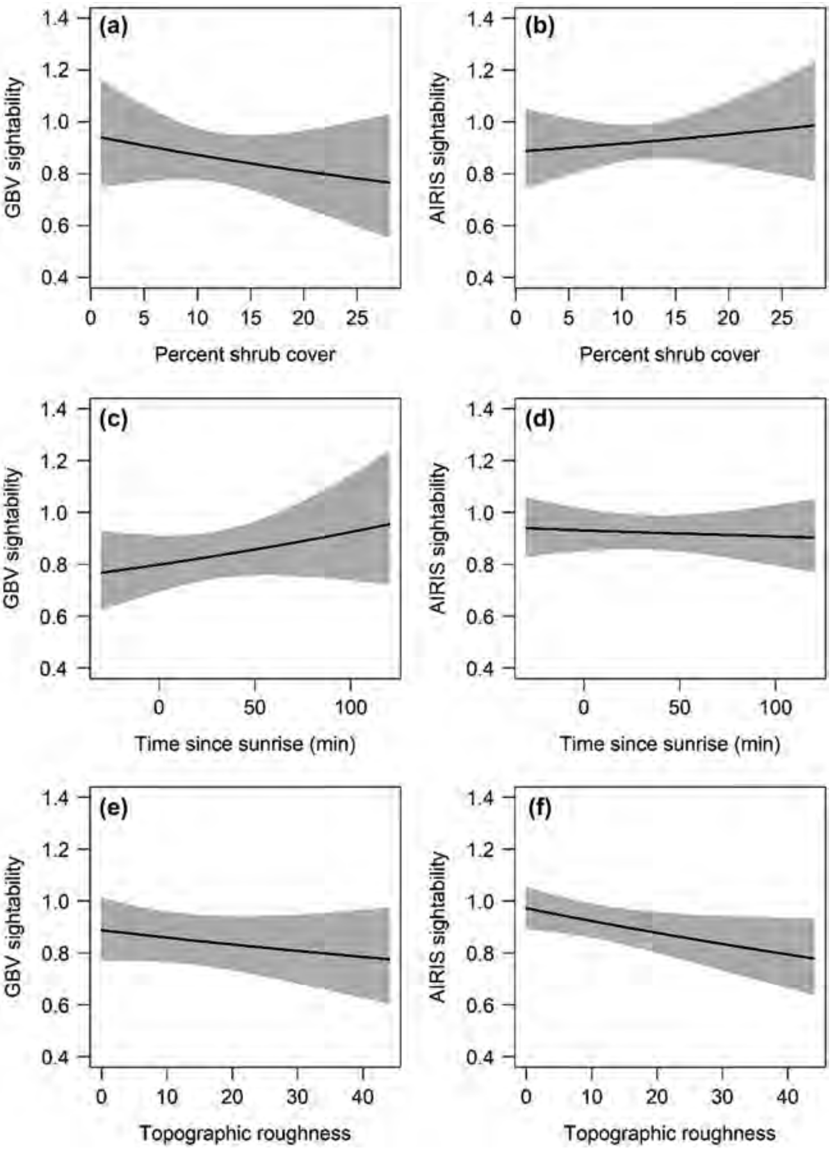

Figure 4. Effects of shrub cover (a and b), time since sunrise (c and d), and topographic roughness (e and f) on sightability estimates for ground-based visual (GBV) surveys (left column) at real leks with unknown numbers of greater sage-grouse *Centrocercus urophasianus* and aerial integrated infrared imaging system (AIRIS) surveys (right column) at pseudo-leks with known numbers of ring-necked pheasant *Phasianus colchicus* or chukar *Alectoris chukar*. GBV (2015–2017) and AIRIS (2016–2017) surveys were conducted at multiple study sites within the Great Basin.

Table 2. Parameter estimates from sightability models fit to pseudo-lek data (AIRIS sightability model) collected from the air (ring-necked pheasant *Phasianus colchicus* and chukar *Alectoris chukar*) and real lek data (GBV sightability model) collected in the air and on the ground (greater sage-grouse *Centrocercus urophasianus*) at study areas in the Great Basin. Coefficients (β) are reported for different covariates with their associated median and 95% credible intervals (CI). Subscripts indicate covariates which included shrub cover ('shrub'), time since sunrise ('tsr'), terrain roughness ('rough'), and intercepts.

Lek type	Parameter	Median β	95% CI	P (β = 1)*
Pseudo-lek	$\beta_{intercept}$	−0.060	−0.253 to 0.135	na
	β_{shrub}	0.004	−0.010 to 0.017	0.435
	β_{tsr}	0.000	−0.002 to 0.001	0.488
	β_{rough}	−0.005	−0.010 to 0.000	0.505
Real lek	$\beta_{intercept}$	−0.145	−0.466 to 0.171	na
	β_{shrub}	−0.008	−0.025 to −0.010	0.640
	β_{tsr}	0.001	−0.001 to 0.003	0.511
	β_{rough}	−0.003	−0.010 to 0.003	0.502

* Indicator function representing whether β is included in the model using stochastic search variable selection (George and McCulloch 1996). Evidence was considered substantial for values >0.6, marginal for 0.5–0.6, and deficient for <0.5.

attributed to decreased strutting activity. That study also observed that cloud cover and presence of females influenced sightability (Baumgardt et al. 2017). While we did not record cloud cover, given the absence of time since sunrise effects in AIRIS surveys, we suspect cloud cover is unlikely to influence the ability of the AIRIS to detect male sage-grouse but may be expected to influence sightability in ground counts. Weak evidence suggested that terrain roughness reduced sightability for AIRIS and GBV. This might be explained by fragmentation of field of view for both survey methods. Importantly, our assessment of using variables from relatively high-resolution GIS layers allows managers to use readily-available spatial data to adjust their estimates based on measurements associated with leks (e.g. shrub cover) remotely following lek monitoring, as opposed to conducting field measurements (Fremgen et al. 2016).

The overall lack of covariate effects on AIRIS sightability provide support for the hypothesis that most environmental predictors should not be as concerning in AIRIS surveys as in GBV surveys (Fremgen et al. 2016, Baumgardt et al. 2017). One explanation is that sightability associated with AIRIS is almost entirely comprised of probability of detection (p_d) and not probability of being available (p_a). This is because the p_a is likely very close to 1.0 given that factors that influence p_a for detection are not influential. In contrast, sightabilty in GBV surveys is likely driven by factors that influence p_a, such as visual obstruction by shrubs.

Several features of our study may have influenced our results and are important to consider for application of our methods to other systems. First, our proxy birds varied from sage-grouse in characteristics such as size and plumage. Mean sage-grouse mass across sexes at breeding (2323 g; Beck and Braun 1978) are substantially larger then female pheasant (954 g; Giudice and Ratti 2001) or chukar (680 g; Nagel 1945), suggesting the larger sage-grouse should be at least as detectable by infrared cameras as our proxy birds. Additionally, we did not observe a difference between pheasant and chukar which may imply that size did not have an effect. Furthermore, while the plumage coloration was different among all three species, infrared imagery does not use the visible spectrum so is unaffected by color, and the high-resolution color camera was only used to distinguish sex in the real lek surveys. Second, while sex was not distinguished in some of the surveys, and we found slight evidence of sightability differences among sexes, we accounted for the different survey types in the model and only report sightability estimates for males because male sage-grouse are the primary interest for wildlife agencies and land managers (WAFWA 2015). In using AIRIS for lek surveys, we stress the importance of separating males and females in the counts and having trained technicians capable of accurately identifying the sex of sage-grouse. Third, while our study assessed sightability (i.e. $p_a p_d$), it did not account for other components important for true population abundance estimates previously described by Nichols et al. (2009). One such component was the probability of sage-grouse being present on lek during the time of sampling (p_p) which can vary substantially throughout the season and among years (Wann et al. 2019). Additionally, not all lek locations are known (Sedinger 2007), which can lead to underestimation of population abundance, and sage-grouse leks that are easily accessible (e.g. near roads) are more likely to be surveyed which can introduce sampling bias (Applegate 2000, Anderson 2001, Walsh et al. 2004). Our study was not designed to address these issues, but they should be considered when assessing populations. We note, however, the potential application of AIRIS in locating unknown leks and surveying inaccessible leks, and we urge assessments of such uses.

Although AIRIS is a promising tool for lek surveys, this method has advantages and disadvantages compared to GBV surveys. First, AIRIS can be costly, currently averaging approximately $800 per hour (Gillette et al. 2015), whereas GBV methods to survey the same number of leks has approximately one third the cost. However, under time constraints, substantially more leks can be counted in a single morning using AIRIS than conventional methods of GBV surveys (Gillette et al. 2015). Second, flight time often must be scheduled well in advance because of limited availability of suitable aircraft and pilots, potentially constraining the use of AIRIS, whereas GBV surveys can be implemented more readily. Lastly, small aircraft surveys can carry increased safety risk for personnel (Sasse 2003), and weather conditions can additionally limit survey windows (Gillette et al. 2015). An economic assessment contrasting these survey techniques was beyond the scope of our study but see Gillette et al. (2015) for thorough cost-comparison between AIRIS and GBV.

In conclusion, our study provides information that can be used to improve inference to population sizes and trends and can help advance lek survey methods. While decisions of using AIRIS techniques over those of conventional GBV might be based on multiple factors including differences in costs, lek access, etc., likely a combination of both techniques will allow for most effective surveying for population assessments. We found GBV methods captured approximately 86% of males attending leks, while AIRIS increased the proportion of sage-grouse detected to about 93%, on average. Thus, for management application, our estimates may serve as general baseline adjustments on single lek counts for AIRIS and GBV (i.e. maximum counts) methods aimed at standardizing databases and accounting for detection uncertainty. Moreover, we provide adjustments in sightability for specific sites as a function of environmental covariates derived from widely available GIS layers. Lastly, *N*-mixture models using repeated within-morning ground counts from a single observer are useful to estimate sightability and lek abundance, which should be useful in accounting for spatial and temporal trends in observation error. These methods provide multiple options for managers to improve previously collected data and refine their monitoring programs to make better use of lek data for population studies.

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Supplementary material (available online as Appendix wlb-00552 at <www.wildlifebiology.org/appendix/wlb-00552>). Appendix 1–3.

6-1-2013

Common Raven Density and Greater Sage-Grouse Nesting Success in Southern Wyoming: Potential Conservation and Management Implications

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COMMON RAVEN DENSITY AND GREATER SAGE-GROUSE NESTING SUCCESS IN SOUTHERN WYOMING: POTENTIAL CONSERVATION AND MANAGEMENT IMPLICATIONS

by

Jonathan B. Dinkins

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Wildlife Biology

Approved:

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David N. Koons Committee Member	Terry A. Messmer Committee Member
Wayne A. Wurtsbaugh Committee Member	Mark R. McLellan Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2013

ABSTRACT

Common Raven Density and Greater Sage-Grouse Nesting Success in Southwest Wyoming: Potential Conservation and Management Implications

by

Jonathan B. Dinkins, Doctor of Philosophy

Utah State University, 2013

Major Professors: Dr. Michael R. Conover and Dr. Shandra Nicole Frey
Department: Wildland Resources

My research was focused on greater sage-grouse (*Centrocercus urophasianus*; hereafter "sage-grouse") nest-site selection, nest success, and hen survival in relation to avian predators. The trade-off between using habitat and avoiding predators is a common decision for prey species including sage-grouse. In Chapter 2, I compared avian predator densities at sage-grouse nest and brood locations to random locations. Sage-grouse were located where densities of small, medium, and large avian predators were 65–68% less than random locations.

The effects of anthropogenic and landscape features on habitat use of sage-grouse hens have not been evaluated relative to avian predator densities. In Chapter 3, I compared anthropogenic and landscape features and avian predator densities among sage-grouse locations (nest, early-brood, late-brood) and random locations. I found sage-grouse hens chose locations with lower avian predator densities compared to random locations, and selected locations farther away from anthropogenic and landscape features.

Depredation of sage-grouse nests can be an influential factor limiting their productivity. Predator removal has been simultaneously proposed and criticized as a potential mitigation measure for low reproductive rates of sage-grouse. In Chapter 4, I hypothesized that sage-grouse nest success would be greater in areas where Wildlife Services lowered common raven (*Corvus corax*: hereafter "raven") density. I found that Wildlife Services decreased raven density by 61% during 2008–2011 but I did not detect a direct improvement to sage-grouse nest success. However, sage-grouse nest success was 22% when ravens were detected within 550 m of a sage-grouse nest and 41% when no raven was detected within 550 m. In Chapter 5, I assessed interactive effects of corvid densities relative to anthropogenic and landscape features on sage-grouse nest success. I found that sage-grouse nest success was positively correlated with rugged habitat.

Survival of breeding-age birds is the most important demographic parameter driving sage-grouse abundance. In Chapter 6, I evaluated the effect of raptor densities, proximity to anthropogenic and landscape features, and hen behavior on survival of sage-grouse hens. I found that sage-grouse hen survival was negatively correlated with golden eagle (*Aquila chrysaetos*) density, proximity to anthropogenic and landscape features, and hen parental investment (nesting and brood-rearing).

(311 pages)

PUBLIC ABSTRACT

Common Raven Density and Greater Sage-Grouse Nesting Success in Southwest Wyoming: Potential Conservation and Management Implications

by

Jonathan B. Dinkins, Doctor of Philosophy

Utah State University, 2013

Declines in the distribution and abundance of greater sage-grouse (*Centrocercus urophasianus*; hereafter "sage-grouse") in western North America over the past century have been severe. The goal of my research was to increase the understanding of factors influencing where sage-grouse hens placed their nests, how common ravens (*Corvus corax*: hereafter "raven") impacted sage-grouse nest success, and whether high raptor densities negatively impacted hen survival of sage-grouse. I compared raven and raptor densities at sage-grouse nest and brood locations to available habitat. I also assessed how sage-grouse positioned their nests and broods relative to proximity to man-made structures, forested and riparian habitat, and rough topography. While evaluating the effect of ravens on nest success of sage-grouse, I hypothesized that nest success of sage-grouse would be greater in areas where Wildlife Services lowered the density of ravens. Finally, I evaluated the effect of raptor densities, proximity to man-made structures and forested and riparian habitat, rough topography, and hen behavior on survival of sage-grouse hens.

Several studies on birds have shown that avoidance of predators and dangerous habitat can have dramatic effects on habitat use by prey species. Sage-grouse hens chose locations with lower raven and raptor densities, selected locations farther away from man-made structures and forested habitat, and used locations that were flatter. Depredation of sage-grouse nests can be an influential factor limiting their populations. I found that Wildlife Services decreased raven density, but I did not detect a direct improvement to sage-grouse nest success. However, sage-grouse nest success was 22% when ravens were seen near a sage-grouse nest and 41% when no raven was seen near a sage-grouse nest. Survival of adult female sage-grouse has been demonstrated to be the most important aspect of a sage-grouse's life-cycle with respect to population growth. I found that sage-grouse hen survival was negatively related with golden eagle (*Aquila chrysaetos*) density when topography was flatter, proximity to man-made structures and forested habitat, and a hen's nesting and brood-rearing status (i.e., whether the hen was incubating eggs for caring for chicks).

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Jonathan B. Dinkins

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Greater sage-grouse (*Centrocercus urophasianus*: hereafter "sage-grouse") distribution and abundance in western North America has declined over the last century (Connelly et al. 2004, Schroeder et al. 2004, Connelly et al. 2011). In 2000, sage-grouse inhabited approximately 56% of their range compared to pre-European settlement (Schroeder et al. 2004), and abundance has declined an average of 2% annually from 1965–2003 (Connelly et al. 2004). This decline led the U.S. Fish and Wildlife Service (2010) to conclude that sage-grouse are warranted for protection under the Endangered Species Act of 1973, but the listing was precluded because other species were at greater threat of extinction. Many factors have been attributed to this decline including reduction of quality sagebrush habitat (human development, drought, and wildfire) and factors affecting survival (i.e., predation, West Nile virus, and hunting; Braun 1998, Connelly et al. 2004, Schroeder et al. 2004, Connelly et al. 2011).

Sage-grouse are highly associated with sagebrush (*Artemisia* spp.) ecosystems, because they rely on sagebrush for food during most of the year, nesting, shelter, and escape cover (Connelly et al. 2004, Schroeder et al. 2004, Connelly et al. 2011). Loss, degradation, and fragmentation of sagebrush habitats have been detrimental to sage-grouse populations. Several studies have suggested that quantity and condition of breeding habitat is the most important factor that dictates the productivity of sage-grouse, because given adequate habitat, sage-grouse would be buffered from other threats

(Connelly et al. 1994, Braun 1998, Schroeder and Baydack 2001, Connelly et al. 2011). However, there are increasing levels of human development in sage-grouse habitat (Connelly et al. 2004, Leu et al. 2008, Doherty et al. 2010, Kirol 2012). One of the consequences of habitat modification and fragmentation associated with human development in native grouse habitats may be increased predation rates (Schroeder and Baydack 2001).

A diverse array of generalist predators have increased in distribution and abundance in sagebrush steppe habitats throughout the western United States by capitalizing on fragmented habitats and human provided resources. For example, densities of common ravens (*Corvus corax*; hereafter "ravens") have increased in Wyoming and throughout the historic range of sage-grouse during the last century, (Andrén 1992, Engel and Young 1992, Boarman et al. 1995, Sauer et al. 2011). Densities of generalist predators are not limited by the density of a particular species of prey (Schroeder and Baydack 2001, Evans 2004, Manzer and Hannon 2005, Coates 2007), and breeding success and survival of ground-nesting birds has been shown to be suppressed by generalist predators, such as ravens (Evans 2004, Manzer and Hannon 2005, Baxter et al. 2007, Bui et al. 2010, Coates and Delehanty 2010).

Trade-offs between using habitat and avoiding predators are common decisions for prey species. Prey species including sage-grouse may minimize risk of predation by avoiding predators, which can be achieved by using habitat with lower abundance of predators and selecting habitat with lower risk of predation (Lima 1998, Verdolin 2006, Cresswell 2008; see also Chapter 2). Thus, sage-grouse may not select optimal nesting or brood-rearing habitat when the risk of predation is high.

Sage-grouse select nest and brood sites at various scales. At the landscape scale, sage-grouse may avoid areas where there are high densities of avian predators—specifically, American kestrels (*Falco sparverius*; hereafter “kestrels”), *Buteo* hawks, black-billed magpies (*Pica hudsonia*; hereafter “magpies”), golden eagles (*Aquila chrysaetos*), northern harriers (*Circus cyaneus*; hereafter “harriers”), and ravens (Manzer and Hannon 2005, Mezquida et al. 2006, Dinkins et al. 2012). At the microhabitat scale (habitat directly surrounding a sage-grouse location—typically measured <25 m from a sage-grouse nest or brood), sage-grouse predominately choose nest sites in vegetation cover (Connelly et al. 2004). Several studies have reported that sage-grouse select nest sites based on a preference for different microhabitat characteristics, such as sagebrush density (Wallestad and Pyrah 1974, Connelly et al. 2003), sagebrush cover (Doherty et al. 2010, Kirol et al. 2012), shrub height (Gregg et al. 1994), grass height (Gregg et al. 1994, Holloran et al. 2005, Kirol et al. 2012), and grass cover (Kaczor 2008, Kirol et al. 2012). Variability in reported microhabitat characteristic preferences of sage-grouse, with reference to nest and brood site selection, may indicate local differences in available microhabitat. Differences in available microhabitat among studies suggest that cover, in general, is important regardless of the type of vegetation cover that is available (e.g. sagebrush density, shrub height, or grass height). Alternatively, sage-grouse living in areas with different predator compositions may prefer different types of vegetation cover (Connelly et al. 2004, Coates and Delehanty 2010). Thus, the microhabitat characteristics upon which sage-grouse base their selection of nest-sites and the success of those nests may be a result of available vegetation and predator composition. For example, Coates and Delehanty (2010) found that microhabitat at sage-grouse nest-sites had a variable impact on nest depredation depending on whether a raven or a badger (*Taxidea taxus*) depredated the nest (greater cover protected from ravens, but exposed sage-grouse to greater badger depredation and vice versa).

Although reduction of quality sagebrush habitat is the driving factor that reduced populations of sage-grouse, nest success and hen survival are widely thought to be potential limiting factors for bird populations including sage-grouse (Connelly et al. 2004). Johnson and Braun (1999) and Taylor et al. (2012) found that adult hen survival was the most influential demographic parameter on sage-grouse population growth. Chick survival then nest success were the next most important factors affecting population growth for sage-grouse following adult hen survival. These conclusions may be related to the fact that sage-grouse are relatively long-lived ground-nesting birds with low productivity (Connelly et al. 2000b, Holloran et al. 2005, Connelly et al. 2011). Thus, many aspects of recruiting new individuals into a population are connected to sage-grouse hens (i.e., nest success and chick survival).

Local predator densities can affect habitat selection, nest success, survival, and parental behavior of ground-nesting birds such as prairie grouse species (Schroeder and Baydack 2001, Manzer and Hannon 2005, Coates and Delehanty 2010), farmland birds (Evans 2004), ducks (Sargeant et al. 1995), shorebirds (Smith et al. 2007), and passerines (Norrdahl and Korpimäki 1998, Roos and Pärt 2004, Thomson et al. 2006, Chalfoun and Martin 2009).

Unlike other population limiting factors (e.g., habitat condition, weather, and drought), reduction of predator numbers may be more feasible for wildlife management agencies to reduce predation rates (Cote and Sutherland 1997). For example, raven depredation of sage-grouse nests has been implicated as a potential factor limiting sage-grouse productivity in fragmented habitats (Batterson and Morse 1948, Willis et al. 1993, Gregg et al. 1994, Schroeder and Baydack 2001, Coates et al. 2008, Bui et al. 2010, Coates and Delehanty 2010). Predator removal has been simultaneously proposed and criticized as a potential mitigation measure for low reproductive rates of sage-grouse, specifically nest success. However, there are no predators that specialize on sage-grouse during any life history stage (egg, chick, or adult), and sage-grouse have relatively high nest and adult survival rates compared to other gallinaceous birds (Connelly et al. 2011). No predator management study has provided evidence that lethal removal of predators would benefit sage-grouse on a large scale (Hagen 2011). Thus, Hagen (2011) suggested that predation was not limiting sage-grouse populations, and predator removal may only serve to provide a short-term release of predation rates in fragmented habitats and areas with human-subsidized predator populations.

Survival of breeding-age birds in relation to predator communities has been a focus of sage-grouse research and conservation. Survival and nest success related to predator communities were not likely to have been a problem during pre-European settlement because sage-grouse co-evolved with the predator communities present in sagebrush ecosystems (Schroeder et al. 1999, Schroeder et al. 2001). However, areas of habitat fragmentation and areas with human-subsidized predator populations have drastically increased in the recent past (Leu et al. 2008). For example, red fox (*Vulpes vulpes*), common raccoon (*Procyon lotor*), and raven have increased in abundance in sage-grouse habitat, especially near human activities (Connelly et al. 2000b, Baxter et al. 2007, Hagen 2011, Sauer et al. 2011). In addition, raptors and corvids use anthropogenic structures as perches and nesting structure (Lammers and Collopy 2007, Prather and Messmer 2010, Slater and Smith 2010).

Sage-grouse hen survival has been related to habitat variables, such as topographic ruggedness and grass, forb, and sagebrush cover, by several studies and reviews (Connelly et al. 1994, Holloran 1999, Schroeder and Baydack 2001, Zablan et al. 2003, Moynahan et al. 2006, Kirol 2012). However, Dahlgren (2009) reported high sage-grouse hen survival rates (0.78 in a high survival year to 0.42 in a low survival year) with relatively lower quality habitat on Parker Mountain, Utah. Dahlgren (2006) described large contiguous sagebrush habitat and minimal vertical structure from human development at Parker Mountain, which may contribute to higher hen survival rates due to a lack of potential roost and nest sites for avian predators. Sage-grouse hens have been known to have high annual survival (48–78% in Wyoming; Holloran 2005, Connelly et al. 2011) with the breeding season having the lowest seasonal survival rate for sage-grouse hens (Connelly et al. 2000a).

RESEARCH OBJECTIVES

Although sage-grouse biology has been well studied, there has been little research regarding the effects of avian predator abundance on habitat selection of adult sage-grouse hens, nest success, and survival. My research provides information relative to the potential influences of avian predators on sage-grouse habitat selection, nest success, and survival of sage-grouse hens in relation to anthropogenic (oil and gas infrastructure, roads, power lines) and landscape (forested and riparian habitat and topographic ruggedness) features, and microhabitat.

In Chapter 2, I compared avian predator densities at sage-grouse nests and brood locations to available habitat. This comparison allowed me to assess the ability of sage-grouse to use locations with fewer avian predators during nesting and early brood rearing. In accordance with the predator-avoidance hypothesis, I hypothesized that at the landscape scale, sage-grouse would avoid nesting or raising broods in areas with high densities of avian predators, specifically kestrels, magpies, golden eagles, hawks (*Buteo* spp.), harriers, and ravens. Further, I hypothesized that adult survival would take precedence over nest or brood survival, and that sage-grouse habitat use would be shaped primarily by avoidance of avian predators that were a threat to adult hen survival, and secondarily by avoidance of avian predators that were a threat only to nests and broods. The effects of anthropogenic and landscape features on habitat selection of sage-grouse hens have not been evaluated in the context of avian predator abundance. In Chapter 3, I compared anthropogenic and landscape features and densities of avian predators among sage-grouse locations (nest, early-brood, late-brood) and available habitat.

Subsidized raven populations of increasing size have been anecdotally documented in southwest and south-central Wyoming associated with human activities such as livestock and natural gas development (R. J. Merrell, United States Department of Agriculture Animal and Plant Health Inspection Service Wildlife Services [WS], personal communication), and raven abundance has increased in Wyoming during the past decade, 2001–2010 (Sauer et al. 2011). Raven control (lethal removal) efforts of varying intensity have been carried out by WS in Carbon, Lincoln, Sweetwater, and Uinta counties in Wyoming, 2007–2011 for the protection of livestock, which provided a unique opportunity to study the potential effects of raven removal on sage-grouse nest success. In Chapter 4, I hypothesized that sage-grouse nest success would be greater in areas where WS lowered the abundance of common ravens (*Corvus corax*: hereafter "raven"). To test this hypothesis, I assessed the change in density of ravens and sage-grouse nest success in areas associated with WS raven removal efforts and areas farther away during 2008–2011. As secondary objectives, I evaluated differences between yearling and adult sage-grouse nest success, and the effect of ravens on nest success at the sage-grouse nest level in relation to microhabitat. In Chapter 5, I tested the hypothesis that the negative effects of corvids would be amplified in areas closer to potential perches and areas with subsidized food resources (anthropogenic and landscape features).

Although avian predators have been reported to prey on sage-grouse, densities of avian predators have not been correlated with sage-grouse survival rates. For example, golden eagles have been implicated as the major sage-grouse predators (Willis et al. 1993, Connelly et al. 2000, Danvir 2002, Dahlgren 2006, Mezquida et al. 2006), and high golden eagle abundance has been suggested to decrease sage-grouse survival (Danvir 2002). However, no sage-grouse study has directly related site-specific densities of avian predators, including golden eagles, to sage-grouse hen survival. In Chapter 6, I evaluated the effect of raptor densities, proximity to anthropogenic and landscape features, and hen behavior on survival of sage-grouse hens.

The chapters of my dissertation are written as stand-alone manuscripts with Chapters 2 and 3 in the format of the Auk and Chapters 1 and 4–7 in the format of the Journal of Wildlife Management.

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CHAPTER 2

GREATER SAGE-GROUSE (*CENTROCERCUS UROPHASIANUS*) SELECT NEST-SITES AND BROOD-SITES AWAY FROM AVIAN PREDATORS[*]

ABSTRACT.–Greater Sage-Grouse (*Centrocercus urophasianus*; hereafter "sage-grouse") distribution and abundance in western North America has declined over the last century. Depredation of sage-grouse nests and predation of chicks can be two of the most influential factors limiting their productivity. Prey species utilize anti-predation behaviors, such as predator avoidance, to reduce the risk of predation. Birds in general balance the dual necessity of selecting cover to hide from visual and olfactory predators to enhance prospects of survival and reproductive success, which may also be achieved by selecting habitat with relatively fewer predators. I compared avian predator densities at sage-grouse nests and brood locations to random locations within available sage-grouse habitat in Wyoming. This comparison allowed me to assess the ability of sage-grouse to avoid avian predators during nesting and early brood-rearing. During 2008–2010, I conducted 10-min point-count surveys at 218 sage-grouse nests, 249 sage-grouse brood locations from 83 sage-grouse broods, and 496 random locations. I found that random locations had higher densities of avian predators compared to sage-grouse nest and brood locations. Sage-grouse nested in areas where there were lower densities of Common Ravens (*Corvus corax*), Black-billed Magpies (*Pica hudsonia*), Golden Eagles (*Aquila chrysaetos*), and *Buteo* hawks compared to random locations. Additionally, sage-grouse selected brood-rearing locations that had lower densities of the same avian

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predators as during nesting, plus American Kestrels (*Falco sparverius*) compared to random. By selecting nest and brood-rearing locations with lower avian predator densities, sage-grouse may reduce the risk of nest depredation and predation on eggs, chicks, and hens.

INTRODUCTION

FOOD AND RISK of predation are two factors widely thought to have important influences on the choice of breeding habitat by birds and other animals, and actual habitat choice has often been described as a trade-off between access to resources and risk of predation (Verdolin 2006). Thus, avian species may not select optimal nesting or brood-rearing habitat for foraging when the risk of predation is high. Prey species utilize anti-predation behaviors, such as predator avoidance (predator-avoidance hypothesis), to reduce the risk of predation (Cresswell 2008, and references therein). Local predator densities can affect the productivity, parental behavior, and nest-site selection of ground-nesting birds such as prairie grouse species (Schroeder and Baydack 2001, Manzer and Hannon 2005, Coates and Delehanty 2010), farmland birds (Evans 2004), ducks (Sargeant et al. 1995), shorebirds (Smith et al. 2007), and passerines (Norrdahl and Korpimäki 1998, Roos and Pärt 2004, Thomson et al. 2006, Chalfoun and Martin 2009).

Declines in Greater Sage-Grouse (*Centrocercus urophasianus*; hereafter "sage-grouse") abundance in western North America over the last century have been severe (Gregg et al. 1994, Johnsgard 2002, Connelly et al. 2004), and recently led the U.S. Fish and Wildlife Service (2010) to conclude that sage-grouse are warranted for protection under the Endangered Species Act of 1973. Many factors have contributed to this decline including habitat loss, habitat fragmentation, habitat degradation, and predation (Braun 1998, Schroeder et al. 2004). Despite the U.S. Fish and Wildlife Service's assessment, listing was precluded in favor of other species under more severe threat of extinction.

Direct effects of nest predation on nesting productivity of birds is widely recognized, and even in high quality sage-grouse habitat, most sage-grouse nests are lost to predators (Gregg et al. 1994, Connelly et al. 2004, Coates et al. 2008). For example, Common Raven (*Corvus corax*; hereafter "raven") depredation of sage-grouse nests has been documented as a common occurrence in northeastern Nevada on the basis of infrared video cameras set up at nest sites (Coates et al. 2008). High mortality rates on chicks have also been attributed to predators, especially during early brood-rearing (Aldridge 2005, Gregg and Crawford 2009, Guttery 2011).

In addition to direct predator effects, perceived predation risk may have dramatic effects on nest success and chick survival (Cresswell 2008, Martin and Briskie 2009), and prey's perception of predation risk may have negative effects that are strong enough to effect population growth rates (Creel and Christianson 2008, Cresswell 2008, Zanette et al. 2011). For example, Zanette et al. (2011) manipulated perceived predation risk while excluding predators from Song Sparrow (*Melospiza melodia*) nests. In the absence of direct predation, Zanette et al. (2011) found a 40% reduction in offspring production as a result of reduction in the number of eggs laid, proportion of eggs hatched, and proportion of nestlings fledged.

In response to predation risk to adults and their nests, sage-grouse and other birds hide nests from predators by placing them primarily in areas with greater visual obstruction (Connelly et al. 1994, Braun 1998, Connelly et al. 2004, Kirol et al. 2012); hens and broods hide from avian predators through a combination of habitat selection and cryptic behavior (Gregg and Crawford 2009, Guttery 2011). Several studies have reported that sage-grouse select nest-sites based on greater sagebrush density (Wallestad and Pyrah 1974, Connelly et al. 2003), sagebrush cover (Doherty et al. 2010, Kirol et al. 2012), shrub height (Gregg et al. 1994), grass height (Gregg et al. 1994, Holloran et al. 2005), and grass cover (Kaczor 2008, Kirol et al. 2012). Kirol et al. (2012) and Aldridge and Brigham (2002) found that sage-grouse brood hens selected locations with greater percentages of sagebrush and grass cover compared to random locations. Variability in reported nest and brood site habitat use among studies may indicate local differences in habitat and/or predator community composition. However, consistent placement of nests and broods in sites with greater visual cover, regardless of differences in the structure of local habitats, suggests that vertical (e.g., grass and shrub height) and horizontal (e.g., grass and shrub canopy cover) cover influence nest-site and brood-site selection.

Current evidence (Conover et al. 2010) suggests that sage-grouse use nest locations that hide their nests from visual but not olfactory predators. Conover et al. (2010) found that sage-grouse placed nests in areas that had greater vertical and horizontal concealment, taller shrubs, but also fewer updrafts, lower turbulence, and slower wind speeds than random locations. Updrafts, high turbulence, and high wind speeds are weather conditions that make it difficult for mammalian predators to use olfaction to locate nests (Conover 2007). These results are consistent with results of other sage-grouse research that showed sage-grouse preferred to nest in areas with greater visual cover. Further, locations that have good visual cover often have fewer updrafts, less atmospheric turbulence, and lower wind speeds. Thus, sage-grouse, and birds in general, often balance the dual necessity of selecting cover to hide from visual and olfactory predators to improve chances of surviving to breed successfully. Selection of nest-sites that conceal sage-grouse from visual predators but not olfactory predators suggests that the former are a greater threat to sage-grouse nests. On the other hand, it may be that sage-grouse cannot use olfactory cues to influence nest choice decisions, and visual predators may be a greater threat because their numbers have increased in association with anthropogenic development.

Sage-grouse select nest-sites based on habitat characteristics at local (habitat directly around a nest) and landscape scales (Doherty et al. 2010). In accordance with the predator-avoidance hypothesis, I hypothesized that at the landscape-scale, sage-grouse would avoid nesting or raising broods in areas of high densities of avian predators, specifically, American Kestrels (*Falco sparverius*; hereafter “kestrel”), Black-billed Magpies (*Pica hudsonia*; hereafter “magpies”), Golden Eagles (*Aquila chrysaetos*), hawks (*Buteo* spp.), Northern Harriers (*Circus cyaneus*; hereafter “harrier”), and ravens. Further, I hypothesized that adult survival would take precedence to nest or brood survival, and that sage-grouse habitat use would be shaped primarily by avoidance of avian predators that were a threat to adult hen survival, and secondarily to avian predators that were a threat only to nests and broods. I tested these hypotheses by comparing avian predator densities at sage-grouse (1) nest and (2) brood locations, and (3) random locations within nesting and brood-rearing habitat.

METHODS

Study Areas.—My study was conducted in southwest and south-central Wyoming at 12 study sites that were either 16 km (*n* = 8) or 24 km (*n* = 4) in diameter (Fig. 2-1). Sage-grouse are lekking species, and Holloran and Anderson (2005) found that 384 of 415 (92.5%) sage-grouse nests were within 8.5 km of leks in central and southwest Wyoming. Thus, the study sites in southwest Wyoming were 16-km diameter and approximately centered around leks where hens were captured. I used larger 24-km study sites in south-central Wyoming because sage-grouse were captured at several leks spread over a larger area. Five study sites were located in Lincoln County (16-km diameter each), two in Sweetwater County (one 16-km and one 24-km diameter), two in Uinta County (both 16-km diameter), and three in Carbon County (24-km diameter each). Study sites were chosen to provide a representation of overall sage-grouse nesting habitat in southern Wyoming with a variety of land uses and topographic features. Elevation ranged from 1,950 m to 2,530 m among study sites. Most of my sites were owned and administered by the Bureau of Land Management (BLM) with a small percentage of private lands. Domestic sheep and cattle grazing were the dominant land uses in my study sites. All study sites had anthropogenic development consisting mostly of unimproved 4-wheel drive roads. Conventional natural gas, coalbed methane natural gas, and/or conventional oil extraction activities were present in six (50%) of my study sites; well density within study sites averaged 0.12 ± 0.22 (SD) wells km^{-2} (range = 0.0–0.64 wells km^{-2}).

Sagebrush (*Artemisia* spp.) dominated the landscape at all study sites; Wyoming Big Sagebrush (*A. tridentata wyomingensis*) and Mountain Big Sagebrush (*A. t. vaseyana*) were the most common. Black Sagebrush (*A. nova*) and Dwarf Sagebrush (*A. arbuscula*) were found on exposed ridges. Other common shrub species in my study sites included: Antelope Bitterbrush (*Purshia tridentata*), Common Snowberry (*Symphoricarpos albus*), Chokecherry (*Prunus virginiana*), Alderleaf Mountain Mahogany (*Cercocarpus montanus*), Rabbitbrush (*Chrysothamnus* and *Ericameria* spp.), Greasewood (Sarcobatus vermiculatus), Saskatoon Serviceberry (*Amelanchier alnifolia*), and Spiny Hopsage (*Grayia spinosa*). Isolated stands of juniper (*Juniperus* spp.) and Quaking Aspen (*Populus tremuloides*) were found at the higher elevations on north-facing hillsides.

Sage-grouse Capture and Monitoring.—I monitored sage-grouse hens during nesting and early brood-rearing from 2008 through 2010. Hens were captured, radio-collared, and released in April of each year. Capture occurred at night using ATVs, spotlights, and hoop-nets (Giesen et al. 1982, Wakkinen et al. 1992). Sage-grouse hens were fitted with 17.5-g or 22-g (<1.5% body mass) necklace radio collars (Holohil Systems Ltd, RI-2D, Ontario, Canada or Advanced Telemetry Systems Inc, A4060, Isanti, Minnesota).

I located hens on a weekly basis with Communications Specialists

(Communications Specialists, R-1000, Orange, California) receivers and 3-way Yagi antennas (Communications Specialists, Orange, California). Potential nests were identified by binoculars at a distance of ~15 m by circling a radio-marked hen until she was sighted under a shrub. Nests were verified by triangulating the hen under the same shrub from >50 m away or thoroughly searching the area of the potential nest when the hen was absent. I continued monitoring nests weekly until it either hatched or failed. I assessed nest fate as successful or unsuccessful after a hen had left its nest. A successful nest was defined as having evidence that at least one egg hatched as determined by shell membrane condition (Wallestad and Pyrah 1974). I classified unsuccessful nests as abandoned (eggs not depredated or hatched) or depredated (at least one egg with evidence of depredation and no eggs hatched).

I located the broods of radio-marked hens weekly with binoculars from a distance of ~15 m. Brood hens were identified by either visually detecting chicks or observing hen behavior that indicated the presence of a brood (e.g., hesitation to flush, feigning injury, or clucking). I classified a sage-grouse hen as a brood hen if there was at least 1 chick with her. Monitoring of broods continued for as long as possible, which was usually until the chicks were at least 3-weeks old, the hen lost her brood, the hen died, or the hen could no longer be located.

Avian Predator Monitoring.—Between May and August of each year (sage-grouse nesting and brood-rearing season), I conducted point-count surveys at sage-grouse nests, sage-grouse brood locations, and random locations (hereafter; nest, brood, and random locations) within each study site to compare avian predator densities. Random locations were selected in habitat considered to be available to sage-grouse for nesting within each study site. To restrict random locations to available nesting habitat, I used ArcMap version 9.2 (ESRI Inc., Redlands, California) to generate random locations only in sagebrush-dominated habitat, which was classified by the Northwest GAP landcover data from 2008. Random locations were at least 1,000 m apart, but in practice, random points in all years averaged over 2,000 m apart (Table 2-1). I generated 12 random locations in each 16-km diameter study site and 18 random locations in each 24-km diameter study site per year (total n = 504). A new set of random locations was generated each year to avoid spatial autocorrelation; thus, random locations between years were independent.

I used standard distance sampling techniques (Buckland et al. 1993, Ralph et al. 1995, Thomas et al. 2010) to count and record distance to all corvids and raptors observed during point-counts. I recorded distance from the observer when standing at the center point to where predators were first located (Ralph et al. 1995, Thomas et al. 2010); this minimized possible bias associated with avian predators being attracted to or flushed away from an observer. In the uncommon event that an avian predator was displaced from the center of a point-count location as an observer approached (6% of detected birds), I recorded distance from that avian predator to the center of the point-count location while the observer approached as suggested by Ralph et al. (1995). A 1,500–m rangefinder (American Technologies Network Corp., RE-1500 m, San Francisco, California) was used in conjunction with a GPS unit to estimate distances directly or to validate visually estimated distances.

I conducted 10-min point-count surveys during daylight hours on a weekly basis at each study site. I visited each point-count location 1 to 8 times with most locations visited ≥ 3 times. I did not survey during inclement weather (i.e., in rain or with wind speeds ≥25 km/h; Ralph et al. 1995). Avian predators that could not be identified to species were not included in analyses—2% of detections within truncated distances. Nest and brood point-counts were performed after nests and broods were initially located; thus, nest point-counts were conducted in May and June and brood point-counts were conducted from mid-May to early-August. I performed random point-counts throughout the nesting and early brood-rearing season (May to early-August).

I intermixed the sampling of nest, brood, and random point-counts within each study site, and each week I changed the time of day and the observer that conducted individual point-counts within a study site. The observers conducting point-counts within a particular study site changed each year, but all observers were trained and tested in corvid and raptor identification before conducting point-counts.

To avoid disturbing an incubating hen, nest point-counts were conducted 100 m to 200 m away from a sage-grouse nest but within a line-of-sight of that nest. I also performed brood point-counts 100 m to 200 m away from a brood hen—estimated by triangulation—immediately before verifying that a radio-marked brood hen was still with chicks. This was intended to record avian predator densities before the observer disturbed any avian predators and to avoid flushing a brood hen when a predator was nearby. If the hen did not have chicks, the brood point-count was discarded.

Data Analyses.—I used conventional distance sampling in DISTANCE 6.0

release 2 (Thomas et al. 2010) to estimate Ferruginous Hawk (*Buteo regalis*), Golden Eagle, harrier, kestrel, magpie, raven, Red-tailed Hawk (*Buteo jamaicensis*), and Swainson's Hawk (*Buteo swainsoni*) densities for nest, brood, and random locations across all years and all study sites. Ferruginous Hawks (*n* = 34), Red-tailed Hawks (*n* = 218), and Swainson's Hawks (*n* = 46) were combined into a single group (*Buteo* hawks) for analyses because all *Buteo* hawks likely had a similar effect on sage-grouse nest-site selection and most observed *Buteo* hawks were Red-tailed Hawks. For DISTANCE analyses, Golden Eagle, harrier, magpie, and raven detection distances were right truncated 5%; *Buteo* hawk detection distances were right truncated 7.5%; and kestrel detection distances were not right truncated (Table 2-2). I chose truncation distances by determining the smallest truncation that allowed for adequate fit of DISTANCE models.

I fit half-normal and hazard-rate key detection functions with cosine, simple polynomial, and hermite polynomial adjustments. I compared the fit of all possible detection functions with detection varying among point-count types to detection held constant among point-count types. I selected the appropriate key detection function and detection function adjustment for each avian predator species separately using Akaike's information criterion corrected for small sample sizes (AIC_c; Burnham and Anderson 2002). For all avian predator species, DISTANCE models with detection held constant were at least 4 AIC_c lower than models with detection varying by point-count type. This was not surprising because all point-counts were in sagebrush-dominated habitat.

I used DISTANCE to estimate observer effective detection radius (EDR), which was defined as the distance that the number of detected birds beyond EDR was equal to the undetected birds within EDR (Buckland et al. 2001). For example, an EDR of 500 m for hawks would indicate that the number of detected hawks beyond 500 m was equal to the number of undetected hawks less than 500 m from an observer. I also fit DISTANCE models with detection allowed to vary among observers to assess differences in detection among observers, but the latter models did not fit the data well. For this reason, and because EDR did not differ among observers (95% confidence intervals [CI] around EDRs of all observers overlapped for all avian predator species), I did not incorporate observer differences in detection into my DISTANCE analyses.

I adjusted density estimates for survey effort (difference in the number of visits per point-count location) and scaled my density estimates by the maximum number of visits per point-count location. Survey effort was accounted for in DISTANCE by dividing the total number of detected avian predators at each point-count location by that point-count's proportion of actual visits to the maximum number of visits (e.g., the total number of Golden Eagles detected at point-count x = 3, visits to point-count x = 5, total visits possible = 8; thus, for DISTANCE analyses point-count x was given a golden eagle count of 3 / 0.625 = 4.8, which was then scaled appropriately in DISTANCE by dividing by 8; Thomas et al. 2010).

I used 95% CIs to compare raven, magpie, Golden Eagle, *Buteo* hawk, harrier, and kestrel densities separately at nest, brood, and random locations. Confidence intervals were generated empirically using density estimates and standard errors from DISTANCE with avian predator counts pooled over all study sites and years.

In addition to DISTANCE analyses, I modeled differences in avian predator densities between locations used by sage-grouse (nest and brood locations) and random locations with an information theoretic approach (Anderson 2008). Modeling was done with binomial generalized linear mixed models (GLMM) with restricted maximum likelihood (REML) estimation of degrees of freedom; locations used by sage-grouse were coded 1 and random locations 0. I fit GLMMs with function lmer in package lme4 (R 2.10.1; The R Foundation for Statistical Computing 2009). I calculated avian predator densities from the raw count data within the DISTANCE estimated EDR for each avian predator species. I thus compared avian predator densities using species-specific EDRs because I did not find differences in detection among brood, nest, and random point-count types. The raw densities were standardized by the number of visits to each point-count location. I log transformed raw avian predator densities to reduce the affects of influential observations. I used log transformed raw avian predator species densities to create additive variables (Table 2-3). This allowed me to compare 6 models between locations used by sage-grouse and random locations in which avian predator species were treated either (1) individually, (2) as a single group that ignored size and behavior, (3) as small or large predators, (4) as small, medium, or large predators, (5) by distinguishing between low-flying predators (L), omnivores (O), or soaring (S) species, or (6) by separating species as a threat primarily to adult hen (A), incubating hen (N), or brood-rearing hen (B) (Table 2-3). I compared models with associated variables with AIC_c and Akaike weights (w_i). Multicollinearity was not a problem because no avian predator species were correlated ($r \leq 0.17$) and variance inflation factors (VIF) for avian predator species were VIF ≤ 1.18. Mixed models were used to incorporate study site as a random factor, which accounted for study site differences including fragmentation, anthropogenic structures, landscape features, and vegetation.

DISTANCE estimates are known to be robust to spatial autocorrelation (Thomas et al. 2010). Nonetheless, spatial autocorrelation violates the independence assumption for GLMM, and therefore I used spline correlograms of Pearson residuals with 95% point-wise bootstrap CIs to assess spatial autocorrelation. GLMM residuals were spatially autocorrelated $\leq$ 2,500 m (Fig. 2-2). I used spatial eigenvector mapping (SEVM) as specified by Dormann et al. (2007) to account for spatial autocorrelation in model residuals (Fig. 2-2). I created an inverse weighted distance matrix to generate eigenvectors, where point-count locations > 8 km apart were not considered to be correlated. This distance related directly to the radius of my 16-km diameter study sites; however, 8 km was also larger than the home range size of breeding Golden Eagles (1.9–92.0 km^2; DeLong 2004) and breeding ravens (0.3–45.8 km^2; Boarman and Heinrich 1999), which had the largest home ranges of the avian predators in this study. Furthermore, I treated all point-count locations, regardless of type or year, within 8 km as correlated with the degree of correlation related to the distance among point-count locations. I found the smallest number of eigenvectors required to remove spatial autocorrelation (Moran's similarity index: $P \geq 0.1$) for each GLMM by using function ME in package spdep (R 2.10.1; The R Foundation for Statistical Computing 2009); I then refit each GLMM with eigenvectors included as fixed effects to account for residual spatial autocorrelation.

RESULTS

I conducted 3,006 point-count surveys over the three years at 963 point-count locations. This comprised 218 sage-grouse nest locations, 249 sage-grouse brood locations (with 83 separate broods), and 496 random locations (Table 2-1). On the whole, sage-grouse selected nest and brood locations with lower densities of avian predators than random locations (Fig. 2-3). I visited each brood between 1 to 9 weeks posthatch (mean = 3.04 ± 2.13 SD). In all years, distance to nearest neighboring location was shortest for broods. Distance between nearest nest and random locations were 2 to 3 times greater than brood locations and similar to each other (Table 2-1). Golden Eagles and ravens were the most commonly detected avian predators, *Buteo* hawks and magpies had an intermediate number of detections, and harriers and kestrels had the lowest number of detections (Table 2-2). EDR estimates ranged from 294 m for magpies to 1,006 m for Golden Eagles, and differed by avian predator species (Table 2-2). This verified the necessity of selecting detection functions for each avian predator species separately. All avian predator species or species groups had more than the 60–80 detections that Buckland et al. (1993) suggested was necessary for reliable density estimates (Table 2-2).

Comparison of 95% CIs showed that *Buteo* hawk, Golden Eagle, magpie, and raven estimated densities were significantly lower at sage-grouse nest and brood locations than random locations (Fig. 2-3). Kestrel densities were significantly lower at sage-grouse brood locations but similar at sage-grouse nest locations compared to random locations (Fig. 2-3). Harrier densities were similar at sage-grouse nest, brood, and random locations (Fig. 2-3); however, random and brood location CIs were only slightly overlapping.

The spline correlogram of Pearson residuals from the top AIC_c ranked GLMM showed that SEVM with 34 eigenvectors accounted for spatial autocorrelation (Fig. 2-2). The top AIC_c ranked GLMM model with SEVM was that which recognized and distinguished among small, medium, and large species (Table 2-4); coefficients for all three size classes were negative and did not overlap zero (Table 2-5). Negative coefficients indicated lower small, medium, and large avian predator densities at locations used by sage-grouse compared to random locations. Sage-grouse nest and brood locations had lower densities of all three size classes of avian predators (Table 2-5).

DISCUSSION

I found that sage-grouse selected habitat with lower densities of avian predators at nests and brood locations as predicted by the predator-avoidance hypothesis. By selecting habitat with lower densities of avian predators, sage-grouse lower their exposure to avian predation, and risk of reproductive failure. My three-size class model had $w_i = 0.91$ (Table 2-4), suggesting that sage-grouse avoided avian predators at nest and brood locations on the basis of the size of avian predators rather than individual species identity, equivalence of all species, foraging behavior of predators, or presumed threat to sage-grouse reproductive stage.

Although I estimated avian predator densities across all years, I did not expect the pattern of sage-grouse avoidance of avian predators to differ among years. The inclusion of SEVM in my GLMM analyses dealt with spatial autocorrelation and bias associated with nest-site fidelity between years, weekly movements of broods, and similarities in habitat within and among study sites. DISTANCE estimates are known to be robust to lack of independence of observation locations because distance sampling is setup to be a snap-shot in time (Thomas et al. 2010). My sampling was designed to attempt to count the greatest proportion of avian predators within a study site each week as suggested by Thomas et al. (2010) and Ralph et al. (1995). Conducting all point-counts within a study site in one day reduced the possibility of double-counting individual avian predators during that week's visit. Counting the same individual during different weeks, regardless of the particular point-count location, was properly scaled by accounting for survey effort. Replication of point-counts by sampling multiple weeks was done to increase the proportion of avian predators detected as suggested by Thomas et al. (2010).

I found raven abundances at sage-grouse nest and brood locations were lower than at random locations in available sagebrush habitat. In western Wyoming, Bui et al. (2010) claimed that raven density around sage-grouse nesting and brood-rearing areas (1.0 ± 0.2 [SE] ravens/km^2) was marginally higher than raven densities in available sagebrush habitat (0.7 ± 0.2 [SE] ravens/km^2); however, these results were not significantly different. The discrepancy between my results and Bui et al. (2010) may be a function of greater anthropogenic development and human activity in their study areas or raven behavioral adaptations related to available resources. Regardless, I agree with Bui et al. (2010) that as avian predators, especially ravens, increase in abundance in sage-grouse habitat, quality nesting and brood-rearing habitat will become more limited. This is consistent with predation risk trade-offs and non-lethal predator effects, such as avoidance of risky habitats or habitats occupied by predators (Evans 2004, Verdolin 2006, Cresswell 2008).

To my knowledge, my study is the first to document raven densities potentially impacting sage-grouse nest-site selection. However, my finding is not surprising because raven densities impact the nest success of prairie grouse species (Gregg et al. 1994, Manzer and Hannon 2005, Coates and Delehanty 2010). In southern Alberta, sharp-tailed grouse (*Tympanuchus phasianellus*) had 8-times greater nest success in landscapes with less than three corvids/km^2 as opposed to landscapes with greater than or equal to three corvids/km^2 (Manzer and Hannon 2005). Sage-grouse nest success in northeastern Nevada was related to the number of ravens per 10-km transect with the odds of a nest failure increasing 7.4% with every additional raven (Coates and Delehanty 2010). Around Jackson and Pinedale, Wyoming, Bui et al. (2010) found that higher occupancy rates of ravens was correlated with failed sage-grouse nests.

Magpies depredate sage-grouse nests (Holloran and Anderson 2003), and they are capable of consuming animals as large as sage-grouse chicks (Trost 1999). Magpies are known to be associated with riparian areas but also forage in sagebrush habitats (Trost 1999). Thus, sage-grouse avoidance of magpies during nesting may be related to sage-grouse avoidance of riparian areas within or adjacent to sagebrush habitat; however, sage-grouse are known to utilize riparian areas for foraging chicks (Connelly et al. 2004, Crawford et al. 2004). My results indicate sage-grouse select habitat for brood rearing with lower abundances of magpies, even while balancing the need to utilize habitats, such as riparian habitats, that provide forage to meet the energetic requirements of chicks. Sage-grouse hens typically move broods to riparian areas after early-brood rearing (Crawford et al. 2004, Gregg and Crawford 2009), which may correspond with chicks being more mobile and less susceptible to predation by magpies.

Golden Eagles are the primary predator of adult sage-grouse (Schroeder et al. 1999, Schroeder and Baydack 2001, Mezquida et al. 2006). In southwestern Wyoming, MacLaren et al. (1988) found that birds contributed to approximately 9% of the diet of nesting Golden Eagles, and sage-grouse was their primary avian prey. In Utah, 55% of radio-marked sage-grouse were killed by raptors, which Danvir (2002) attributed mainly to Golden Eagles. Hence, I was not surprised that sage-grouse pay particular attention to them in locating where to nest and raise their brood. Ferruginous Hawks, Red-tailed Hawks, and Swainson's Hawks take some adult sage-grouse but probably not substantial numbers of them (MacLaren 1988); harriers have been witnessed hunting sage-grouse adults and chicks (Schroeder et al. 1999, Schroeder and Baydack 2001, Fletcher et al. 2003). My GLMM analysis indicated that sage-grouse were avoiding all *Buteo* hawks, harriers, and ravens as a group based on their body size rather than differentiating among them.

My GLMM results showed that sage-grouse were able to avoid small, medium, and large avian predators. This suggests that sage-grouse are not subject to predator facilitation by avian predators. Predator facilitation predicts that anti-predation behaviors that protect prey species from one type of predator may expose them to predation from other types of predators (Kotler et al. 1992, Korpimäki et al. 1996). For example, the risk of predation by Eurasian Eagle Owls (*Bubo bubo*) resulted in gerbils (*Gerbillus allenbyi* and *G. pyramidum*) selecting habitat that increased their exposure to predation by Greater Sand Vipers (*Cerastes cerastes*; Kotler et al. 1992). By hiding from and avoiding avian predators, sage-grouse may reduce their risk of predation from avian predators of multiple sizes, while potentially exposing themselves to olfactory (mammalian) predation. However, the possible effects of predator facilitation between visual predators and olfactory predators are beyond the scope of this study and warrant further research.

Sage-grouse preferentially select for greater visual concealment cover for nesting to hide themselves and their nests from visual predators (Conover et al. 2010), and the probability of raven depredation of a sage-grouse nest has been found to be greater at nests with relatively less canopy cover (Coates and Delehanty 2010). This selection for hiding from and avoiding visual predators through indirect (i.e., habitat features and anthropogenic structures) and possibly direct means entails selection at multiple scales. At the local-scale, sage-grouse appear to be selecting for sites where they are visually concealed from avian predators (Connelly et al. 2004, Doherty et al. 2010, Kirol et al. 2012). At landscape-scales, sage-grouse may be selecting for areas where avian predators are less abundant. Sage-grouse selection of habitat at multiple scales achieves the same thing—reduced risk from avian predators.

Predator avoidance behavior is a common consequence of predation risk (Cresswell 2008). Sage-grouse avoidance of predators has been addressed in the context of using cover to hide from predators; however, nesting and brood-rearing sage-grouse may also directly avoid avian predators. Previous research has not looked at the possibility of sage-grouse directly avoiding predators, but studies on other avian species have demonstrated direct avoidance of avian predators. For example, large numbers of Western Sandpipers (*Calidris mauri*) avoided migration stopover areas with Peregrine Falcons (*Falco peregrinus*) present (Ydenberg et al. 2002), sandpipers also shortened duration at migratory stopover locations possibly to avoid migrating Peregrine Falcons (Ydenberg et al. 2004), Tengmalm's Owls (*Aegolius funereus*) nested away from Ural Owl (*Strix uralensis*) nests (Hakkarainen and Korpimäki 1996), Black Kite (*Milvus migrans*) nests were located away from nesting Eurasian Eagle Owls (Sergio et al. 2003), Skylarks (*Alauda arvensi*) and Yellowhammers (*Emberiza citrinella*) avoided nesting close to European Kestrel (*Falco tinnunculus*) nests (Norrdahl and Korpimäki 1998), Red-backed Shrikes (*Lanius collurio*) avoided nesting near magpie and Hooded Crow (*Corvus corone cornix*) breeding territories (Roos and Pärt 2004), and nesting Pied Flycatchers (*Ficedula hypoleuca*) avoided Eurasian Sparrowhawk (*Accipiter nisus*) nests (Thomson et al. 2006).

Increases in avian predator densities are likely to result in higher depredation rates on sage-grouse nests and reduced chick survival (Evans 2004, Cresswell 2008). Sage-grouse hens likely avoid avian predators for their own survival in addition to reducing depredation rates on their nests and chicks. Thus, the presence of greater abundances of avian predators, specifically corvids and raptors, may induce changes in sage-grouse behavior associated to habitat usage. Sage-grouse have been found to reduce time off of their nests when they inhabit areas near high abundances of ravens (Coates and

Delehanty 2008); thus, in addition to using indirect mechanisms, sage-grouse may be using avian predator abundance directly to evaluate predation risk while nesting. Habitat that has high quality cover and forage may become functionally unavailable to sage-grouse when avian predator densities are at high levels. In Cresswell's (2008) review of non-lethal effects of predator-avoidance, he illustrated that several studies on birds indicate that presence of a predator had dramatic impacts on prey species use of habitat. These effects were found to be as great or greater than the effects of direct predation. Regardless of the mechanisms behind sage-grouse hen selection of habitat with fewer avian predators, My results illustrate that sage-grouse were capable of avoiding areas with relatively higher densities of small, medium, and large avian predators or more specifically ravens, magpies, Golden Eagles, *Buteo* hawks, and kestrels compared to available sagebrush habitat.

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TABLE 2-1. Summary of minimum, maximum, and mean distance (m) to nearest neighbor by location type (brood, nest, or random) reported by year. Data were collected in southwestern and south-central Wyoming, USA during 2008–2010.

Year	Location Type	*n*	Min	Mean	Max	SD
2008	Brood	92	15.3	790.7	4272.1	917.6
	Nest	54	240.6	2302.0	11811.8	2356.3
	Random	160	1000.0	2011.9	7215.6	1305.1
2009	Brood	103	2.8	831.5	5718.8	1120.3
	Nest	78	102.5	2099.0	8911.5	2091.8
	Random	174	1000.0	2122.1	7073.1	1093.9
2010	Brood	54	61.8	1128.4	9675.9	1707.8
	Nest	86	106.5	2042.6	10011.4	2279.2
	Random	162	1030.8	2493.0	6135.5	1016.0

TABLE 2-2. Truncated distance (m), number of separate detections of avian predators, and number of avian predators seen from 963 point-count locations. Data were collected in southwestern and south-central, Wyoming, USA during 2008–2010. Program DISTANCE was used to estimate effective detection radii (EDR; m) and standard error (SE).

Avian predator species	Truncated distance	Number of detections	Avian predators counted	EDR	SE
Common Raven	1800	546	853	606.8	22.3
Black-billed Magpie	850	138	157	294.2	19.1
Golden Eagle	2500	376	434	1006.3	42.7
Buteo hawk	1650	242	298	439.1	26.0
Northern Harrier	1100	100	107	318.4	26.3
American Kestrel	1500	118	129	397.1	36.1

TABLE 2-3. Model categories and variables considered in generalized linear mixed modeling with spatial eigenvector mapping to account for spatial autocorrelation. Models were developed to compare avian predator densities at locations used by sage-grouse (nest and brood locations) versus random. Data were collected at 963 point-count locations from eight 16-km and four 24-km study sites, 2008–2010, southwestern and south-central, Wyoming, USA.

Model categories	Variables
Individual species[a]	GOEA = Golden Eagle
	BUT = *Buteo* hawks
	CORA = Common Raven
	NOHA = Northern Harrier
	BBMA = Black-billed Magpie
	AMKE = American Kestrel
Single group	GOEA+BUT+CORA+NOHA+BBMA+AMKE
Small and large	Small = BBMA+AMKE
	Large = GOEA+BUT+CORA+NOHA
Small, medium and large	Small = BBMA+AMKE
	Medium = BUT+CORA+NOHA
	Large = GOEA
Behavior	Soaring = GOEA+BUT
	Low flight = NOHA+AMKE

	Omnivore = CORA+BBMA
Stage	Adults = GOEA+BUT+NOHA
	Brooding hen = AMKE
	Nesting hen = CORA+BBMA

[a] Variables in this model were used to compile the variables in all other model categorizations

TABLE 2-4. Generalized linear mixed models comparing avian predator densities between locations used by sage-grouse (nest and brood sites) and random locations. Avian predator models with associated variables were compared with Akaike's information criterion (adjusted for small sample sizes; AIC_c) and Akaike weights (w_i). All compared models include parameters generated with spatial eigenvector mapping (SEVM) to correct for spatial autocorrelation. Data were collected at 963 point-count locations from eight 16-km and four 24-km study sites, 2008–2010, southwestern and south-central, Wyoming, USA.

Models	k	AIC_c	ΔAIC_c	w_i
Small, medium and large[a]	39	675.01	0.00	0.91
Small and large[a]	36	679.71	4.69	0.09
GOEA+CORA+BBMA	37	690.39	15.38	0.00
GOEA+BUT+CORA+NOHA+BBMA+AMKE[a]	39	691.65	16.64	0.00
GOEA+BUT+CORA+NOHA+BBMA	38	692.25	17.24	0.00
ALL[a]	34	695.57	20.56	0.00
Medium and large	36	698.17	23.15	0.00
Small	35	698.67	23.66	0.00
GOEA+BUT+CORA+BBMA+AMKE	38	699.46	24.45	0.00
Adult +Brood hen+Nesting hen[a]	36	704.95	29.94	0.00
Intercept-only model = 1,259.13				

[a] Denotes models with all species of avian predators incorporated into the model.

TABLE 2-5. Parameter estimates with *P* values and 95% confidence intervals (CI) from top AIC$_c$ selected generalized linear mixed model (GLMM) with spatial eigenvector mapping (SEVM). The top model compared log transformed avian predator densities between locations used by sage-grouse and random locations based on three size classes (small = magpie + kestrel, medium = raven + *Buteo* hawk + harrier, and large = Golden Eagle). SEVM was used to correct for spatial autocorrelation. Data were collected at 963 point-count locations from eight 16-km and four 24-km study sites, 2008–2010, southwestern and south-central, Wyoming, USA.

					95% CI	
Variable[a]	Estimate	SE	*Z*	*P*	Lower	Upper
Small	-0.19	0.05	-3.653	<0.0001	-0.30	0.09
Medium	-0.23	0.04	-5.906	<0.0001	-0.31	0.15
Large	-0.31	0.08	-3.975	<0.0001	-0.47	0.16

[a] Model included 34 SEVM variables

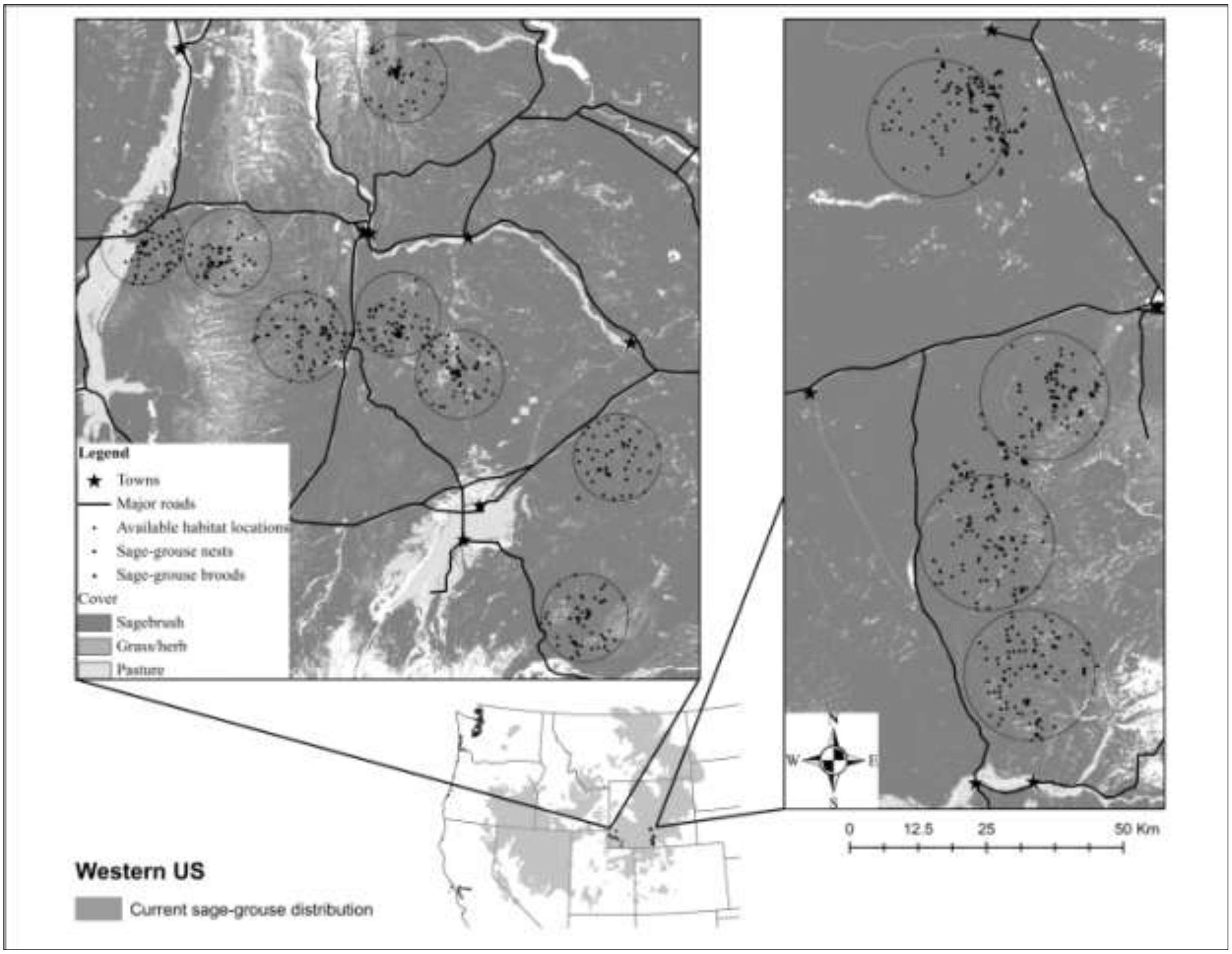

FIG. 2-1. Location map of southern Wyoming depicting eight 16-km diameter and four 24-km diameter study sites, 2008–2010, southwestern and south-central, Wyoming, USA. Magnified sections correspond on left to southwest and on right to south-central Wyoming.

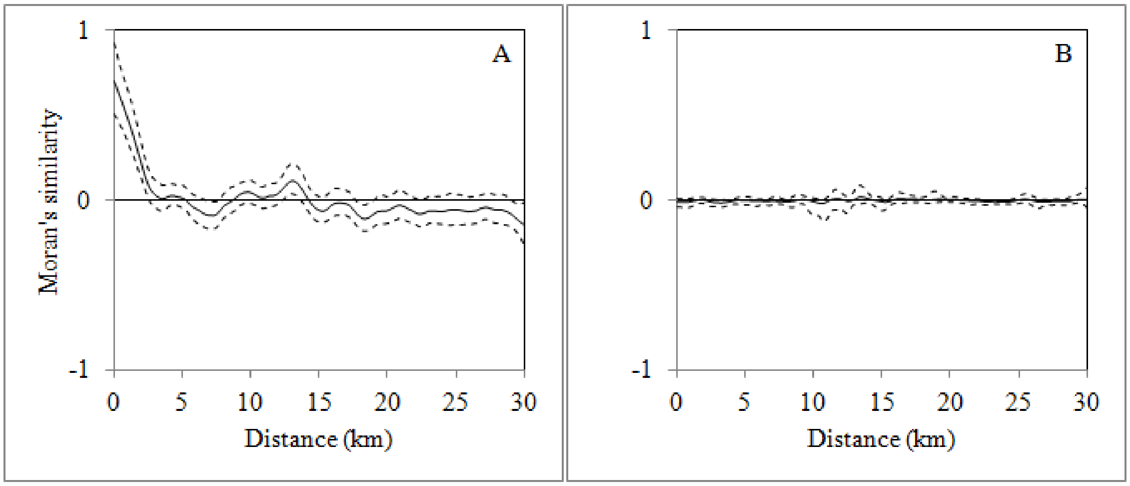

FIG. 2-2. Spline correlograms of Pearson residuals from the best ΔAIC_c ranked generalized linear mixed model with 95% point-wise bootstrapped confidence intervals (A) without spatial eigenvector mapping (SEVM) and (B) with SEVM. Spatial autocorrelation between model residuals was assessed with Moran's similarity index from 0 to 30 (km).

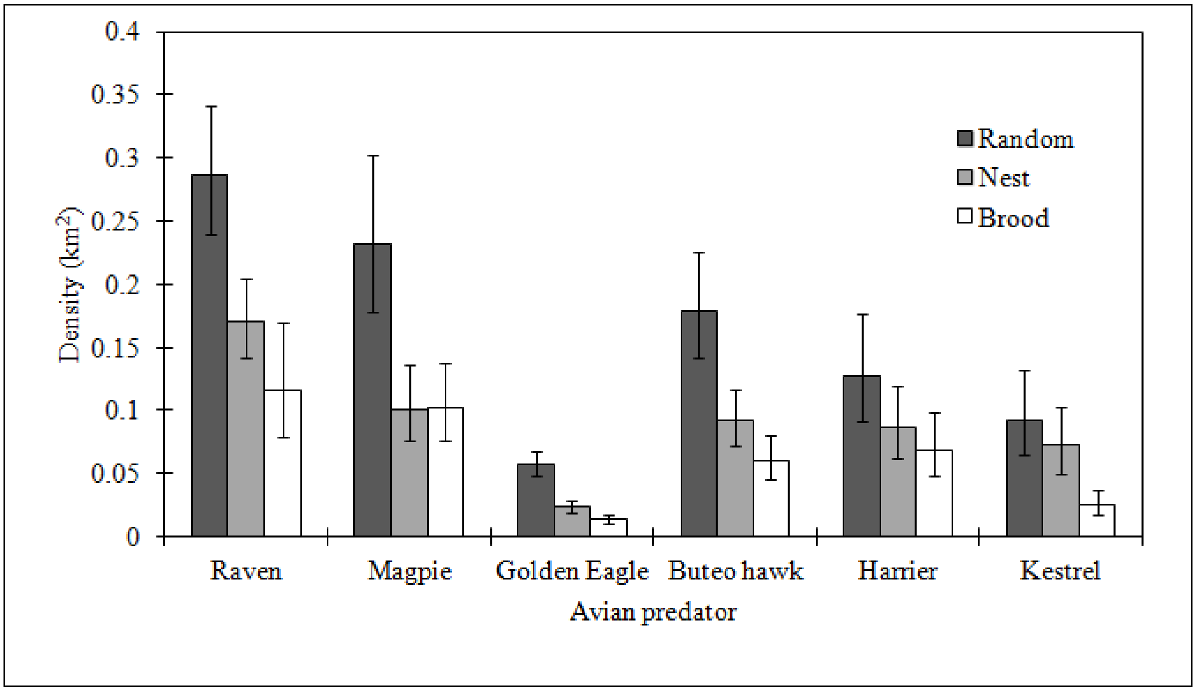

FIG. 2-3. Comparison of raven, magpie, Golden Eagle, *Buteo* hawk, harrier, and kestrel densities (per km^2) among sage-grouse nests, sage-grouse brood locations, and random locations. Data from 3,006 point-count surveys during 2008-2010 at 963 total point-count locations—218 sage-grouse nest locations, 249 sage-grouse brood locations (with 83 separate broods), and 496 random locations—in southwestern and south-central, Wyoming, USA. Densities were generated using radial point-count surveys and DISTANCE at sage-grouse nests, sage-grouse brood locations, and random locations. Error bars are 95% confidence intervals.

CHAPTER 3

GREATER SAGE-GROUSE NEST-SITE AND BROOD-SITE SELECTION IN RELATION TO AVIAN PREDATORS AND ANTHROPOGENIC AND LANDSCAPE FEATURES

ABSTRACT.—Trade-offs between using habitat and avoiding predators are common decisions for prey species such as ground-nesting birds. Prey species including Greater Sage-Grouse (*Centrocercus urophasianus*; hereafter “sage-grouse”) minimize risk of predation by avoiding predators through direct (avoid predators that are seen) and indirect (avoid riskier habitat) mechanisms. Effects of anthropogenic and landscape features on habitat selection of sage-grouse hens have not been evaluated in the context of local predator communities. From 2008–2011, I conducted 10-min point count surveys at 792 sage-grouse locations (340 nests, 331 early-brood [chicks <4 weeks of age], and 121 late-brood [chicks 4–8 weeks of age]) and 660 random locations. Brood locations were compiled from 124 separate sage-grouse broods. Using multinomial logistic regression, I compared anthropogenic and landscape features and densities of small (American Kestrel [*Falco sparverius*] and Black-billed Magpie [*Pica hudsonia*]), medium (*Buteo* spp., Common Raven [*Corvus corax*], and Northern Harrier [*Circus cyaneus*]), and large (Golden Eagle [*Aquila chrysaetos*]) avian predators among nest, early-brood, late-brood, and random locations within available sage-grouse habitat. Anthropogenic features included proximity to oil and gas structures, communication towers, power lines, roads, and rural houses; and landscape features included proximity to forested and riparian

habitats and topographic ruggedness. These comparisons allowed me to assess the relative importance of direct and indirect mechanisms of avian predator avoidance and habitat partitioning of sage-grouse hens at different reproductive stages. I found sage-grouse hens used both direct and indirect mechanisms to lower their exposure to predation and nest depredation, but avian predator densities independently described habitat selection of sage-grouse better than anthropogenic and landscape features combined. For direct avoidance, sage-grouse chose locations with lower densities of small, medium, and large avian predators compared to random locations. For indirect avoidance, sage-grouse selected locations farther away from oil and gas structures and major roads at all reproductive stages, power lines at brood locations, and riparian habitat at nest locations compared to random locations. Sage-grouse used locations closer to riparian habitat during late brood-rearing, which indicates use of areas with relatively more food to meet energy requirements of growing chicks. My analysis also suggested sage-grouse chose flatter locations at nest locations compared to random locations. My results suggest that the magnitude of direct avoidance of avian predators and the selection of proximity to anthropogenic and landscape features by sage-grouse hens were dependent on a sage-grouse’s reproductive stage. Avoidance of avian predators and anthropogenic and landscape features allowed female sage-grouse to lower their risk of predation and nest depredation, while using habitat to meet energetic requirements of hens and chicks.

INTRODUCTION

PREDATOR-AVOIDANCE BEHAVIORS can have dramatic effects on the selection of habitat by birds and other terrestrial animals and can be achieved indirectly by reducing use of risky habitats (habitats correlated with higher risk of predation) or directly by avoiding predators that are seen (Lima 1998, Verdolin 2006, Cresswell 2008; see Chapter 2). Both indirect and direct mechanisms of predator avoidance are connected to an animal's perceived risk of predation (Cresswell 2008, Martin and Briskie 2009). Greater Sage-Grouse (*Centrocercus urophasianus*; hereafter "sage-grouse"), a species of conservation concern (Braun 1998, Schroeder et al. 2004, Connelly et al. 2011), have recently been shown to select habitat with lower densities of avian predators (see Chapter 2). In Chapter 2, findings are presented showing that sage-grouse avoided avian predators at nest and brood locations based on the size of avian predator species rather than individual species identity. However, there were no comparisons of potential mechanisms of avoidance, such as indirect versus direct avoidance.

Anthropogenic features can be used as perches or nest structure by avian predators or can be areas that provide food subsides. American Kestrels (*Falco sparverius*; hereafter "kestrel"), Common Ravens (*Corvus corax*; hereafter "raven"), Golden Eagles (*Aquila chrysaetos*), Ferruginous Hawks (*Buteo regalis*), Red-tailed Hawks (*Buteo jamaicensis*), and Swainson's Hawks (*Buteo swainsoni*) have been found to use power lines for nesting and perching and areas around power lines for foraging (Lammers and Collopy 2007, Prather and Messmer 2010, Slater and Smith 2010). Roads provide food resources in the form of animals killed by vehicles that attract predators. Mammalian (Bradley and Fagre 1988, Frey and Conover 2006) and avian (Boarman 1993, Boarman et al. 1995) predators also use areas near roads, because predators have increased search ability and foraging efficiency in these areas. Several studies have demonstrated sage-grouse avoid habitat with man-made features, such as oil and gas infrastructure (Aldridge 2005, Holloran 2005, Walker et al. 2007, Doherty 2008, Carpenter et al. 2010, Holloran et al. 2010), power-lines (Hanser et al. 2011), and roads (Holloran 2005, Aldridge and Boyce 2007). Thus, birds including sage-grouse may avoid man-made features to avoid the avian predators they attract.

In addition to avoidance of tall man-made structures (structures >2 m tall) and roads, prey species including sage-grouse may avoid avian predators by avoiding landscape features that represent riskier habitat such as riparian areas, conifer forests, and rough terrain. In northeastern Wyoming, Doherty et al. (2010) found that sage-grouse selected nesting habitat with lower terrain roughness and percent cover of conifer, grassland, and riparian habitat; they also found that sage-grouse selected areas with greater density of sagebrush (*Artemisia* spp.) at the patch-scale (100 m to 350 m) compared to random locations within sagebrush. Greater density of sagebrush at relatively larger scales may reduce the foraging efficiency (i.e., predator’s search ability) of visual predators by increasing the number of locations available for a sage-grouse to be located, which has the potential to increase sage-grouse demographic parameters such as survival and nest success. For example, Brewer’s Sparrows’ (*Spizella breweri*) nesting in areas with greater shrub cover and greater density of vacant potential nest-sites had better nest success (Chalfoun and Martin 2009).

Previous research has not compared the relative importance of indirect versus direct predator avoidance in prey species' use of habitat. Sage-grouse may avoid avian predators indirectly by avoiding anthropogenic or landscape features that might attract avian predators or directly by observing them; however, it is more likely that sage-grouse use both indirect and direct means. Thus, I used sage-grouse as a model prey species to test the importance of both indirect and direct predator avoidance. From 2008–2011, I recorded avian predator densities and calculated distances from anthropogenic and landscape features to determine the importance of direct predator avoidance relative to indirect avoidance by sage-grouse hens. I hypothesized that sage-grouse primarily avoid nesting and raising their chicks in areas with high densities of avian predators and secondarily avoid anthropogenic and landscape features that posed greater risk of predation.

As a secondary objective, I evaluated habitat partitioning of sage-grouse females during different reproductive stages (nesting, early-brood-rearing [hereafter early-brood], and late-brood-rearing [hereafter late-brood]) in relation to avian predator densities and distance to anthropogenic and landscape features. Habitat partitioning is the differential use of habitat among groups of animals, and it commonly occurs between different reproductive stages (Bañuelos et al. 2008; e.g., the food resource and shelter requirements of hens on nests are different than brood-rearing hens). Predator avoidance may also be connected to prey species' decision making process regarding partitioning of habitat. Thus, I hypothesized that sage-grouse hens (1) primarily avoided avian predators that were a threat to adult hen survival during all reproductive stages, and secondarily avoided avian predators that were only a threat to nests and chicks; and (2) selected riparian habitat to meet the energetic requirement of adults and chicks after chicks were less vulnerable to predation.

METHODS

Study Areas.—My study was conducted in southwest and south-central Wyoming. I had 12 study sites, each 16 or 24 km in diameter (eight study sites of 16-km diameter and four study sites of 24-km diameter). Holloran and Anderson (2005) found that 92.5% of 415 observed nests were within 8.5 km of leks where they were captured in central and southwest Wyoming. Thus, the study sites in southwest Wyoming were 16-km diameter and approximately centered around leks where hens were captured. Study sites in south-central Wyoming were 24-km, because sage-grouse were captured at several nearby leks over a larger area. Five study sites were located in Lincoln County (16-km diameter each), two in Sweetwater County (one 16-km diameter and one 24-km diameter), two in Uinta County (both 16-km diameter), and three in Carbon County (24-km diameter each). Study sites were chosen to provide a representation of overall sage-grouse nesting habitat in southern Wyoming with a variety of land uses and topographic features. Elevation ranged from 1,950 m to 2,600 m among all study sites. Most of my study sites were federally owned and administered by the Bureau of Land Management with a small percentage of private lands. Domestic sheep and cattle grazing were the dominant land uses in my study sites. All study sites had anthropogenic development, which consisted mostly of unimproved 4-wheel drive roads. Conventional natural gas, coalbed methane natural gas, and/or conventional oil extraction activities were present in six (50%) of my study sites; mean well density among all study sites was 0.12 ± 0.22 SD wells km^{-2} (min–max = 0.0–0.64 wells km^{-2}).

The landscape at all study sites was dominated by sagebrush; Wyoming Big Sagebrush (*A. tridentata wyomingensis*) and Mountain Big Sagebrush (*A. t. vaseyana*) were the most common. Black Sagebrush (*A. nova*) and Dwarf Sagebrush (*A. arbuscula*) were found on exposed ridges. Other common shrub species in the study sites included Alderleaf Mountain Mahogany (*Cercocarpus montanus*), Antelope Bitterbrush (*Purshia tridentata*), Chokecherry (*Prunus virginiana*), Common Snowberry (*Symphoricarpos albus*), Greasewood (*Sarcobatus vermiculatus*), Rabbitbrush (*Chrysothamnus* and *Ericameria* spp.), Saskatoon Serviceberry (*Amelanchier alnifolia*), and Spiny Hopsage (*Grayia spinosa*). Isolated stands of juniper (*Juniperus* spp.) and Quaking Aspen (*Populus tremuloides*) were found at the higher elevations on north-facing hillsides. Common forb species included Arrowleaf Balsamroot (*Balsamorhiza sagittata*), Buckwheat (*Eriogonum* spp.), Common Yarrow (*Achillea millefolium*), Dandelion (*Taraxacum* spp.), Desert Parsley (*Cymopterus* spp.), Phlox (*Phlox* spp.), Lupine (*Lupinus* spp.), Sego Lily (*Calochortus nuttallii*), and Wild Onion (*Allium* spp.). Common grass species included: Bluegrasses (*Poa* spp.), Bluebunch Wheatgrass (*Pseudoroegneria* spicata), Green Needlegrass (*Nassella viridula*), Needle and Thread (*Hesperostipa comata*), Prairie Junegrass (*Koeleria macrantha*), and Western Wheatgrass (*Pascopyrum smithii*). Cheatgrass (*Bromus tectorum*) was present, but not widespread in any of the study sites.

Sage-grouse Capture and Monitoring.—I monitored sage-grouse hens during nesting and brood-rearing from 2008-2011. Hens were captured, radio-collared, and released in April of each year. I captured hens at night using ATVs, spotlights, and hoop-nets (Giesen et al. 1982, Wakkinen et al. 1992). Sage-grouse hens were fitted with 17.5-g or 22-g (<1.5% body mass) necklace radio collars (RI-2D, Holohil Systems Ltd, Ontario, Canada; or A4060, Advanced Telemetry Systems Inc, Isanti, Minnesota).

I located hens on a weekly basis with Communications Specialists (R-1000, Communications Specialists, Orange, California) receivers and 3-way Yagi antennas (Communications Specialists, Orange, California). Potential nests were identified with binoculars from ~15 m by circling a radio-marked hen until she was visually spotted under a shrub. Nests were verified by triangulating the hen under the same shrub from ≥50 m away or thoroughly searching the area of the potential nest when the hen was absent. I continued monitoring nests weekly until the nest hatched or failed. I assessed nest fate as successful or unsuccessful after a hen had left her nest. A successful nest was defined as having evidence that at least one egg hatched as determined by shell membrane condition (Wallestad and Pyrah 1974). I classified unsuccessful nests as abandoned (eggs not depredated or hatched) or depredated (at least one egg with evidence of depredation and no eggs hatched).

I located the broods of radio-marked hens weekly with binoculars from ~15 m. Brood hens were identified by either visually detecting chicks or observing hen behavior that indicated the presence of a brood (e.g., hesitation to flush, feigning injury, or clucking). I classified a sage-grouse hen as a brood hen if there was evidence of at least one chick with that hen. Monitoring of broods continued for as long as possible, which was usually until the chicks were at least 3 weeks old, the hen lost her brood, the hen died, or the hen could no longer be located (most broods were monitored 3–8 weeks post-hatch).

Avian Predator Monitoring.—Between May and August of each year (sage-grouse nesting and brood-rearing season), I conducted point count surveys at sage-grouse nests, sage-grouse brood locations, and random locations (hereafter; nest, brood, and random locations respectively) within each study site to compare avian predator densities. Random locations were selected in habitat considered to be available to sage-grouse for nesting within each study site. To restrict random locations to available nesting habitat, I used ArcMap version 9.2 and 10.0 (ESRI Inc., Redlands, California) to generate random locations only in sagebrush-dominated habitat, which was classified by the Northwest ReGAP landcover data from 2008 (Lennartz 2007). Random locations were designated to be ≥1,000 m apart, but after random selection average nearest neighbor distances among random point count locations was >2,000 m. I generated 12 random locations in each 16-km diameter study site and 18 random locations in each 24-km diameter study site per year. A new set of random locations was generated each year to avoid spatial autocorrelation; thus, random locations among years were independent.

To quantify avian predators, I used standard distance sampling techniques (Ralph et al. 1995, Buckland et al. 2001, Thomas et al. 2010), which entailed counting all avian predators observed during point counts and recording their distance from the observer (when standing at the center of the point count location). I recorded distance as the distance from the observer to where an avian predator was first located (Ralph et al. 1995, Thomas et al. 2010); this minimized possible bias associated with avian predators being attracted to or flushed away from an observer. When an avian predator was displaced from the center of a point count location as an observer approached (6% of all detected birds), I recorded distance from that avian predator to the center of the point count location while the observer approached as suggested by Ralph et al. (1995). This was done when the approach of an observer resulted in an avian predator moving away from the center of the point count location. A 1500–m rangefinder (RE-1500 m, American Technologies Network Corp., San Francisco, California) in conjunction with a global positioning system (GPS) was used to estimate distances directly or to validate visually estimated distances.

To avoid disturbing an incubating hen, nest point counts were conducted 100–200 m away from a sage-grouse nest but within a line-of-sight of that sage-grouse nest. I also performed brood point counts 100–200 m away from a brood hen—estimated by triangulation—immediately before verifying that a radio-marked brood hen was still with chicks. This was intended to record avian predator densities before the observer disturbed any avian predators and to avoid flushing a brood hen when a predator was nearby. If the hen did not have chicks, the brood point count was discarded.

Observers were trained and tested in corvid and raptor identification before conducting point counts. Point counts were 10 min in length, and I conducted them during daylight hours on a weekly basis at each study site. I visited each point count location 1 to 8 times with most locations visited ≥3 occasions. I did not survey for avian predators in inclement weather (i.e., when raining or wind speeds greater than 25 km/h; Ralph et al. 1995). Unidentified birds were not included in analyses; these contributed 2% of detections within truncated observation distances. Nest and brood point counts were performed after nests or broods were initially located; thus, nest point counts were conducted in May and June and brood point counts were conducted from mid-May to early-August. I performed random point counts throughout the nesting and early brood-rearing season (May to early-August).

I intermixed the sampling of nest, brood, and random point counts within each study site. To minimize observer bias, I changed the time of day and the observer that conducted individual point counts within a study site each week (i.e., each individual point count location regardless of type—nest, brood, or random—would be conducted at a different time of day each week and by a different observer as best as possible). The observers conducting point counts within a particular study site changed each year. Thus, I minimized observer bias by changing the observer who collected data at each individual point count location.

All avian predator variables were calculated from the raw count data within effective detection radii (EDR) estimated with DISTANCE, version 6.0 release 2 (Thomas et al. 2010) as specified in Chapter 2. Thus, *Buteo* hawk, Golden Eagle, Northern Harrier (*Circus cyaneus*; hereafter “harrier”), kestrel, Black-billed Magpie (*Pica hudsonia*; hereafter “magpie”), and raven densities were individually calculated within 450 m, 1000 m, 350 m, 400 m, 300 m, and 600 m, respectively, of each point count location (see Chapter 2 for further details). The raw densities were standardized by the number of visits to each point count location. I used raw avian predator densities calculated by species to create small (magpie and kestrel), medium (*Buteo* hawk, harrier, and raven), and large (Golden Eagle) avian predator variables, which was shown in Chapter 2 to best describe sage-grouse avoidance of avian predators. I log transformed raw avian predator densities to reduce the effect of influential observations.

Anthropogenic and Landscape Feature Variables.—I used ArcMap 10.0 to calculate point count proximity (Euclidean distance) to anthropogenic features that could be used as perch or nest sites by avian predators or could provide food subsidies. Anthropogenic structures that were >2 m in height were considered available for perching or nesting by avian predators. I quantified the distance from point count locations to the nearest oil and gas structure (energy well, compressor station, transfer station, refinery, or other energy extraction related buildings), major road, gravel road, communication tower, house, and power line for each point count location. Ongoing energy development was occurring in half of my study sites, which required me to assess the dates that energy-related structures and roads were added or removed from the landscape.

In distance calculations, I only included oil and gas structures and roads that existed when each point count was conducted. I obtained information on oil and gas structures, including date construction started on the structure and date when wells were plugged and abandoned (date structure was removed), from the Wyoming Oil and Gas Conservation Commission (WOGCC; 2012). I verified the spatial location and existence of older structures with color aerial satellite imagery from summer 2006 and August 2009 obtained from the National Agriculture Imagery Program (NAIP; U.S. Department of Agriculture [USDA] 2010). Aerial imagery from NAIP is produced by the USDA on a 3-year rotation; thus, I used WOGCC data and on the ground GPS units to map energy development that occurred after August 2009.

I used 2009 NAIP imagery to digitize the location of major roads, all roads, communication towers, and houses within a 5-km buffer around study sites; roads constructed between August 2009 and September 2011 were mapped on the ground with GPS units. Major roads included paved, improved gravel roads, and railroads; whereas, all roads included major roads and all unimproved 4-wheel drive roads. All transmission and distribution power lines within a 5-km buffer around study sites were mapped on the ground with GPS units; telephone lines not associated with a power line were included in power line mapping.

Neither sage-grouse nor avian predators were likely to discriminate between many of different types of anthropogenic structures. Thus, I created 2 anthropogenic structure variables that represented the nearest (1) distance to either an oil and gas structure, communication tower, or house (WCH); and (2) distance to either an oil and gas structure, communication tower, house, or power line (ANTH). This was in addition to distances from point count locations to individual types of anthropogenic structures.

Similar to anthropogenic features, some types of landscape features could be used as perches or nest structure by avian predators, or could be areas with higher productivity that attract predators. Thus, I used ArcMap 10.0 to calculate the distance from every point count location to forested (deciduous or conifer stands) and riparian habitats. Tree stands and riparian habitat were identified with Northwest ReGAP landcover data from 2011 (Lennartz 2007), and verified with NAIP imagery from 2009. Topography with greater surface roughness has the potential to create topographic structures (e.g., hilltops, knolls, and cliff edges) that provide vantage points similar to perches. For every point count location, I used ArcMap 10.0 to extract topographic ruggedness index (TRI) values generated by Hanser et al. (2011) for the Wyoming Basins Ecoregion; TRI variables were developed using a moving window analysis at 0.27-km, 0.54-km, 1-km, and 3-km radii (0.23-km^2, 0.92-km^2, 3.14-km^2, and 28.26-km^2 scales, respectively). Riley et al. (1999) created TRI to describe the roughness of landscapes, and the index is quantified as the difference in elevation among adjacent pixels of a digital elevation map; the index is then averaged over a user-defined area.

Euclidean distance is not a good measure of habitat selection by wildlife, because the response of a species to anthropogenic or landscape features often decline as distance increases (Carpenter et al. 2010, Fedy and Martin 2011, Hanser et al. 2011). Thus, I calculated distance decay functions to allow for nonlinear avoidance of anthropogenic or landscape features, which were expressed as:

Decay function = exp^(Euclidean distance to feature (km)/-decay distance) 1)

I calculated all decay functions with 3 decay distances (0.25 km, 0.50 km, and 1 km). Decay functions scaled distance variables between 0 and 1 with greater values corresponding to point count locations closer to anthropogenic or landscape features.

Data Analyses.—To evaluate habitat selection of nesting and brood-rearing sage-grouse hens in reference to avoidance of avian predators and anthropogenic and landscape features, I fit multinomial logistic regression models with maximum likelihood using function multinom in package nnet version 7.3-4 in R (R 2.14.2; R Foundation for Statistical Computing 2009). Multinomial logistic regression models have been used to model habitat selection of wildlife species with >2 response categories. I categorized point count locations into 4 response categories (1) random, (2) sage-grouse nest, (3) early-brood (chicks <4 weeks of age), and (4) late-brood (chicks 4–8 weeks of age). Multinomial logistic regression uses 1 category as the reference for comparisons with all other categories. To compare sage-grouse habitat selection to available sagebrush habitat (random locations), I made comparisons of sage-grouse locations to random locations by coding random locations as the reference category. I then alternated nest and early-brood as the reference category to compare between sage-grouse locations. Modeling of sage-grouse habitat selection was conducted with an information theoretic approach (Anderson 2008). I compared models with Akaike's information criterion corrected for small sample sizes (AIC_c) and Akaike weights (w_i; Burnham and Anderson 2002) with function aictab in package aiccmodavg version 1.25 in R. I employed sequential AIC_c modeling of covariate sets, which was suggested by Arnold (2010) as an appropriate approach for identifying and ranking the most parsimonious models. Non-informative covariates (85% confidence intervals [CIs] of parameter estimates overlapped 0) were eliminated within each covariate set before comparing top AIC_c selected models among covariate sets (Arnold 2010). I classified models within 2 AIC_c of the null model as being non-competitive (Burnham and Anderson 2002); thus, any model within 2 AIC_c of the null was omitted from further analyses.

Anthropogenic and landscape covariate sets were evaluated sequentially (Step 1) then compared with the best avian predator model from Chapter 2 (Step 2). Details on avian predator modeling procedures can be found in Chapter 2. I did not include WCH or ANTH with any anthropogenic structure variable that was used to create WCH or ANTH. The best variable describing the effect of anthropogenic structures on habitat selection by sage-grouse was determined through AIC_c selection within the anthropogenic feature covariate set. For all distance decay functions, I chose the best decay distance (0.25 km, 0.50 km, and 1 km) for each distance variable by comparing all 3 decay distances with AIC_c. I compared models with individual TRI variables measured at 0.27-km, 0.54-km, 1-km, and 3-km radii with AIC_c to choose the best spatial scale for the TRI variable to be used in the landscape feature covariate set; the TRI variable scale with the lowest AIC_c was used in all further modeling. As the final modeling step, I compared all top AIC_c selected models from every covariate set (models within 2 AIC_c of the top model within each covariate set) among each other and as additive models with combinations of the avian predator model and anthropogenic and landscape feature covariate set models. I based my inference on models within 2 AIC_c of the top selected model (Burnham and Anderson 2002). I prevented multicollinearity by only including one variable of any pair of variables that co-varied in any model (r >0.65) as determined with a Pearson’s correlation matrix. In this situation I eliminated one co-varying variable from further analysis by retaining the variable that made the most biological sense. Variance inflation factors (VIF) for all predictor variables were ≤5, which indicated that the variances of coefficient values were not drastically increased by the inclusion of any predictor variable; thus, collinearity was not a major problem.

Although I could not test for spatial autocorrelation in multinomial logistic regressions, avian predator densities derived from distance sampling techniques are robust to lack of independence of observation locations because distance sampling is setup to be a snap-shot in time (Thomas et al. 2010). My avian predator sampling was designed to count the greatest proportion of avian predators within a study site each week while not counting the same avian predator more than once per week as suggested by Ralph et al. (1995) and Thomas et al. (2010). Conducting all point counts within a study site in one day reduced the possibility of double-counting individual avian predators during that week’s visit. Counting the same individual avian predator during different weeks, regardless of the particular point count location, was properly scaled by accounting for survey effort. Replication of point counts by sampling multiple weeks was done to increase the proportion of avian predators detected as suggested by Thomas et al. (2010). When evaluating avian predator densities between sage-grouse and random locations, the findings from Chapter 2 accounted for spatial autocorrelation in generalized linear mixed models; however, accounting for spatial autocorrelation did not significantly change coefficient values of their avian predator models. Furthermore, multinomial logistic regression only requires that successive habitat selection choices be independent (Agresti 2007). I made the assumption that successive locations from the same sage-grouse were sufficiently far apart in time to be effectively independent. This was reasonable because sage-grouse locations were ~1 week apart in my study.

RESULTS

I conducted 4,441 point count surveys at 1,452 locations during 2008–2011 including 340 sage-grouse nest, 331 sage-grouse early-brood, 121 sage-grouse late-brood, and 660 random locations. Brood locations were compiled from 124 separate sage-grouse broods. I counted 196 *Buteo* hawks, 295 Golden Eagles, 77 harriers, 105 kestrels, 143 magpies, and 688 ravens within species-specific EDRs (see Chapter 2), which equated to 248 small, 961 medium, and 295 large avian predators. Brood, nest, and random locations were on average 841 m, 1,997 m, and 2,301 m apart, respectively. There was no evidence of multicollinearity between avian predator variables and anthropogenic or landscape feature variables, because avian predator variables did not co-vary with any other variable ($r^2 < 0.02$) and VIF ≤ 5.

During Step 1 of sequential modeling, I found sage-grouse selection of nest and brood locations was partially based on anthropogenic and landscape feature variables (Table 3-1). The top AIC$_c$ selected anthropogenic feature model ($w_i = 0.99$) included proximity to oil and gas structures, power lines, rural houses, and major roads; and the top AIC$_c$ selected landscape feature model ($w_i = 0.50$) included proximity to riparian habitat and TRI (Table 3-1). Proximity to oil and gas structures was best described as a distance decay function calculated with the 0.25-km distance decay (OGS$_{0.25}$). Power lines, rural houses, major roads, and riparian habitat were best described as distance decay functions calculated with the 1-km distance decay (POW$_{1.0}$, HOM$_{1.0}$, MRD$_{1.0}$, and RIP$_{1.0}$, respectively). Thus, the effect of proximity to oil and gas structures on sage-grouse selection of nesting and brood locations became negligible closer to sage-grouse locations compared to proximity to all other predictive anthropogenic and landscape features (i.e., the effect of distance from sage-grouse locations to oil and gas structures [0.25-km distance decay function] decayed faster than the effects of distance to power lines, rural houses, major roads, and riparian habitat [1-km distance decay functions]). I found TRI calculated at the 0.54-km radius ($TRI_{0.54}$) fit the data best.

During Step 2 of sequential modeling, my analyses indicated that sage-grouse hen selection of nest and brood locations was best described by avian predator densities in conjunction with proximity to anthropogenic and landscape features with $w_i = 1.00$ (Table 3-2). Even though the best model incorporated avian predator densities and anthropogenic and landscape feature variables, the avian predator density model (AIC_c = 88.57) independently described sage-grouse selection of nest and brood locations much better than the anthropogenic and landscape feature (AIC_c = 313.52) model (Table 3-2). This indicated that small, medium, and large avian predators had a relatively greater correlation with sage-grouse selection of nest and brood locations compared to anthropogenic and landscape features.

Greater densities of small, medium, and large avian predators were negatively correlated with sage-grouse nest, early-brood, and late-brood locations compared to random locations (Table 3-3). My analysis also indicated that early-brood and late-brood sage-grouse locations had lower avian predator densities compared to nesting sage-grouse (Table 3-4). During each reproductive stage, sage-grouse avoided small and medium avian predators at similar magnitudes, and also exhibited greater avoidance of large avian predators than small or medium avian predators (Tables 3-3 and 3-4).

Sage-grouse responded to anthropogenic features by avoiding them regardless of the sage-grouse's reproductive stage. I found nesting, early-brood, and late-brood sage-grouse were farther away from oil and gas structures and major roads compared to random locations (Table 3-3). Early-brood and late-brood sage-grouse were farther away from power lines compared to random locations (Table 3-3). In contrast to the avoidance of other anthropogenic structures, my analysis indicated that early-brood and late-brood sage-grouse were closer to houses compared to random locations and nest locations (Tables 3-3 and 3-4).

For landscape feature variables, I found sage-grouse differed in their response to proximity to riparian habitat and TRI depending on their reproductive stage. Compared to random locations, sage-grouse selected nest locations farther away from riparian habitat, early-brood sage-grouse neither selected for nor avoided habitat based on proximity to riparian habitat, and late-brood sage-grouse selected locations closer to riparian habitat (Table 3-3). However, both early-brood and late-brood locations were closer to riparian habitat compared to nest locations, and late-brood locations were closer to riparian habitat than early-brood locations (Table 3-4). Sage-grouse nest-sites were located in areas with flatter topography compared to random locations (Table 3); I did not find this effect at sage-grouse early-brood or late-brood locations. Sage-grouse at early-brood and late-brood locations selected relatively more rugged topography compared to nesting sage-grouse (Table 3-4).

DISCUSSION

Sage-grouse hens used direct and indirect mechanisms to lower their exposure to predation and nest depredation particularly from avian predators. In general, sage-grouse avoided risky habitat by directly avoiding areas with higher densities of small, medium, and large avian predators and indirectly by avoiding areas close to anthropogenic and landscape features. Similar to previous research, my analyses confirmed that sage-grouse select locations farther away from anthropogenic and landscape features that could be used as perches or provide subsidized food resources for predators, which included oil and gas structures (Aldridge 2005, Holloran 2005, Walker et al. 2007, Doherty 2008, Holloran et al. 2010, Kirol 2012) and major roads (Holloran 2005, Aldridge and Boyce 2007) at all reproductive stages, power lines (Hanser et al. 2011) at brood locations, and riparian habitat (Doherty et al. 2010, Dzialak et al. 2011) at nest locations. Sage-grouse also chose flatter locations at nest-sites similar to findings from Doherty et al. (2010), Dzialak et al. (2011), and Kirol (2012). Habitat partitioning during vulnerable reproductive stages by female sage-grouse relative to predation risk and food availability was a means for sage-grouse hens to lower their risk of predation and nest depredation, while using habitat to meet energetic requirements of hens and chicks (Connelly et al. 2004, Aldridge and Boyce 2007, Dzialak et al. 2011).

High densities of avian predators including *Buteo* hawks (MacLaren et al. 1988, Schroeder et al. 1999, Schroeder and Baydack 2001), Golden Eagles (MacLaren et al. 1988, Danvir 2002), harriers (Schroeder et al. 1999, Thirgood et al. 2000, Fletcher et al.

2003), kestrels (Schroeder et al. 1999), magpies (Holloran and Anderson 2003, Vander Haegen et al. 2002), and ravens (Manzer and Hannon 2005, Bui et al. 2010, Coates and Delehanty 2010) have the potential to negatively affect nest success or adult and chick survival of grouse species, and one of the responses of prey species to the presence of these predators is avoidance (Lima 1998, Evans 2004, Cresswell 2008, Dinkins et al. 2012). Similar to Dinkins et al. (2012), my analysis indicated that sage-grouse avoidance of avian predators occurred during many reproductive stages—nesting, early-brood, and late-brood—but at different magnitudes. My results also suggest sage-grouse hens have the ability to distinguish between threats to their survival, nests, and offspring.

Large avian predators (Golden Eagles) were avoided by sage-grouse hens at greater magnitudes than smaller avian predators within each reproductive stage suggesting sage-grouse hens were predominantly concerned with their own survival (i.e., smaller parameter estimates for large avian predators compared to small and medium avian predators when comparing sage-grouse locations to random locations; Table 3-3). It was not surprising that sage-grouse hens protected themselves from their primary predator (Golden Eagle; Schroeder et al. 1999, Schroeder and Baydack 2001, Mezquida et al. 2006), because sage-grouse are a relatively long-lived bird (Connelly et al. 2011). Johnson and Braun (1999) and Taylor et al. (2012) found adult survival was the most influential demographic parameter on sage-grouse population growth, and they also illustrated that following adult survival, chick survival then nest success were the next most important factors affecting population growth for sage-grouse. My results also indicate that early-brood and late-brood locations had greater magnitudes of avian predator avoidance than nest locations, which can be explained by the greater mobility of broods compared to nests and the duration of time spent in a particular location. Thus, reducing risk of nest depredation and chick mortality by avoiding small and medium sized avian predators likely increased sage-grouse reproductive output.

In addition to avoidance of avian predators, sage-grouse selected habitat in response to anthropogenic and landscape features. As expected, I found that sage-grouse primarily used direct avoidance of avian predators and secondarily avoided riskier habitat. Direct and indirect avoidance of avian predators were not necessarily linked (correlated) from the perspective of a sage-grouse, because indirect cues (perches and areas with subsidized food for predators) were not correlated with any avian predator species ($r^2 < 0.02$). This indicated that anthropogenic and landscape features may not be the best indicators of potential predation risk, but represent areas of greater perceived risk of predation by sage-grouse. Prey species' ability to predict and avoid risky habitat increases survival and reproductive success, but the ability to directly avoid predators is more beneficial than indirect cues of predation risk (Thomson et al. 2006). Both mechanisms presumably achieve reduced predation rates; however, there may be other population limiting effects as a result of predator avoidance such as reduced foraging ability of prey species in areas of lower habitat quality (Lima 1998, Evans 2004, Cresswell 2008).

Habitat use is a trade-off among protection from exposure to the environment (weather), starvation, and predation (Verdolin 2006), which can be considered habitat partitioning. Similar to Dzialak et al. (2011), my results confirmed that sage-grouse have opposing responses to proximity to riparian habitat depending on reproductive stage. Sage-grouse were farther away from riparian habitat while nesting, but chose locations closer to riparian areas during late-brood. Nesting occurred away from riparian areas, because starvation was not a factor for nesting sage-grouse hens. However, chicks have increasing energetic demands as they grow, and sage-grouse hens typically move broods to riparian areas after early-brood-rearing (Crawford et al. 2004, Gregg and Crawford 2009). Riparian habitats provide forbs and invertebrates that meet the energetic demands of growing sage-grouse chicks (Connelly et al. 2004, Aldridge and Boyce 2007, Dzialak et al. 2011). Sage-grouse appear to minimize the negative effects of increased predation risk associated with riparian areas by directly avoiding avian predators and indirectly by avoiding riparian habitat during relatively more vulnerable reproductive stages (nest and early-brood). Sage-grouse early-brood and late-brood locations were closer to rural houses compared to random and nest locations, which may be explained by the distribution of rural houses in higher quality sagebrush habitat (more productive); however, this is speculative and deserves more research. Thus, sage-grouse selection of brood locations closer to rural houses was likely a response similar to their response to riparian habitat.

Predation risk trade-offs and non-lethal predator effects, such as avoidance of risky habitats and habitats occupied by greater density of avian predators (Evans 2004, Verdolin 2006, Cresswell 2008), are mechanisms that explain habitat partitioning of female sage-grouse. High densities of avian predators and close proximity to anthropogenic and landscape features—specifically oil and gas infrastructure, power lines, major roads, riparian habitat, and rugged topography—are likely to result in reduced adult survival and higher depredation rates on sage-grouse nests (Lima 1998, Evans 2004, Cresswell 2008). My results indicated that both direct (avian predators) and indirect (oil and gas structures, power lines, roads, rugged topography, and riparian habitat) mechanisms were used by sage-grouse to presumably avoid predation and nest depredation. Sage-grouse use of habitat was negatively connected to avian predator densities with quality sage-grouse habitat presumably having lower densities of small, medium, and large avian predators. The presence of greater abundances of avian predators may induce changes in sage-grouse behavior associated to habitat usage. Thus, human manipulation of habitat that structurally changes habitat and promotes greater density of avian predators may limit sage-grouse populations, because habitat that has high quality cover and forage may become functionally unavailable to sage-grouse when avian predator densities are at high levels and anthropogenic features are nearby.

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TABLE 3-1. Multinomial logistic regression models comparing proximity to anthropogenic and landscape features among locations used by sage-grouse (nest, early-brood, and late-brood locations) and random locations. Anthropogenic and landscape features covariate sets were compared separately with Akaike's information criterion (adjusted for small sample sizes; AIC$_c$) and Akaike weights (w_i). The anthropogenic feature covariate set included distance decay functions to the nearest oil and gas structure (0.25-km decay function; OGS$_{0.25}$); power line (1.0-km decay function; POW$_{1.0}$); rural house (1.0-km decay function; HOM$_{1.0}$); major road (1.0-km decay function; MRD$_{1.0}$); gravel road (1.0-km decay function; GRD$_{1.0}$); closest oil and gas structure, communication tower, or house (0.25-km decay function; WCH$_{0.25}$); and closest oil and gas structure, communication tower, house, or power line (0.50-km decay function; ANTH$_{0.50}$). The landscape feature covariate set included distance decay functions to riparian (1.0-km decay function; RIP$_{1.0}$) and forested (0.25-km decay function; TREE$_{0.25}$) habitat and topographic ruggedness calculated at 0.54-km radius (TRI$_{0.54}$). Data were collected from 1,452 point count locations—340 sage-grouse nests, 331 sage-grouse early-brood locations, 121 sage-grouse late-brood locations, and 660 random locations—from eight study sites (16-km diameter) and four study sites (24-km diameter) in southern Wyoming, USA, 2008–2011.

Models[a]	k	ΔAIC$_c$	w_i	Deviance
Anthropogenic covariate set				
OGS$_{0.25}$, POW$_{1.0}$, HOM$_{1.0}$, MRD$_{1.0}$ [a]	15	0.00	0.99	3539.60

$OGS_{0.25}$, $POW_{1.0}$, $HOM_{1.0}$	12	9.19	0.01	3554.92
$OGS_{0.25}$, $POW_{1.0}$, $MRD_{1.0}$	12	17.88	0.00	3563.60
$OGS_{0.25}$, $POW_{1.0}$	9	20.77	0.00	3572.58
$OGS_{0.25}$, $MRD_{1.0}$	9	26.80	0.00	3578.60
$HOM_{1.0}$, $MRD_{1.0}$	9	28.28	0.00	3580.10
$WCH_{0.25}$, $POW_{1.0}$, $MRD_{1.0}$	12	28.89	0.00	3574.62
$WCH_{0.25}$, $POW_{1.0}$	9	30.63	0.00	3582.44
$POW_{1.0}$, $MRD_{1.0}$	9	33.42	0.00	3585.24
$POW_{1.0}$	6	35.25	0.00	3593.12
$ANTH_{0.50}$, $MRD_{1.0}$	9	36.44	0.00	3588.26
$OGS_{0.25}$	6	38.26	0.00	3596.14
$WCH_{0.25}$, $MRD_{1.0}$	9	38.41	0.00	3590.22
$ANTH_{0.50}$	6	44.67	0.00	3602.54
$MRD_{1.0}$	6	44.72	0.00	3602.60
$HOM_{1.0}$	6	47.03	0.00	3604.90
$WCH_{0.25}$	6	48.28	0.00	3606.16
$GRD_{1.0}$	6	49.44	0.00	3607.32
Intercept only	3	55.20	0.00	3619.12
Landscape covariate set				
$RIP_{1.0}$, $TRI_{0.54}$ [b]	9	0.00	0.50	3569.22
$TREE_{0.25}$, $RIP_{1.0}$	9	1.26	0.27	3570.48

$TREE_{0.25}$, $RIP_{1.0}$, $TRI_{0.54}$	12	1.60	0.22	3564.74
$RIP_{1.0}$	6	8.52	0.01	3583.80
$TRI_{0.54}$	6	25.38	0.00	3600.66
$TREE_{0.25}$, $TRI_{0.54}$	9	27.68	0.00	3596.90
$TREE_{0.25}$	6	29.81	0.00	3605.10
Intercept only	3	37.79	0.00	3619.12

[a] AIC_c = 3569.94

[b] AIC_c = 3587.34

TABLE 3-2. Multinomial logistic regression models comparing avian predator densities and proximity to anthropogenic and landscape features among locations used by sage-grouse (nest, early-brood, and late-brood locations) and random locations. Combinations of singular and additive models created from the top AIC_c selected avian predator model and anthropogenic and landscape feature models were compared with Akaike's information criterion (adjusted for small sample sizes; AIC_c) and Akaike weights (w_i). The avian predator model (avian) included log transformed small, medium, and large avian predator densities. The anthropogenic feature model (anthropogenic) included distance decay functions to nearest oil and gas structure (0.25-km decay function; $\mathrm{OGS}_{0.25}$), power line (1.0-km decay function; $\mathrm{POW}_{1.0}$), rural house (1.0-km decay function; $\mathrm{HOM}_{1.0}$), and major road (1.0-km decay function; $\mathrm{MRD}_{1.0}$). The landscape feature model (landscape) included a distance decay function to the nearest riparian habitat (1.0-km decay function; $\mathrm{RIP}_{1.0}$) and topographic ruggedness calculated at 0.54-km radius ($\mathrm{TRI}_{0.54}$). Data were collected from 1,452 point count locations—340 sage-grouse nests, 331 sage-grouse early-brood locations, 121 sage-grouse late-brood locations, and 660 random locations—from eight study sites (16-km diameter) and four study sites (24-km diameter) in southern Wyoming, USA, 2008–2011.

Models	k	$\Delta\mathrm{AIC}_c$	w_i	Deviance
Avian, anthropogenic, landscape[a]	30	0.00	1.00	3171.92
Avian, anthropogenic	24	36.56	0.00	3220.94
Avian, landscape	18	50.67	0.00	3247.42

Avian	12	88.57	0.00	3297.58
Anthropogenic, landscape	18	313.52	0.00	3510.26
Anthropogenic	12	351.18	0.00	3560.18
Landscape	9	354.13	0.00	3569.22
Intercept only	3	391.92	0.00	3619.12

[a] $AIC_c = 3125.62$

TABLE 3-3. Parameter estimates with 95% confidence intervals (CI) from top AIC_c selected multinomial logistic regression. The top model compared log transformed avian predator densities (small, medium, and large avian predators); distance decay functions to nearest oil and gas structure (0.25-km decay function; $OGS_{0.25}$), power line (1.0-km decay function; $POW_{1.0}$), rural house (1.0-km decay function; $HOM_{1.0}$), major road (1.0-km decay function; $MRD_{1.0}$), and riparian habitat (1.0-km decay function; $RIP_{1.0}$); and topographic ruggedness calculated at 0.54-km radius ($TRI_{0.54}$) among locations used by sage-grouse (nest, early-brood, and late-brood locations) and random (reference level) locations. Data were collected from 1,452 point count locations—340 sage-grouse nests, 331 sage-grouse early-brood locations, 121 sage-grouse late-brood locations, and 660 random locations—from eight study sites (16-km diameter) and four study sites (24-km diameter) in southern Wyoming, USA, 2008–2011.

				95% CI	
Group	Variable	Estimate	SE	Lower	Upper
Nest					
	Intercept	-2.63	0.58	-3.79	-1.48^{*}
	Small avian predator	-0.06	0.03	-0.12	-0.00^{*}
	Medium avian predator	-0.08	0.02	-0.13	-0.04^{**}
	Large avian predator	-0.17	0.04	-0.25	-0.08^{*}
	$OGS_{0.25}$	-1.63	0.80	-3.21	-0.05^{*}
	$POW_{1.0}$	-0.54	0.47	-1.47	0.39

	HOM$_{1.0}$	1.31	0.77	-0.21	2.82
	MRD$_{1.0}$	-2.64	0.87	-4.35	-0.94*
	RIP$_{1.0}$	-0.63	0.26	-1.14	-0.12*
	TRI$_{0.54}$	-0.02	0.01	-0.04	-0.01*
Early brood					
	Intercept	-13.03	1.30	-15.58	-10.47*
	Small avian predator	-0.33	0.06	-0.46	-0.21*
	Medium avian predator	-0.32	0.04	-0.40	-0.24*
	Large avian predator	-0.62	0.12	-0.85	-0.39*
	OGS$_{0.25}$	-3.11	1.12	-5.32	-0.89*
	POW$_{1.0}$	-1.65	0.59	-2.83	-0.49*
	HOM$_{1.0}$	3.21	0.79	1.64	4.78*
	MRD$_{1.0}$	-2.14	0.86	-3.83	-0.44*
	RIP$_{1.0}$	-0.01	0.27	-0.55	0.59
	TRI$_{0.54}$	-0.01	0.01	-0.03	0.01
Late brood					
	Intercept	-13.49	1.66	-16.76	-10.21*
	Small avian predator	-0.30	0.08	-0.46	-0.14*
	Medium avian predator	-0.32	0.06	-0.43	-0.21*
	Large avian predator	-0.49	0.14	-0.76	-0.22*
	OGS$_{0.25}$	-10.01	4.18	-18.23	-1.78*

$POW_{1.0}$	-1.77	0.86	-3.46	-0.07*
$HOM_{1.0}$	4.19	0.92	2.37	6.01*
$MRD_{1.0}$	-3.01	1.45	-5.87	-0.16*
$RIP_{1.0}$	1.43	0.37	0.70	2.16*
$TRI_{0.54}$	0.00	0.01	-0.01	0.02

*Denotes a 95% confidence interval that does not include zero.

TABLE 3-4. Parameter estimates with 95% confidence intervals (CI) from top AIC_c selected multinomial logistic regression. The top model compared log transformed avian predator densities (small, medium, and large avian predators); distance decay functions to nearest oil and gas structure (0.25-km decay function; $OGS_{0.25}$), power line (1.0-km decay function; $POW_{1.0}$), rural house (1.0-km decay function; $HOM_{1.0}$), major road (1.0-km decay function; $MRD_{1.0}$), and riparian habitat (1.0-km decay function; $RIP_{1.0}$); and topographic ruggedness calculated at 0.54-km radius ($TRI_{0.54}$) among sage-grouse locations (nest, early-brood, and late-brood locations) by alternating the reference level. Data were collected from 1,452 point count locations—340 sage-grouse nests, 331 sage-grouse early-brood locations, 121 sage-grouse late-brood locations, and 660 random locations—from eight study sites (16-km diameter) and four study sites (24-km diameter) in southern Wyoming, USA, 2008–2011.

				95% CI	
Group [a]	Variable	Estimate	SE	Lower	Upper
Early-brood vs. Nest					
	Intercept	-11.14	1.39	-13.88	-8.40[*]
	Small avian predator	-0.26	0.07	-0.39	-0.13[*]
	Medium avian predator	-0.20	0.03	-0.27	-0.14[*]
	Large avian predator	-0.45	0.12	-0.69	-0.22[*]
	$OGS_{0.25}$	-1.53	1.25	-3.97	0.92
	$POW_{1.0}$	-0.99	0.65	-2.27	0.28

	HOM$_{1.0}$	1.86	0.84	0.20	3.52*
	MRD$_{1.0}$	0.65	1.08	-1.47	2.77
	RIP$_{1.0}$	0.61	0.30	0.03	1.19*
	TRI$_{0.54}$	0.02	0.01	0.00	0.03*
Late-brood vs. Nest					
	Intercept	-11.40	1.76	-14.88	-7.93*
	Small avian predator	-0.22	0.09	-0.39	-0.05*
	Medium avian predator	-0.20	0.05	-0.29	-0.10*
	Large avian predator	-0.32	0.14	-0.60	-0.05*
	OGS$_{0.25}$	-8.52	4.20	-16.80	-0.24*
	POW$_{1.0}$	-1.09	0.90	-2.86	0.68
	HOM$_{1.0}$	2.85	0.96	0.95	4.75*
	MRD$_{1.0}$	-0.32	1.61	-3.49	2.84
	RIP$_{1.0}$	2.05	0.39	1.28	2.82*
	TRI$_{0.54}$	0.03	0.01	0.01	0.04*
Late-brood vs. Early-brood					
	Intercept	-0.26	2.08	-4.35	3.84
	Small avian predator	0.04	0.10	-0.16	0.24
	Medium avian predator	0.01	0.05	-0.10	0.11
	Large avian predator	0.13	0.18	-0.22	0.47
	OGS$_{0.25}$	-6.99	4.23	-15.32	1.33

$\text{POW}_{1.0}$	-0.10	0.92	-1.90	1.71
$\text{HOM}_{1.0}$	0.99	0.83	-0.64	2.62
$\text{MRD}_{1.0}$	-0.97	1.52	-3.97	2.02
$\text{RIP}_{1.0}$	1.44	0.38	0.70	2.18[*]
$\text{TRI}_{0.54}$	0.01	0.01	-0.01	0.03

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[a] The second category was denoted as the reference level to display parameter estimates.

[*] Denotes a 95% confidence interval that does not include zero.

CHAPTER 4

EFFECTS OF COMMON RAVEN REMOVAL ON GREATER SAGE-GROUSE NESTING SUCCESS IN SOUTHERN WYOMING

ABSTRACT Predator removal has been simultaneously proposed and criticized as a potential mitigation measure for low reproductive rates of greater sage-grouse (*Centrocercus urophasianus*; hereafter "sage-grouse"). Depredation of sage-grouse nests can be an influential factor limiting their productivity, and most failed sage-grouse nests are depredated by predators including common ravens (*Corvus corax*: hereafter "raven"). In Wyoming, lethal removal of ravens was conducted by USDA/APHIS/Wildlife Services (WS) for the protection of livestock. I hypothesized that sage-grouse nest success would be greater in areas where WS lowered the abundance of ravens. I assessed the change in density of ravens and nest success of sage-grouse in areas within 15 km of WS raven removal efforts and areas farther away. I also evaluated sage-grouse nest success in relation to: 1) differences between yearling and adult sage-grouse, and 2) the effect of ravens (nest site-level and study site-level) on nest success of sage-grouse in relation to microhabitat. During 2008–2011, I conducted 3,842 10-minute point count surveys at 341 sage-grouse nests and 660 random locations in southern Wyoming. Point counts were conducted to assess raven density. I found that raven densities at removal study sites decreased 61% between 2008 and 2011, whereas raven densities at non-removal study sites increased 42% between 2008 and 2011. A year × study site type (removal or non-removal) model did not fit the data well, which suggested that I did not detect a direct improvement to nest success of sage-grouse from reduction of ravens by WS; however, generalized linear modeling indicated that higher nest success of sage-grouse was correlated with study sites that had lower values of site-specific change in raven density (raven density relative to a particular study site [study site-level] with lower values of site-specific change in raven density found in removal study sites after removal had occurred). Nest success of sage-grouse was negatively impacted by occupancy of ravens within 550 m of a sage-grouse nest (nest site-level). Nest success of sage-grouse nests that were not occupied by ravens during the last nest check was estimated at 41% (95% confidence interval [CI] = 35% to 46%) using a 28-day incubation period with Program MARK; whereas, the success of nests occupied by ravens was estimated at only 22% (95% CI = 11% to 37%). My mixed results with respect to the potential benefit of raven removal by WS indicated that there was not a strong connection between raven removal and increased sage-grouse nest success; nevertheless, predator removal may have a place in sage-grouse management as an interim mitigation measure when sage-grouse populations are subjected to high densities of ravens. However, long-term solutions to reduce human-subsidized raven populations are necessary to address the growing raven and sage-grouse conflict.

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*: hereafter “sage-grouse”) distribution and abundance in western North America has declined over the last century (Gregg et al. 1994, Johnsgard 2002, Connelly et al. 2004). This decline has recently led the U.S. Fish and Wildlife Service (2010) to conclude that sage-grouse are warranted for protection under the Endangered Species Act of 1973, but the listing was precluded in favor of other species under severe threat of extinction. Many factors have been attributed to this decline including habitat loss, habitat fragmentation, habitat degradation, and predation (Braun 1998, Schroeder et al. 2004). Several studies have suggested that quantity and condition of breeding habitat is the most important factor that dictates the productivity of sage-grouse (Connelly et al. 1994, Braun 1998, Schroeder and Baydack 2001, Coates 2007, Hagen 2011). However, even in excellent sage-grouse habitat, most sage-grouse nests are lost to predators such as red fox (*Vulpes vulpes*), badgers (*Taxidea taxus*), coyotes (*Canis latrans*), black-billed magpies (*Pica hudsonia*: hereafter "magpie"), and common ravens (*Corvus corax*: hereafter "ravens"; Willis et al. 1993, Gregg et al. 1994, Heath et al. 1997, Holloran 1999, Connelly et al. 2004). Unlike other population limiting factors (e.g., habitat, weather, and drought), predation can realistically be reduced by wildlife management agencies (Cote and Sutherland 1997). However, there are no predators that specialize on sage-grouse during any life history stage (egg, chick, or adult), and sage-grouse have relatively high nest and adult survival rates (Connelly et al. 2011). Thus, Hagen (2011) suggested that in general predation is not limiting sage-grouse populations, and predator removal may only serve to provide a short-term release of predation rates in fragmented habitats and areas with human-subsidized predator populations.

In contrast, breeding success of other ground-nesting birds has been shown to be suppressed by generalist predators, such as ravens, magpies, red fox, coyotes, and badgers (Evans 2004). Generalist predators can reach high densities in landscapes with human-associated resources. Their densities are not limited by the density of a particular species of prey (Schroeder and Baydack 2001, Evans 2004, Manzer and Hannon 2005, Coates 2007). These factors enable a generalist predator to potentially suppress prey populations. Sage-grouse populations may also be impacted by increases in generalist predator populations, or decreases in the primary prey of generalist predators that cause these predators to switch prey (Schroeder and Baydack 2001, Connelly et al. 2004).

There are increasing levels of human development in sage-grouse habitat, which has brought a range of new stresses to sage-grouse from habitat fragmentation to predation (Connelly et al. 2004, Doherty et al. 2010, Kirol 2012). Human activities are impacting sage-grouse habitat resulting in increased fragmentation, and one of the consequences of fragmentation may be increased predation rates (Schroeder and Baydack 2001). During the last century, densities of ravens have increased in Wyoming and throughout the historic range of sage-grouse (Larsen and Dietrich 1970, Andrén 1992, Engel and Young 1992, Boarman et al. 1995, Sauer et al. 2011). Ravens utilize human-provided food resources, such as road-kill, dead livestock, and garbage (Knight and Call 1980, Boarman 1993, Boarman et al. 1995), especially during winter. Raven depredation of sage-grouse nests has been implicated as a potential factor limiting sage-grouse productivity in fragmented habitats (Batterson and Morse 1948, Willis et al. 1993, Gregg et al. 1994, Schroeder and Baydack 2001, Coates and Delehanty 2010, Bui et al. 2010). Raven depredation on sage-grouse nests is a common occurrence in northeast Nevada based on infrared video cameras set up at nest sites (Coates et al. 2008), and sage-grouse nest success in northeast Nevada was related to the number of ravens per 10-km transect with nest failure rates increasing 7.4% with every additional raven/10 km (Coates and Delehanty 2010).

Leu et al. (2008) developed a corvid-presence risk model to predict the presence of ravens in sage-grouse habitat based on average daily raven movements from Boarman and Heinrich (1999). Factors used to model the increased risk of corvid-presence were populated areas, campgrounds, rest stops, agricultural land, and landfills (Leu et al. 2008). In the corvid-presence risk model, 58% of all sage-grouse habitat was classified as high or medium risk of corvid presence, whereas only 7% of sage-grouse habitat was classified as negligible risk of corvid presence (Leu et al. 2008). In addition, lambing and calving areas are known to provide short-term food rich areas that attract ravens from vast distances during the spring (Heinrich 1988, Marzluff and Heinrich 1991). Higher raven densities around livestock areas increase the likelihood that ravens will depredate sage-grouse nests around these areas.

Subsidized raven populations of increasing size have been anecdotally documented in southwest and south-central Wyoming associated with human activities (e.g., livestock and natural gas development; R. J. Merrell, United States Department of Agriculture Animal and Plant Health Inspection Service Wildlife Services [WS], personal communication), and raven abundance has increased in Wyoming during the past decade, 2001–2010 (Sauer et al. 2011). Raven control (lethal removal; hereafter “raven removal”) efforts of varying intensity have been carried out by WS in Carbon, Lincoln, Sweetwater, and Uinta counties in Wyoming, 2007–2011 for the protection of livestock, which provided a unique opportunity to study the potential effects of raven removal on sage-grouse nest success. I hypothesized that sage-grouse nest success would be greater in areas where WS lowered the abundance of ravens. To test this hypothesis, I assessed the change in density of ravens and sage-grouse nest success in areas associated with WS raven removal efforts and areas farther away during 2008–2011. As secondary objectives, I evaluated differences between yearling and adult sage-grouse nest success, and the effect of ravens on nest success at the sage-grouse nest level in relation to microhabitat.

STUDY AREA

My study was conducted in southwest and south-central Wyoming. I had 12 study sites, each 16 or 24 km in diameter (eight study sites of 16-km diameter and four study sites of 24-km diameter; Fig. 4-1). To evaluate sage-grouse response to raven removal in a similar area, study sites in southwest Wyoming were 16-km diameter and approximately centered around leks where hens were captured based on results found by Holloran and Anderson (2005). Study sites in south-central Wyoming were 24 km, because sage-grouse were captured at several nearby leks over a larger area. Five out of 12 study sites were within 15 km of WS raven removal activities (Fig. 4-1). Study sites within 15 km of WS raven removal were considered ‘removal study sites’, those at a distance >15 km were considered ‘non-removal study sites’. Five study sites were located in Lincoln County, two in Sweetwater County, two in Uinta County, and three in Carbon County. Study sites were chosen to provide a representation of overall sage-grouse nesting habitat in southern Wyoming with a variety of land uses, topographic features, and raven management.

Removal and non-removal study sites had similar topographic features, weather, and vegetation. Elevation ranged from 1,950 m to 2,600 m among removal study sites and 1,925 m to 2,550 m among non-removal study sites. Most of the land within all of the study sites was federally owned and administered by the Bureau of Land Management with a small percentage of private lands. Domestic sheep and cattle grazing were the dominant land uses in the study sites. All study sites had anthropogenic development, which consisted mostly of unimproved 4-wheel drive roads. Conventional natural gas, coalbed methane natural gas, and/or conventional oil extraction activities were present in two of the removal study sites and four of the non-removal study sites.

The landscape at all study sites was dominated by sagebrush (*Artemisia* spp.); Wyoming big sagebrush (*A. tridentata wyomingensis*) and mountain big sagebrush (*A. t. vaseyana*) were the most common. Black sagebrush (*A. nova*) and dwarf sagebrush (*A. arbuscula*) were found on exposed ridges. Other common shrub species in the study sites included alderleaf mountain mahogany (*Cercocarpus montanus*), antelope bitterbrush (*Purshia tridentata*), chokecherry (*Prunus virginiana*), common snowberry (*Symphoricarpos albus*), greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus* and *Ericameria* spp.), Saskatoon serviceberry (*Amelanchier alnifolia*), and spiny hopsage (*Grayia spinosa*). Isolated stands of juniper (*Juniperus* spp.) and quaking aspen (*Populus tremuloides*) were found at the higher elevations on north-facing hillsides. Common forb species included arrowleaf balsamroot (*Balsamorhiza sagittata*), buckwheat (*Eriogonum* spp.), common yarrow (*Achillea millefolium*), dandelion (*Taraxacum* spp.), desert parsley (*Cymopterus* spp.), phlox (*Phlox* spp.), lupine (*Lupinus* spp.), sego lily (*Calochortus nuttallii*), and wild onion (*Allium* spp.). Common grass species included: bluegrasses (*Poa* spp.), bluebunch wheatgrass (*Pseudoroegneria spicata*), green needlegrass (*Nassella viridula*), needle and thread (*Hesperostipa comata*), prairie junegrass (*Koeleria macrantha*), and western wheatgrass (*Pascopyrum smithii*). Cheatgrass (*Bromus tectorum*) was present, but not widespread in any of the study sites.

METHODS

Sage-grouse Capture and Monitoring

From 2008 to 2011, I monitored sage-grouse hens during the nesting season (late-April to mid-July). Hens were captured, radio-collared, and released in April of each year. I captured hens at night using ATVs, spotlights, and hoop-nets (Giesen et al. 1982, Wakkinen et al. 1992, Connelly et al. 2003). Sage-grouse hens were fitted with 17.5-g or 22-g (<1.5% body mass) necklace radio collars (Holohil Systems Ltd, RI-2D, Ontario, Canada or Advanced Telemetry Systems Inc, A4060, Isanti, MN, USA). I aged sage-grouse hens as yearlings or adults by examining outer primaries (Patterson 1952).

Between May 1 and July 15, I located hens weekly with VHF receivers (Communications Specialists, R-1000, Orange, CA, USA) and 3-way Yagi antennas (Communications Specialists, Orange, CA, USA). Potential nests were identified with binoculars from ~15 m by circling a radio-marked hen until she was visually spotted under a shrub. I used handheld global positioning system (GPS) units (eTrex, Garmin

Inc., Olathe, Kansas) to record hen locations. Location accuracy on the GPS ranged from 2 – 8 m.

Nests were verified by triangulating the hen under the same shrub from ≥50 m away or thoroughly searching the area of the potential nest when the hen was absent. I continued monitoring nests weekly until the nest hatched or failed. I assessed nest fate as successful or unsuccessful after a hen had left her nest. A successful nest was defined as having evidence that at least 1 egg hatched as determined by shell membrane condition (Wallestad and Pyrah 1974). I classified unsuccessful nests as abandoned (eggs not depredated or hatched) or depredated (at least one egg with evidence of depredation).

Raven Abundance Monitoring

Between May 1 and August 1 of each year, I conducted point count surveys at sage-grouse nests and random locations within each study site to compare raven densities. To avoid disturbing an incubating hen, nest point counts were conducted 100–200 m away from a sage-grouse nest but within a line-of-sight of that sage-grouse nest. Random locations were selected in habitat considered to be available to sage-grouse for nesting within each study site. To restrict random locations to available nesting habitat, I used ArcMap 10.0 (ESRI Inc., Redlands, California) to generate random locations only in sagebrush-dominated habitat, which was classified by the Northwest GAP landcover data from 2008. Random locations were designated to be >1000 m apart; however, random selection led to average nearest neighbor distances among random point count locations of >2000 m (Table 4-1). I generated 12 random locations in each 16-km diameter study site and 18 random locations in each 24-km diameter study site per year. I generated a new set of random locations each year to avoid spatial autocorrelation; thus, random locations among years were independent.

I used standard distance sampling techniques (Ralph et al. 1995, Buckland et al. 2001, Thomas et al. 2010), which entailed counting all ravens observed during point counts and recording each raven's distance from the observer (when standing at the center of the point count location). I recorded distance as the distance from the observer to where a raven was first located (Ralph et al. 1995, Thomas et al. 2010); this minimized possible bias associated with ravens being attracted to or flushed away from an observer. When a raven was displaced from the center of a point count location as an observer approached (6.4% of all detected ravens), I recorded distance from that raven to the center of the point count location while the observer approached as suggested by Ralph et al. (1995). This was done when the approach of an observer resulted in a raven moving away from the center of the point count location. A 1500–m rangefinder (American Technologies Network Corp., RE-1500 m, San Francisco, California) in conjunction with a GPS was used to estimate distances directly or to validate visually estimated distances.

Observers were trained and tested in corvid and raptor identification before conducting point counts. Point counts were 10 min in length, and I conducted them during daylight hours on a weekly basis at each study site. I visited each point count location 1 to 8 times with most locations visited ≥3 occasions. I did not survey for ravens in inclement weather (i.e., when raining or wind speeds greater than 25 km/h; Ralph et al. 1995). Unidentified birds were not included in analyses; these contributed to 2% of detections within truncated observation distances. Nest point counts were performed after nests were initially located; thus, nest point counts were conducted in May to early-July. I performed random point counts May to 1 August each year.

I intermixed the sampling of nest and random point counts within each study site. To minimize observer bias, I changed the time of day and the observer that conducted individual point counts within a study site each week (i.e., each individual point count location regardless of type—nest or random—was conducted at a different time of day each week and by a different observer as best as possible). The observers conducting point counts within a particular study site changed each year.

Raven Removal

WS began lethally removing ravens in Carbon, Lincoln, and Sweetwater counties in March 2007 and Uinta County in February 2008 (R. J. Merrell, personal communication). Removal of ravens was conducted in response to livestock depredation; thus, WS removal activities were implemented at raven foraging areas or roosts near areas used by livestock (0–15 km). WS removal activities were more focused on raven foraging areas (lambing and calving grounds and landfills; Table 4-2) from February 2009 to June 2011.

WS personnel performed concentrated raven removal using DRC-1339 (3-chloro-p-toluidine hydrochloride) by treating 1.3-cm meat cubes or dog food or shooting them with shotguns (R. J. Merrell, personal communication); however, direct removal was uncommon (Carbon, Lincoln, Sweetwater, and Uinta counties four year total $n = 57$

ravens). Typical WS raven removal methods entailed pre-baiting with non-treated bait for a few days to acclimate ravens to foraging on bait (meat cubes or dog food) before applying DRC-1339 to bait (R. J. Merrell, personal communication). The amount of DRC-1339 and bait applied at individual removal locations was proportional to the number of ravens WS personnel witnessed in that area. DRC-1339 concentration was applied as specified by the U.S. Environmental Protection Agency label (LD_{50} = 5.6 mg/kg; Larsen and Dietrich 1970). Each spatiotemporal specific application of DRC-1339 or direct removal was considered a ‘removal event’.

To assess the efficacy of WS raven removal, I constructed spatiotemporal variables to describe the number of proportional removal events around nest and random point count locations during 2008–2011. Time was incorporated by including all removal events that occurred within 3 or 6 months prior to a sage-grouse nest’s fate or prior to the last date a random point count was conducted. The distance to the nearest removal event within 3 or 6 months was calculated for each point count location with ArcMap 10.0. The total number of removal events within 7 km, 15 km, or 25 km of a point count location were calculated for 3 and 6 months with ArcMap 10.0. I also calculated the number of removal events at landfills and other locations separately within 3 and 6 months. Removal events at landfills were calculated within 25 km under the assumption that ravens may be drawn into landfills from farther away, while non-landfill removal events were calculated at 7 km, 15 km, and 25 km from a point count location for 3 and 6 months excluding removal events at landfills. I report means (SE) of all removal event variables for removal and non-removal study sites (Table 4-3). I adapted the 7-km (153.9

km^2), 15-km (706.5 km^2), and 25-km (1962.5 km^2) search radii around point count locations to correspond to reported raven average home-range (California 0.3–45.8 km^2 [Linz et al. 1992], Minnesota 27.3–195 km^2 [Bruggers 1988]), average daily movements (Mojave Desert 4.5 km [Boarman et al. 1995], Idaho 6.9 km [>95% of movements within 12.5 km; Engel and Young 1992]), and documented roaming distances (Minnesota average 1,252 km^2 [Bruggers 1988], Maine >1,800 km^2 [Heinrich 1988], and Michigan average radius 27 km [range 3–147 km; Boarman and Heinrich 1999]). The smallest home-ranges correspond to breeding pairs, and larger distances correspond to non-breeding individuals.

Vegetation Variables

I sampled vegetation at sage-grouse nests in late-May to early-July 1 to 2 weeks after sage-grouse nests hatched or failed. I recorded the max height and the average canopy cover of the nest shrub. I quantified vegetation within 5 m surrounding sage-grouse nests by orienting 2 vegetation transects—each 10 m in length—at the cardinal directions and intersecting at a sage-grouse nest. Vegetation transects were conducted to measure average total shrub cover—including antelope bitterbrush, greasewood, rabbitbrush, sagebrush, Saskatoon serviceberry, and snowberry—using the line-intercept method (Canfield 1941). Average percent cover of shrubs was calculated by dividing the total shrub intercepted line length (cm) by the total line length (2000 cm) and then multiplying by 100. Gaps <3 cm were not recorded (Wambolt et al. 2006), and no section of shrub cover was measured more than once. I averaged the height of shrubs that intersected the vegetation transect for average total shrub height; shrub heights excluded inflorescences. I calculated percent cover of grass, perennial grass, forbs, bare ground, and litter in six cover classes (1 = 0–1%, 2 = 1.1–5%, 3 = 5.1–25%, 4 = 25.1–50%, 5 = 50.1–75%, and 6 = 75.1–100%; Kirol et al. 2012) by averaging 9 20-cm × 50-cm quadrats placed along vegetation transects at 2 m, 4 m, 5 m, 6 m, and 8 m (Daubenmire 1959). Perennial grass height was measured by recording the maximum grown height (droop height) excluding flowering stalks within 1 m of the 9 quadrats. The lowest visible 5-cm section of a Robel pole—that was placed in the center of a sage-grouse nest—was recorded to provide an index of general line-of-sight obstruction (hereafter “visual obstruction”; Robel et al. 1970). I recorded Robel pole readings from 1 m off the ground and 5 m away at the 4 cardinal directions and averaged these values to report 1 visual obstruction measurement per site. I report means and standard errors (SE) for vegetation variables used in models for removal and non-removal study sites (Table 4-4).

Data Analyses

I implemented a spatiotemporal modeling strategy to evaluate general trends in 1) the effects of WS removal activities on raven abundance and 2) the effects of study site-level and sage-grouse nest-level raven abundance and microhabitat on sage-grouse nest success. A spatiotemporal strategy was implemented because many variables describing raven abundance and sage-grouse nest survival were exclusive to a given year or study site type (removal or non-removal). Modeling of raven abundance and sage-grouse nest survival were conducted with an information theoretic approach (Anderson 2008), and I compared models with Akaike's information criterion adjusted for sample size (AIC_c) and Akaike weights (w_i; Burnham and Anderson 2002). I classified models <2 AIC_c compared to the null model as having moderate support, and models with <4 AIC_c compared to the null as having a greater degree of support (Burnham and Anderson 2002, Arnold 2010). To allow for direct comparison of raven and microhabitat variables, I reported all *a priori* models with explanations of non-informative variables as suggested by Arnold (2010). I evaluated goodness-of-fit of top selected AIC_c models by computing a ratio of Zheng's (2000) proportional reduction of deviance (RDR) for covariate models to spatiotemporally saturated models (maximum proportional reduction in deviance; Iles 2012), which has been considered appropriate for generalized linear models (Zheng 2000, Aubry et al. 2011, Iles 2012). Deviance reduction for each spatiotemporally saturated model and top covariate models of interest were calculated relative to null models (time and study site type invariant):

$$\mathrm{D}_{\mathrm{int}} = 1 - (\mathrm{deviance}_{\mathrm{interest}}/\mathrm{deviance}_{\mathrm{null}}) \qquad (1)$$

$$\mathrm{D}_{\mathrm{sat}} = 1 - (\mathrm{deviance}_{\mathrm{saturated}}/\mathrm{deviance}_{\mathrm{null}})$$

$$\mathrm{RDR} = \mathrm{D}_{\mathrm{int}} / \mathrm{D}_{\mathrm{saturated}} \qquad (2)$$

thus, the ratio gives an assessment of a covariate model's relative ability to explain spatiotemporal processes effecting raven abundance and sage-grouse nest survival. The ratio is 1 for the spatiotemporally saturated model and 0 for the null model (Iles 2012). I prevented multicollinearity by only including one variable of any pair of variables that co-varied in any model (r >0.65) as determined with a Pearson's correlation matrix. In this situation I eliminated one co-varying variable from further analysis by retaining the variable that made the most biological sense. Variance inflation factors (VIF) for all predictor variables were ≤5, which indicated that the variances of coefficient values were not drastically increased by the inclusion of any predictor variable; thus, collinearity was not a major problem.

Raven density analysis.– I used function ‘distsamp’ in package UNMARKED version 0.9-5 (Fiske and Chandler 2011) in R (R 2.14.2, www.r-project.org, accessed 15 Apr 2012) to model the effects of year, year trend, point count type (nest or random), and removal event variables on the abundance of ravens in removal and non-removal study sites. I assessed general annual raven abundance within removal and non-removal study sites by modeling year, year trend, and point count type. I compared year and year trend in additive models with point count type to assess which form of year best described raven density; thus, year and year trend were not combined in any single model.

For models describing WS removal events, I only included distance to the nearest removal event, number of removal events per area (total and landfill excluded), and landfill removal events that were calculated at the same temporal scale in all modeling. I did not include landfill removal event variables in models with total number of removal events. To assess WS removal effects, the top AIC_c selected WS removal event variable model was compared to a spatiotemporally saturated model with RDR. The saturated model included year, point count type, and year × point count type for removal and non-removal study sites modeled separately. The ‘distsamp’ function fits a multinomial-Poisson mixture model (Royle et al. 2004) that allows for analysis of standard distance sampling data (Ralph et al. 1995, Buckland et al. 2001, Thomas et al. 2010) at discrete distance intervals, while simultaneously modeling detection and abundance (Fiske and Chandler 2011).

For ‘distsamp’ analyses, raven detection distances were binned into 250-m intervals and right truncated at 1500 m. I chose distance intervals and truncation distances by determining the smallest interval and largest truncation that allowed for adequate fit of distance sampling models. I used 95% confidence intervals (CI) to compare parameter estimates from top AIC$_c$ selected ‘distsamp’ models. I generated CIs empirically using parameter estimates and SE from ‘distsamp’.

I fit half-normal, hazard-rate, uniform, and exponential key detection functions. I compared the fit of all possible key detection functions with detection held constant between point count types (random and nest) and allowing detection to vary between point count types. I selected the appropriate key detection function for removal and non-removal study sites separately using AIC$_c$. For removal and non-removal study sites, ‘distsamp’ models with hazard-rate key detection functions held constant were at least 10 AIC$_c$ lower than models with all other key detection functions and detection varying by point count type. This was not surprising, because all point counts were in sagebrush-dominated habitat. I adjusted ‘distsamp’ parameter estimates for survey effort (difference in the number of visits per point count location) by incorporating the number of visits per point count location as an offset, which is similar to the procedure used in Program DISTANCE (Thomas et al. 2010).

I used ‘distsamp’ to estimate observer effective detection radius (EDR), which was defined as the distance from the observer that the number of detected ravens beyond EDR was equal to the undetected ravens within EDR (Thomas et al. 2002). ‘Distsamp’ does not allow fitting of observation specific covariates; thus, I was unable to compare models with detection varying among observers; however, I did not find differences in EDR among observers on data collected for the first 3 years of this study in Chapter 2. Thus, I did not incorporate differences in detection among observers into my ‘distsamp’ analyses.

Sage-grouse nest success analysis.– I analyzed daily survival rate (DSR) of sage-grouse nests by fitting generalized linear models of DSR using maximum likelihood in Program MARK (White and Burnham 1999). Model building was conducted in a two-step process to increase efficiency and avoid model dredging. For “Step 1,” I evaluated the effect of year, year trend, study site type, a nesting sage-grouse’s age (AGE), raven density at the study site-level, and raven density or occupancy at the sage-grouse nest-level on sage-grouse nest DSR. For “Step 2,” I used the top AIC_c selected model from Step 1 to evaluate raven abundance effects on sage-grouse nest DSR in comparison to microhabitat variables associated with the nest shrub and habitat directly surrounding the nest (5 m).

I calculated all raven variables from the raw count data within 550 m, which was the ‘distsamp’ estimated EDR. The raw densities were weighted by the number of visits to each point count location. Raven density at the study site-level was calculated at the study site-level by averaging the raven density at all random locations within each study site separately. I had noted through observation that relative changes in raven density within many study sites had positive or negative effects on nest success of sage-grouse. I attributed this phenomenon to the possibility of ravens being more or less effective predators on sage-grouse nests depending on the study site due to overall characteristics of a particular study site (combination of individual raven behavior, topographic roughness, large scale cover, anthropogenic development, etc.). The combination of multiple large scale differences in study sites were not accounted for with the microhabitat variables that I used, such as shrub cover within 5 m around a nest. In addition to landscape raven densities, I calculated site-specific change in raven density—from random point count locations—as the increase or decrease in landscape raven density (annual density) relative to the raven density in a particular study site at the beginning of the study (2008). Thus, site-specific change in raven density was 0 for all study sites in 2008. The site-specific change in raven density variable was intended to look at relative change in risk of depredation within each study site (i.e., does site specific increase or decrease of raven densities effect nest success of sage-grouse). Thus, site-specific change in raven density was not quantifying the effect of the exact density of ravens on nest success of sage-grouse among all study sites. Rather, it was assessing site-specific change in exposure to ravens, which more directly related to the potential effects of WS reducing raven populations within a study site (reducing risk of raven depredation with a study site). Sage-grouse nest-level raven abundance was calculated from nest point counts as 1) raven density (hereafter “nest-level raven density”) at the nest and 2) occupancy (0 or 1) of at least 1 raven during the last nest check when the sage-grouse hen was still on the nest (hereafter “raven occupancy”). In addition to additive models, I included interactions between year × study site type and year trend × study site type to directly assess the effect of WS removal activities at removal study sites on DSR of sage-grouse nests; year and year trend were not included in models with raven variables because raven variables were temporally explicit to year. I did not include both nest-level raven density and raven occupancy in any model, because nest-level raven density and raven occupancy were measured at the same spatiotemporal scale.

I compared the top AIC$_c$ selected sage-grouse nest DSR models from Steps 1 and 2 to a spatiotemporally saturated model with RDR. The saturated model for sage-grouse nest DSR included year; study site type; max nest shrub, average total shrub, and average perennial grass height; average nest shrub, total shrub, grass, forb, bare ground, and litter cover; and visual obstruction. Grass and perennial grass cover were highly correlated ($r > 0.65$), and grass cover fit the data better than perennial grass cover; thus, I included grass cover in modeling instead of perennial grass cover.

Spatial autocorrelation.– Distance sampling estimates are known to be robust to spatial autocorrelation (Thomas et al. 2010); however, spatial autocorrelation violates the independence assumption for generalized linear models. Thus, I created an inverse weighted distance matrix to assess spatial autocorrelation among sage-grouse nests, where nest locations >12 km apart were not considered to be correlated. This distance was used to directly relate to the radius of my 24-km diameter study sites; however, 12 km was also larger than the home range size of breeding ravens (0.3–45.8 km^{-2}; Boarman and Heinrich 1999). Furthermore, I treated all sage-grouse nests, regardless of year, as correlated within 12 km with the degree of correlation related to the distance among nests. I used function 'moran.test' in package SPDEP version 0.5-46 in R to calculate Moran's I for Pearson residuals of top AIC_c selected generalized linear models of sage-grouse nest success.

RESULTS

Raven Density

I conducted 3,842 point count surveys (1,621 at removal study sites and 2,221 at non-removal study sites) during 2008–2011 at 1,001 total point count locations with 341 sage-grouse nest locations and 660 random locations (Table 4-1). I counted 1179 ravens (687 at removal study sites and 492 at non-removal study sites), and 'distsamp' estimated EDR was 552 m. The number of detected ravens was greater than 60–80 detections, which Buckland et al. (1993) suggested was necessary for reliable density estimates.

I found that raven densities at removal study sites decreased over time, whereas raven densities at non-removal study sites increased over time (Tables 4-5 and 4-6; Fig. 4-2). For removal and non-removal study sites, raven densities at sage-grouse nests were lower than raven densities at random locations (Table 4-6). The average nearest removal event was 14.5 km (0.4 SE) and 39.3 km (1.0 SE) for removal study sites and non-removal study sites, respectively (Table 4-3).

For models describing general annual raven abundance, top AIC_c ranked 'distsamp' models included year and point count type for both removal and non-removal study sites ($w_i = 0.65$ and $w_i = 0.45$, respectively; Table 4-5). In removal study sites, I found that 2009 raven densities were only moderately lower than 2009 (95% CI overlapped 0; Table 4-6, Fig. 4-2); whereas, raven densities in 2010 and 2011 were lower than 2008 (Table 4-6, Fig. 4-2). The top removal study site model also included year × point count type (Table 4-5). The interaction between year and point count type indicated that raven density at sage-grouse nests was lower in all years but the difference in raven density at sage-grouse nests and random locations was not as large in 2011. Thus, the density of ravens at sage-grouse nests was similar for 2008 and 2011 and lower in 2009 and 2010 (Table 4-6).

For models describing removal events, I found that removal events calculated at 6 months fit better than removal events at 3 months. Decreases in raven density at removal study sites were best described by the parameter estimates of the number of landfill removal events (-0.073; 95% CI = -0.092 to -0.054), the number of non-landfill removal events within 15 km (-0.134; 95% CI = -0.188 to -0.080), and the distance to the nearest removal event (-0.002; 95% CI = -0.013 to 0.010; Table 4-7, Fig. 4-3). Increases in raven density at non-removal study sites were best described by the parameter estimate of the number of non-landfill removal events within 25 km (0.060; 95% CI = 0.031 to 0.089; Table 4-7, Fig. 4-4). Raven density at removal study sites was not affected by the distance to the nearest removal event, but the distance to the nearest removal event contributed to describing the data. There were 156 out of 593 point counts (26%) within non-removal study sites that had a number of non-landfill removal events within 25 km >0, whereas removal study sites had 358 out of 407 point counts (88%) >0. The top selected AIC$_c$ model for removal study sites (w_i = 1.00) had RDR = 0.908, whereas, the top selected AIC$_c$ model for non-removal study sites (w_i = 0.44) had RDR = 0.491. Thus, removal event variables accounted for most of the reduction in deviance in removal study sites and approximately half of the deviance in non-removal study sites.

Sage-grouse Nest Success

In the four years of study (2008–2011), I found 121 sage-grouse nests in removal study sites with 52%, 35%, 50%, and 57% apparent nest success, respectively, and 220 sage-grouse nests in non-removal study sites with 54%, 57%, 45%, and 43% apparent nest success, respectively (Fig. 4-5). I did not find any differences in DSR of sage-grouse nests among year, year trend, study site type (removal or non-removal), and landscape raven density from Program MARK models; all models with year, year trend, study site type, and raven density at the study site-level had AIC$_c$ values greater than the null model (Table 4-8). However, I found that sage-grouse nest DSR was negatively impacted by site-specific change in raven density (study site-level) and raven occupancy (nest site-level), and microhabitat variables did not greatly improve the fit of DSR models (Tables 4-8 and 4-9). Average DSR for sage-grouse nests that were not occupied by a raven was 0.969 (± 0.003 SE), which yielded an estimated 41% (95% CI = 35% to 46%) nest survival using a 28-day incubation period. This estimate was lower than the apparent nest success of all but one year by study site combination, and highlighted the necessity to account for nests that were depredated or abandoned before I found them by using the nest survival model in Program MARK. Average DSR for sage-grouse nests that were occupied by a raven was 0.948 (± 0.010 SE), which yielded an estimated 22% (95% CI = 11% to 37%) nest survival using a 28-day incubation period. Spatial autocorrelation was not a problem for the top AIC$_c$ selected sage-grouse nest DSR models (Moran's I: $P > 0.4$).

Step 1 of sage-grouse nest DSR modeling illustrated that raven occupancy fit the data better than nest-level raven density, and nest level (raven occupancy) and site-level (site-specific change in raven density) variables explained the sage-grouse nest success data better than models with year, year trend, study site type, year × study site type, year trend × study site type, or AGE (Table 4-8). Models with raven occupancy and site-specific change in raven density accounted for 45% and 33% of the cumulative w_i, respectively; whereas, models with year, year trend, study site type, or AGE accounted for lower w_i (13%, 9%, 12%, and 4%, respectively; Table 4-8). Thus, the sage-grouse nest DSR model with raven occupancy + site-specific change in raven density was used in step 2 to compare with microhabitat variables. In step 2, all models that explained the data better than the null model included raven occupancy and site-specific change in raven density, and no microhabitat only model was better than the null (Table 4-9). The best model from Step 2 included raven occupancy, site-specific change in raven density, and average perennial grass height (Table 4-9). The parameter estimates of raven occupancy (-0.52; 95% CI = -0.96 to -0.07) and site-specific change in raven density (-1.27; 95% CI = -2.71 to 0.17) were negatively associated with sage-grouse nest DSR (Fig. 4-6), and the parameter estimate of average perennial grass height was positively associated with sage-grouse nest DSR (0.01; 95% CI = -0.01 to 0.03; Fig. 4-6). Site-specific change in raven density and average perennial grass height were imprecise predictors (95% CI overlapped zero); however, parameter estimates for site-specific change in raven density (95% CI was slightly overlapping 0) had greater explanatory power than average perennial grass height (95% CI was drastically overlapping 0). The top AIC$_c$ model from Step 2 and the raven occupancy + site-specific change in raven density both had $w_i = 0.12$ (Table 4-9). The best Step 1 model had RDR = 0.54 versus RDR = 0.72 for the best Step 2 model; thus, average perennial grass height decreased the deviance but did not add much to w_i or prediction of DSR.

DISCUSSION

Sage-grouse nest success was negatively impacted by the presence of ravens near sage-grouse nests (local scale) and greater values of site-specific change in raven density (landscape scale); although, site-specific change in raven density was a slightly imprecise predictor. My sage-grouse nest success results suggest that sage-grouse nesting in areas with subsidized raven populations may have suppressed nest success, which may contribute to lower sage-grouse population growth rates. I did not find an overall difference in sage-grouse nest DSR between removal and non-removal study sites, which may indicate that all study sites had a similar sage-grouse nest DSR capacity. However, study site differences in raven abundance were accounted for by calculating the change in raven abundance relative to abundance within a study site at the start of the study. Alternatively, there may have been variability in sage-grouse nest DSR among study sites related to factors other than ravens and microhabitat, such as weather. The best sage-grouse nest DSR model had an RDR = 0.72, which indicated that a large proportion of spatiotemporal variability in sage-grouse nest success was not accounted for in my models. The negative effect of ravens on the nest success of grouse has been well documented (Manzer and Hannon 2005, Bui et al. 2010, Coates and Delehanty 2010). For example sharp-tailed grouse (*Tympanuchus phasianellus*) in southern Alberta had 8-times greater nest success in landscapes with <3 corvids/km^2 as opposed to landscapes with ≥3 corvids/km^2 (Manzer and Hannon 2005). Around Jackson and Pinedale, Wyoming, Bui et al. (2010) found that higher occupancy rates of ravens were correlated with failed sage-grouse nests.

Although I could not test for spatial autocorrelation in 'distsamp' analyses, densities derived from distance sampling are robust to lack of independence of observation locations because distance sampling is setup to be a snap-shot in time (Thomas et al. 2010). My raven sampling was designed to count the greatest proportion of ravens within a study site each week as suggested by Ralph et al. (1995) and Thomas et al. (2010). Conducting all point counts within a study site in one day reduced the possibility of double-counting individual ravens during that week's visit. Counting the same individual raven during different weeks, regardless of the particular point count location, was properly scaled by accounting for survey effort. Replication of point counts by sampling multiple weeks was done to increase the proportion of ravens detected as suggested by Thomas et al. (2010). Spatial autocorrelation was not found to be a problem with nest success models.

Microhabitat variables did not substantially differ between successful and unsuccessful sage-grouse nests, which indicated that all sage-grouse selected nest-sites with relatively equal concealment cover (relative to the habitat that was available) and microhabitat was not a limiting factor. Simultaneous comparison of raven and microhabitat vegetation variables accounted for differences among study sites in relation to sage-grouse nest-site selection. Thus, differences in nest success may be attributed to local and landscape scale raven abundance, local scale composition of other predators, weather, and habitat fragmentation (anthropogenic features).

Local predator densities can impact parental behavior, nest-site selection, and productivity of several prairie grouse species (Gregg et al. 1994, Schroeder and Baydack 2001, Manzer and Hannon 2005, Coates 2007). The presence of predators may induce changes in sage-grouse behavior associated with habitat usage. For instance, sage-grouse reduced time off of their nests when nesting in areas with high abundances of ravens (Coates and Delehanty 2008). Sage-grouse select nest sites at various scales. At the microhabitat scale, sage-grouse predominately choose nest sites in vegetation cover (Connelly et al. 2004). Several studies have reported that sage-grouse select nest sites based on a preference for different microhabitat characteristics, such as: sagebrush density (Wallestad and Pyrah 1974, Connelly et al. 2003), sagebrush cover (Doherty et al. 2010, Kirol et al. 2012), shrub height (Gregg et al. 1994), grass height (Gregg et al. 1994, Holloran et al. 2005, Kirol et al. 2012), and grass cover (Kaczor 2008, Kirol et al. 2012). Variability in reported microhabitat characteristic preferences of sage-grouse, with reference to nest-site selection, may indicate local differences in available microhabitat. Differences in available microhabitat among studies suggest that cover, in general, is important regardless of the type of vegetation cover that is available (e.g. sagebrush density, shrub height, or grass height). Alternatively, sage-grouse living in areas with different predator compositions, such as avian or mammalian predators, may prefer different types of vegetation cover (Connelly et al. 2004, Coates and Delehanty 2010). Thus, the microhabitat characteristics upon which sage-grouse base their selection of nest-sites and the success of those nests may be a result of available vegetation and predator composition. For example, Coates and Delehanty (2010) found that microhabitat at sage-grouse nest-sites was correlated to nest failure depending on whether a raven or a badger depredated the nest (greater cover protected from ravens, but exposed sage-grouse to greater badger depredation and vice versa—predator facilitation). At the landscape scale, sage-grouse may avoid areas where there are high densities of ravens (Manzer and Hannon 2005, Mezquida et al. 2006; see Chapter 2).

I found that sage-grouse nested in areas with lower densities of ravens in both removal and non-removal study sites compared to random locations as predicted by the predator-avoidance hypothesis. Only 11% of sage-grouse nests had a raven detected during the last nest check with the hen on the nest. In Chapter 2, I found that in general sage-grouse nests had lower densities of avian predators, including ravens, compared to random locations in sagebrush habitat. This pattern of avoidance of avian predators was present when looking at average avian predator densities across years and study sites. My results from 'distsamp' for general annual raven abundance indicate that sage-grouse selected nest-sites with fewer ravens compared to the habitat available to them—within a removal or non-removal study site. By selecting habitat with lower raven densities, sage-grouse lower their exposure to avian predation, and risk of reproductive failure. In western Wyoming, Bui et al. (2010) claimed that raven density around sage-grouse nesting and brood-rearing areas (1.0 ± 0.2 [SE] ravens/km^2) was marginally higher than raven densities in available sagebrush habitat (0.7 ± 0.2 [SE] ravens/km^2). The discrepancy between my results and Bui et al. (2010) may be a function of greater anthropogenic development and human activity in their study areas, or raven behavioral adaptations related to available resources (i.e., availability of nesting structure within sage-grouse nesting habitat and sage-grouse eggs).

Sage-grouse may avoid ravens indirectly by avoiding habitats with features that attract ravens (e.g., roads, livestock, rough topography, and tall structures) or directly by watching them; it is more likely that sage-grouse use both indirect and direct means. Arguments against only indirect avoidance include the fact that over half of my study sites had few anthropogenic structures (8 out of 12 study sites had <0.04 km^{-2} of well infrastructure or communication towers). Yet, I found that sage-grouse avoided ravens in all of my study sites. Perhaps in addition to avoiding risky habitats (e.g., near anthropogenic features), sage-grouse also avoid nesting in areas where they see ravens. Clearly more research needs to be done before conclusions can be drawn about the mechanisms behind sage-grouse avoidance of ravens.

My spatiotemporal modeling strategy allowed me to evaluate the general effect of WS removal efforts on raven abundance and raven abundance on sage-grouse nesting success. By using Iles's (2012) ratio of deviance reduction, I was able to assess the relative explanatory power of covariates compared to spatial and temporal processes—fully saturated spatiotemporal models. Raven management conducted by WS during this study was not implemented as a regimented experiment—it was carried out where ravens were causing problems for livestock operations; thus, some spatial locations of removal events changed among years, and DRC-1339 and the number of baits with toxicant were applied proportional to the number of ravens in an area. Thus, utilizing a modeling strategy that acknowledged and incorporated spatiotemporal processes into the evaluation of the data allowed for interpretation of the relative effect of WS raven management compared to annual and spatial variation. Proportional raven removal conducted by WS did not allow me to investigate variability in the concentration of DRC-1339, amount of DRC-1339 laced bait placed in an area, or the type of bait (e.g., meat or dog food). Even without rigorous implementation of WS raven management, my assessment of raven density and sage-grouse nest DSR was beneficial to assessing management as it can be provided from a practical logistics point-of-view.

Raven densities were reduced by WS up to 15 km from locations where WS was controlling ravens for the benefit of livestock (removal study sites; RDR = 0.908). The number of removal events conducted by WS within 15–25 km of non-removal study sites predicted higher raven densities; however, this only partially (RDR = 0.49) accounted for the change in the annual abundance of ravens. There was more anthropogenic development associated with natural gas extraction in non-removal study sites compared to removal study sites; thus, increases in raven density may have also been connected to human activity in non-removal study sites. Removal events were performed near areas with high densities of ravens (areas of raven conflict with livestock). Thus, my results indicate that higher densities of ravens in non-removal study sites were correlated with the point counts within non-removal study sites that were closer to areas with inherently higher densities of ravens (a potential spill-over effect).

Coates (2007) studied the effect of raven removal on sage-grouse nest success at four study areas in Nevada—1 study area with raven removal and 3 study areas without raven removal. Ravens were removed with DRC-1339 treated egg baits (Coates 2007, Coates et al. 2007). With every 1 km increase in distance away from raven removal routes, Coates (2007) found that sage-grouse nests were 2.1% more likely to fail, and ravens were 13% more likely to be the culprit. This information provided a good indication that reduction of raven abundance by WS may provide a benefit for sage-grouse nesting in areas with subsidized raven populations. My study verified that WS raven management can reduce the abundance of ravens at a relatively large scale (15-km radius or 706.5 km^2, Fig. 4-2), and higher sage-grouse nest success was correlated with lower densities of ravens on the landscape (Fig. 4-6). Even though my year × study site type model did not fit the data well, site-specific change in raven density (density of ravens on the landscape) was lowest in study sites that had the greatest WS removal effort within a given year and those were the areas with the highest sage-grouse nest success.

Raven removal by WS during my study most likely removed transient ravens that traveled vast distances from roost to foraging sites. In removal study sites, average distance to the nearest removal event was 14.5 (0.4 SE) km with no removal event conducted <1.1 km from a point count location, which indicates that most breeding ravens (coastal California median home range radius = 0.62 km and Mojave Desert California average home range radius = 0.57 km [Boarman and Heinrich 1999]) were not likely to have encountered removal events. Breeding pairs of ravens actively forage close to their nests, which entails relying on natural food sources (including sage-grouse eggs) more than food subsidies associated with human activities (road-kill, dead livestock, and landfills). Bui et al. (2010) hypothesized that higher densities of ravens near sage-grouse nesting areas were associated with breeding pairs of ravens, and occupancy of breeding pairs was negatively correlated with sage-grouse nest success. Increased anthropogenic structures in natural gas fields potentially allowed for greater overlap of breeding ravens and sage-grouse nesting areas (Bui et al. 2010). Coates (2007) results indicated that sage-grouse nests closer to removal routes had higher nest success, which may have been associated with a reduction in the number of raven breeding pairs. My results indicate that local scale and landscape scale raven abundance had negative consequences for sage-grouse nest success, which was likely correlated with breeding and non-breeding ravens. Kristan and Boarman (2003) found that breeding and non-breeding ravens were associated with increased predation of desert tortoises (*Gopherus agassizii*). Thus, both breeding and transient ravens may contribute to sage-grouse nest failure with greater abundances of transient ravens associated with incidental sage-grouse nest depredations.

Increased raven densities, regardless of breeding status, are likely to result in higher depredation rates on sage-grouse nests (Evans 2004, Bui et al. 2010, Coates and Delehanty 2010). As sagebrush habitat is developed, raven occupancy and density will increase in areas adjacent to and overlapping quality sage-grouse habitat. Increases in the human footprint have occurred and are likely to continue throughout most of the range of sage-grouse (Leu et al. 2008). In addition, high-quality sagebrush habitat may become functionally unavailable to sage-grouse when raven densities are high (see Chapter 2). In removal study sites, I found that the density of ravens at sage-grouse nests was similar in 2008 and 2011; however, the density of ravens on the landscape was much less in 2011 (Table 4-6). This suggests that sage-grouse may have been utilizing a greater proportion of sagebrush habitat in 2011. Thus, habitat availability in removal study sites may not have been as limited in 2011 as opposed to 2008. Holloran and Anderson (2005) suggested that large intact sagebrush habitat with low sage-grouse nest densities was necessary to retain a viable sage-grouse population. In some areas, reductions in raven density at a landscape level may increase the amount of functional habitat for sage-grouse. Several studies on predator-avoidance in birds indicate that the presence of a predator has dramatic impacts on prey species use of habitat (Cresswell 2008). These non-lethal effects were found to be as great or greater than the effects of direct predation. Thus, quality nesting habitat for sage-grouse has become more limited from the loss of functional habitat, which has also resulted in more direct depredation of nests.

MANAGEMENT IMPLICATIONS

The management of ravens may be a potential mitigating strategy for areas of low sage-grouse nest success. Coates (2007), Bui et al. (2010), and Hagen (2011) suggested that predator removal may provide a short-term release in predation rates within fragmented habitats and areas with subsidized predator populations. However, Hagen (2011) indicated that predator removal will not mitigate sage-grouse population declines throughout the range of sage-grouse. I agree that the positive effects of raven removal for sage-grouse nest success are likely short-lived gains. I monitored WS raven management as it applied to livestock depredation; thus, targeted raven management to benefit sage-grouse may produce better results. However, identification of areas where sage-grouse may benefit from raven removal and implementation of a raven removal program targeted at benefitting sage-grouse will not be an easy task. Management of both breeding and transient ravens will be necessary, which will present many challenges. Predator removal may have a place in sage-grouse management when sage-grouse populations are subjected to high densities of ravens as an interim mitigation measure. However, low reproductive rates may persist in many areas due to compensatory predation by other predators (Coates 2007, Bui et al. 2010). Long-term solutions to reduce human-subsidized raven populations are necessary to address the growing raven and sage-grouse conflict. Reducing raven abundance may be possible through non-lethal means, such as reducing availability of supplemental food (road-kill, dead livestock, and garbage) and nesting and perching structures (oil and gas structures, power lines, telephone poles, communication towers, etc.; Jiménez and Conover 2001). More research needs to be focused on understanding raven population dynamics in sagebrush ecosystems, and how to reduce the utility of anthropogenic subsidies (food and nesting structure) for ravens.

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Table 4-1. Summary of minimum, maximum, and mean distance (m) to nearest neighbor by location type (nest or random) reported by year. Data were collected in southwestern and south-central Wyoming, USA during 2008–2011.

Year	Location Type	*n*	Min	Mean	Max	SD
	Nest	63	241	2194	11812	2671
2008	Random	152	1000	2026	7216	1308
	Nest	85	103	1724.5	7195	1624
2009	Random	172	1000	2138	7073	1091
	Nest	83	107	2009	10011	2313
2010	Random	162	1031	2493	6136	1016
	Nest	109	124	1766	10086	1970
2011	Random	174	1061	2599	8450	1230

Table 4-2. Raven removal was conducted by USDA/APHIS Wildlife Services in southwest and south-central Wyoming during 2007–2011. Total number of removal events at raven foraging and roost sites around removal study sites. Number of removal events at landfills near removal study sites reported in parenthesis. Removal events quantified as the maximum number of events within 3 and 6 months prior to the last point count (sage-grouse nest or random) within a given year.

Year	Number removal events 3 months	Number removal events 6 months
2007	16 (0 landfill)	16 (0 landfill)
2008	6 (0 landfill)	7 (0 landfill)
2009	30 (6 landfill)	44 (6 landfill)
2010	33 (13 landfill)	40 (15 landfill)
2011	16 (1 landfill)	27 (8 landfill)

Table 4-3. Means and standard errors (SE) of variables used to model USDA/APHIS/Wildlife Services (WS) raven removal. Data were collected from 407 and 593 point count locations in removal and non-removal study sites, respectively, in southwestern and south-central Wyoming, USA during 2008–2011.

	Removal study sites		Non-removal study sites	
Variable description	mean	SE	mean	SE
Nearest (km) WS removal event within prior 3 mon	15.8	0.4	39.7	1.0
Nearest (km) WS removal event within prior 6 mon	14.5	0.4	39.3	1.0
Total # WS removal events within 7 km during prior 3 mon	0.2	0.0	0.0	0.0
Total # WS removal events within 7 km during prior 6 mon	0.2	0.0	0.0	0.0
Total # WS removal events within 15 km during prior 3 mon	1.6	0.2	0.0	0.0
Total # WS removal events within 15 km during prior 6 mon	2.1	0.2	0.0	0.0
Total # WS removal events within 25 km during prior 3 mon	3.9	0.2	1.0	0.1
Total # WS removal events within 25 km during prior 6 mon	5.7	0.3	1.3	0.1

# WS removal events at landfills within 25 km during prior 3 mon	2.4	0.2	0.1	0.0
# WS removal events at landfills within 25 km during prior 6 mon	3.3	0.3	0.1	0.1
# WS removal events within 7 km during prior 3 mon	0.2	0.0	0.0	0.0
# WS removal events within 7 km during prior 6 mon	0.2	0.0	0.0	0.0
# WS removal events within 15 km during prior 3 mon	1.3	0.1	0.0	0.0
# WS removal events within 15 km during prior 6 mon	1.6	0.1	0.0	0.0
# WS removal events within 25 km during prior 3 mon	2.2	0.2	0.9	0.1
# WS removal events within 25 km during prior 6 mon	3.3	0.2	1.2	0.1

Table 4-4. Means and standard errors (SE) of variables used to model sage-grouse nest daily survival rate (DSR). Data were collected from 121 and 220 sage-grouse nests at raven removal and non-removal study sites, respectively, in southwestern and south-central Wyoming, USA during 2008–2011.

	Removal study sites		Non-removal study sites	
Variable description	mean	SE	mean	SE
Max height of nest shrub (cm)	61.8	1.8	60.8	1.3
Average canopy cover of nest shrub (cm)	109.6	3.5	113.7	4.7
Total shrub cover (%) within 5 m	42.1	1.3	45.0	1.0
Sagebrush cover (%) at within 5 m	36.0	1.3	37.0	1.0
Average total shrub height (cm) within 5 m	40.3	1.4	39.2	0.9
Average sagebrush height (cm) within 5 m	41.6	1.7	39.9	1.1
Grass cover (%) within 5 m	15.8	1.4	17.4	1.1
Perennial grass cover (%) within 5 m	12.1	0.8	15.5	0.7
Average perennial grass height (cm) within 5 m	21.5	0.9	23.0	0.6
Forb cover (%) within 5 m	6.9	0.7	8.6	0.6
Bare ground cover (%) within 5 m	29.2	1.6	21.9	1.0
Litter cover (%) within 5 m	38.3	1.8	36.9	1.3
Horizontal visual obstruction (dm)	3.2	0.2	3.3	0.1
Raven density at the study site-level (no./ km^2) within	0.2	0.2	0.11	0.1

550 m of random locations				
Site-specific change in raven density (no./km^2) within 550 m of random locations calculated as the change in raven density within a study site relative to 2008	-0.1	0.0	0.0	0.0
Raven density (no./km^2) within 550 m of a sage-grouse nest while sage-grouse on nest	0.1	0.0	0.1	0.0
Raven occupancy (0, 1) within 550 m of a sage-grouse nest during last nest check with hen on nest	N/A	N/A	N/A	N/A
Sage-grouse <1 or ≥1 year at time of capture (AGE)	N/A	N/A	N/A	N/A

Table 4-5. Multinomial-Poisson mixture models assessing the effect of year, year trend, and point count type (sage-grouse nest or random) on raven densities using ‘distsamp’ in R. Models were analyzed separately for removal and non-removal study sites and then compared with Akaike’s information criterion (adjusted for small sample sizes; AIC_c) and Akaike weights (w_i). Standard distance sampling data were collected at 250 m discrete distance intervals during May to early-Aug. Data were collected from eight 16-km and four 24-km study sites in southwestern and south-central, Wyoming, USA (n = 121 and 220 nests and n = 287and 373 random point count locations for removal and non-removal study sites, respectively) during 2008–2011.

Models	k	ΔAIC_c	w_i	Deviance
Removal study sites				
Year+point count type+year×point count type[a]	10	0.00	0.65	3326.24
Year+point count type	7	1.24	0.35	3333.76
Year trend+point count type+year trend×point count type	6	24.79	0.00	3359.38
Year	6	25.33	0.00	3359.92
Year trend+point count type	5	31.11	0.00	3367.76
Year trend	4	51.16	0.00	3389.86
Point count type	4	63.05	0.00	3401.76
Null	2	90.08	0.00	3430.82
Non-removal study sites				
Year+point count type[b]	7	0.00	0.45	2721.74

Year trend+point count type	5	1.57	0.20	2727.40
Year+point count type+year×point count type	10	2.25	0.15	2717.80
Year trend+point count type+year trend×point count type	6	2.92	0.10	2726.70
Point count type	4	3.05	0.10	2730.90
Year	6	13.41	0.00	2737.20
Year trend	4	16.72	0.00	2744.58
Null	2	18.43	0.00	2748.32

[a] $AIC_c = 3346.80$

[b] $AIC_c = 2735.93$

Table 4-6. Parameter estimates of raven density with *P*-values and 95% confidence intervals (CI) from top AIC$_c$ selected multinomial-Poisson mixture models using 'distsamp' in R. Raven densities were modeled with random locations as the reference. Data were collected from eight 16-km and four 24-km study sites in southwestern and south-central, Wyoming, USA (*n* = 121 and 220 nests and *n* = 287 and 373 random point count locations for removal and non-removal study sites, respectively) during May to early-Aug, 2008–2011.

					95% CI	
Variable	Estimate[a]	SE	*Z*	*P*	Lower	Upper
Removal study sites						
Intercept	-0.46	0.13	-3.40	<0.001	-0.72	-0.19*
Year 2009	-0.12	0.11	-1.12	0.26	-0.34	0.09
Year 2010	-0.94	0.14	-7.00	<0.001	-1.21	-0.68*
Year 2011	-0.57	0.12	-4.71	<0.001	-0.80	-0.33*
Point count type[a]	-0.82	0.26	-3.13	0.002	-1.33	-0.31*
Year 2009×point count type[a]	-0.22	0.42	-0.53	0.60	-1.04	0.60
Year 2010×point count type[a]	-0.01	0.47	-0.02	0.99	-0.93	0.92
Year 2011×point count type[a]	0.60	0.32	1.90	0.06	-0.02	1.22
Non-removal study sites						
Intercept	-1.74	0.26	-6.80	<0.001	-2.24	-1.24*
Year 2009	0.51	0.20	2.59	0.01	0.12	0.90*

Year 2010	0.41	0.20	2.03	0.04	0.01	0.80[*]
Year 2011	0.53	0.20	2.72	0.007	0.15	0.91[*]
Point count type[a]	-0.48	0.13	-3.74	<0.001	-0.73	-0.23[*]

[*] Denotes a 95% confidence interval that does not include zero.

[a] Point count type (nest or random locations) with random point count locations coded as the reference category.

Table 4-7. Multinomial-Poisson mixture models assessing the effect of removal event variables on raven densities using 'distsamp' in R. Models were analyzed separately for removal and non-removal study sites and then compared with Akaike's information criterion (adjusted for small sample sizes; AIC_c) and Akaike weights (w_i). Only the top 10 models for removal and non-removal study sites were reported. Removal event variables used in modeling include removal distance, total removal events, removal events at landfills, and removal events other than at landfills. Removal events were analyzed at 7 km, 15 km, and 25 km. The temporal scale (3 or 6 months prior to nest fate or last point count at a random location) of each model is denoted in parenthesis. Standard distance sampling data were collected at 250 m discrete distance intervals during May to early-Aug. Data were collected from eight 16-km and four 24-km study sites in southwestern and south-central, Wyoming, USA (n = 407 and n = 593 for removal and non-removal study sites, respectively) during 2008–2011.

Models	k	ΔAIC_c	w_i	Deviance
Removal study sites				
Removal 15k+removal dist+landfill removal (6 month)[a]	6	0.00	1.00	3335.84
Removal 25k+removal dist+landfill removal (6 month)	6	29.36	0.00	3365.20
Removal 15k+landfill removal (3 month)	5	30.04	0.00	3367.92
Removal 15k+removal dist+ landfill removal (3 month)	6	30.52	0.00	3366.34
Removal 25k+landfill removal (6 month)	5	31.58	0.00	3369.48
Removal 7k+removal dist+landfill removal (6 month)	6	32.95	0.00	3368.78

Landfill removal (6 month)	4	37.55	0.00	3377.50
Removal 7k+landfill removal (6 month)	5	39.10	0.00	3377.00
Removal 25k+landfill removal (3 month)	5	50.35	0.00	3388.24
Removal 25k+removal dist+landfill removal (3 month)	6	52.27	0.00	3388.10
Non-removal study sites				
Removal 25k (6 month)[b]	4	0.00	0.44	2733.32
Removal 25k+landfill removal (6 month)	5	0.99	0.27	2732.26
Removal 25k+removal dist+landfill removal (6 month)	6	2.73	0.11	2731.96
Removal 25k (3 month)	4	3.57	0.07	2736.88
Total removal 25k (6 month)	4	4.91	0.04	2738.22
Removal 25k+landfill removal (3 month)	5	5.10	0.03	2736.38
Total removal 25k+removal dist (6 month)	5	6.98	0.01	2738.26
Removal 25k+removal dist+landfill removal (3 month)	6	7.09	0.01	2736.32
Total removal 25k (3 month)	4	7.57	0.01	2740.88
Total removal 25k+removal dist (3 month)	5	9.61	0.00	2740.88

[a] AIC_c = 3348.04

[b] AIC_c = 2741.38

Table 4-8. Generalized linear models assessing daily survival rate (DSR) of sage-grouse nests using Program MARK. Variables used in modeling include sage-grouse age (AGE), year, year trend, study site type (removal or non-removal), raven occupancy (raven occupancy) and density (raven density) at the sage-grouse nest level, and raven density (landscape raven density) and site-specific change in density of ravens at the study site-level. Models were compared with Akaike's information criterion (adjusted for small sample sizes; AIC_c) and Akaike weights (w_i). Data were collected from 121 and 220 sage-grouse nests at removal and non-removal study sites, respectively. Sage-grouse were located in eight 16-km and four 24-km study sites in southwestern and south-central, Wyoming, USA during 2008–2011.

Models	k	ΔAIC_c	w_i	Deviance
Raven occupancy+site-specific change in raven density[a]	3	0.00	0.25	811.58
Raven occupancy	2	0.39	0.20	813.97
Site-specific change in raven density	2	2.07	0.09	815.66
Null	1	2.14	0.09	817.72
Year	4	3.10	0.05	812.67
Year+study site type+year×study site type	8	3.11	0.05	804.67
Year trend	2	3.54	0.04	817.12
Nest-level raven density	2	3.63	0.04	817.22
Study site type	2	3.64	0.04	817.22
AGE	2	3.69	0.04	817.27

Landscape raven density	2	4.14	0.03	817.72
Year trend+study site type+year trend×study site type	4	4.15	0.03	813.73
Year+study site type	5	4.77	0.02	812.34
Year trend+study site type	3	4.94	0.02	816.52

[a] AIC_c = 817.59

Table 4-9. Generalized linear models assessing sage-grouse nest daily survival rate (DSR) using Program MARK. Variables used in modeling include sage-grouse nest level (raven occupancy) and site-specific change in raven density (Δ site-level raven; site-level raven), max nest shrub height, average nest shrub canopy cover, Robel visual obstruction, total shrub cover, average total shrub height, grass cover, forb cover, bare ground cover, litter cover, and average perennial grass height. Models were compared with Akaike's information criterion (adjusted for small sample sizes; AIC_c) and Akaike weights (w_i). A fully saturated spatiotemporal model was included to assess goodness-of-fit; the fully saturated model included all microhabitat variables, year and study site type (removal and non-removal). Data were collected from 121 and 220 sage-grouse nests at removal and non-removal study sites, respectively. Sage-grouse were located in eight 16-km and four 24-km study sites in southwestern and south-central, Wyoming, USA during 2008–2011.

Models	k	ΔAIC_c	w_i	Deviance
Raven occupancy+Δ site-level raven+perennial grass height	4	0.00	0.12	809.54
Raven occupancy+Δ site-level raven	3	0.04	0.12	811.58
Raven occupancy+Δ site-level raven+visual obstruction	4	0.33	0.11	809.87
Raven occupancy+Δ site-level raven+bare ground	4	1.56	0.06	811.10
Raven occupancy+Δ site-level raven+forb cover	4	1.76	0.05	811.30
Raven occupancy+Δ site-level raven+total shrub height	4	1.77	0.05	811.31

Raven occupancy+Δ site-level raven+grass cover	4	1.81	0.05	811.35
Raven occupancy+Δ site-level raven+total shrub cover	4	1.85	0.05	811.39
Raven occupancy+Δ site-level raven+nest shrub cover	4	1.87	0.05	811.41
Raven occupancy+Δ site-level raven+litter	4	1.99	0.05	811.53
Raven occupancy+Δ site-level raven+nest shrub height	4	2.01	0.05	811.55
Null	1	2.18	0.04	817.72
Visual obstruction	2	2.26	0.04	815.80
Perennial grass height	2	3.25	0.02	816.80
Bare ground	2	3.59	0.02	817.14
Total shrub height	2	3.78	0.02	817.32
Forb cover	2	3.98	0.02	817.53
Nest shrub cover	2	4.00	0.02	817.54
Nest shrub height	2	4.03	0.02	817.57
Total shrub cover	2	4.12	0.02	817.66
Grass cover	2	4.12	0.02	817.67
Litter	2	4.17	0.02	817.72
Spatiotemporally saturated	15	18.93	0.00	806.38

[a] AIC$_c$ = 817.55

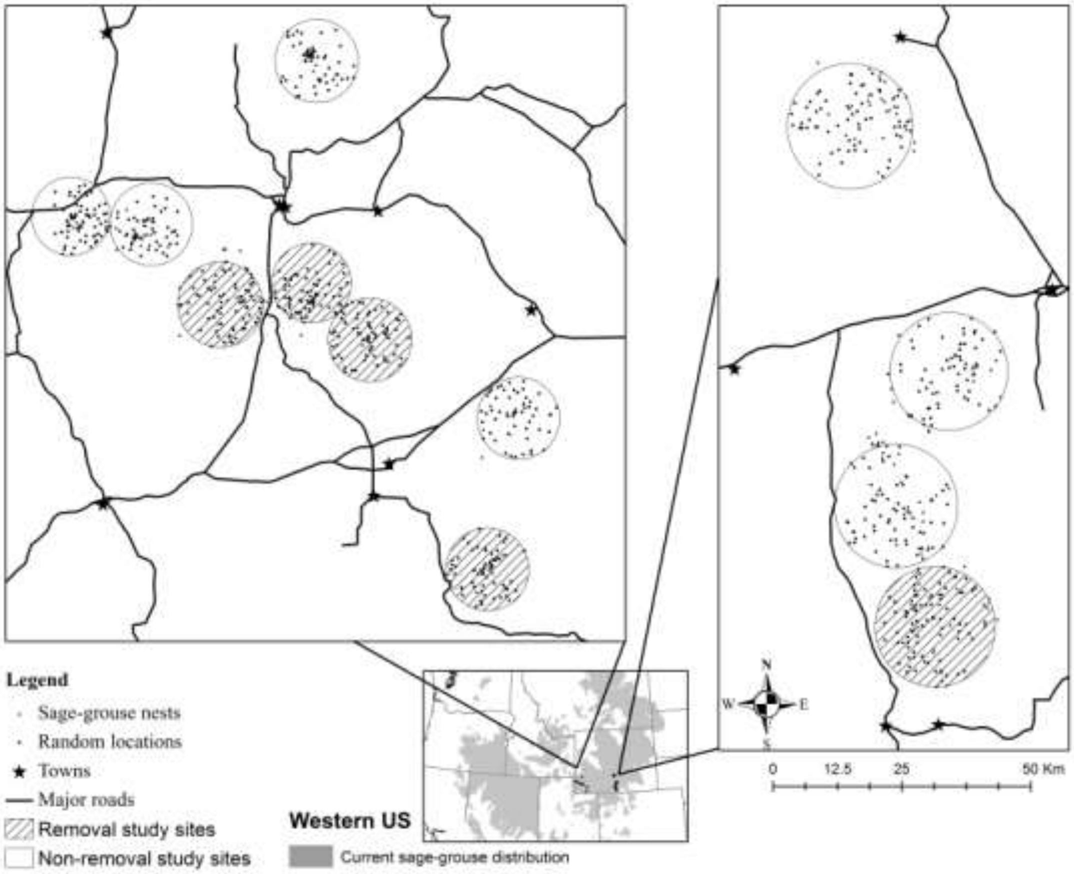

Figure 4-1. Location map of southern Wyoming depicting eight 16-km diameter and four 24-km diameter study sites, southwestern and south-central, Wyoming, USA, 2008–2011. Magnified sections correspond on left to southwest and on right to south-central Wyoming. Map includes locations of 2008–2011 sage-grouse nests, random locations, landfills, towns, and major roads.

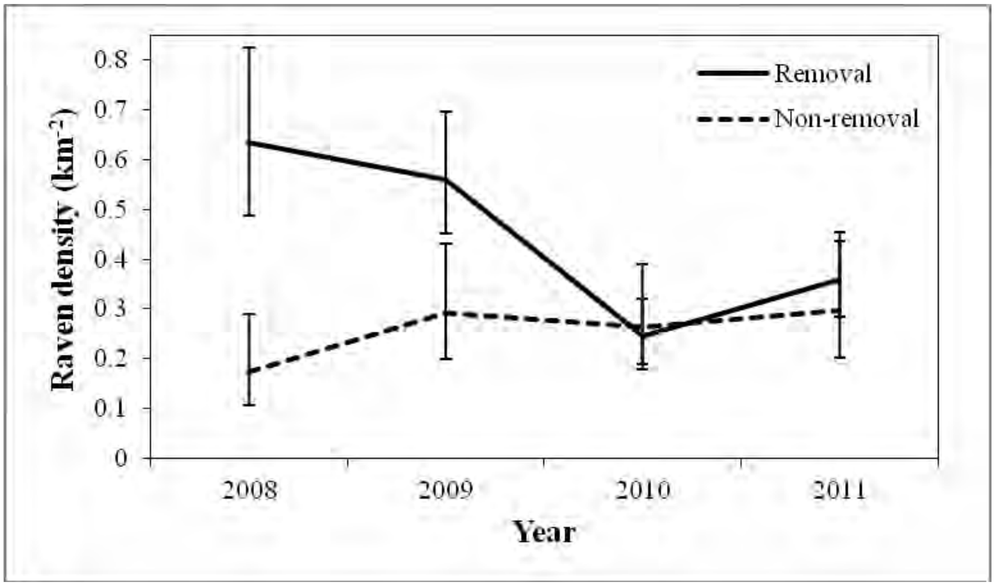

Figure 4-2. Raven density (no./km^2) estimates by year, 2008–2011, from the top AIC$_c$ selected multinomial-Poisson mixture models for removal and non-removal study sites. Estimates of raven density were modeled from 287 and 373 random locations in removal and non-removal study sites, respectively. Error bars indicate 95% confidence intervals. Data were collected from four 16-km and one 24-km removal study sites and four 16-km and three 24-km non-removal study sites in southwestern and south-central, Wyoming, USA.

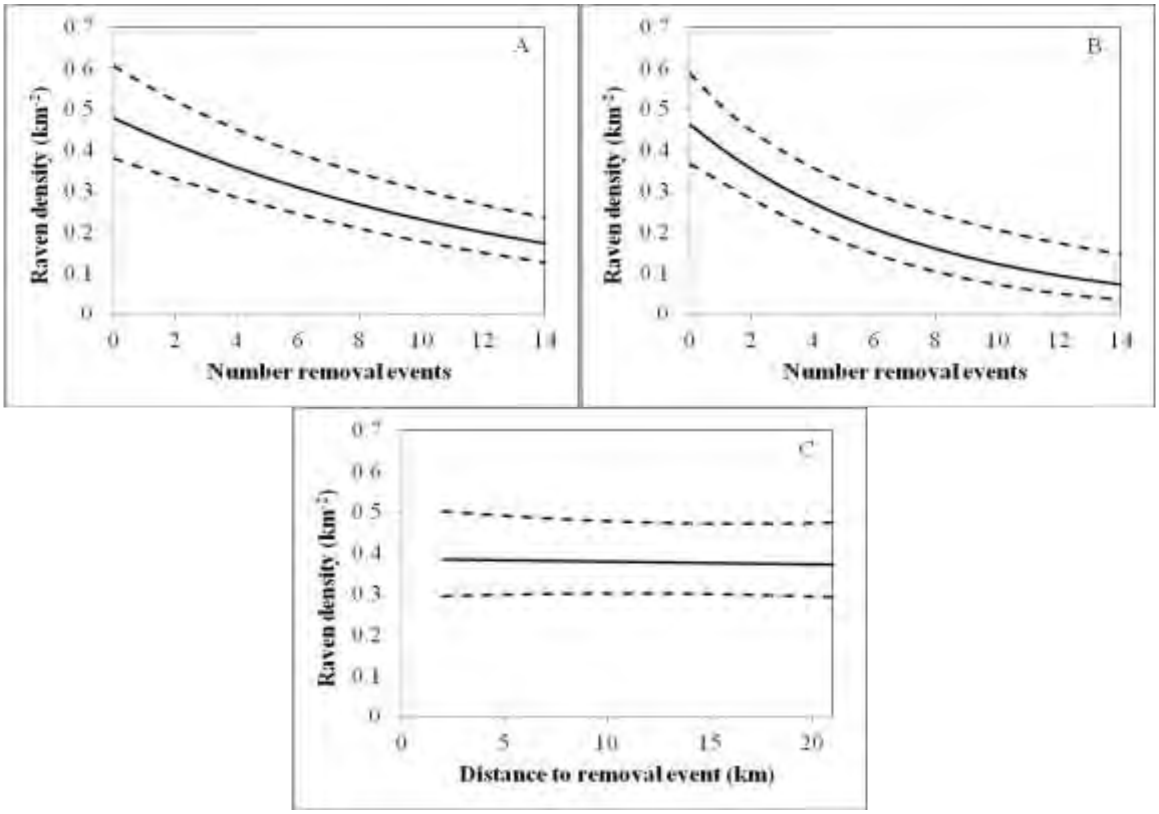

Figure 4-3. Predictions of raven density (no./km^2) from the top AIC$_c$ selected multinomial-Poisson mixture model of USDA/APHIS/Wildlife Services (WS) removal events at removal study sites with 95% confidence intervals. Predicted effects of the number of landfill (A; within 25 km) and non-landfill (B; within 15 km) based removal events conducted by WS and the effect of distance to nearest removal event (C). All variables calculated within six months of the fate of a sage-grouse nest or last recorded point count at a random location. Data were collected from four 16-km and one 24-km study sites in southwestern and south-central, Wyoming, USA (*n* = 121 sage-grouse nests and *n* = 287 random locations), 2008–2011.

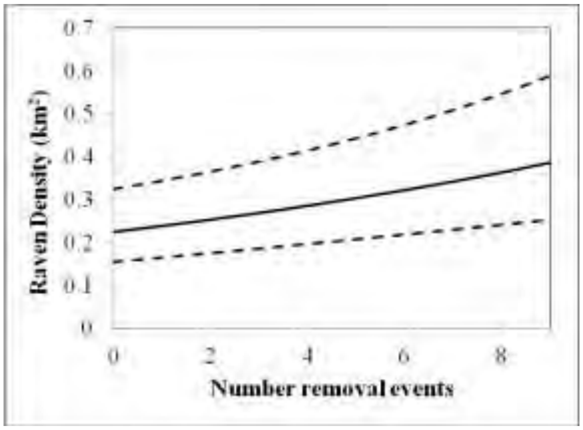

Figure 4-4. Predictions of raven density (no./km^2) from the top AIC$_c$ selected multinomial-Poisson mixture model of USDA/APHIS/Wildlife Services (WS) removal events at non-removal study sites with 95% confidence intervals. Predicted effects of the number of removal events conducted by WS between 15 and 25 km and within six months of the fate of a sage-grouse nest or last recorded point count at a random location. Data were collected from four 16-km and three 24-km study sites in southwestern and south-central, Wyoming, USA (*n* = 220 sage-grouse nests and *n* = 373 random locations), 2008–2011.

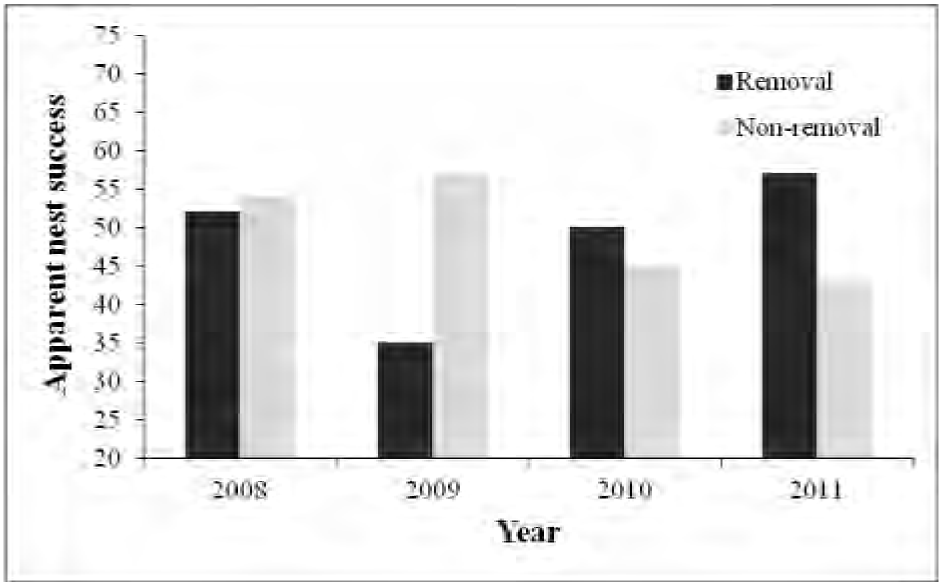

Figure 4-5. Apparent nest success (%) of 341 sage-grouse nests found in removal and non-removal study sites. Apparent nest success was calculated as the number of hatched nests divided by the total number of nests found. Removal study sites had 23, 28, 28, and 42 nests in 2008–2011, respectively. Non-removal study sites had 41, 57, 55, and 67 nests found during 2008–2011, respectively. Data were collected from four 16-km and one 24-km removal study sites and four 16-km and three 24-km non-removal study sites in southwestern and south-central, Wyoming, USA.

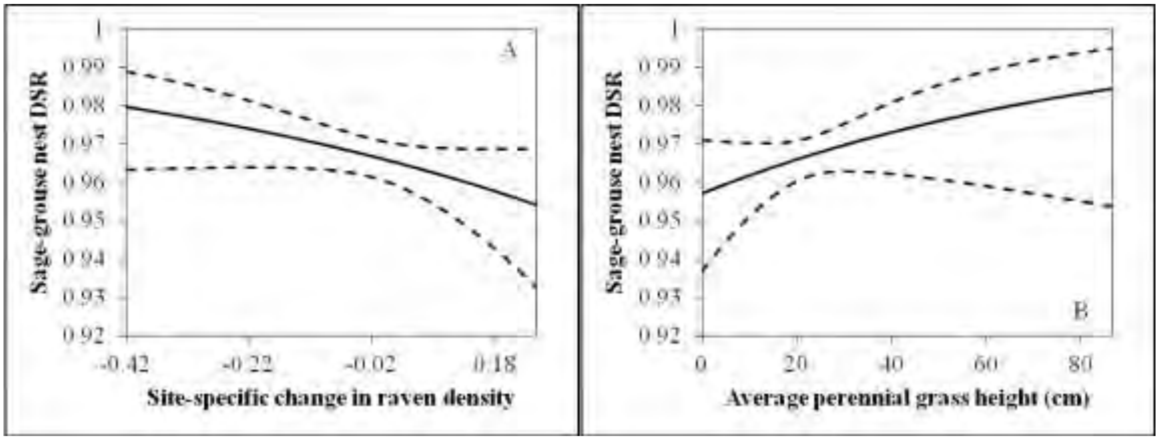

Figure 4-6. Predictions of daily survival rate (DSR) of sage-grouse nests from the top AIC$_c$ selected generalized linear model using Program MARK at removal and non-removal study sites with 95% confidence intervals. Predicted effects of site-specific change in raven density (no./km^2) at a study site relative to 2008 (A) and average perennial grass height within 5 m (B) on sage-grouse nest DSR. Raven variables calculated within EDR (550 m) of 'distsamp'. Data were collected from eight 16-km and four 24-km study sites in southwestern and south-central, Wyoming, USA (n = 341 sage-grouse nests), 2008–2011.

CHAPTER 5

GREATER SAGE-GROUSE NEST SUCCESS IN RELATION TO CORVIDS, PROXIMITY TO ANTHROPOGENIC AND LANDSCAPE FEATURES, AND MICROHABITAT IN SOUTHERN WYOMING

ABSTRACT Nest success of greater sage-grouse (*Centrocercus urophasianus*: hereafter "sage-grouse") has been well studied, but the effects of anthropogenic and landscape features on nest success have not been evaluated simultaneously with the potential effects of predators. Depredation of sage-grouse nests can be an influential factor limiting their productivity, and most failed sage-grouse nests are depredated by predators. Black-billed magpies (*Pica hudsonia*: hereafter "magpie") and common ravens (*Corvus corax*: hereafter "raven") have been verified with video as predators of ground nests, and the negative effect of ravens on the nest success of sage-grouse has been well documented. I collected nest success data from 341 sage-grouse nests in eight study sites (16 km diameter each) and four study sites (24 km diameter each) in southern Wyoming, USA during 2008–2011. I used the nest survival model in Program MARK to evaluate the effects of 4 covariate sets including corvid densities (nest-level and study site-level), anthropogenic features, landscape features, and microhabitat on sage-grouse nest success. Interactions between study site-level corvid densities (raven and magpie independently) and variables within all other covariate sets were also assessed. I tested the hypothesis that the negative effects of corvids would be amplified in areas closer to potential perches and areas with subsidized food resources. I did not find any evidence that anthropogenic

features or magpies had a negative impact on sage-grouse nest success. I found that nest success was positively correlated with rugged habitat measured at 1-km radius ($TRI_{1.0}$), and negatively impacted by the presence of ravens. My results highlight the necessity to assess habitat and predator community dynamics concurrently when designing management plans.

INTRODUCTION

Several studies have suggested that quantity and condition of breeding habitat is the most important factor that dictates the productivity of sage-grouse (Connelly et al. 1994, Braun 1998, Schroeder and Baydack 2001, Connelly et al. 2011, Hagen 2011). However, even in excellent sage-grouse habitat, most greater sage-grouse (*Centrocercus urophasianus*: hereafter “sage-grouse”) nests are lost to predators such as red fox (*Vulpes vulpes*), badgers (*Taxidea taxus*), coyotes (*Canis latrans*), black-billed magpies (*Pica hudsonia*: hereafter “magpie”), and common ravens (*Corvus corax*: hereafter “ravens”; Willis et al. 1993, Gregg et al. 1994, Heath et al. 1997, Holloran 1999, Connelly et al. 2004, Baxter et al. 2007). Sage-grouse are a species of conservation concern, because their distribution and abundance in western North America has declined over the last century (Gregg et al. 1994, Johnsgard 2002, Connelly et al. 2004), and many factors have been attributed to this decline including predation, habitat loss, and habitat fragmentation (Braun 1998).

Johnson and Braun (1999) and Taylor et al. (2012) found, that along with chick and adult survival, nest success was an important demographic parameter for population growth of sage-grouse. Nest success in relation to predator communities has not been the focus of sage-grouse research and conservation. However, nest success related to predator communities was not likely to have been a problem during pre-European settlement, because sage-grouse co-evolved with the predator communities present in sagebrush ecosystems (Schroeder et al. 1999, Schroeder et al. 2001). There are currently no predators that specialize on sage-grouse during any life history stage (egg, chick, or adult; Hagen 2011, Connelly et al. 2011). Thus, Hagen (2011) suggested that in general predation is not limiting sage-grouse populations; he also indicated that predators may only negatively affect sage-grouse populations in fragmented habitats and areas with human-subsidized predator populations. However, these areas of habitat fragmentation and areas with human-subsidized predator populations have drastically increased in the recent past (Leu et al. 2008); mostly via human endeavors in sagebrush steppe. For example, red fox and common raccoon (*Procyon lotor*) have increased in abundance in sage-grouse habitat, especially near human activities (Connelly et al. 2000, Baxter et al. 2007, Hagen 2011), and densities of ravens have increased in Wyoming and throughout the historic range of sage-grouse (Larsen and Dietrich 1970, Andrén 1992, Engel and Young 1992, Boarman et al. 1995, Sauer et al. 2011).

Increased habitat fragmentation has brought a range of new stresses to sage-grouse including increased predation rates (Schroeder and Baydack 2001, Connelly et al. 2004). Corvids, specifically ravens and magpies, have been known to utilize fragmented habitats with anthropogenic structures and features that provide subsidized food resources (anthropogenic features for ease of discussion; Andrén 1992, Vander Haegen 2002). For example, Bui et al. (2010) found that higher raven occupancy of the landscape was correlated with a greater frequency of failed sage-grouse nests around Jackson and Pinedale, Wyoming. Bui et al. (2010) suggested that increased raven occupancy could have been attributed to increased availability of nest structure for ravens from anthropogenic structures in sagebrush habitat; over half of their study was located in an intensely developed natural gas field. Videos have verified that magpies and ravens are predators of ground nests (Vander Haegen et al. 2002); they found that both species depredated nests in fragmented habitat more often than intact shrubsteppe habitat (magpies especially utilized fragmented habitat). Furthermore, passerine nest success in fragmented habitat was shown to be lower than intact shrubsteppe habitat (Vander Haegen et al. 2002). In addition to the direct negative effect of corvid abundance on sage-grouse nest success, there are potentially additive impacts of anthropogenic features on sage-grouse nest success, such as increased hunting efficiency, increased number of nesting structures, and increased carrying capacity of corvids within sage-grouse breeding habitat. Sources of perch and nesting structure for corvids include oil and gas related structures, residential houses (on buildings or in trees associated with houses), communication towers, and power lines (Engel et al. 1992, Knight and Kawashima 1993, Trost 1999, Lammers and Collopy 2007, Prather and Messmer 2010, Slater and Smith 2010); whereas, sources of reliable food subsidies include residential houses, campgrounds, landfills, and roads, which provide road-kill, dead livestock, and garbage (Knight and Call 1980, Boarman 1993, Knight and Kawashima 1993, Boarman et al. 1995, Trost 1999, Kristan et al. 2004, Marzluff and Neatherlin 2006).

Corvid depredation of sage-grouse nests has been implicated as a potential factor limiting sage-grouse productivity, especially in fragmented habitats (Batterson and Morse 1948, Willis et al. 1993, Gregg et al. 1994, Schroeder and Baydack 2001, Vander Haegen 2002, Coates and Delehanty 2010, Bui et al. 2010). Yet, it is unclear why anthropogenic features affect corvid depredation of sage-grouse nests.

Connelly et al. (2011) recommended that conservation efforts for sage-grouse should include research to quantify predator communities in relation to sage-grouse demographic rates (including nest success) and potential additive effects of predators and anthropogenic features. Increased size of corvid populations, especially ravens, in areas with subsidized resources has been anecdotally documented in southwest and south-central Wyoming associated with human activities (e.g., livestock and natural gas development; R. J. Merrell, United States Department of Agriculture Animal and Plant Health Inspection Service Wildlife Services, personal communication), and raven abundance has increased in Wyoming during the past decade, 2001–2010 (Sauer et al. 2011). Thus, I recorded corvid densities associated with sage-grouse nesting and brood-rearing areas from 2008–2011 to determine if corvids were important sage-grouse nest predators. I hypothesized that sage-grouse nest success would be lower in areas and years with greater abundance of corvids, specifically, ravens and magpies. In addition, I hypothesized that this effect would be intensified in areas closer to potential perches and areas with food subsidies, such as oil and gas structures, power lines, houses, roads, towns, and landfills. To test these hypotheses, I assessed sage-grouse nest success in relation to sage-grouse exposure to corvids, potential perches, and proximity to areas associated with human provided food subsidies. As secondary objectives, I evaluated the potential effects of landscape features and microhabitat in relation to corvid abundance. Similar to anthropogenic features, landscape features could be used as perches or nest structure by raptors, or could be areas with higher productivity that attract predators. Thus, I hypothesized that sage-grouse nest success would be lower in areas closer to forested and riparian habitat, rougher topography, and lower microhabitat quality.

STUDY AREA

My study was conducted in southwest and south-central Wyoming. I had 12 circular study sites, eight were 16 km in diameter and four were 24 km in diameter. Study sites in southwest Wyoming were 16-km diameter and approximately centered around leks where hens were captured based on results found by Holloran and Anderson (2005). Study sites in south-central Wyoming were 24 km, because sage-grouse were captured at several nearby leks over a larger area. Five study sites were located in Lincoln County, two in Sweetwater County, two in Uinta County, and three in Carbon County. Study sites were chosen to provide a representation of overall sage-grouse nesting habitat in southern Wyoming. During 2007–2011, raven control (lethal removal) efforts of varying intensity were carried out by USDA/APHIS/Wildlife Services (WS) near five of the 12 study sites for the protection of livestock.

Removal and non-removal study sites had similar topographic features, weather, and vegetation. Elevation ranged from 1,950 m to 2,600 m among removal study sites and 1,925 m to 2,550 m among non-removal study sites. Most of the land within all of the study sites was federally owned and administered by the U.S. Bureau of Land Management with a small percentage of private lands. Domestic sheep and cattle grazing were the dominant land uses in the study sites. All study sites had anthropogenic development, which consisted mostly of unimproved 4-wheel drive roads. Conventional natural gas, coalbed methane natural gas, and/or conventional oil extraction activities were present in two of the removal study sites and four of the non-removal study sites.

The landscape at all study sites was dominated by sagebrush (*Artemisia* spp.); Wyoming big sagebrush (*A. tridentata wyomingensis*) and mountain big sagebrush (*A. t. vaseyana*) were the most common. Black sagebrush (*A. nova*) and dwarf sagebrush (*A. arbuscula*) were found on exposed ridges. Other common shrub species in the study sites included alderleaf mountain mahogany (*Cercocarpus montanus*), antelope bitterbrush (*Purshia tridentata*), chokecherry (*Prunus virginiana*), common snowberry (*Symphoricarpos albus*), greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus* and *Ericameria* spp.), Saskatoon serviceberry (*Amelanchier alnifolia*), and spiny hopsage (*Grayia spinosa*). Isolated stands of juniper (*Juniperus* spp.) and quaking aspen (*Populus tremuloides*) were found at the higher elevations on north-facing hillsides. Common forb species included arrowleaf balsamroot (*Balsamorhiza sagittata*), buckwheat (*Eriogonum* spp.), common yarrow (*Achillea millefolium*), dandelion (*Taraxacum* spp.), desert parsley (*Cymopterus* spp.), phlox (*Phlox* spp.), lupine (*Lupinus* spp.), sego lily (*Calochortus nuttallii*), and wild onion (*Allium* spp.). Common grass species included: bluegrasses (*Poa* spp.), bluebunch wheatgrass (Ps*eudoroegneria* *spicata*), green needlegrass (*Nassella viridula*), needle and thread (*Hesperostipa comata*), prairie junegrass (*Koeleria macrantha*), and western wheatgrass (*Pascopyrum smithii*). Cheatgrass (*Bromus tectorum*) was present, but not widespread in any of the study sites.

METHODS

Sage-grouse Capture and Monitoring

From 2008 to 2011, I monitored sage-grouse hens during the nesting season (late-April to mid-July). Hens were captured, radio-collared, and released in April of each year. I captured hens at night using ATVs, spotlights, and hoop-nets (Giesen et al. 1982, Wakkinen et al. 1992, Connelly et al. 2003). Sage-grouse hens were fitted with 17.5-g or 22-g (<1.5% body mass) necklace radio collars (Holohil Systems Ltd, RI-2D, Ontario, Canada or Advanced Telemetry Systems Inc, A4060, Isanti, MN, USA). I aged sage-grouse hens as yearlings or adults by examining outer primaries (Patterson 1952).

Between May 1 and July 15, I located hens weekly with VHF receivers (Communications Specialists, R-1000, Orange, CA, USA) and 3-way Yagi antennas (Communications Specialists, Orange, CA, USA). Potential nests were identified with binoculars from ~15 m by circling a radio-marked hen until she was visually spotted under a shrub. I used handheld global positioning system (GPS) units (eTrex, Garmin Inc., Olathe, KS) to record hen locations. Location accuracy on the GPS ranged from 2–8 m.

Nests were verified by triangulating the hen under the same shrub from ≥50 m away or thoroughly searching the area of the potential nest when the hen was absent. I continued monitoring nests weekly until the nest hatched or failed. I assessed nest fate as successful or unsuccessful after a hen had left her nest. A successful nest was defined as having evidence that at least 1 egg hatched as determined by shell membrane condition (Wallestad and Pyrah 1974). I classified unsuccessful nests as abandoned (eggs not depredated or hatched) or depredated (at least one egg with evidence of depredation).

Corvid Variables

Between 1 May and 1 August of each year, I conducted point count surveys at sage-grouse nests and random locations within each study site to compare corvid densities. Ravens and magpies were quantified separately, but will be referred to as corvids for ease of discussion. To avoid disturbing an incubating hen, nest point counts were conducted 100–200 m away from a sage-grouse nest but within a line-of-sight of that sage-grouse nest. Random locations were selected in habitat considered to be available to sage-grouse for nesting within each study site. To restrict random locations to available nesting habitat, I used ArcMap 10.0 (ESRI Inc., Redlands, California) to generate random locations only in sagebrush-dominated habitat, which was classified by the Northwest ReGAP landcover data from 2008 (Lennartz 2007). Random locations were designated to be >1,000 m apart; however, random selection led to average nearest neighbor distances among random point count locations of >2,000 m (Chapter 2). I generated 12 random locations in each 16-km diameter study site and 18 random locations in each 24-km diameter study site per year. I generated a new set of random locations each year to avoid spatial autocorrelation; thus, random locations among years were independent.

I used standard distance sampling techniques (Ralph et al. 1995, Buckland et al. 2001, Thomas et al. 2010), which entailed counting all corvids observed during point counts and recording each corvid's distance from the observer (when standing at the center of the point count location). I recorded distance as the distance from the observer to where a corvid was first located (Ralph et al. 1995, Thomas et al. 2010); this minimized possible bias associated with corvids being attracted to or flushed away from an observer. When a corvid was displaced from the center of a point count location as an observer approached (6% of all detected birds), I recorded distance from that corvid to the center of the point count location while the observer approached as suggested by Ralph et al. (1995). This was done when the approach of an observer resulted in a corvid moving away from the center of the point count location. A 1500–m rangefinder (American Technologies Network Corp., RE-1500 m, San Francisco, California) in conjunction with a GPS was used to estimate distances directly or to validate visually estimated distances.

Observers were trained and tested in corvid and raptor identification before conducting point counts. Point counts were 10 min in length, and I conducted them during daylight hours on a weekly basis at each study site. I visited each point count location 1 to 8 times with most locations visited ≥3 occasions. I did not survey for corvids in inclement weather (i.e., when raining or wind speeds greater than 25 km/h; Ralph et al. 1995). Unidentified birds were not included in analyses; these contributed

2% of detections within truncated observation distances. Nest point counts were performed after nests were initially located; thus, nest point counts were conducted in May to early-July. I performed random point counts May to 1 August each year.

I intermixed the sampling of nest and random point counts within each study site. To minimize observer bias, I changed the time of day and the observer that conducted individual point counts within a study site each week (i.e., each individual point count location regardless of type—nest or random—was conducted at a different time of day each week and by a different observer as best as possible). The observers conducting point counts within a particular study site changed each year.

All corvid variables were calculated from the raw count data within effective detection radii (EDR; 600 m for ravens and 300 m for magpies) estimated with DISTANCE, version 6.0 release 2 (Thomas et al. 2010) as specified in Chapter 2. The raw densities were weighted by the number of visits to each point count location. Raven and magpie study site-level variables were individually calculated from random point count locations. Sage-grouse nest-level corvid abundance was calculated from point counts at sage-grouse nests within species-specific EDRs as 1) raven density (number/km^2 and hereafter "nest-level raven density") or magpie density (number/km^2 and hereafter "nest-level magpie density") at the nest and 2) occupancy (0 or 1) of at least 1 raven or 1 magpie during the last nest check when the sage-grouse hen was still on her nest (hereafter: "raven occupancy" or "magpie occupancy"). I did not include both nest-level raven density and raven occupancy in any model, because nest-level raven density and raven occupancy were measured at the same spatiotemporal scale. Study site-level corvid densities were calculated at each study site by averaging the raven or magpie densities at all random locations. I had noted through observation that relative changes in corvid densities within many study sites had positive or negative effects on nest success of sage-grouse. I attributed this phenomenon to the possibility of corvids being more or less effective predators on sage-grouse nests depending on the study site due to overall characteristics of a particular study site (combination of individual corvid behavior, topographic roughness, large scale cover, anthropogenic development, etc.). In addition to study site-level raven densities, I calculated site-specific change in corvid density—from random point count locations—as the increase or decrease in landscape corvid density (annual density) relative to the corvid density in a particular study site at the beginning of the study (2008). Thus, site-specific change in corvid density was 0 for all study sites in 2008. The site-specific change in corvid density variables were intended to look at relative change in risk of depredation within each study site (i.e., does site specific increase or decrease of corvid densities effect nest success of sage-grouse). Thus, site-specific change in corvid densities were not quantifying the effect of the exact density of corvids on nest success of sage-grouse among all study sites. Rather, they were assessing site-specific change in exposure to corvids.

Anthropogenic and Landscape Feature Variables

I calculated sage-grouse proximity to anthropogenic features that could be used as a perch by corvids, a nest structure by ravens, or had the potential to generate food subsidies that were provided by humans (e.g., road-kill, dead livestock, and garbage) with

ArcMap 10.0. Anthropogenic structures that were >2 m in height were considered available for perching or nesting by corvids. I quantified the distance from sage-grouse locations to the nearest oil and gas structure (energy well, compressor station, transfer station, refinery, or other energy extraction related buildings), major road, all roads, communication tower, house, town, landfill, and power line for each sage-grouse nest. Most (>95%) oil and gas structures were energy wells. Ongoing energy development was occurring in half of my study sites, which required me to assess the dates that energy related structures and roads were added or removed from the landscape. In distance calculations, I only included oil and gas structures and roads that were physically on the ground when each sage-grouse nest was located. I obtained information on oil and gas structures, including date construction started on the structure and date when wells were plugged and abandoned (date structure was removed), from the Wyoming Oil and Gas Conservation Commission (WOGCC; 2012). I verified the spatial location and existence of older structures with color aerial satellite imagery from summer 2006 and August 2009 obtained from the National Agriculture Imagery Program (NAIP; U.S. Department of Agriculture [USDA] 2010). Aerial imagery from NAIP was produced by the USDA on a 3-year rotation; thus, I used WOGCC data and on the ground GPS units to map energy development that occurred after August 2009. However, energy development reported to WOGCC after August 2009 had better reporting of location, spud date, and plug abandon date. I used 2009 NAIP imagery to digitize the location of major roads, all roads, communication towers, houses, towns, and landfills within a 5-km buffer around study sites; roads constructed between August 2009 and September 2011 were mapped on the ground with GPS units. Major roads included paved, improved gravel roads, and railroads; whereas, all roads included major roads and all unimproved 4-wheel drive roads. All transmission and distribution power lines within a 5-km buffer around study sites were mapped on the ground with GPS units; telephone lines not associated with a power line were included in power line mapping. Neither sage-grouse nor corvids were likely to discriminate between many of the different types of anthropogenic structures; thus, I created 2 anthropogenic structure variables that represented the nearest 1) distance to either an oil and gas structure, communication tower, or house (DIST_WCH); and 2) distance to either an oil and gas structure, communication tower, house, or power line (ANTH). This was in addition to distances from sage-grouse nests to individual types of anthropogenic structures. I report means and standard errors (SE) for distances to anthropogenic feature variables for successful and unsuccessful nests (Table 5-1).

Similar to anthropogenic features, landscape features could be used as perches or nest structures by corvids or could be areas with higher productivity that attract predators. For example, magpies have been associated with riparian habitats for food availability and nesting (Trost 1999). Thus, I used ArcMap 10.0 to calculate the distance from every sage-grouse nest to forest (deciduous and conifer stands) and riparian habitats. Tree stands and riparian habitat were identified with Northwest ReGAP landcover data from 2011 (Lennartz 2007), and verified with NAIP imagery from 2009. Topography with greater surface roughness has the potential to create topographic structures (e.g., hilltops, knolls, and cliff edges) that provide vantage points similar to perches, and sage-grouse have been found to avoid rougher topography during nesting (Jensen 2006, Doherty et al. 2010). For sage-grouse nests, I used ArcMap 10.0 to extract topographic ruggedness index (TRI) values generated by Hanser et al. (2011) for the Wyoming Basins Ecoregion; TRI variables were developed using a moving window analysis at 0.27-km, 0.54-km, 1-km, and 3-km radii (0.23 km^2, 0.92 km^2, 3.14 km^2, and 28.26 km^2 scales, respectively). Riley et al. (1999) created TRI to describe the roughness of landscapes, and the index is quantified as the difference in elevation among adjacent pixels of a digital elevation map; the index is then averaged over a user defined area. I report means and standard errors (SE) for distances to landscape feature variables for successful and unsuccessful nests (Table 5-1).

Microhabitat Variables

I sampled vegetation at sage-grouse nests in late-May to early-July 1 to 2 weeks after sage-grouse nests hatched or failed. I recorded the maximum height and the average canopy cover of the nest shrub. I quantified vegetation within 5 m surrounding sage-grouse nests by orienting 2 vegetation transects—each 10 m in length—at the cardinal directions and intersecting at a sage-grouse nest. Vegetation transects were conducted to measure average total shrub cover—including antelope bitterbrush, greasewood, rabbitbrush, sagebrush, Saskatoon serviceberry, and snowberry (Canfield 1941). Average percent cover of shrubs was calculated by dividing the total shrub intercepted line length (cm) by the total line length (2000 cm) and then multiplying by 100. Gaps <3 cm were not recorded (Wambolt et al. 2006), and no section of shrub cover was measured more than once. I averaged the height of shrubs that intersected the vegetation transect for average total shrub height; shrub heights excluded inflorescences. I calculated percent cover of grass, perennial grass, forbs, bare ground, and litter in six cover classes (1 = 0–1%, 2 = 1.1–5%, 3 = 5.1–25%, 4 = 25.1–50%, 5 = 50.1–75%, and 6 = 75.1–100%; Kirol et al. 2012) by averaging 9, 20-cm × 50-cm quadrats placed along vegetation transects at 2 m, 4 m, 5 m, 6 m, and 8 m (Daubenmire 1959). Perennial grass height was measured by recording the maximum grown height (droop height) excluding flowering stalks within 1 m of the 9 quadrats. The lowest visible 5-cm section of a Robel pole—that was placed in the center of a sage-grouse nest—was recorded to provide an index of general line-of-sight obstruction (hereafter "visual obstruction"; Robel et al. 1970). I recorded Robel pole readings from 1 m off the ground and 5 m away at the 4 cardinal directions and averaged these values to report 1 visual obstruction measurement per site. I report means and standard errors (SE) for vegetation variables used in models for successful and unsuccessful nests (Table 5-1).

Data Analyses

I analyzed daily survival rate (DSR) of sage-grouse nests by fitting generalized linear models of DSR using maximum likelihood in Program MARK (White and Burnham 1999). I evaluated the effect of a nesting sage-grouse's age (AGE), study site-level corvid densities, site-specific change in corvid densities, nest-level corvid occupancy or density, anthropogenic features, landscape features, and microhabitat on sage-grouse nest DSR. Modeling of sage-grouse nest DSR was conducted with an information theoretic approach (Anderson 2008). I compared models with Akaike's information criterion corrected for small sample sizes (AIC_c) and Akaike weights (w_i; Burnham and Anderson 2002). I employed sequential AIC_c modeling of covariate sets, which was suggested by Arnold (2010) as an appropriate approach for identifying and ranking the most parsimonious models. Non-informative covariates (85% confidence intervals [CIs] of parameter estimates overlapped 0) were eliminated within each covariate set before comparing top AIC_c selected models among covariate sets (Arnold 2010).

Four covariate sets were evaluated sequentially, and consisted of 1) nest-level and site-specific change in corvid densities, 2) anthropogenic features, 3) landscape features, and 4) microhabitat variables. I evaluated the effect of a sage-grouse's age (AGE) on sage-grouse nest DSR within the sage-grouse corvid abundance covariate set. I included site-specific change in corvid densities × anthropogenic feature variables, site-specific change in corvid densities × landscape feature variables, and site-specific change in corvid densities × microhabitat as pairwise interactions within each respective covariate set. Pairwise interactions with site-specific change in corvid densities were included to assess whether negative effects of site-specific change in corvid densities were intensified in areas closer to potential perches or corvid nest structure, in areas closer to human provided food subsidies, or in areas with poorer quality microhabitat. I did not include DIST_WCH or ANTH with any other anthropogenic structure variable, because DIST_WCH and ANTH were derived from a combination of distance from sage-grouse nests to energy wells, communication towers, houses, and power lines. The best variable describing the effect of anthropogenic structures on sage-grouse nest DSR was determined through AIC$_c$ selection within the anthropogenic feature covariate set. I compared models with individual TRI variables measured at 0.27 km, 0.54 km, 1 km, and 3 km radii with AIC$_c$ to choose the best spatial scale for the TRI variable to be used in the landscape feature covariate set; the TRI variable scale with the lowest AIC$_c$ was used in all further modeling. As the final modeling step, I compared all top AIC$_c$ selected models from every covariate set (models within 2 AIC$_c$ of the top model within each covariate set) among each other and as additive models with combinations of all 4 covariate sets. I based my inference on models within 2 AIC$_c$ of the top selected model (Burnham and Anderson 2002). I prevented multicollinearity by only including one variable of any pair of variables that co-varied in any model (r >0.65) as determined with a Pearson's correlation matrix. In this situation I eliminated one co-varying variable from further analysis by retaining the variable that made the most biological sense. Variance inflation factors (VIF) for all predictor variables were ≤5, which indicated that the variances of coefficient values were not drastically increased by the inclusion of any predictor variable; thus, collinearity was not a major problem.

In addition to AIC$_c$ model comparison, I implemented a spatiotemporal modeling strategy to evaluate general trends in sage-grouse nest DSR in relation to site-specific change in corvid densities, anthropogenic features, landscape features, and microhabitat. A spatiotemporal strategy was implemented because many variables describing raven abundance and sage-grouse nest survival were exclusive to a given year or type of study site (removal or non-removal). I assessed goodness-of-fit of top AIC$_c$ selected models by computing a ratio of Zheng's (2000) proportional reduction of deviance (RDR) for covariate models to spatiotemporally saturated models (maximum proportional reduction in deviance; Iles 2012), which has been considered appropriate for generalized linear models (Zheng 2000, Aubry et al. 2011). Deviance reduction for each spatiotemporally saturated model and top AIC$_c$ selected models were calculated relative to null models (time and study site invariant):

$$D_{int} = 1 - (\text{deviance}_{interest}/\text{deviance}_{null}) \tag{1}$$

$$D_{sat} = 1 - (\text{deviance}_{saturated}/\text{deviance}_{null})$$

$$RDR = D_{int} / D_{saturated} \tag{2}$$

thus, the ratio gives an assessment of a covariate model's relative ability to explain spatiotemporal processes effecting sage-grouse nest DSR. The ratio is 1 for the spatiotemporally saturated model and 0 for the null model (Iles 2012). I compared the top AIC$_c$ selected models of sage-grouse nest DSR to a spatiotemporally saturated model with RDR. The saturated model for sage-grouse nest DSR included year; type of study site; max nest shrub, average total shrub, and average perennial grass heights; average nest shrub, total shrub, grass, forb, bare ground, and litter cover; visual obstruction; distance to town, landfill, energy well, communication tower, house, power line, all road, and riparian and forested habitat; and the top selected TRI variable.

Spatial autocorrelation violates the independence assumption for generalized linear models. Thus, I created an inverse weighted distance matrix to assess spatial autocorrelation among sage-grouse nests, where nest locations >12 km apart were not considered to be correlated. This distance was used to directly relate to the radius of my

24-km diameter study sites; however, 12 km was also larger than the home range size of breeding ravens (0.3–45.8 ravens/km^2; Boarman and Heinrich 1999). Furthermore, I treated all sage-grouse nests within 12km of each other, regardless of year, as correlated with the degree of correlation related to the distance among nests. I used function 'moran.test' in package SPDEP version 0.5-46 in R to calculate Moran's *I* for Pearson residuals of top AIC$_c$ selected generalized linear models of sage-grouse nest success.

RESULTS

I found 341 sage-grouse nests (170 hatched [50.0%], 5 abandoned [1.5%], and 166 failed [48.5%]). Average annual DSR for all sage-grouse nests was estimated at 0.968 (± 0.003 SE) from Program MARK, which yielded an estimated 40% (95% CI = 34% to 48%) nest survival using a 28-day incubation period. This estimate differed from the apparent nest success of 49.9%, and highlighted the necessity to account for nests that were depredated or abandoned before I found them by using the nest survival model in Program MARK. To assess the effect of corvid abundance on sage-grouse nest success, I conducted 3,842 point count surveys during 2008–2011 at 1,001 total point count locations with 341 sage-grouse nest locations and 660 random locations. I counted 559 ravens and 121 magpies within species-specific EDR (600 m and 300 m, respectively). Spatial autocorrelation was not a problem for the top AIC$_c$ selected sage-grouse nest DSR model (Moran's *I*: $P > 0.5$).

Nest-level raven occupancy negatively affected sage-grouse nest success, but I did not find any effects of magpies on nest success of sage-grouse (parameter estimates for magpie occupancy and site-level magpie density had 85% CI that overlapped 0). No anthropogenic variable described differences in sage-grouse nest DSR (parameter estimates with 85% CI that overlapped 0). I found that $\mathrm{TRI}_{1.0}$ (1-km radius) from the landscape feature covariate set described sage-grouse nest DSR best. Thus, the top AIC_c selected model included raven occupancy and $\mathrm{TRI}_{1.0}$ (Table 5-2, Fig 5-1), which had $w_i = 0.26$ and RDR = 0.37. The second AIC_c ranked model had $w_i = 0.25$ and $\Delta\mathrm{AIC}_c = 0.01$. I will only discuss the top model for parsimony, because the second AIC_c ranked model was a more complicated version of the top model. The parameter estimate of $\mathrm{TRI}_{1.0}$ was positively associated with sage-grouse nest DSR (0.02; 95% CI = 0.01 to 0.04; Table 5-3), which indicated that sage-grouse had better nest success in more rugged terrain. The parameter estimate of raven occupancy (-0.45; 95% CI = -0.89 to -0.02) was negatively associated with sage-grouse nest DSR (Table 5-3).

DISCUSSION

Nest success of sage-grouse was negatively impacted by the presence and abundance of ravens (nest-level and site-level; Chapter 4). I did not find any evidence that magpies had a negative impact on sage-grouse nest success regardless of microhabitat characteristics near the nest or proximity to anthropogenic or landscape features. Similar to Aldridge and Boyce (2007) and Kirol (2012), I did not find any significant correlations between nest success and proximity to anthropogenic development, and there was no evidence of interactive effects between microhabitat or anthropogenic or landscaped features and corvid densities. Although the landscape features that I assessed represented riskier habitat, I found that nest success was positively correlated with relatively rugged habitat measured within 1 km from nests ($TRI_{1.0}$). My sage-grouse nest success results suggest that sage-grouse nesting in areas with elevated raven populations may have suppressed nest success. The best sage-grouse nest success model had RDR = 0.37, which indicated that a large proportion of spatiotemporal variability in sage-grouse nest success was not accounted for in my models. Thus, there may have been variability in sage-grouse nest DSR among study sites related to factors such as weather or different predator communities. The positive correlation between rugged terrain and increased nest success of sage-grouse was counterintuitive because Kirol 2012 found that rugged terrain was negatively correlated with adult hen survival, which is the most important factor affecting sage-grouse population growth (Taylor et al. 2012).

Corvids have been found to use anthropogenic structures as perches and nesting structure (Trost 1999, Lammers and Collopy 2007, Prather and Messmer 2010, Slater and Smith 2010). Several studies have demonstrated that sage-grouse avoided habitat with man-made features, such as oil and gas infrastructure, while nesting (Holloran 2005, Kaiser 2006, Aldridge and Boyce 2007, Holloran et al. 2010, Kirol 2012). Man-made structures are potential perches, nest structure, or provide reliable food subsidies for corvids. I did not find any sage-grouse study that found a direct decrease in sage-grouse nest success in relation to proximity to potential perches. However, sharp-tailed grouse (*Tympanuchus phasianellus*) nest success was correlated to the distance from potential perch sites for corvids and raptors (i.e. nests that were >75 m away from a potential perch were more successful; Manzer and Hannon 2005). Kirol (2012) and I (Chapter 3) found that sage-grouse avoided oil and gas wells while nesting. Sage-grouse may be avoiding man-made structures to reduce risk of nest depredation and predation from corvids and raptors (i.e., sage-grouse may treat anthropogenic features as riskier areas); anthropogenic features do not directly cause any depredations of sage-grouse nests, but anthropogenic features are likely stressors that elevate predation risk in previously suitable habitat. Thus, I hypothesized that sage-grouse nest success would be lower near anthropogenic features and that this effect would be amplified when there was also greater values of site-specific change in corvid densities. However, I did not find support for this hypothesis, because neither independent anthropogenic feature variables nor anthropogenic features in conjunction with site-specific change in corvid densities had an effect on sage-grouse nest success. This indicates that anthropogenic features do not necessarily predict riskier habitat either because sage-grouse avoidance of anthropogenic features masked any effects on nest success or anthropogenic disturbance was not greater than a potential threshold. Proximity to an anthropogenic feature may not be indicative of lower nest success, but rather the quantity of anthropogenic features in close proximity.

In Chapter 4, I did not look at interactive effects of site-specific change in raven density with aspects of habitat (including microhabitat), because I was interested in evaluating direct effects of ravens on sage-grouse nest success in the context of reduction of raven density as a management tool. Simultaneous comparison of the main effects of raven and microhabitat vegetation variables in Chapter 4 was intended to account for differences among study sites in relation to sage-grouse nest-site selection. Thus, differences in nest success could be attributed to local and landscape scale raven abundance. It was possible that the microhabitat at a nest site impacted a nest's success (Holloran et al. 2005, Moynahan et al. 2007) in fragmented habitat.

The negative effect of ravens on the nest success of sharp-tailed and sage grouse has been well documented (Manzer and Hannon 2005, Bui et al. 2010, Coates and Delehanty 2010, Chapter 4). Coates and Delehanty (2010) found that sage-grouse nests were more likely to be depredated by a raven when nesting in relatively lower total shrub cover (50 m^2 scale), but sage-grouse nests in relatively high visual obstruction (presumably higher total shrub cover) were more likely to be depredated by a badger. This indicates that microhabitat conditions near a sage-grouse nest have different effects on nest success depending on the predator composition of an area, and the presence of different types of predators may induce changes in sage-grouse behavior associated with habitat usage. For instance, sage-grouse reduced time off of their nests when nesting in areas with high abundances of ravens (Coates and Delehanty 2008), which may reduce a sage-grouse's risk of nest depredation. Sometimes visual predators find nests of ground-nesting birds, including sage-grouse, by watching hens leave or return to nests (Manzer and Hannon 2005, Coates 2007). Sage-grouse also predominately choose nest sites in vegetation cover at the microhabitat scale (Connelly et al. 2004). Several studies have reported that sage-grouse select nest sites based on a preference for different microhabitat characteristics, such as: sagebrush density (Wallestad and Pyrah 1974, Connelly et al.

2003), sagebrush cover (Doherty et al. 2010, Kirol et al. 2012), shrub height (Gregg et al. 1994), grass height (Gregg et al. 1994, Holloran et al. 2005, Kirol et al. 2012), and grass cover (Kaczor 2008, Kirol et al. 2012). Sage-grouse living in areas with different predator compositions, such as avian or mammalian predators, may prefer different types of vegetation cover (Connelly et al. 2004, Coates and Delehanty 2010). Thus, I hypothesized that higher percent concealment cover and vegetation height (microhabitat characteristics) would have a greater positive effect on nest success when there was higher corvid abundance (interactive effect). However, I did not find any evidence of interactive effects of microhabitat variables and site-specific change in corvid densities on sage-grouse nest success. Interactive mechanisms effecting sage-grouse nest success between predators and habitat characteristics are difficult to detect, but are commonly cited as potential factors effecting nest success; thus, there clearly needs to be more research before conclusions are made.

Magpies have been found to depredate sage-grouse nests (Holloran and Anderson 2003), and magpies have been found to be effective nest depredators in fragmented habitats (Andrén 1992, Vander Haegen et al. 2002). I found a slight negative effect of magpie occupancy (parameter estimate -0.25; 95% CI: -1.27 to 0.77) on sage-grouse nest success, but the magpie occupancy model in the corvid covariate set was below the null model. Thus, I did not find any evidence for increased depredation of sage-grouse nests in areas with greater values of site-specific change in magpie density. Magpie populations may have been too stable to detect direct negative effects of magpie abundance on sage-grouse nest success (i.e., there may not have been enough temporal variation in the values of site-specific change in magpie density to detect differences in sage-grouse nest success). Sage-grouse may have reduced the risk of nest depredation by magpies by not nesting near areas used by magpies (see Chapter 2). Magpies are known to be associated with riparian areas but also forage in sagebrush habitats (Trost 1999). In Chapter 3, I also found that sage-grouse placed their nests away from riparian habitat; therefore, sage-grouse may avoid magpies and the habitat that most frequently has magpies. However, this could also indicate that sage-grouse and magpies select different habitat (differential habitat selection). Within the range of proximity to riparian habitat where sage-grouse nested, the proximity of a sage-grouse's nest to riparian habitat did not affect nest success. Sage-grouse nest success may not have had detectible negative effects from proximity to riparian habitat, because sage-grouse placement of nests was beyond a threshold distance from riparian habitat.

The only landscape feature predictive of sage-grouse nest success was $TRI_{1.0}$, and sage-grouse hens nesting in more rugged habitat at a relatively large scale (1-km radius) were more likely to succeed. I hypothesized that rugged terrain would be riskier habitat and high corvid densities would intensify this effect, because hilltops, knolls, and cliff edges associated with rugged terrain would act as perches for corvids. In addition, moderately rugged terrain may be correlated to greater risk of predation from olfactory predators (mammalian predators), which have been known to hunt in areas such as drainage bottoms. Thus, rugged terrain would correlate with greater exposure to nest depredation from corvids and mammalian predators. Contrary to my hypothesis, I found a positive effect of $TRI_{1.0}$ (Table 5-3). Two potential explanations for this finding include

1) rugged topography may provide some refugia from visual predators (e.g., ravens and magpies), because topographic features such as slight depressions may decrease the effective distance that a corvid can detect a sage-grouse on the ground; and 2) rugged terrain creates atmospheric turbulence, and higher turbulence decreases an olfactory predator's ability to detect prey (Conover 2007). However, Conover et al. (2010) found that sage-grouse use nest locations that hide their nests from visual but not olfactory predators. Even though sage-grouse do not generally nest in locations that provide concealment from olfactory predators, sage-grouse that tend to nest in more rugged topography may experience less nest depredation by olfactory predators. The relationship of topography related to corvid and mammalian depredation of sage-grouse nests was beyond the scope of my study, and more research is needed before conclusions can be drawn about the impact of interactions between landscape features and predator community dynamics on sage-grouse nest success.

MANAGEMENT IMPLICATIONS

A diverse array of generalist predators have encroached into sagebrush steppe habitats throughout the western United States. These generalist predators have been able to sustain elevated populations by capitalizing on structural and forage resources associated with habitat fragmented by humans. Thus, their densities are not limited by the density of a particular species of prey (Schroeder and Baydack 2001, Evans 2004, Manzer and Hannon 2005, Coates 2007). Ravens, magpies, red foxes, and coyotes are generalist predators that use different hunting strategies to obtain prey, and they can suppress the breeding success of ground-nesting birds (Evans 2004). These factors produce complex predator community dynamics that interact with prey species behavior including selection of available habitat. For this reason, management agencies need to understand how interactions among anthropogenic and landscape features, microhabitat, and the predator community relate to sage-grouse demographic rates (e.g., nest success). The aspects of habitat (anthropogenic and landscape features) that present riskier areas for prey species are confounded by the predator composition that reside in those areas. For example, the effect of concealment cover on nest success of sage-grouse can be dependent upon the species of predator near nests (Coates and Delehanty 2010). Likewise, it was unclear how rugged topography related to the risk of nest depredation. Prey species select habitat that reduces the risk of predation; however, selecting nesting habitat that provides them some protection against one predator species may increase their vulnerability to another predator species. Thus, selection of habitat to protect against visual predators may force sage-grouse to nest in riskier habitats with respect to mammalian predators. However, sage-grouse have been found to select habitat that provides concealment from visual and not olfactory predators (Conover et al. 2010). It is imperative to understand the anthropogenic and landscape feature and predator community conditions that reduce sage-grouse exposure to all predators while nesting. My results highlight the necessity to assess habitat and predator community dynamics concurrently when designing management plans.

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Table 5-1. Means and standard errors (SE) of variables used to model sage-grouse nest daily survival rate (DSR) for successful and unsuccessful nests. Data were collected from 341 sage-grouse nests at eight 16-km and four 24-km diameter study sites in southwestern and south-central Wyoming, USA during 2008–2011.

	Successful		Unsuccessful	
Variable description	Mean	SE	Mean	SE
Max height of nest shrub (cm)	60.34	1.47	61.90	1.48
Average canopy cover of nest shrub (cm)	112.62	5.93	111.90	2.72
Total shrub cover (%) within 5 m	43.47	1.21	44.38	1.02
Average total shrub height (cm) within 5 m	38.90	1.10	40.34	1.07
Grass cover (%) within 5 m	20.31	1.11	19.88	1.17
Perennial grass cover (%) within 5 m	14.17	0.70	14.32	0.86
Average perennial grass height (cm) within 5 m	22.81	0.83	22.15	0.65
Forb cover (%) within 5 m	7.90	0.65	8.06	0.62
Bare ground cover (%) within 5 m	25.46	1.24	23.50	1.26
Litter cover (%) within 5 m	36.96	1.46	37.76	1.52
Horizontal visual obstruction (dm)	3.12	0.13	3.34	0.12
Site-level raven density (no./km^2) within 550 m of random locations	0.15	0.13	0.15	0.13
Site-specific change in raven density (no./km^2) within 550 m of random locations calculated as the	-0.04	0.01	-0.02	0.01

change in raven density within a study site relative to 2008				
Site-level magpie density (no./km^2) within 550 m of random locations	0.14	0.19	0.16	0.20
Site-specific change in magpie density (no./km^2) within 550 m of random locations calculated as the change in raven density within a study site relative to 2008	-0.09	0.02	-0.10	0.02
Raven occupancy (0, 1) within 550 m of a sage-grouse nest during last nest check with hen on nest	N/A	N/A	N/A	N/A
Magpie occupancy (0, 1) within 300 m of a sage-grouse nest during last nest check with hen on nest	N/A	N/A	N/A	N/A
Sage-grouse <1 or ≥1 year old at time of capture (AGE)	N/A	N/A	N/A	N/A
Distance (km) from sage-grouse nest to nearest oil and gas structure (energy well, compressor station, transfer station, refinery, or other energy extraction related buildings)	5.71	0.39	5.00	0.33
Distance (km) from sage-grouse nest to nearest major road including paved roads, railroad, and improved gravel roads	1.41	0.10	1.33	0.09

Distance (km) from sage-grouse nest to nearest road including paved roads, railroad, improved gravel roads, and unimproved 4-wheel drive roads	0.34	0.02	0.33	0.02
Distance (km) from sage-grouse nest to nearest communication tower	10.16	0.63	10.04	0.63
Distance (km) from sage-grouse nest to nearest residential house	7.41	0.43	7.49	0.47
Distance (km) from sage-grouse nest to nearest overhead line (transmission or distribution power lines, or telephone line)	7.93	0.39	8.11	0.39
Distance (km) from sage-grouse nest to nearest anthropogenic perch (ANTH; oil and gas structure, communication tower, residential house, or power lines)	3.11	0.18	2.97	0.18
Distance (km) from sage-grouse nest to nearest town	3.46	0.19	3.27	0.19
Distance (km) from sage-grouse nest to nearest landfill	23.77	0.59	24.14	0.52
Distance (km) from sage-grouse nest to nearest oil and gas structure, communication tower, or residential house (DIST_WCH)	28.16	0.82	28.07	0.70
Distance (km) from sage-grouse nest to nearest	2.61	0.24	3.15	0.28

forested habitat including deciduous and conifer stands				
Distance (km) from sage-grouse nest to nearest riparian habitat	1.70	0.11	1.55	0.10
Topographic ruggedness index within 0.27-km radius (0.23 km^2 scale)	19.66	1.03	16.36	0.80
Topographic ruggedness index within 0.54-km radius (0.92 km^2 scale)	19.68	0.93	16.70	0.73
Topographic ruggedness index within 1-km radius (3.14 km^2 scale)	20.63	0.86	17.66	0.69
Topographic ruggedness index within 3-km radius (28.26 km^2 scale)	22.00	0.72	21.33	0.63

Table 5-2. Generalized linear models assessing sage-grouse nest daily survival rate using Program MARK. Variables used in modeling included sage-grouse nest-level occupancy and site-specific change in corvid densities (study site-level), anthropogenic and landscape features, and microhabitat. Models were compared with Akaike's information criterion (adjusted for small sample sizes; AIC_c) and Akaike weights (w_i). A fully saturated spatiotemporal model was included to assess goodness-of-fit; the saturated model included year; study site type; distance to town, landfill, energy well, communication tower, house, power line, all road, and riparian and forested habitat; topographic ruggedness at 1 km radius ($TRI_{1.0}$) variable; and all microhabitat variables.

Models	k	ΔAIC_c	w_i	Deviance
Raven occupancy, $TRI_{1.0}$ [a]	3	0.00	0.26	806.51
Raven occupancy, site-level raven, $TRI_{1.0}$	4	0.10	0.25	804.61
$TRI_{1.0}$	2	1.76	0.11	810.27
Raven occupancy, site-level raven, forest distance, $TRI_{1.0}$	5	1.81	0.11	804.31
Site-level raven, $TRI_{1.0}$	3	2.10	0.09	808.61
Raven occupancy, forest distance	3	2.57	0.07	809.08
Raven occupancy, site-level raven, forest distance	4	3.60	0.04	808.10
Raven occupancy, site-level raven	3	5.07	0.02	811.58
Forest distance	2	5.31	0.02	813.82
Raven occupancy	2	5.46	0.02	813.97

Site-level raven	2	7.15	0.01	815.66
Null	1	7.21	0.01	817.72
Fully saturated	25	25.13	0.00	787.36

[a] AIC_c = 812.51

Table 5-3. Parameter estimates with 95% confidence intervals (CI) from the top AIC$_c$ selected generalized linear model (see Table 5-2) assessing sage-grouse nest daily survival rate (DSR) using Program MARK. Sage-grouse nest-level raven (raven occupancy) was recorded as raven occupancy during last nest check with sage-grouse on her nest, and topographic ruggedness index at 1 km radius (TRI$_{1.0}$) was quantified as the difference in elevation among adjacent pixels of a digital elevation map.

			95% CI	
Variable	Estimate[a]	SE	Lower	Upper
Intercept	3.02	0.17	2.69	3.34[*]
Raven occupancy	-0.45	0.22	-0.89	-0.02[*]
TRI$_{1.0}$	0.02	0.01	0.01	0.04[*]

[*] Denotes a 95% confidence interval that does not include zero.

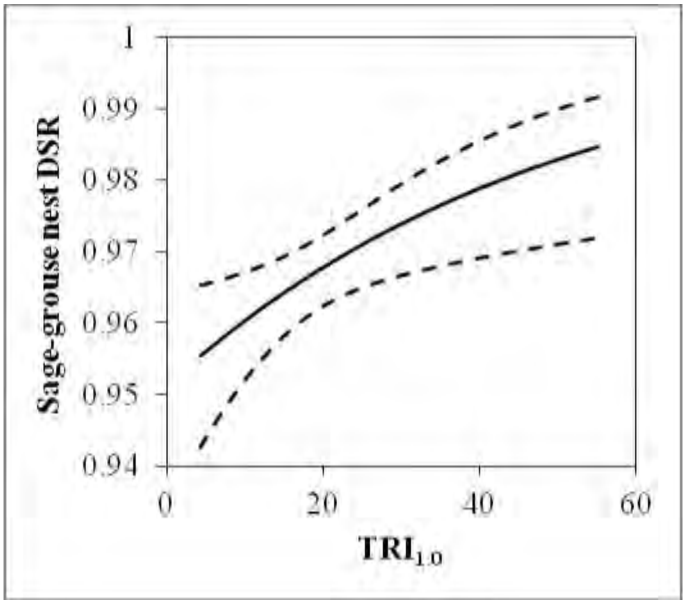

Figure 5-1. Predictions of daily survival rate (DSR) of sage-grouse nests from the top AIC$_c$ selected generalized linear model using Program MARK with 95% confidence intervals. Predicted effects of topographic ruggedness calculated at 1 km radius (TRI$_{1.0}$) on DSR of sage-grouse nests. Data were collected from eight 16-km and four 24-km study sites in southwestern and south-central, Wyoming, USA (*n* = 341 sage-grouse nests), 2008–2011.

CHAPTER 6

GREATER SAGE-GROUSE HEN SURVIVAL: EFFECTS OF RAPTORS, ANTHROPOGENIC AND LANDSCAPE FEATURES, AND HEN BEHAVIOR

ABSTRACT Survival of breeding-age hens is the most important demographic parameter driving greater sage-grouse (*Centrocercus urophasianus*: hereafter “sage-grouse”) populations. Effects of anthropogenic and landscape features on survival of sage-grouse hens have not been evaluated in the context of predator communities. In addition, management agencies would benefit from more information on the effects of parental investment and anti-predation strategies on sage-grouse survival. During 2008–2011, I collected survival data for 427 sage-grouse hens at 12 study sites (eight 16-km diameter sites and four 24-km diameter sites) in southern Wyoming, USA. Between 1 May and 31 August each year, there were 132, 162, 156, and 165 hens monitored, respectively. Cox proportional hazard (Cox PH) models were used to assess the effects of four covariate sets including: raptor densities, anthropogenic features, landscape features, and sage-grouse behavior on sage-grouse hen survival. Cox PH models were analyzed in two separate steps; 1) parental investment analysis and 2) anti-predation strategy analysis. Data for the parental investment analysis included 3,523 survival intervals with 380 nests and 162 broods; whereas, data for the anti-predation strategy analysis included 2,304 survival intervals from non-reproductive sage-grouse hens. I found that sage-grouse summer survival was correlated with landscape features that represented riskier habitat, especially risk of predation from raptors. Breeding season survival of sage-grouse was negatively associated with proximity to trees (deciduous and coniferous), topographic ruggedness at a 0.27 km scale ($TRI_{0.27}$), and site-specific change in golden eagle (*Aquila chrysaetos*) density (site-specific change in golden eagle density was calculated as the increase or decrease in study site-level golden eagle density [annual density] relative to the raptor density in a particular study site at the beginning of the study [2008]). However, site-specific change in golden eagle density was negatively associated with sage-grouse survival only when taking $TRI_{0.27}$ into context (interactive effect). This interaction indicated that the negative effect of both site-specific change in golden eagle density and $TRI_{0.27}$ was dampened in areas with higher $TRI_{0.27}$ and greater values of site-specific change in golden eagle density. My sage-grouse survival results indicated that survival of non-reproductive hens was greater than brooding or nesting hens. Hens that stayed in intermediate-size flocks and yearling hens had higher survival than hens in small or large flocks and hens >2 years old. Topographic ruggedness in conjunction with site-specific change in golden eagle density had a dynamic effect on sage-grouse survival, which illustrates the importance of considering predator communities in tandem with habitat components.

INTRODUCTION

Survival of breeding age birds in direct relation to predator communities has not been a main focus of greater sage-grouse (*Centrocercus urophasianus*: hereafter "sage-grouse") research. Survival related to predator communities was not likely to have been a problem during pre-European settlement because sage-grouse co-evolved with the predator communities present in sagebrush ecosystems (Schroeder et al. 1999, Schroeder et al. 2001). There are currently no predators that specialize on sage-grouse during any life history stage (egg, chick, or adult; Connelly et al. 2011). Thus, Hagen (2011) indicated that predators may only be negatively affecting sage-grouse populations in fragmented habitats and areas with human-subsidized predator populations. However, these areas of habitat fragmentation and areas with human-subsidized predator populations have drastically increased in the recent past (Leu et al. 2008). For example, red fox (*Vulpes vulpes*) and common raccoon (*Procyon lotor*) have increased in abundance in sage-grouse habitat, especially near human activities (Connelly et al. 2000b, Baxter et al. 2007, Hagen 2011). In addition, golden eagles (*Aquila chrysaetos*) use anthropogenic structures as perches and nesting structure (Lammers and Collopy 2007, Prather and Messmer 2010, Slater and Smith 2010).

Recent research has indicated that sage-grouse hen survival may be the most important demographic parameter driving sage-grouse productivity (Johnson and Braun 1999, Taylor et al. 2012). Taylor et al. (2012) found that sage-grouse hen survival was the most influential demographic rate on population growth, and Johnson and Braun (1999) found that adult and juvenile sage-grouse survival were the most limiting demographic parameters for a population in northern Colorado. This should not be surprising, because sage-grouse are relatively long-lived ground-nesting birds with low productivity (Connelly et al. 2000b, Holloran et al. 2005, Connelly et al. 2011). Thus, many aspects of recruiting new individuals into a population are connected to sage-grouse hens (i.e., nest success and chick survival). Juvenile survival may also be partially connected to learned behaviors from when an individual sage-grouse was a chick (Thompson 2012).

Sage-grouse hens have been known to have high annual survival (48–78% in Wyoming; Holloran 2005, Connelly et al. 2011) with the breeding season having the lowest seasonal survival rate for sage-grouse hens (Connelly et al. 2000a). There has been little published on seasonal survival estimates for female sage-grouse (Connelly et al. 2011); however, Connelly et al. (2000a) found that 52% of sage-grouse hen mortalities occurred in spring and summer. Sage-grouse are a species of conservation concern because their distribution and abundance in western North America have declined over the last century (Gregg et al. 1994, Johnsgard 2002, Connelly et al. 2004); many factors have been attributed to this decline including predation, habitat loss, and habitat fragmentation (Braun 1998). Research designed to evaluate potential factors affecting summer survival of sage-grouse in relation to predators and habitat quality will help guide management practices. Furthermore, low productivity of sage-grouse in combination with increased predation rates in fragmented habitats has the potential to decrease or extirpate local sage-grouse populations.

Increasing levels of human development in sage-grouse habitat have brought a range of new stresses to sage-grouse from habitat fragmentation to predation (Connelly et al. 2004, Doherty et al. 2010, Kirol 2012). Potentially additive impacts of human development on sage-grouse survival include increased hunting efficiency of raptors (perches), number of nesting structures, and carrying capacity of generalist predators.

Sources of perch and nesting structure for raptors include oil and gas structures, residential houses, communication towers, power lines, trees, and rugged terrain.

Although raptors have been reported to prey on sage-grouse, raptor densities have not been directly correlated to sage-grouse survival rates or population growth. Golden eagles have been suggested as the major sage-grouse predator (Willis et al. 1993, Connelly et al. 2000a, Danvir 2002, Dahlgren 2006, Mezquida et al. 2006), and high golden eagle abundance was associated with decreased sage-grouse survival (Danvir 2002). However, no sage-grouse study has directly related site-specific densities of raptors to sage-grouse hen survival. I recorded raptor densities associated with sage-grouse nesting and brood-rearing areas from 2008–2011 to determine if raptors were important sage-grouse predators and impact sage-grouse hen survival during the summer. I hypothesized that sage-grouse hen survival would be greater in areas and years with fewer raptors, specifically, golden eagles, *Buteo* hawks (*Buteo* spp.), and northern harriers (*Circus cyaneus*; hereafter "harrier"). In addition, I hypothesized that this effect would be intensified in areas closer to potential perches, such as oil and gas structures, power lines, houses, trees, and rougher topography. To test these hypotheses, I assessed sage-grouse hen survival in relation to sage-grouse exposure to raptors, potential raptor perches, and proximity to areas associated with natural or human provided food subsidies. As secondary objectives, I evaluated differences between yearling and adult sage-grouse hen survival, and the effect of sage-grouse hen behavior (parental investment, weekly movement, and flock size) in relation to survival. I hypothesized that lower parental investment, shorter weekly movements, and an optimal flock size would increase hen survival.

STUDY AREA

My study was conducted in southwest and south-central Wyoming. I chose 12 circular study sites, each 16 or 24 km in diameter (eight study sites of 16-km diameter and four study sites of 24-km diameter). Study sites in southwest Wyoming were 16-km diameter and approximately centered around leks where hens were captured based on results found by Holloran and Anderson (2005). Study sites in south-central Wyoming were 24 km in diameter, because sage-grouse were captured at several nearby leks over a larger area. Five study sites were located in Lincoln County, two in Sweetwater County, two in Uinta County, and three in Carbon County. Study sites were chosen to provide a representation of overall sage-grouse nesting habitat in southern Wyoming. Elevation of study sites ranged from 1,925 m – 2,550 m. Most of the land within all of the study sites was federally owned and administered by the Bureau of Land Management with a small percentage of private lands. Domestic sheep and cattle grazing were the dominant land uses in the study sites. All study sites had anthropogenic development, which consisted mostly of unimproved 4-wheel drive roads. Conventional natural gas, coalbed methane natural gas, and/or conventional oil extraction activities were present in six (50%) of the study sites; well density within study sites averaged 0.12 ± 0.22 (SD) wells km^{-2} (range = 0.0–0.64 wells km^{-2}).

The landscape at all study sites was dominated by sagebrush (*Artemisia* spp.);

Wyoming big sagebrush (*A. tridentata wyomingensis*) and mountain big sagebrush (*A. t. vaseyana*) were the most common. Black sagebrush (*A. nova*) and dwarf sagebrush (*A. arbuscula*) were found on exposed ridges. Other common shrub species in the study sites included alderleaf mountain mahogany (*Cercocarpus montanus*), antelope bitterbrush (*Purshia tridentata*), chokecherry (*Prunus virginiana*), common snowberry (*Symphoricarpos albus*), greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus* and *Ericameria* spp.), Saskatoon serviceberry (*Amelanchier alnifolia*), and spiny hopsage (*Grayia spinosa*). Isolated stands of juniper (*Juniperus* spp.) and quaking aspen (*Populus tremuloides*) were found at the higher elevations on north-facing hillsides. Common forb species included arrowleaf balsamroot (*Balsamorhiza sagittata*), buckwheat (*Eriogonum* spp.), common yarrow (*Achillea millefolium*), dandelion (*Taraxacum* spp.), desert parsley (*Cymopterus* spp.), phlox (*Phlox* spp.), lupine (*Lupinus* spp.), sego lily (*Calochortus nuttallii*), and wild onion (*Allium* spp.). Common grass species included: bluegrasses (*Poa* spp.), bluebunch wheatgrass (*Pseudoroegneria spicata*), green needlegrass (*Nassella viridula*), needle and thread (*Hesperostipa comata*), prairie junegrass (*Koeleria macrantha*), and western wheatgrass (*Pascopyrum smithii*). Cheatgrass (*Bromus tectorum*) was present, but not widespread in any of the study sites.

METHODS

Sage-grouse Capture and Monitoring

From 2008 to 2011, I monitored sage-grouse hen survival during late spring and summer (May through August). Hens were captured, radio-collared, and released in April of each year. I captured hens at night using ATVs, spotlights, and hoop-nets (Giesen et al. 1982, Wakkinen et al. 1992, Connelly et al. 2003) and fitted them with 17.5-g or 22-g (<1.5% body mass) necklace radio collars (Holohil Systems Ltd, RI-2D, Ontario, Canada or Advanced Telemetry Systems Inc, A4060, Isanti, MN, USA). Collars were equipped with motion-sensors (pulse rate of transmitter increased after 8 hours without bird movement), which allowed me to detect mortalities from a distance. I aged sage-grouse hens at the time of capture as yearlings or >2 years of age by examining outer primaries feathers (Patterson 1952).

I visually located hens weekly with VHF receivers (Communications Specialists, R-1000, Orange, CA, USA) and 3-way Yagi antennas (Communications Specialists, Orange, CA, USA) to locate and monitor nests. To assess the effects of parental investment on survival, I classified sage-grouse hen status as nesting, brooding, or non-reproductive each week (hen status was a surrogate for differences in parental investment). Potential nests were identified with binoculars from ~15 m by circling a radio-marked hen until she was visually spotted under a shrub. Nests were verified by triangulating the hen under the same shrub from ≥50 m away or thoroughly searching the area of the potential nest when the hen was absent. After 1 July, I continued to visually locate brooding hens weekly; whereas, non-reproductive hens were visually located bi-weekly. Brood hens were identified by either visually detecting chicks or observing hen behavior that indicated the presence of a brood (e.g., hesitation to flush, feigning injury, or clucking). I classified a sage-grouse hen as a brood hen if there was evidence of at least 1 chick with that hen. A non-reproductive hen was a hen that never nested, her nest failed, or her brood failed. I reclassified a brooding hen as non-reproductive when I did not detect evidence of a brood during 2 consecutive telemetry visits. The reproductive status of an individual sage-grouse hen was re-assessed every time a hen was visually located. I documented sage-grouse hen survival with telemetry equipment from a distance when a visual location was not possible, and telemetry signal from a distance was used as often as possible to identify mortality dates; thus, a live or dead signal for most sage-grouse was obtained >1 per week. I used handheld global positioning system (GPS) units (eTrex, Garmin Inc., Olathe, KS, USA) to record hen locations. Location accuracy on the GPS ranged from 2–8 m.

Sage-grouse Behavior Variables

I used visual sage-grouse locations to record minimum flock size and minimum weekly movements. Both of these metrics were collected as indicators of exposure to predation. The minimum flock size each week was recorded as the number of adult sage-grouse near (within ~50 m^2) a radio-collared hen including the radio-collared hen. I considered this count a minimum flock size, because there were probably individuals that were not detected during each count. Flock size was averaged across all visits for each individual hen during a summer. Movement distances between a sage-grouse's sequential locations were calculated using Geospatial Modeling Environment version 0.7.1.0 (Spatial Ecology LLC, Marshfield, WI, USA) and ArcMap version 10.0 (ESRI Inc., Redlands, CA, USA). I standardized movement distance between sequential visits to minimum weekly movement distances by dividing each distance between telemetry

locations by the number of days that had elapsed between telemetry locations,
I then averaged all weekly movement distances for each sage-grouse. This produced a minimum distance, because sage-grouse movements between telemetry locations were unknown.

Raptor Variables

From May 1 – August 1 of each year, I conducted point count surveys at random locations within each study site to compare raptor densities. Random locations were selected in habitat considered to be available to sage-grouse hens during the summer within each study site. To restrict random locations to available nesting habitat, I used ArcMap 10.0 to generate random locations only in sagebrush-dominated habitat, which was classified by the Northwest ReGAP landcover data from 2008 (Lennartz 2007). Random locations were designated to be ≥1000 m apart, but average nearest neighbor distances among random point count locations was >2000 m after random selection. I generated 12 random locations in each 16-km diameter study site and 18 random locations in each 24-km diameter study site per year. I generated a new set of random locations each year to avoid spatial autocorrelation; thus, random locations among years were independent.

I used standard distance sampling techniques (Ralph et al. 1995, Buckland et al. 2001, Thomas et al. 2010), which entailed counting all raptors observed during point counts and recording each raptor's distance from the observer (when standing at the center of the point count location). Observers recorded the distance from the observer to where a raptor was first located (Ralph et al. 1995, Thomas et al. 2010); this minimized possible bias associated with raptors being attracted to or flushed away from an observer. When a raptor was displaced from the center of a point count location as an observer approached (6% of all detected birds), I recorded distance from that raptor to the center of the point count location while the observer approached as suggested by Ralph et al. (1995). A 1500–m rangefinder (American Technologies Network Corp., RE-1500 m, San Francisco, CA, USA) in conjunction with a GPS was used to estimate distances directly or to validate visually estimated distances.

Observers were trained and tested in raptor identification before conducting point counts. Point counts were 10 minutes in length, and we conducted them during daylight hours on a weekly basis at each study site. We visited each point count location 1–8 times with most locations visited ≥3 occasions. We did not survey for raptors in inclement weather (i.e., when raining or wind speeds were greater than 25 km/h; Ralph et al. 1995). Unidentified birds were not included in analyses; these contributed to 2% of detections within truncated observation distances. To minimize observer bias, I changed the time of day and the observer that conducted individual point counts within a study site each week. The observers conducting point counts within a particular study site changed each year.

I calculated average annual densities of raptors at the study site-level (number / 100 km^2). All raptor variables were calculated from the raw count data within Program DISTANCE estimated effective detection radii (EDR) as specified in Chapter 2. Study site-level density of golden eagles, *Buteo* hawks, and harriers were individually calculated within species-specific EDRs (1000 m, 450 m, and 350 m, respectively) of each random point count location within a study site (see Chapter 2 for further details). I had noted through observation that relative changes in raptor densities within many study sites had positive or negative effects on survival of sage-grouse. I attributed this phenomenon to the possibility of raptors being more or less effective predators on sage-grouse depending on the study site due to overall characteristics of a particular study site (combination of individual raptor behavior, topographic roughness, large scale cover, anthropogenic development, etc.). In addition to study site-level raptor densities, I calculated site-specific change in raptor densities—from random point count locations—as the increase or decrease in study site-level raptor density (annual density) relative to the raptor density in a particular study site at the beginning of the study (2008). Thus, site-specific change in raptor density was 0 for all study sites in 2008. These site-specific change in raptor density variables were intended to look at relative change in risk of predation within each study site (i.e., does site specific increase or decrease of raptor densities effect survival of sage-grouse). Thus, site-specific change in raptor densities were not quantifying the effect of the exact density of raptors on survival of sage-grouse among all study sites. Rather, they were assessing site-specific change in exposure to raptors.

Anthropogenic and Landscape Feature Variables

I calculated sage-grouse proximity to anthropogenic features that could be used as perch or nest sites by raptors or could provide food subsidies with ArcMap 10.0.

Anthropogenic structures that were >2 m in height were considered available for perching or nesting by raptors. I quantified the distance from sage-grouse locations to the nearest oil and gas structure (energy well, compressor station, transfer station, refinery, or other energy extraction related buildings), major road, all roads, communication tower, house, and power line for each sage-grouse location. Most (>95%) oil and gas structures were energy wells. Ongoing energy development was occurring in half of my study sites, which required me to assess the dates that energy related structures and roads were added or removed from the landscape.

In distance calculations, I only included oil and gas structures and roads that were physically on the ground when each sage-grouse was located. I obtained information on oil and gas structures, including date construction started on the structure and date when wells were plugged and abandoned (date structure was removed), from the Wyoming Oil and Gas Conservation Commission (WOGCC; 2012). I verified the spatial location and existence of older structures with color aerial satellite imagery from summer 2006 and August 2009 obtained from the National Agriculture Imagery Program (NAIP; U.S. Department of Agriculture [USDA] 2010). Aerial imagery from NAIP is produced by the USDA on a 3-year rotation; thus, I used WOGCC data and on the ground GPS units to map energy development that occurred after August 2009. However, energy development reported to WOGCC after August 2009 had better reporting of location, spud date, and plug abandon date.

I used 2009 NAIP imagery to digitize the location of major roads, all roads, communication towers, and houses within a 5-km buffer around study sites; roads constructed between August 2009 and September 2011 were mapped on the ground with GPS units. Major roads included paved, improved gravel roads, and railroads; whereas, all roads included major roads and all unimproved 4-wheel drive roads. All transmission and distribution power lines within a 5-km buffer around study sites were mapped on the ground with GPS units; telephone lines not associated with a power line were included in power line mapping.

Neither sage-grouse nor raptors were likely to discriminate between many different types of anthropogenic structures. Thus, I created 2 anthropogenic structure variables that represented the nearest 1) distance to either an oil and gas structure, communication tower, or house (DIST_WCH); and 2) distance to either an oil and gas structure, communication tower, house, or power line (ANTH). This was in addition to distances from sage-grouse locations to individual types of anthropogenic structures. I report means and standard errors (SE) for distances to anthropogenic feature variables (Table 6-1).

Similar to anthropogenic features, landscape features could be used as perches or nest structure by raptors, or could be areas with higher productivity that attract predators. Thus, I used ArcMap 10.0 to calculate the distance from every sage-grouse location to forested (deciduous and conifer stands) and riparian habitats. Stands of trees and riparian habitat were identified with Northwest ReGAP landcover data from 2011 (Lennartz 2007), and verified with NAIP imagery from 2009. Topography with greater surface roughness has the potential to create topographic structures (e.g., hilltops, knolls, and cliff edges) that provide vantage points similar to perches. For every sage-grouse location, I used ArcMap 10.0 to extract topographic ruggedness index (TRI) values generated by Hanser et al. (2011) for the Wyoming Basins Ecoregion; TRI variables were developed using a moving window analysis at 0.27-km ($TRI_{0.27}$), 0.54-km ($TRI_{0.54}$), 1-km (TRI_1), and 3-km (TRI_3) radii (0.23-km^2, 0.92-km^2, 3.14-km^2, and 28.26-km^2 scales, respectively). Riley et al. (1999) created TRI to describe the roughness of landscapes, and the index is quantified as the difference in elevation among adjacent pixels of a digital elevation map; the index is then averaged over a user defined area. I report means and standard errors (SE) for distances to landscape feature variables in Table 6-1.

Data Analyses

I analyzed sage-grouse hen survival with the Anderson-Gill formulation of the Cox proportional hazard (Cox PH) model using function ‘coxph’ in package SURVIVAL version 2.36-14 in R (R 2.14.2, www.r-project.org, accessed 15 Apr 2012). Cox PH models are robust semi-parametric models that are commonly used to analyze time-to-event data (Cox 1972), such as survival obtained from telemetry. The risk of mortality (hazard ratio [$h(t|x_t)$]) is a function of the non-parametric baseline hazard ($h_0(t)$) and the parametric covariates (x’s) affecting survival (Hosmer and Lemeshow 1999) with the Cox PH equation expressed as:

$$h(t|x_t) = h_0(t) \times \exp(\beta_1 x_{i1} + \beta_2 x_i + \beta_k x_{ik}) \qquad (1)$$

Coefficient values were expressed as mortality hazard; thus, positive values would be associated with greater risk of mortality and lower survival.

Data can be left censored for individuals entering the study at different times and right censored for individuals that did not die during the study. In Cox PH models, fixed (time-independent; average exposure for an individual) and time-dependent (exposure of individual during each survival interval) covariates can be fit to assess their effect on survival (Hosmer and Lemeshow 1999). The baseline hazard is allowed to vary with time in Cox PH, and time-dependent variables are included by constructing time intervals for each unique individual (Therneau and Grambsch 2000). However, covariates in Cox PH models are assumed to have proportional mortality hazard over time (proportional hazard assumption; Hosmer and Lemeshow 1999). Thus, I used function 'cox.zph' in package SURVIVAL in R (Therneau and Grambsch 2000) to test the proportional hazard assumption for each covariate in all models; the proportionality of each covariate was validated with $P > 0.05$ for each covariate.

In addition, I calculated dfbetas (statistic that measures the scaled change in each parameter estimate by iteratively deleting each observation) and generated leverage plots to evaluate if there were any influential observations; no observations were omitted as a result of high influence. I prevented multicollinearity by only including one variable of any pair of variables that co-varied in any Cox PH model ($r > 0.65$) as determined with a Pearson's correlation matrix; thus, I eliminated one co-varying variable from further analysis by retaining the variable that made the most biological sense. Variance inflation factors (VIF) for all predictor variables were ≤ 5, which indicated that the variances of coefficient values were not drastically increased by the inclusion of any predictor variable; thus, collinearity was not a major problem.

I constructed time intervals for each individual sage-grouse hen by calculating the day that corresponded to halfway between each time that I located a sage-grouse. Unless mortality date could be more accurately assessed by evidence from a carcass, mortality date was estimated as the time equal to halfway between the last date the hen was known to be alive and the date mortality was detected. During each year, time was started at $t = 0$ upon the first visual location of each sage-grouse hen that was relocated at least 2 weeks after radio-collaring. I did not include survival data collected directly after radio-collaring, because survival may have been affected by trapping stress or the bird adjusting to the collar (Winterstein et al. 2001); this excluded 4 birds from analyses. There were approximately 110 days of exposure time for each sage-grouse per summer (i.e., summer survival was assessed from $t = 0$ to $t = 110$, which corresponded to 1 May to 31 August).

I included study site-level raptor densities and site-specific change in raptor densities as fixed variables (average exposure to raptors over a summer), and anthropogenic and landscape feature variables as time-dependent variables (calculated from all sage-grouse locations where the hen was visually located). Study site-level raptor densities and site-specific change in raptor densities were defined as fixed variables, because raptor variables were quantified as annual densities (across an entire summer) at the study site-level. Anthropogenic and landscape features were incorporated as time-dependent variables, because the effect of these variables on survival was likely different depending on the bird's location relative to these features, which changed as the bird moved through its environment over time. The distance to houses and forested habitat were highly correlated ($r > 0.65$), and distance to forested habitat fit the data better than distance to houses; thus, I included distance to forested habitat in modeling instead of distance to houses. However, distance to houses was incorporated into the DIST_WCH and ANTH variables.

Modeling of sage-grouse survival was conducted with an information theoretic approach (Anderson 2008). I compared Cox PH models with Akaike's information criterion corrected for small sample sizes (AIC_c) and Akaike weights (w_i; Burnham and Anderson 2002) with function 'aictab' in package AICCMODAVG version 1.25 in R. I employed sequential AIC_c modeling of covariate sets, which was suggested by Arnold (2010) as an appropriate approach for identifying and ranking the most parsimonious models. Non-informative covariates (85% confidence intervals [CI] of parameter estimates overlapped 0) were eliminated within each covariate set before comparing top AIC_c selected models among covariate sets (Arnold 2010). I classified models within 2 AIC_c of the null model as being non-competitive (Burnham and Anderson 2002); thus, any model <2 AIC_c of the null was omitted from further analyses. Four covariate sets were evaluated sequentially: 1) raptor variables, 2) anthropogenic features, 3) landscape features, and 4) sage-grouse behavior. Cox PH models with raptor variables were compared as single variable models for each raptor species individually with AIC_c to choose which type (study site-level or site-specific change in density) of raptor variable fit the data best; thus, the raptor variable type with the lowest AIC_c was used in all further modeling. I evaluated the effect of a sage-grouse's age (AGE) on survival within the sage-grouse behavior covariate set. I included raptor variables × anthropogenic structure variables and raptor variables × landscape feature variables as pairwise interactions within anthropogenic and landscape feature covariate sets. Pairwise interactions with raptor variables were included to assess whether negative effects of raptor variables were intensified in areas closer to potential perches or nest structure or in areas closer to natural or human provided food subsidies. I did not include DIST_WCH or ANTH with any other anthropogenic structure variable, because DIST_WCH and ANTH were derived from a combination of distance from sage-grouse locations to energy wells, communication towers, houses, and power lines. The best variable describing the effect of anthropogenic structures on survival was determined through AIC_c selection within the anthropogenic feature covariate set. I compared Cox PH models with individual TRI variables measured at 0.27-km, 0.54-km, 1-km, and 3-km radii with AIC_c to choose the best spatial scale for the TRI variable to be used in the landscape feature covariate set; the TRI variable scale with the lowest AIC_c was used in all further modeling. As the final modeling step, I compared all top AIC_c selected models from every covariate set (models within 2 AIC_c of the top model within each covariate set) among each other and as additive models with combinations of all 3 covariate sets. I based my inference on Cox PH models within 2 AIC_c of the top selected model (Burnham and Anderson 2002).

The effects of sage-grouse behavior on survival in relation to raptors and anthropogenic and landscape features had to be analyzed as 2 separate Cox PH analysis steps. The sequential modeling procedure described above was applied to both the Cox PH analysis steps. In “Step 1” (parental investment analysis), I evaluated parental investment (hen status) with raptors and anthropogenic and landscape features by using all sage-grouse locations (nesting, brooding, and roosting locations). However, I excluded potential anti-predation behaviors (average weekly movement and average flock size) from Step 1 model building, because all variables that potentially described an anti-predation behavior were constant for 2 of 3 of the parental investment categories (nesting and brooding). In “Step 2” (anti-predation strategy analysis), I used non-reproductive locations to evaluate the effects of weekly movements and average flock size with raptors and anthropogenic and landscape features on sage-grouse survival. Average flock size was compared as a linear and quadratic variable in the sage-grouse behavior covariate set to assess the possibility of an optimal flock size. In Step 2, I included an interaction between average flock size and AGE to assess if yearling sage-grouse in larger flocks had higher survival.

In addition to AIC_c model comparison, I implemented a spatiotemporal modeling strategy to evaluate general trends in sage-grouse hen survival in relation to raptor variables, anthropogenic features, landscape features, and sage-grouse behavior. A spatiotemporal strategy was implemented to Cox PH model evaluation because many variables describing sage-grouse survival were exclusive to a given year or study site. I assessed goodness-of-fit of the top Cox PH models by computing a ratio of Zheng’s (2000) proportional reduction of deviance (RDR) for covariate models to spatiotemporally saturated models (maximum proportional reduction in deviance; Iles 2012), which has been considered appropriate for Cox PH models (Zheng 2000, Aubry et al. 2011). Deviance reduction for each spatiotemporally saturated model and top covariate models of interest were calculated relative to null models (time and study site invariant):

$$D_{int} = 1 - (\text{deviance}_{interest}/\text{deviance}_{null}) \quad (2)$$

$$D_{sat} = 1 - (\text{deviance}_{saturated}/\text{deviance}_{null})$$

$$RDR = D_{int} / D_{saturated} \quad (3)$$

thus, the ratio gives an assessment of a covariate model's relative ability to explain spatiotemporal processes effecting sage-grouse survival. The ratio is 1 for the spatiotemporally saturated model and 0 for the null model (Iles 2012). I compared the top AIC_c selected Cox PH models of sage-grouse survival from Step 1 and 2 to a spatiotemporally saturated model with RDR. The saturated model for sage-grouse survival included year; study site; distance to energy well, communication tower, house, power line, all road, and tree stand; the top selected TRI variable; and distance to riparian habitat.

Although I could not test for spatial autocorrelation in Cox PH analyses, raptor densities derived from distance sampling techniques are robust to lack of independence of observation locations because distance sampling is setup to be a snap-shot in time (Thomas et al. 2010). My raptor sampling was designed to count the greatest proportion of raptors within a study site each week while not counting the same raptor more than once per week as suggested by Ralph et al. (1995) and Thomas et al. (2010). Conducting all point counts within a study site in one day reduced the possibility of double-counting individual raptors during that week's visit. Counting the same individual raptor during different weeks, regardless of the particular point count location, was properly scaled by accounting for survey effort. Replication of point counts by sampling multiple weeks was done to increase the proportion of raptors detected as suggested by Thomas et al. (2010). Furthermore, study site-level and site-specific change in raptor densities were averaged by study site and year; thus, the lowest unit of measurement was at the study site-level annually. Time-dependent variables for Cox PH analyses were not subject to spatial autocorrelation, because Cox PH treats each time interval as a separate observation (Hosmer and Lemeshow 1999).

RESULTS

During 2008–2011, I captured 427 sage-grouse hens that were included in my Cox PH analyses because they were available to monitor (i.e., they did not go missing or die within 2 weeks of radio-collaring). Fifty, 76, and 69 sage-grouse hens survived into a subsequent year, 2009, 2010, and 2011, respectively; thus, there were 132, 162, 156, and 165 sage-grouse hens in 2008, 2009, 2010, and 2011, respectively. From 1 May – 31 August, I found 88 sage-grouse hen mortalities (22 nesting, 19 brooding, and 47 non-reproductive sage-grouse), which yielded apparent summer survival estimates of 81–89% annually. There were 3,523 time intervals for analyzing survival (402 nesting, 817 brooding, and 2,304 non-reproductive locations). I monitored 380 nesting sage-grouse and 162 brooding sage-grouse. The proportional hazards assumption was not violated for any model within 2 AIC_c of the top selected model.

To evaluate the effect of raptor densities on sage-grouse survival, I conducted 2,948 point count surveys during 2008–2011 at 660 total random point count locations. I counted 252 golden eagles, 138 *Buteo* hawks, and 57 harriers within species-specific EDRs (see Chapter 2). Neither study site-level nor site-specific change in golden eagle, *Buteo* hawk, and harrier densities had an individual effect on sage-grouse summer survival (all main effects of raptor variables had 85% CIs that overlapped 0). Variables describing site-specific changes in raptor densities fit the data better than landscape densities of raptors; thus, I used site-specific change in raptor densities in interactive models.

I found that landscape variables and sage-grouse behavior variables described summer sage-grouse survival best for both the parental investment and anti-predation analyses. I found that TRI at the 0.27-km radius ($TRI_{0.27}$) fit the data best for all analyses. No anthropogenic variable described differences in summer survival of sage-grouse hens (parameter estimates had 85% CI that overlapped 0) for either the parental investment or anti-predation analyses. In the parental investment analysis, I found that the top AIC_c selected Cox PH model included AGE, sage-grouse hen status (nesting, brooding, or non-reproductive), and site-specific change in golden eagle density × $TRI_{0.27}$ (Table 6-2), which had $w_i = 0.96$ and RDR = 0.82. The anti-predation strategy analysis had 3 models within 2 AIC_c (Table 6-2). However, the top 2 AIC_c ranked models had $w_i = 0.38$ and $w_i = 0.32$, respectively, and the third AIC_c ranked model had $w_i = 0.17$ (Table 6-2); thus, I will only discuss the top 2 models. Both top AIC_c ranked models included average flock size, quadratic effect of flock size, AGE, AGE × average flock size, distance to forested habitat, and $TRI_{0.27}$ (Table 6-2). In addition, I found that the top AIC_c ranked model for the anti-predator strategy analysis included the site-specific change in golden eagle density × $TRI_{0.27}$ interaction and had RDR = 0.98 (Table 6-2). Whereas, the simpler second AIC_c ranked model for the anti-predator strategy analysis had RDR = 0.90. The near 1 values of RDR for all top AIC_c selected models indicated that a high proportion of the maximum explainable deviance for sage-grouse summer survival was accounted for in my top selected models.

Topographic ruggedness index at 0.27 km radius was the landscape feature variable that most consistently explained sage-grouse summer survival. I found that higher $TRI_{0.27}$ values were correlated with lower sage-grouse summer survival (Tables 6-3 and 6-4). In the anti-predator analysis, there was support for lower survival of sage-grouse closer to forested habitat at non-reproductive locations from all top AIC_c ranked models from the anti-predator strategy analysis (Tables 6-2 and 6-4, Fig. 6-1). Parameter estimates for distance to forested habitat were -0.15 (0.08 SE; 95% CI = -0.31 to 0.02) and -0.15 (0.08 SE; 95% CI = -0.31 to 0.01) for the top and second AIC_c ranked models, respectively (Table 6-4).

Even though raptor densities (study site-level and site-specific change) by themselves did not describe sage-grouse survival, I found that the interaction between site-specific change in golden eagle density and $TRI_{0.27}$ was highly explanative of sage-grouse summer survival (Tables 6-3 and 6-4). Site-specific change in golden eagle density was negatively associated with sage-grouse summer survival only when taking $TRI_{0.27}$ into context. When site-specific change in golden eagle density was relatively high and sage-grouse were in areas with more rugged terrain, I found that the negative effect of site-specific change in golden eagle density and $TRI_{0.27}$ were dampened (Fig. 6-

2). The site-specific change in golden eagle density × $TRI_{0.27}$ parameter estimate was -0.01 (0.00 SE; 95% CI = -0.01 to -0.00) and -0.01 (0.00 SE; 95% CI = -0.02 to -0.00) for the parental investment analysis and anti-predation analyses, respectively (Tables 6-3 and 6-4).

For variables describing the effect of sage-grouse behavior on sage-grouse summer survival, I found that non-reproductive sage-grouse had marginally higher survival than nesting (parameter estimate 0.45 [0.27 SE]; 95% CI = -0.09 to 0.99) or brooding (parameter estimate 0.51 [0.28 SE]; 95% CI = -0.04 to 1.07) sage-grouse hens in the parental investment analysis (Table 6-3). In the anti-predation strategy analysis, I found that non-reproductive adults that flocked in intermediate numbers had higher survival (Table 6-4, Fig. 6-3A); thus, sage-grouse hens in small flocks (by themselves or another hen) and large flocks had lower summer survival. Average flock size parameter estimates were -0.55 (0.18 SE; 95% CI = -0.89 to -0.20) with quadratic 0.03 (0.01 SE; 95% CI = 0.01 to 0.05) for the top AIC_c ranked model, and -0.55 (0.18 SE; 95% CI = -0.90 to -0.21) for the second AIC_c ranked model with the same quadratic parameter estimate as the top AIC_c ranked model. All top AIC_c ranked Cox PH models included AGE. However, yearling sage-grouse hens had higher survival (parameter estimate -0.69 [0.30 SE]; 95% CI = -1.27 to -0.11) in the parental investment analysis, but marginally lower survival (parameter estimates: top model = 1.26 [0.78 SE]; 95% CI = -0.28 to 2.80; and second model = 1.23 [0.78 SE]; 95% CI = -0.28 to 2.80) in both of the top AIC_c selected models from the anti-predation strategy analysis when a yearling hen was in a flock of <3 birds (Table 6-4, Fig. 6-3B). In the anti-predation strategy analysis, I also found the AGE × average flock size interaction term was marginally significant for the top 2 AIC$_c$ selected models, which indicated that yearlings that on average chose to flock in greater numbers had greater survival (interaction parameter estimates: top model = -0.86 [0.48 SE]; 95% CI = -1.80 to 0.08; and second model = -0.87 [0.48 SE]; 95% CI = -1.81 to 0.07).

DISCUSSION

I found that sage-grouse summer survival was negatively correlated with landscape features that represented riskier habitat, especially risk of predation from raptors. Breeding season survival of sage-grouse was negatively impacted by proximity to trees (deciduous and coniferous) and greater values of $TRI_{0.27}$ and site-specific change in golden eagle density (study site relative change in golden eagle density among years). Kirol (2012) also found that terrain roughness was negatively correlated with sage-grouse summer survival in south-central Wyoming. His study indicated that proximity to anthropogenic features had no effect on sage-grouse survival, and I found no evidence of an interactive effect between anthropogenic features and raptor densities. My results also suggest that survival was greater for non-reproductive hens, hens that stayed in intermediate size flocks, and yearling hens. The best sage-grouse survival models had RDR = 0.82 to 0.98, which indicated that a large proportion of spatiotemporal variability in sage-grouse survival was accounted for in my models. My apparent late spring and summer survival rate was 79%, which was within estimated annual survival rates in Wyoming (Connelly et al. 2011). Thus, landscape features in conjunction with site-specific change in golden eagle density and sage-grouse behavior had dynamic effects on survival.

It was possible that distance variables associated with time intervals for mortalities were biased due to a predator moving a sage-grouse carcass. However, I did not find summer mortalities with evidence of drastic predator movements (>1 km), and sage-grouse carcasses were typically found close to the last location where the sage-grouse was known to be alive. For example, sage-grouse killed while nesting were found on average 0.38 km from their nest, and only 2 of 22 (9%) were found >1 km away from their nest. The average distance from sage-grouse nest to mortality location (0.38 km) was within the 0.54 km diameter of the $TRI_{0.27}$ variable, and topographic ruggedness variables at 0.27 km, 0.54 km, 1 km, and 3 km radii all had a negative effect on sage-grouse survival.

Previous research has shown that most sage-grouse mortalities in the spring and summer can be attributed to predation (Connelly et al. 2011), but other possible sources of mortality include collisions with vehicles, fences, and power lines (Braun 1998, Connelly et al. 2000a, Connelly et al. 2004, Beck et al. 2006); and West Nile virus (Naugle et al. 2004, Walker et al. 2007b, Walker and Naugle 2011). I did not find evidence of any sage-grouse colliding with a fence or power line (no carcasses near fences or under power lines). West Nile virus was not likely to have killed many birds in this study, because West Nile virus was not known to be prominent in my study sites during this study (Walker and Naugle 2011). In addition, mortalities from West Nile virus usually occur July to mid-September (Walker et al. 2007b, Walker and Naugle

2011), and I only found 17 of the 88 mortalities after 5 July. Sage-grouse survival has been documented to be lowest from March to June and relatively higher after July (Connelly et al. 2000a, Connelly et al. 2011, Walker and Naugle 2011); thus the timing of mortalities in my study coincides with typical sage-grouse summer survival.

Golden eagle, *Buteo* hawk, and harrier densities (study site level or site-specific change) did not independently predict sage-grouse survival. Raptor populations may have been too stable over time for me to detect direct negative effects of raptor abundance on sage-grouse survival. However, I found moderate support for lower sage-grouse survival when sage-grouse were exposed to a greater density of golden eagles within a study site (site-specific change in golden eagle density) while simultaneously taking $TRI_{0.27}$ into account (site-specific change in golden eagle density × $TRI_{0.27}$; Tables 6-3 and 6-4), and high values of $TRI_{0.27}$ negatively affected sage-grouse survival. Marzluff et al. (1997) found that golden eagles in sagebrush habitat selected areas with more rock outcrops and cliffs in southern Idaho. I hypothesized that rugged terrain would be riskier habitat and high raptor densities would intensify this effect because hilltops, knolls, and cliff edges associated with rugged terrain would act as perch or nesting structure for raptors. Thus, rugged terrain would correlate with greater exposure to predation from raptors. Contrary to my hypothesis, I found that the negative effect of $TRI_{0.27}$ and site-specific change in golden eagle density was dampened by the combination of greater rugged terrain and greater values of site-specific change in golden eagle density (Tables 6-3 and 6-4). Two potential explanations for this finding include; 1) rugged topography may provide some refugia from visual predators (e.g., golden eagles), because topographic features such as slight depressions may decrease the effective distance that a raptor can detect a sage-grouse on the ground; and 2) greater abundance of golden eagles in rugged topography (risky habitat) may competitively exclude other predators. Golden eagles and coyotes are known to be the top predators in sagebrush ecosystems (Mezquida et al. 2006, Hagen 2011), and presence of golden eagles may reduce the hunting efficiency of mammalian predators. I found that nesting and brooding sage-grouse selected locations with lower topographic ruggedness compared to the landscape at random in Chapter 3, which has been verified by other sage-grouse research (Jensen 2006, Doherty et al. 2010, Hanser et al. 2011, Kirol 2012); thus, sage-grouse avoided extremely rugged terrain. The moderately rugged topography (relative to the landscape) where sage-grouse had higher mortality may have been correlated to greater risk of predation from olfactory predators (mammalian predators), which have been known to hunt in areas such as drainage bottoms (Conover 2007).

Other landscape features such as forested and riparian habitats have the potential to pose a higher risk of predation for sage-grouse. Sage-grouse avoidance of forested habitat, especially pinyon (*Pinus* spp.)-juniper (*Juniperus* spp.), has been documented (Doherty et al. 2010), but there has been little research looking at the impact of proximity to forested areas on sage-grouse survival. I found that proximity to trees was negatively related to the survival of non-reproductive hens; although distance from sage-grouse locations to forested habitat was an imprecise predictor (95% CI overlapped 0; Table 6-4). There has been some documentation of the negative effect of proximity to trees on sage-grouse survival, but this topic clearly needs more study. For example, Commons et al. (1999) found higher spring counts of male Gunnison sage-grouse (*Centrocercus minimus*) on leks after removal of pinyon-juniper in southwestern Colorado; they attributed this to lower densities of raptors after pinyon-juniper was removed. Nesting and early brood-rearing sage-grouse avoid riparian habitat (Doherty et al. 2010, Chapter 3), presumably due to increased risk of predation. However, I did not find a connection of low hen survival and proximity to riparian habitats.

Several studies have demonstrated that sage-grouse avoid habitat with man-made features, such as oil and gas infrastructure (Aldridge 2005, Holloran 2005, Walker et al. 2007a, Kirol 2012), power-lines (Hanser et al. 2011), and roads (Holloran 2005, Aldridge and Boyce 2007), which are potential perches or nest structure for raptors or provide reliable food subsidies. In fact, golden eagles, red-tailed hawks (*Buteo jamaicensis*), ferruginous hawks (*Buteo regalis*), and Swainson's hawks (*Buteo swainsoni*) have been found to use power lines for perch sites and areas around power lines for foraging (Lammers and Collopy 2007, Prather and Messmer 2010 , Slater and Smith 2010). Holloran (2005) found that annual survival of adult female sage-grouse was lower in a natural gas field, and collisions with vehicles are known to cause sage-grouse mortalities (Braun 1998). Thus, I hypothesized that sage-grouse survival would be lower near anthropogenic features and that this effect would be amplified when there were also high densities of raptors. However, I did not find support for this hypothesis indicating that anthropogenic features do not necessarily predict riskier habitats or sage-grouse avoidance of anthropogenic features masked any effects on survival.

Behaviors associated with parental investment and anti-predation strategies have the potential to influence survival rates of animals. Increased experience, quantified as age, should also be positively correlated with survival. However, yearling sage-grouse have been found to have higher survival than adults ≥2 years of age (Zablan et al. 2003, Holloran 2005, Connelly et al. 2011). For example, Zablan et al. (2003) found 77% and 59% survival for yearling and adult female sage-grouse in Colorado, respectively. Connelly et al. (1993), Holloran (2005), and Moynahan et al. (2007) documented that yearling sage-grouse hens initiated nests and re-nested less often than adult hens. I found similar results with 56% and 60% apparent nest initiation for yearling and adult hens, respectively, and 11 of 14 re-nesting events were from adult hens. Adult sage-grouse hens have higher nest success compared to yearlings, which indicates that adults are more likely to have a brood (Connelly et al. 2011). I found broods with 19% and 30% of yearling and adult sage-grouse hens, respectively, and I found that sage-grouse hens that were nesting or brooding had lower survival than hens without a nest or brood (Table 6-3). Thus, yearling sage-grouse hens may have had higher survival, because they were less likely to be incubating or tending a brood. This provides some evidence that differential behavior related to parental investment may account for higher survival rates of yearling sage-grouse hens.

In contrast, Moynahan et al. (2006) found nesting sage-grouse in Montana had higher survival than non-nesting hens. They attributed their findings to better physical condition of nesters versus non-nesters, increased visibility of non-nesting hens, or both. The apparent inconsistency with Moynahan et al. (2006) and my results most likely arises from differences in analyses. Moynahan et al. (2006) compared survival of hens that had initiated a nest within a summer versus hens that did not initiate a nest within a summer. On the other hand, I allowed the nesting status (nesting, brooding, or non-reproductive) of each hen to change over time with a time-dependent Cox PH variable; thus, I assigned each mortality to a time-dependent breeding status. In light of my results, Moynahan et al. (2006) results more likely relate to the better physical condition or experience of hens that attempted to nest.

My results from the anti-predation strategy analysis suggested that survival was greater for non-reproductive hens that stayed in intermediate size flocks (Fig. 6-3A). I did not find higher survival of yearlings versus adults when comparing survival of only non-reproductive hens (i.e., the main effect of AGE was not significant; Table 6-4), and yearling hen survival was connected to average flock size (interaction AGE × average flock size; Tables 6-2 and 6-4). In fact, survival of yearling sage-grouse hens was lower than adults when yearlings were in flocks of <3 grouse on average (Fig. 6-3B, Table 6-4). However, the interaction between AGE and average flock size indicated that yearlings that chose to stay in larger groups had higher survival.

I hypothesized that sage-grouse would have higher survival in optimally sized flocks, because small and very large flocks would represent increased risk of predation. Small flocks would decrease the benefits of sentinel behavior (i.e., sage-grouse detecting a predator) and the dilution effect, and large flocks would increase a predator's probability of detecting a flock of sage-grouse. The dilution effect predicts that an individual in a larger flock will have a lower probability of being eaten. Intermediate flock sizes would allow individual sage-grouse to benefit from the dilution effect and sentinel behavior, while avoiding detection by predators. I found support for an optimally sized flock for non-reproductive sage-grouse, which my top AIC$_c$ selected Cox PH model predicted around 3–14 birds (Fig. 6-3A). I also predicted that increased movement distances would be negatively related to survival, because there would be a greater risk of being detected by a visual predator for hens moving greater distances. However, I did not find support for a negative effect of weekly movement distance. This may be attributed to no effect or a lack of detailed information on movements from telemetry techniques. I was only able to record minimum linear movements, which ignore daily movements within a smaller area.

Raptors including golden eagles, *Buteo* hawks, and harriers have been identified as significant threats to sage-grouse survival (Schroeder et al. 1999, Schroeder and Baydack 2001). However, I found that natural abundances of raptors, even in the presence of anthropogenic features, did not seem to adversely affect sage-grouse survival. This may be attributed to sage-grouse avoiding raptors, avoidance of risky habitats, and habitat condition; negative effects of high raptor densities may also have been masked by other spatiotemporal processes such as weather. Dinkins et al. (2012) found that nesting and brooding sage-grouse avoided raptors, and many researchers have found that sage-grouse avoid risky habitats (Aldridge 2005, Holloran 2005, Aldridge and Boyce 2007, Walker et al. 2007a, Doherty et al. 2010, Hanser et al. 2011, Kirol 2012).

MANAGEMENT IMPLICATIONS

Many authors have suggested that ground-nesting bird survival, including sage-grouse, is connected to quantity and quality of habitat, and the presence of adequate sagebrush habitat minimizes predator effects on sage-grouse survival (Connelly et al. 1994, Braun 1998, Aldridge et al. 2008, Connelly et al. 2011). I agree with this, but there needs to be careful consideration of interactive effects of anthropogenic and landscape features and predator community dynamics (risk of predation). For example, sage-grouse hens avoided conventional and natural gas wells (Kirol 2012; Chapter 3), which placed them in areas with higher $TRI_{0.27}$. In addition, areas with higher $TRI_{0.27}$ had lower sage-grouse survival, which was dampened by high densities of golden eagles. However, the overall sage-grouse survival in areas with higher $TRI_{0.27}$ was lower. This indicates that changes in sage-grouse selection of habitat in response to anthropogenic features (fragmentation of habitat) can have dynamic consequences for sage-grouse survival, especially when considering differences in predator compositions. Thus, habitat fragmentation of sagebrush habitats has complex effects on sage-grouse use of the landscape, which in turn can have complex impacts on survival.

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Table 6-1. Descriptions, means, and standard errors (SE) of variables used to model sage-grouse survival with the Anderson-Gill formulation of the Cox proportional hazard model; means and SE were stratified by sage-grouse that survived the duration of the study and those that did not. Variables include raptor densities, anthropogenic features, and landscape features from 3,523 summer (1 May through 31 August) survival intervals. Sage-grouse behavior variables (average weekly movement and average flock size) were from non-reproductive 2,304 sage-grouse locations. Data were collected from eight study sites (each 16-km diameter) and four study sites (each 24-km diameter) in southern Wyoming, USA during 2008–2011.

	Survived			Mortality		
Variable description	*n*	mean	SE	*n*	mean	SE
Study site-level golden eagle density (no./100 km^2)	3435	1.91	2.73	88	2.22	2.84
Study site-level *Buteo* hawk density (no./100 km^2)	3435	6.59	7.44	88	7.66	8.42
Study site-level harrier density (no./100 km^2)	3435	7.02	8.19	88	6.41	6.92
Distance (km) from sage-grouse location to nearest oil and gas structure (energy well, compressor station, transfer station, refinery, or other	3435	7.55	0.12	88	7.38	0.62

energy extraction related buildings)						
Distance (km) from sage-grouse location to nearest major road including paved roads, railroad, and improved gravel roads	3435	1.51	0.02	88	1.71	0.13
Distance (km) from sage-grouse location to nearest road including paved roads, railroad, improved gravel roads, and unimproved 4-wheel drive roads	3435	0.33	0.01	88	0.38	0.03
Distance (km) from sage-grouse location to nearest communication tower	3435	10.13	0.13	88	10.55	0.78
Distance (km) from sage-grouse location to nearest residential house	3435	7.50	0.10	88	6.87	0.52
Distance (km) from sage-grouse location to nearest overhead line (transmission or distribution power lines, or telephone line)	3435	8.57	0.09	88	8.41	0.60
Distance (km) from sage-grouse location to nearest anthropogenic perch (ANTH; oil and gas structure,	3435	3.32	0.04	88	3.46	0.24

communication tower, residential house, or power lines)						
Distance (km) from sage-grouse location to nearest oil and gas structure, communication tower, or residential house (DIST_WCH)	3435	3.64	0.05	88	3.88	0.25
Distance (km) from sage-grouse location to nearest forested habitat including deciduous and conifer stands	3435	2.87	0.05	88	2.00	0.26
Distance (km) from sage-grouse location to nearest riparian habitat	3435	1.65	0.03	88	1.48	0.16
Topographic ruggedness index at 0.27 km radii (0.23-km^2 scale)	3435	16.48	0.19	88	21.76	1.55
Topographic ruggedness index at 0.54 km radii (0.92-km^2 scale)	3435	17.06	0.18	88	21.62	1.38
Topographic ruggedness index at 1 km radii (3.14-km^2 scale)	3435	18.01	0.17	88	21.82	1.28
Topographic ruggedness index at 3 km radii (28.26-km^2 scale)	3435	20.65	0.16	88	23.74	1.04
Average weekly sage-grouse movement distance (km)	2257	1.17	0.05	47	0.99	0.14

Average flock of sage-grouse	2257	3.71	0.06	47	2.07	0.34

Table 6-2. Model comparison of Cox proportional hazard (Cox PH) models from the parental investment and anti-predator strategy analyses. Models assessed the effects of 4 covariate sets including site-specific change in raptor densities, anthropogenic features, landscape features, and sage-grouse behavior on sage-grouse hen survival. Models were compared with Akaike's information criterion (adjusted for small sample sizes; AIC_c) and Akaike weights (w_i). Data were collected from eight study sites (each 16-km diameter) and four study sites (each 24-km diameter) in southern Wyoming, USA. A total of 427 sage-grouse hens were monitored during 2008–2011.

Models [a,d]	k	ΔAIC_c	w_i	Deviance
Parental investment				
AGE, status, GOEA×$TRI_{0.27}$ [b]	6	0.00	0.96	1039.30
GOEA×$TRI_{0.27}$	3	6.44	0.04	1051.76
AGE, status	3	13.71	0.00	1059.02
Null	0	22.83	0.00	1074.16
Fully saturated	22	24.47	0.00	1031.50
Anti-predation strategy				
Flock^2, flock×AGE, forest distance, GOEA×$TRI_{0.27}$ [c]	8	0.00	0.38	479.86
Flock^2, flock×AGE, forest distance, $TRI_{0.27}$	6	0.36	0.32	484.24
Flock^2, forest distance, GOEA×$TRI_{0.27}$	6	1.63	0.17	485.52
Flock^2, forest distance, $TRI_{0.27}$	4	2.14	0.13	490.06
Flock^2, flock×AGE	4	14.31	0.00	502.22

Flock^2	2	15.27	0.00	507.20
Forest distance, GOEA×$TRI_{0.27}$	4	21.71	0.00	509.62
Forest distance, $TRI_{0.27}$	2	22.75	0.00	514.68
Fully saturated	22	27.03	0.00	478.50
Null	0	39.04	0.00	534.96

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[a] Models with interaction terms included all individual variables within the interactions.

[b] $AIC_c = 1051.32$

[c] $AIC_c = 495.93$

[d] Variables included in final Cox PH model selection included sage-grouse age (AGE), sage-grouse parental investment status (status), average flock size (flock), quadratic of average flock size (flock^2), site-specific change in golden eagle density (GOEA), topographic ruggedness index at 0.27-km radius ($TRI_{0.27}$), and distance to forested habitat (deciduous and conifer stands). The saturated model for sage-grouse survival included year; study site; distance to energy well, communication tower, house, power line, all road, and riparian and forested habitats; and the top selected TRI variable.

Table 6-3. Parameter estimates of sage-grouse survival (as hazard ratios—depicting risk of mortality) from top AIC$_c$ selected Cox proportional hazard model for parental investment analysis with *P*-values and 95% confidence intervals. Data were collected from eight study sites (each 16-km diameter) and four study sites (each 24-km diameter) in southern Wyoming, USA during 2008–2011. A total of 427 sage-grouse hens were monitored during 2008–2011.

					95% CI	
Variable [c]	Estimate	SE	*Z*	*P*	Lower	Upper
AGE	-0.69	0.30	-2.3	0.02	-1.27	-0.11*
Status brooding [a]	0.51	0.28	1.8	0.07	-0.04	1.07
Status nesting [b]	0.45	0.27	1.6	0.10	-0.09	0.99
GOEA	0.14	0.08	1.7	0.09	-0.02	0.31
TRI$_{0.27}$	0.02	0.01	2.2	0.03	0.00	0.04*
GOEA×TRI$_{0.27}$	-0.01	0.00	-2.6	0.01	-0.01	-0.00*

*Denotes a 95% confidence interval that does not include zero.

[a] Sage-grouse survival comparing brooding to non-reproductive hens.

[b] Sage-grouse survival comparing nesting to non-reproductive hens.

[c] Variables included in top AIC$_c$ selected Cox PH model include sage-grouse age (AGE), sage-grouse parental investment status (status), site-specific change in golden eagle density (GOEA), and topographic ruggedness index at 0.27-km radius (TRI$_{0.27}$).

Table 6-4. Parameter estimates of sage-grouse survival (as hazard ratios—depicting risk of mortality) from top 2 AIC$_c$ selected Cox proportional hazard models for anti-predation strategy analysis with *P*-values and 95% confidence intervals. Data were collected from eight study sites (each 16-km diameter) and four study sites (each 24-km diameter) in southern Wyoming, USA during 2008–2011. A total of 427 sage-grouse hens were monitored during 2008–2011.

					95% CI	
Variable [a]	Estimate	SE	Z	*P*	Lower	Upper
Top selected						
Flock	-0.55	0.18	-3.11	<0.01	-0.89	-0.20*
Flock^2	0.03	0.01	3.17	<0.01	0.01	0.05*
AGE	1.26	0.78	1.60	0.11	-0.28	2.80
GOEA	0.15	0.12	1.26	0.21	-0.08	0.38
TRI$_{0.27}$	0.02	0.01	1.61	0.11	-0.01	0.05
Forest distance	-0.15	0.08	-1.76	0.08	-0.31	0.02
Flock×AGE	-0.86	0.48	-1.79	0.07	-1.80	0.08
GOEA×TRI$_{0.27}$	-0.01	0.00	-2.13	0.03	-0.02	-0.00*
Second selected						
Flock	-0.55	0.18	-3.11	<0.01	-0.90	-0.21*
Flock^2	0.03	0.01	3.21	<0.01	0.01	0.05*
AGE	1.23	0.78	1.57	0.12	-0.31	2.76

Forest distance	-0.15	0.08	-1.79	0.07	-0.31	0.01
$TRI_{0.27}$	0.03	0.01	2.72	0.01	0.01	0.05*
Flock×AGE	-0.87	0.48	-1.81	0.07	-1.81	0.07

*Denotes a 95% confidence interval that does not include zero.

[a] Variables included in top 2 AIC_c selected Cox PH models include sage-grouse age (AGE), average flock size (flock), quadratic of average flock size (flock^2), site-specific change in golden eagle density (GOEA), topographic ruggedness index at 0.27-km radius ($TRI_{0.27}$), and distance to forested habitat (deciduous and conifer stands).

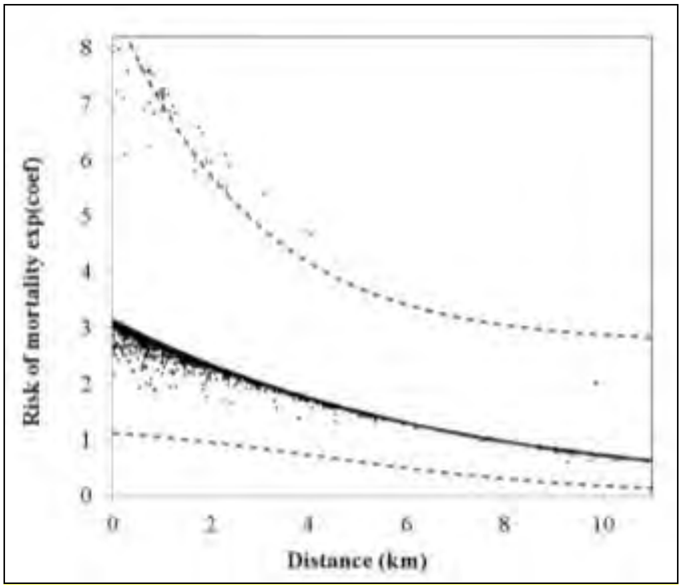

Figure 6-1. Predicted effect with 95% confidence intervals of distance to forested habitat (deciduous and conifer) on sage-grouse hen survival from the top AIC$_c$ selected Cox proportional hazard model from the anti-predation strategy analysis. Predicted effects displayed as the risk of mortality with the y-axis units plotted as exp(coefficient values). All other parameters were held at the mean value. Partial residuals were overlaid on predicted effect plots as solid points. Data from 427 sage-grouse hens were collected from eight study sites (each 16-km diameter) and four study sites (each 24-km diameter) in southern Wyoming, USA during 2008–2011.

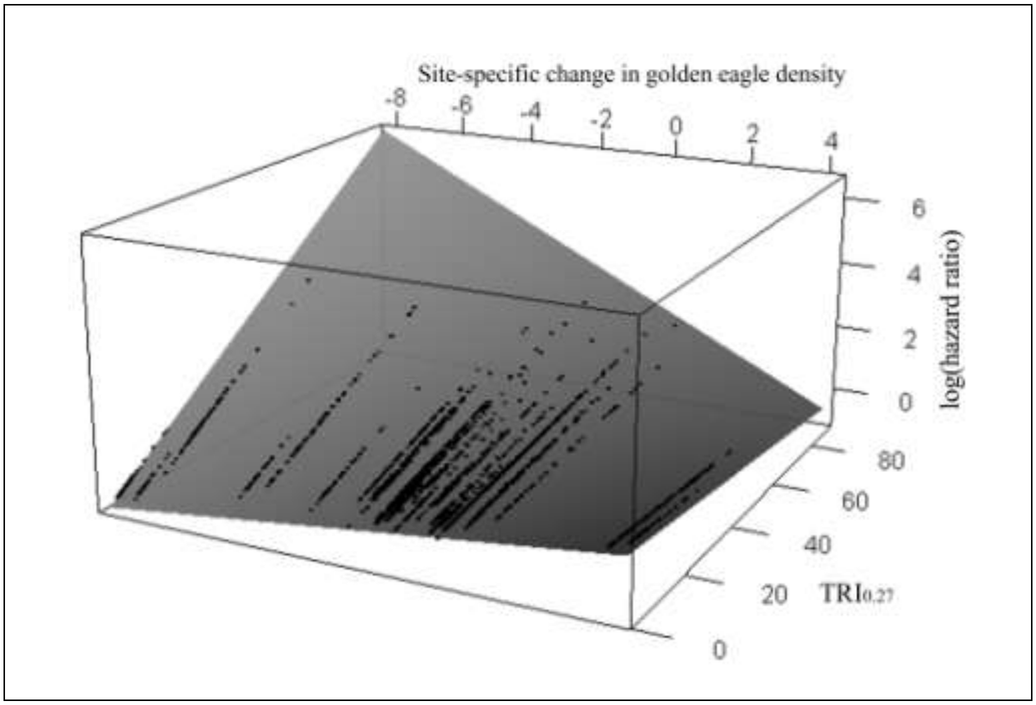

Figure 6-2. Interactive effect of site-specific change in golden eagle density and topographic ruggedness index at 0.27-km radius ($TRI_{0.27}$) on sage-grouse hen survival (as a hazard ratio—depicting risk of mortality) from the parental investment analysis. Predicted effects from the top AIC_c selected Cox proportional hazard model displayed as the risk of mortality with the y-axis units plotted as exp(coefficient values). All other parameters were held at their mean value. Solid points represent observed data overlaid on the predicted surface. Data from 427 sage-grouse hens were collected from eight study sites (each 16-km diameter) and four study sites (each 24-km diameter) in southern Wyoming, USA during 2008–2011.

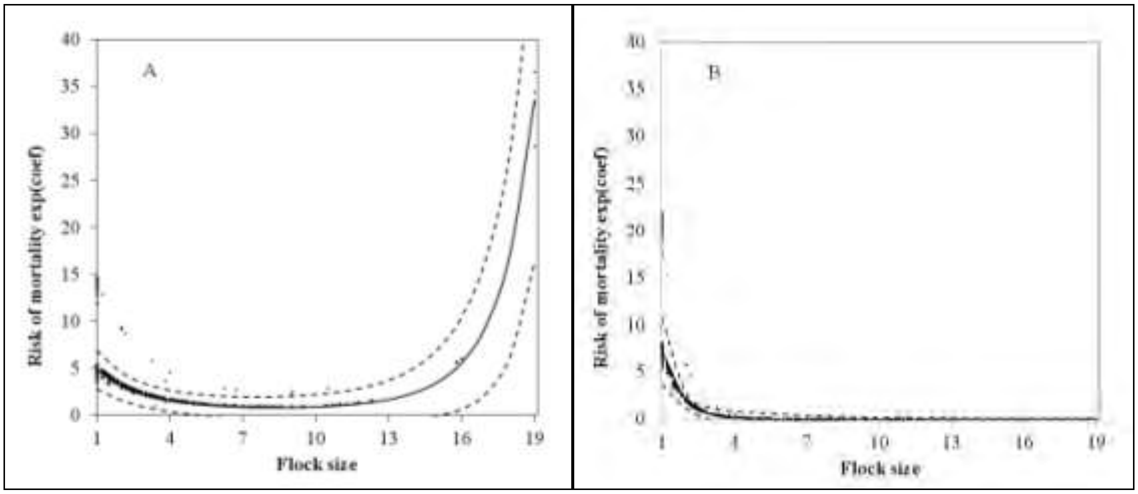

Figure 6-3. Predicted effect of average flock size of sage-grouse hens with 95% confidence intervals from the top AIC$_c$ selected Cox proportional hazard model (from the anti-predation strategy analysis) of sage-grouse hen survival. The model included a quadratic of average flock size and an interaction between flock size and sage-grouse age (adult or yearling). Predicted effects of the average flock size of sage-grouse during the summer for adult (A) and yearling (B) hens. Predicted effects displayed as risk of mortality with the y-axis units plotted as exp(coefficient values). Partial residuals were overlaid on predicted effect plots. Data from 427 sage-grouse hens were collected from eight study sites (each 16-km diameter) and four study sites (each 24-km diameter) in southern Wyoming, USA during 2008–2011.

CHAPTER 7

CONCLUSIONS

There has been a large volume of research on the habitat requirements and population demographic rates of greater sage-grouse (*Centrocercus urophasianus*; hereafter “sage-grouse”) throughout its range (see reviews in Connelly et al. 2004, Connelly et al. 2011). However, there has been little research assessing the influence of predator composition on habitat selection, nest success, and hen survival. Increases in avian predator densities are likely to result in higher depredation rates on sage-grouse nests and reduced chick survival (Evans 2004, Cresswell 2008). Predation has been proposed as a potential threat to sage-grouse populations (Braun 1998); however, there are no predators that specialize on sage-grouse during any life history stage (egg, chick, or adult; Connelly et al. 2011). Hagen (2011) suggested that predation is not limiting sage-grouse populations, and management actions designed to alleviate predation, such as predator removal, may only serve to provide a short-term release of predation rates in fragmented habitats and areas with human-subsidized predator populations. Increases in the human footprint have occurred and are likely to continue throughout most of the range of sage-grouse (Leu et al. 2008), which has increased the abundance of generalist predators throughout the western United States (Andrén 1992, Engel and Young 1992, Boarman et al. 1995, Baxter et al. 2007, Sauer et al. 2011).

In Lima’s (1998) and Cresswell’s (2008) reviews of non-lethal effects of predator-avoidance, they illustrated that presence of a predator had dramatic impacts on use of habitat by prey species. These effects were found to be as great or greater than the effects of direct predation. Thus, the presence of greater abundances of avian predators may induce changes in sage-grouse behavior associated with habitat usage and affect nest success and hen survival. Sage-grouse reduce time off of their nests when they inhabit areas near high abundances of ravens (Coates and Delehanty 2008); thus, in addition to using indirect mechanisms, sage-grouse may be using avian predator abundance directly to evaluate predation risk while nesting. In Chapter 2, I found that sage-grouse were capable of avoiding areas with relatively higher densities of small, medium, and large avian predators—specifically American kestrels (*Falco sparverius*; hereafter; “kestrels”), black-billed magpies (*Pica hudsonia*; hereafter “magpies”), common ravens (*Corvus corax*; hereafter “ravens”), golden eagles (*Aquila chrysaetos*), *Buteo* hawks, and northern harriers (*Circus cyaneus*; hereafter “harriers”)—compared to available sagebrush habitat. My results suggested that sage-grouse avoided avian predators at nest and brood locations on the basis of the size of avian predators rather than individual species identity, equivalence of all species, foraging behavior of predators, or presumed threat to sage-grouse reproductive stage. By selecting habitat with lower densities of avian predators, sage-grouse lower their exposure to avian predation and risk of reproductive failure.

Predation risk trade-offs and non-lethal predator effects, such as avoidance of risky habitats (indirect avoidance) and habitats occupied by greater density of avian predators (direct avoidance; Evans 2004, Verdolin 2006, Cresswell 2008), are mechanisms that explain the differential use of sagebrush habitat (habitat partitioning) by female sage-grouse. High densities of avian predators and close proximity to anthropogenic and landscape features—specifically oil and gas infrastructure, power lines, major roads, riparian habitat, and rugged topography—are likely to result in reduced adult survival and higher depredation rates on sage-grouse nests (Lima 1998, Evans 2004, Cresswell 2008). I found that sage-grouse hens used direct and indirect mechanisms to lower their exposure to predation and nest depredation particularly from avian predators. Sage-grouse use of habitat was negatively connected to avian predator densities with quality sage-grouse habitat presumably having lower densities of small, medium, and large avian predators. In general, sage-grouse avoided risky habitat by directly avoiding areas with higher densities of small, medium, and large avian predators and indirectly by avoiding areas close to anthropogenic and landscape features (see Chapter 3). Similar to previous research, my analyses confirmed that sage-grouse select locations farther away from anthropogenic and landscape features that could be used as perches or provide subsidized food resources for predators, which included oil and gas structures (Aldridge 2005, Holloran 2005, Walker et al. 2007, Doherty 2008, Holloran et al. 2010, Kirol 2012) and major roads (Holloran 2005, Aldridge and Boyce 2007) at all reproductive stages, power lines (Hanser et al. 2011) at brood locations, and riparian habitat (Doherty et al. 2010, Dzialak et al. 2011) at nest locations. I found that sage-grouse also chose flatter locations at nest-sites similar to the findings of Jensen (2006), Doherty et al. (2010), Dzialak et al. (2011), and Kirol (2012). Thus, human manipulation of habitat that structurally changes habitat and promotes greater density of avian predators may limit sage-grouse populations because habitat that has high-quality cover and forage may become functionally unavailable to sage-grouse when avian predator densities are at high levels and anthropogenic features are nearby. Habitat partitioning during vulnerable reproductive stages by female sage-grouse relative to predation risk and food availability was a means for sage-grouse hens to lower their risk of predation and nest depredation, while using habitat to meet energetic requirements of hens and chicks.

As sagebrush habitat is developed, raven occupancy and density will increase in areas adjacent to and overlapping with high-quality sage-grouse habitat. The negative effect of ravens on the nest success of grouse has been well documented (Manzer and Hannon 2005, Bui et al. 2010, Coates and Delehanty 2010). For example sharp-tailed grouse (*Tympanuchus phasianellus*) in southern Alberta had 8-times greater nest success in landscapes with <3 corvids/km^2 as opposed to landscapes with high densities of corvids (Manzer and Hannon 2005). Around Jackson and Pinedale, Wyoming, Bui et al. (2010) found that higher occupancy rates of ravens were correlated with failed sage-grouse nests. Raven depredation on sage-grouse nests was a common occurrence in northeast Nevada based on infrared video cameras set up at nest sites (Coates et al. 2008), and sage-grouse nest success in northeast Nevada was related to the number of ravens per 10-km transect with nest failure rates increasing 7% with every additional raven/10 km (Coates and Delehanty 2010). My results also indicated that sage-grouse nest success was negatively impacted by the presence of ravens near sage-grouse nests (local scale) and higher raven densities at the study site level (landscape scale; see Chapter 4). This suggests that sage-grouse nesting in areas with subsidized raven populations may have suppressed nest success, which may contribute to lower sage-grouse population growth rates.

Coates (2007) studied the effect of raven removal on sage-grouse nest success at 4 study areas in Nevada—1 study area with raven removal and 3 study areas without raven removal. Raven abundance was reduced with DRC-1339 treated-egg baits (Coates 2007, Coates et al. 2007). With every 1 km increase in distance away from raven removal routes, Coates (2007) found that sage-grouse nests were 2.1% more likely to fail, and ravens were 13% more likely to be the culprit. This information provided a good indication that reduction of raven abundance by USDA/APHIS/Wildlife Services (WS) may provide a benefit for sage-grouse nesting in areas with subsidized raven populations. My study verified that WS raven management can reduce the abundance of ravens at a relatively large scale (15-km radius or 706.5 km^2), and sage-grouse nest success was correlated with reduced densities of ravens on the landscape (see Chapter 4).

The management of ravens may be a potential mitigating strategy for areas of low sage-grouse nest success. In some areas, reductions in raven density at a landscape level may increase the amount of functional habitat for sage-grouse. Coates (2007), Bui et al. (2010), and Hagen (2011) suggested that predator removal may provide a short-term release in predation rates within fragmented habitats and areas with subsidized predator populations. However, Hagen (2011) indicated that predator removal will not mitigate sage-grouse population declines throughout the range of sage-grouse. I agree that the positive effects of raven removal for sage-grouse nest success are likely short-lived gains.

In Chapter 4, I monitored WS raven management as it applied to livestock depredation; thus, targeted raven management to benefit sage-grouse may produce better results. However, identification of areas where sage-grouse may benefit from raven removal and implementation of a raven removal program targeted at benefitting sage-grouse will not be an easy task. Management of both breeding and transient ravens will be necessary, which will present many challenges. Predator removal may have a place in sage-grouse management when sage-grouse populations are subjected to high densities of ravens as an interim mitigation measure. However, low reproductive rates may persist in many areas due to compensatory predation by other predators (Coates 2007, Bui et al. 2010). Long-term solutions to reduce human-subsidized raven populations are necessary to address the growing raven and sage-grouse conflict. Reducing raven abundance may be possible through non-lethal means, such as reducing availability of supplemental food (road-kill, dead livestock, and garbage) and nesting and perching structures (oil and gas structures, power lines, telephone poles, communication towers, etc.; Jiménez and Conover 2001). More research needs to be focused on understanding raven population dynamics in sagebrush ecosystems, and how to reduce the utility of anthropogenic subsidies (food and nesting structure) for ravens.

In Chapter 5, I tested the hypothesis that the negative effects of corvids would be amplified in areas closer to potential perches and areas with subsidized food resources (anthropogenic and landscape features). I also evaluated interactive effects between corvid densities and microhabitat. Even though I found a negative effect of the abundance of ravens (nest-site or study-site scale), my results did not suggest any amplifying effect of corvid (raven or magpie) abundance with proximity to any anthropogenic or landscape feature variable. I did not find any evidence that magpies had a negative impact on sage-grouse nest success regardless of the proximity to anthropogenic and landscape features or microhabitat. Similar to Aldridge and Boyce (2007) and Kirol (2012), I did not find any significant correlations between nest success and proximity to anthropogenic development, and there was no evidence of interactive effects between anthropogenic features and corvid densities. Although the landscape features that I assessed represented riskier habitat, I found that nest success was positively correlated with relatively rugged habitat. Rugged terrain, nest-level raven occupancy, and site-level raven density had complex effects on nest success, which has been illustrated as an important factor affecting sage-grouse population growth (Johnson and Braun 1999, Taylor et al. 2012).

Recent research has indicated that sage-grouse hen survival may be the most important demographic parameter driving sage-grouse productivity (Johnson and Braun 1999, Taylor et al. 2012). Effects of anthropogenic and landscape features on survival of sage-grouse hens have not been evaluated in the context of predator communities. In addition, management agencies would benefit from more information on the effects of parental investment and anti-predation strategies on sage-grouse survival, which has not been the focus of sage-grouse research and conservation. Raptors have been identified as significant threats to sage-grouse survival, including golden eagles, *Buteo* hawks, and harriers (Schroeder et al. 1999, Schroeder and Baydack 2001, Danvir 2002). I found that sage-grouse summer survival was negatively correlated with landscape features that represented riskier habitat, especially risk of predation from raptors (see Chapter 6).

Breeding season survival of sage-grouse was negatively impacted by proximity to trees (deciduous and coniferous), more rugged terrain, and golden eagle density when terrain was less rugged. Kirol (2012) also found that terrain roughness was negatively correlated with sage-grouse summer survival in Wyoming. I found lower sage-grouse survival when sage-grouse were exposed to a high density of golden eagles while simultaneously taking topographic ruggedness into account (Chapter 6). I found that the negative effect of topographic ruggedness and golden eagle density was dampened by the combination of greater rugged terrain and high density of golden eagles. Two potential explanations for this finding include 1) rugged topography may provide some refugia from visual predators (e.g., golden eagles), because topographic features such as slight depressions may decrease the effective distance that a raptor can detect a sage-grouse on the ground; and 2) greater density of golden eagles in rugged topography (risky habitat) may competitively exclude other predators. Golden eagles and coyotes are the top predators in sagebrush ecosystems (Mezquida et al. 2006, Hagen 2011), and presence of golden eagles may partially reduce the hunting efficiency of mammalian predators. Thus, landscape features in conjunction with golden eagle density and sage-grouse behavior had dynamic effects on survival. My research also indicated that proximity to anthropogenic features had no effect on sage-grouse survival, and there was no evidence of an interactive effect between anthropogenic features and raptor densities. My sage-grouse survival results also suggest that survival was greater for hens without nests or broods, hens that stayed in intermediate size flocks, and yearling hens.

Many authors have suggested that ground-nesting bird survival, including sage-grouse, is connected to quantity and quality of habitat, and the presence of adequate sagebrush habitat minimizes predator effects on sage-grouse survival (Connelly et al. 1994, Braun 1998, Aldridge et al. 2008, Connelly et al. 2011). I agree with this, but there needs to be careful consideration of interactive effects of anthropogenic and landscape features and predator community dynamics (risk of predation). The aspects of habitat (anthropogenic and landscape features) that present riskier areas for prey species are confounded by the predator composition that reside in those areas. For this reason, management agencies need to understand how interactions among proximity to anthropogenic and landscape features, microhabitat, and the predator community relate to sage-grouse selection of habitat and demographic rates (e.g., nest success and survival). For instance, I found that areas with higher topographic ruggedness had lower sage-grouse survival, which was dampened by high densities of golden eagles. Sage-grouse hens avoided conventional and natural gas wells (Kirol 2012; see also Chapter 3), which placed them in areas with higher topographic ruggedness (natural gas development is typically in flatter areas). However, the overall sage-grouse survival in areas with higher topographic ruggedness was lower. This indicates that changes in sage-grouse selection of habitat in response to anthropogenic features (fragmentation of habitat) can have dynamic consequences for sage-grouse survival, especially when considering differences in predator compositions. Thus, habitat fragmentation of sagebrush habitats has complex effects on sage-grouse use of the landscape, which in turn can have complex impacts on survival. My results highlight the necessity to assess habitat and predator community dynamics concurrently when designing management plans.

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MOSQUITO POPULATIONS IN THE POWDER RIVER BASIN, WYOMING: A COMPARISON OF NATURAL, AGRICULTURAL AND EFFLUENT COAL BED NATURAL GAS AQUATIC HABITATS

By

Melissa Kuckler Doherty

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Approved for the Department of Animal and Range Science

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Melissa Kuckler Doherty
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ABSTRACT

Coal bed natural gas development in northeastern Wyoming has increased surface water in ranching and agricultural areas over undeveloped land. This increase of water increases larval habitat for mosquitoes, potentially increasing adult populations of West Nile virus vector mosquitoes. I compared adult and larval mosquito populations in four different habitat types in the Powder River basin including agricultural, natural, CBNG and upland sagebrush steppe.

Adult mosquitoes were sampled weekly (2004) or bi-weekly (2005) using CDC miniature black-light traps baited with dry ice. A fixed-effect mixed model indicated that in a normal rainfall year (2005) mature CBNG ponds had the highest adult mosquito populations of all sites sampled, and the highest population of the WNV vector *Culex tarsalis*. In a drought year (2004) where total rainfall from May – August was 59% of the seasonal average, agricultural areas had the highest mosquito abundance, likely due to increased irrigation. Adult *Culex tarsalis* tested positive for WNV across the PRB in 2004 and 2005, with highest minimum infection rates in those areas with large *Culex tarsalis* populations.

Larval mosquitoes were sampled bi-weekly from 13 May - 24 August 2005, using a 350 ml dipper in a 20 point vegetated transect along the pond perimeter. Pond vegetation characteristics were recorded between 3 and 17 August including vegetation density, type and class. Larval *Culex tarsalis* were the most abundant mosquito in the region, representing 47.7% of the total sampled population. A fixed-effects mixed model found *Culex tarsalis* produced at similar rates in natural, new, old and outlet CBNG sources; irrigated agriculture produced significantly less ($P \leq 0.02$) *Culex tarsalis* in 2005. New and old CBNG ponds and outlets also produced *Culex tarsalis* over a longer period of time than natural or irrigated agricultural sites.

This study indicates that CBNG ponds are significantly increasing the overall population of vector mosquitoes in the PRB, as well as adding to the duration of larval habitats that would normally be ephemeral. Thus CBNG ponds and associated habitats enhance mosquito abundance and may serve to increase pathogen transmission in an otherwise arid ecosystem.

CHAPTER 1

REVIEW OF RELAVENT LITERATURE

Introduction

The Powder River basin (PRB) includes the Powder River and its tributaries in northeast Wyoming and southeastern Montana. This area reaches east from Gillette, Wyoming, west to the Bighorn Mountains, and north to Miles City, Montana (Environmental Protection Agency 2006) (Figure 1). The PRB is in a semi-arid habitat dominated by sagebrush grassland primarily used for grazing and wildlife management. The dominant shrubs in this system are Wyoming big sagebrush, *Artemisia tridentata wyomingensis* Beetle and Young, and silver sagebrush, *Artemisia cana* Pursh. Smaller patches of native short grass prairie, conifer forest, greasewoods, riparian woodlands and non-native grasses are common throughout the region (Hemstrom et al. 2002; Walker et al. 2004).

Historically, the major industries in the Powder River basin include cattle ranching and coal mining. The latter has now expanded to include coal bed natural gas (CBNG) production (formerly termed coal bed methane). This process extracts natural gas from sub-surface coal seams. Fifteen surface coal mines are located around Gillette, Wyoming, and several large sub-surface coal seams extend west from Gillette toward the Bighorn Mountains (Vicklund 2000). These coal seams contain large amounts of natural

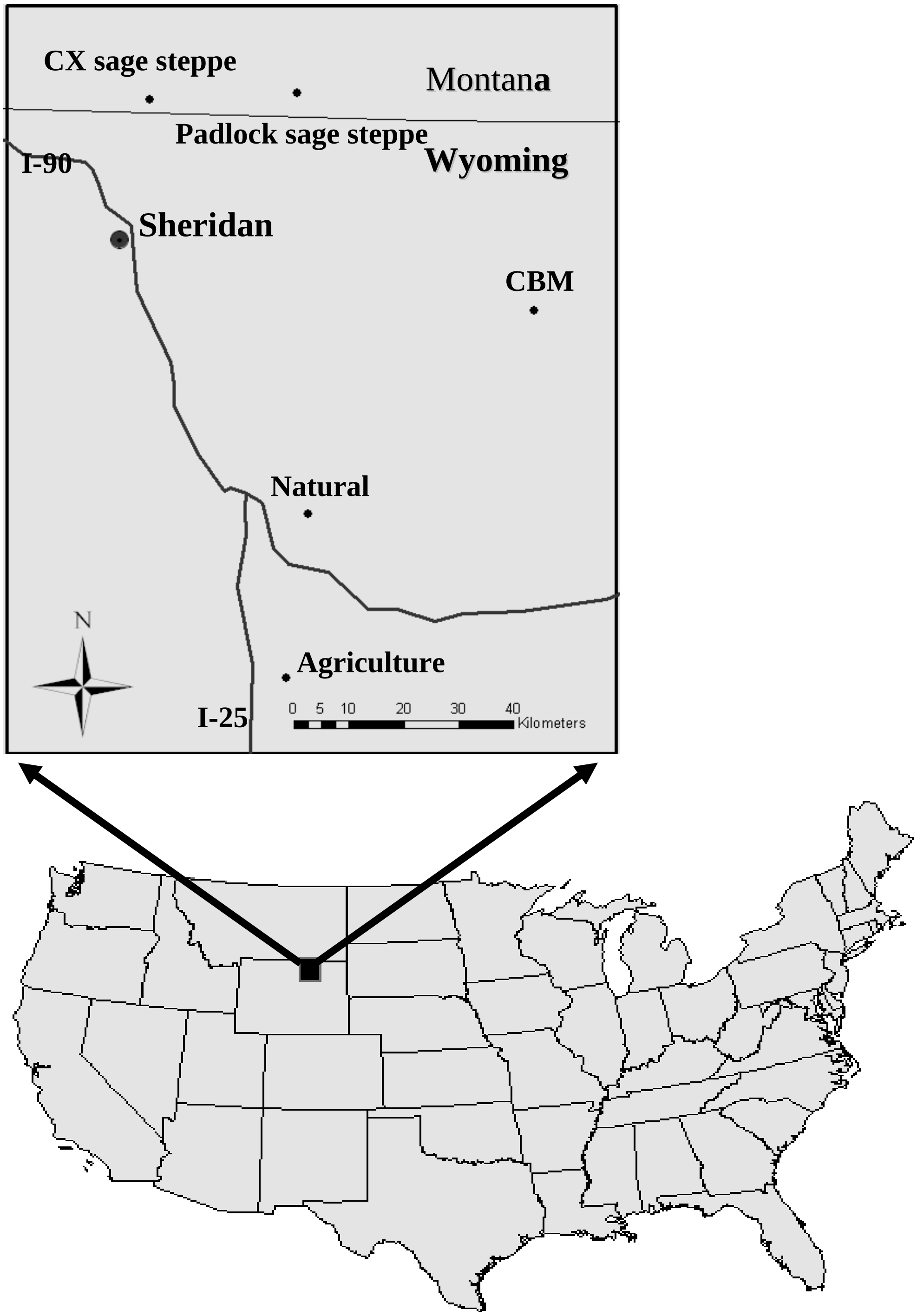

Figure 1. Study site locations for adult mosquito trapping in 2004 and 2005 within the Powder River basin of Wyoming and Montana.

gas (61 Tcf: trillion cubic feet ≈ 1.83×10^{12} cubic meters), which is currently being extracted for commercial use by the natural gas industry at the rate of ≈ 2.33×10^{7} m^3 per day (DOE 2002). Methane extraction includes the removal of groundwater from a coal seam to allow confined natural gas to flow in sub-surface voids. The effluent water is discharged into existing stock ponds, newly constructed ponds, or surface drainages that do not continue in to larger water bodies (Clark et al. 2001). Since 1999, an estimated 19,000 CBNG well heads have been constructed in the PRB, with 20,000 more projected in the next ten years, each of which will produce an estimated 400 barrels of discharge water per pond per day (DOE 2002; USGS 2000). A recent GIS study on mosquito habitat in the PRB indicates that CBNG development has increased potential mosquito larval habitat by 75.2% from 1999 to 2004 (Zou et al. 2006). This corresponds with a recent land-use change study in the same region that indicates a 9-fold increase in surface water in ranching areas, and a 2-fold increase in surface water in agricultural zones (Naugle et al. unpublished data).

Concerns have been expressed by the public as well as local natural resource agencies regarding the environmental impacts of CBNG, including surface disturbances from roads, wells, power lines and ponds; dewatering of local aquifers, and methane discharge water quality (Regele and Stark 2000). While these ponds do provide water to native wildlife and habitat for migratory duck species, CBNG ponds have the potential to produce mosquitoes that could transmit pathogens such as West Nile virus (WNV). An increase in mosquitoes and pathogen transmission in the PRB could pose a health risk to human, livestock and native wildlife in the region. The research project reported here was initiated to monitor WNV in 2003 after the first sage-grouse was detected with WNV in Northeastern Wyoming. My objectives were to assess adult and larval mosquito population trends as well as the impacts of CBNG development on mosquito populations in areas of sage-grouse use in the PRB.

West Nile Virus

Historical Distribution

West Nile virus is an encephalitic virus and a member of the Japanese encephalitis group in the genus *Flavivirus*, family Flaviviridae. WNV is closely related to both eastern equine encephalitis (EEE) and Saint Louis encephalitis (SLE), which are endemic to North America. West Nile virus was first isolated from a febrile woman near the Nile River in Uganda in 1937, and has since caused large human epidemics in Africa, Europe and Asia (Smithburn et al. 1940; Baqar et al. 1993). Human outbreaks of WNV have been documented in southern France in 1962, southern Russia in 1963, Belarus in 1977, the Ukraine in 1985, Romania in 1996, the Czech Republic in 1997 and again in Russia in 1999 (Hubalek and Halouzka 1999). These outbreaks have been geographically associated with wetlands and flooding from heavy rains and are more likely to occur in the summers of warm, wet years.

Eurasian and African outbreaks of WNV have been closely associated with ornithophilic mosquitoes. The virus has been isolated from 43 Old World species of mosquitoes in the genera *Culex* and *Aedes* including the trans-Atlantic species *Culex pipiens* L. and *Aedes aegypti* L. (Hubalek and Halouzka 1999). The primary Old World vectors of WNV include *Culex univittatus* Theobald in Africa, *Culex modestus* Kamimura and Wada and *Culex pipiens* in Europe, and *Culex quinquefasciatus* Say in Asia (Hayes 2005). Further research has shown that WNV is enzootic in wild birds migrating between Africa and Asia, and these animals are considered the primary vertebrate hosts for this disease in the Old World (Hayes 1989). Mammals, reptiles and amphibians do not play a large role in maintaining transmission cycles in natural populaions in the Old World; although, horses, lemurs and frogs have been shown to obtain transmissible infection rates in the laboratory (Rodhain et al. 1985).

North American Distribution

West Nile virus was first detected in the Western Hemisphere in New York City in the summer of 1999. That year, there were 62 human infections in the New York City area, and 7 deaths. Since its introduction to North America, WNV has spread westward across the United States, as well as into Canada, Mexico and parts of the Caribbean (Rochrig et al. 2002).

It is not known how WNV was introduced into the U.S. in the initial 1999 outbreak of WNV in New York City. Speculations regarding WNV transmission to New York include movement of infected mosquitoes via air transportation, illegal importation of exotic birds, lost migrant birds and possible terrorist acts. Biologists confirmed mortalities due to WNV infections in 18 species of native and non-native birds in 1999 including more than 3,000 American crows (*Corvus brachyrhynchos* Brehn). It had been anticipated that, among birds, corvids would be most vulnerable to the virus, as they were highly susceptible to WNV infection via mosquito bites, and had mortality rates >40%

once infected (Hayes 2005; Steele et al. 2000). Since 1999 WNV has spread at a rate of approximately 67 km per month throughout the spring and summer, and now has been found in 284 species of birds in North American (Rappole and Hubalek 2003; CDC 2006). The rapid spread of WNV and its annual reoccurrence in native biota indicates that it will likely remain an enzootic disease in North America.

As of the October 2007, there had been 24,447 human cases of WNV in the United States, with 920 fatalities (CDC 2007). Of the 4,146 reported human WNV cases in the U.S., 71% were neuroinvasive, 28% were uncomplicated West Nile fever, and 6.8% were fatal (O'Leary et al. 2004). The median age for fatal cases in the U.S. is 77.5 years, with the fatality-to-case ratio increasing significantly with age. The risk of WNV is also significantly higher in males among middle aged (>40 years) and elderly individuals, with the fatality-to-case ratio 1.3 times higher for men > 70 years old (O'Leary et al. 2004).

There are several methods used by monitoring agencies in the United States for detecting WNV in the environment. These methods include 1) pooling collected adult mosquitoes for virus detection, 2) collecting dead birds for virus detection, 3) drawing and testing of sentinel chicken blood for antibodies indicating exposure to WNV, and 4) testing non-human mammal serum for WNV antibodies (primarily equine) (Morris et al. 1994). Data collected in 2002 using these methods indicated that 72% of primary detections were from virus-infected dead birds, 18% were from non-human mammals, 6% were from infected mosquitoes, and 2% were from sentinel birds (O'Leary et al. 2004). While it seems that dead bird surveillance is the most effective monitoring technique for WNV surveillance, it is more effective in densely populated areas where dead birds are noticed and reported to the proper authorities. In rural areas, methods such as mosquito monitoring and use of sentinel chickens are the most effective methods for disease monitoring. Dead bird surveillance may become a less effective form of virus monitoring in the future if native bird species acquire immunity to WNV through repeated exposures.

Northeastern Wyoming Distribution

West Nile virus was first documented in Wyoming on 18 August 2002 in a horse in Goshen County, three years after WNV was found in New York. This case, along with reports of two infected humans and 95 other horse cases were reported in the fall of 2002 (Wyoming Department of Health 2006). In 2003 a major outbreak of WNV occurred throughout the western United States including Wyoming, Montana and Colorado. In 2003 Wyoming had a total of 393 human and 230 horse cases, with 10 human fatalities (Table 1).

On 24 July 2003 WNV was detected in a radio-collared greater sage-grouse, *Centrocercus urophasianus urophasianus* Aldrich, hen on the Montana/ Wyoming border. That summer 18 sage-grouse died from WNV among radio-marked individuals in four populations in the western US and southern Canada, creating a 25% average decline in survival for this time period (Naugle et al. 2004). Late-summer survival of sage-grouse in the northern PRB was markedly lower at 1 site with confirmed WNV mortalities (20% survival) than at 2 sites without (76% survival) (Walker et al. 2004). Moreover, declines in male and female lek attendance at the WNV site in spring 2004 indicated that outbreaks have threatened local populations with extirpation (Walker et al. 2004). In 2004 WNV spread to sage grouse populations in Colorado and California, and female survival in late summer was 10% lower at 4 sites with confirmed WNV mortalities (86% survival) than at 8 sites without WNV (96%). West Nile virus mortality decreased to 2% during the cool summer of 2005 (mean temperature = 19ºC), increased again in 2006 when hot temperatures (mean temperature = 22ºC) returned in 2006 (D. Naugle, University of Montana, unpublished data).

Wildlife Susceptibility to West Nile Virus

Historically, the impact of emerging diseases on wildlife populations has not been given much notice by the general public. However, attention has been elevated around WNV outbreaks in wildlife populations because of its potential threat to human health. While we do not know how WNV spread into the Western Hemisphere, we know that wildlife disease emergences historically are amplified by changes in host pathogens or the environment (Daszak et al. 2000). Often these changes introduce pathogens to naïve hosts who have no natural resistance. In the case of WNV, almost all of our North American wildlife fauna was naïve to infection, and it is unknown which species will acquire resistance through immune response (i.e., antibody production); which will become amplifying hosts to the pathogen; and which will remain susceptible.

Clinical Symptoms in Wildlife

West Nile virus is an encephalitic pathogen that affects the brain and neural tissues, causing bleeding, fever, and cell death in infected animals. In general, birds are more susceptible to this virus than other groups of animals. Clinical signs of this disease in birds include weight loss, head tremors, blindness, ataxia, weakness in the legs, and seizures. Birds that survive a WNV infection may have neural damage as well as damage to the pancreas, kidney, and heart (Steele et al. 2000). Detection of WNV in avian carcasses can be done through necropsies of natal bird organ tissues or oral and cloacal swabs, followed by vero cell plaque assays and confirmatory RT-PCR assays to detect WNV (Komar et al. 2002). WNV has also been found in ovarian and testicular tissues in birds, suggesting that infected adults may be able to pass an infection to their offspring, or so-called vertical transmission (Komar et al. 2003).

Avian Susceptibility

While many different species of birds have been found to be infected with WNV, only those that have high viremias can be considered amplifying hosts. Certain birds are the only known amplifying hosts for this pathogen in the Western Hemisphere. In order for a feeding mosquito to become infected, a bird must have a viremic titer of at least $10^{7.1}$ plague forming units (PFU/ml) (Komar et al. 2003). Birds that have been challenged with WNV in the laboratory, and have reached sufficient titers to serve as an amplifying host include those of the orders Passeriformes (perching birds), Charadriiformes (wading shore birds), Strigiformes (owls), and Falconiformes (diurnal birds of prey) (Molaei et al. 2006). Birds able to sustain high viremic levels have a high susceptibility to the disease. Mean infectiousness was ranked for reservoir competence by Komar et al. (2003). The blue jay (*Cyanocitta cristata* L.), the common grackle (*Quiscalus quiscula* L.), the house finch (*Carpodacus mexicanus* Muller) and the

American crow were the top four species of 25 tested as competent reservoirs for WNV in southern California. Of these birds, blue jays and American crows transmitted the virus between infected animals and non-exposed cage mates through fecal and salivary secretions with a cage transmission rate of 1.0 (on a 0 – 1 scale) for both species (Komar et al. 2003). This may have contributed to the high infection rate and mortality seen in the field, because both of these species of birds have social or semi-social behaviors. Young, altricial birds may also be more exposed to mosquito feeding due to incomplete feather covering and immobility. Colonial species, such as the American white pelican *Pelecanus erythrorhynchos* L., may occupy habitats near mosquito production areas, which increases exposure to juvenile birds, and may concentrate the mosquito-avian amplification cycle in some areas (Rocke et al. 2005).

Sage-grouse infected with WNV show symptoms similar to other avian groups. Radio-marked grouse rarely move more than a few meters during the two days before death, and have a weak flight when flushed (Walker et al. 2004). Intact sage-grouse that died from WNV were often found facedown in good condition with no external signs of trauma. Infected grouse may also be at elevated risks of predation, potentially contributing to a reduced survival rate in 2004 and 2005. A total of 363 sera samples were taken from wild grouse across Wyoming, Montana and Alberta; in 2004 and none tested positive for WNV antibodies, indicating that these birds had not yet developed an immune response to this pathogen (Naugle et al. 2005).

Mammal Susceptibility

Equines, as well as several other domestic animals have exhibited WNV symptoms. These symptoms include symmetrical or asymmetrical ataxia, staggering, stumbling, toe dragging, leaning, and wide-based stance (McLean et al. 2002). The strain of WNV that occurs in North America is particularly virulent in horses, causing a clinical infection rate of 42% in seropositive animals and a death rate of 36% in those animals with clinical symptoms (Bunning et al. 2002). A vaccine is available to protect equines from WNV, and its use has greatly reduced the WNV morbidity and mortality. Other mammals that have been experimentally tested for WNV infections include dogs, cats, cattle, sheep, chickens, turkeys, domestic geese, pigs, and goats. None of these animals, including horses, has been found to carry a virus titer high enough for them to serve as amplifying hosts for the New York strain of WNV (Bunning et al. 2002; Austgen et al. 2004; McLean et al. 2002). Many of these animals, including house pets such as dogs and cats, have been found to develop antibodies to this disease, and occasionally mild symptoms such as lethargy and a loss of appetite occur. These symptoms are not debilitating and may go unnoticed (Austgen et al. 2004).

Most wild mammals in the New World appear to be resistant to WNV. Some species including several lagomorphs carry high viremias without showing clinical symptoms, indicating they may serve as reservoir hosts within their range. The majority of those mammals that have been challenged with WNV in the laboratory do not get viremias higher than $10^{7.1}$ PFU/ml, which is the level required for acquisition of virus by a feeding mosquito (Bunning et al. 2002; Austgen et al. 2004). An exception to this is the cottontail rabbit (*Sylvilagus floridanus* L.), which carried WNV titers of $\geq 10^{4.3}$ PFU/ml for approximately 2.2 days (Tiawsirisup et al. 2005). Cottontail rabbits do not show clinical signs of infection and are able to infect *Cx. pipiens* and *Cx. salinarius* with minimum estimated infection rates of 11.5/ 1000 ± 5.5 and 20.5/ 1000 ± 6.4% respectively (Tiawsirisup et al. 2005). While little research has been done on their role in WNV amplification in the field, cottontail rabbits, as well as other lagomorphs, are widespread across the Western Hemisphere south of Canada, and may play a role in virus amplification or virus overwintering in some systems.

West Nile Virus Implication for Wildlife

The effects of WNV on wildlife populations are virtually unknown for any species in the Western Hemisphere. However, research is being conducted to determine which species will experience the greatest consequences from this disease (Marra et al. 2004). The sage-grouse and other birds that are already under stresses due to habitat changes from CBNG, may need additional conservation management in areas affected by WNV to sustain current population levels. There is also some indication that scavenger and predatory species may contract WNV from consuming infected prey, and their populations may be at risk in outbreak years (McLean et al. 2002). Domestic cats presented with up to three infected mice contracted WNV from consuming infected carcasses in the laboratory (Austgen et al. 2004), and there have been several incidental cases of predatory birds such as Cooper’s hawks (*Accipiter cooperii* Bonaparte) and great horned owls (*Bubo virginianus* Gmelin) succumbing to WNV after consuming infected prey in the wild (McLean et al. 2002). As more research is done on WNV epidemiology in natural systems, we will be able to build better models to assess risk factors to wildlife populations, and be more equipped to make informed decisions for wildlife management.

West Nile Virus Vector Biology

Since its appearance in the western United States in 2002, WNV has been one of the most important vector-borne diseases in the region. The competency of the local mosquito vector *Cx. tarsalis*, public and equine health risks, and threat to native wildlife populations has generated many research programs to investigate the biology and ecology of mosquitoes and epidemiology of WNV. We now have a basic knowledge of regional vectors and mosquito infection rates in North America, and are continuing to learn about the regional methods of over-wintering and competent reservoir hosts.

The primary mode of transmission for WNV in North America is by the bite of an infected mosquito. In the United States, WNV has been isolated from 60 mosquito species; however, many of these species are not bridge vectors for this pathogen (Turell et al. 2001, Molaei et al. 2006). Mosquitoes that are bridge vectors must feed on both avian and mammalian hosts forming a link between the amplifying and susceptible hosts (Riesen and Reeves 1990). These are the mosquitoes of greatest concern for human health.

The isolation of WNV from a mosquito does not necessarily mean that a mosquito species is capable of transmission. Primary vectors are insects that are (1) physiologically competent to acquire virus from an infected host and transmit to a susceptible host, (2) are frequently infected with a virus in nature, and (3) naturally occur in areas that are foci for virus transmission (Molaei et al 2006). These insects must feed on both avian and mammalian hosts, and disseminate virus through the midgut in order to transmit virus through the salivary gland. Vector mosquitoes spread WNV between amplifying hosts, thus amplifying the virus in the ecosystem.

In North America, there are fewer than 10 species of mosquitoes that are considered bridge vectors for WNV (Turell et al. 2001). *Culex pipiens* is considered a moderately efficient vector of WNV, and is the primary vector of WNV in the northeast and midwest along with *Culex restuans* and *Culex salinarius* Coquillett (Nasci et al. 2001, Molaei et al. 2006). *Culex pipiens* has the highest percentage of reported positive pools in the United States, 57% in 2001 and 47% in 2002. Outbreaks of Saint Louis encephalitis have been reported in humans with minimum infection rates of 3 per thousand, indicating that this species of mosquito has the ability to spread encephalitic viruses at low infection rates (Nasci et al. 2001). After 2002, infection rates have dropped yet this species remains in the top three for percentage of total positive pools in the U. S. (Hayes 2005).

In the southeastern United States, the southern house mosquito, *Cx. quinquefasciatus,* is a bridge vector of WNV with 51.4% of total positive mosquito pools from the U.S. in 2004 (Hayes 2005). While this species was considered a low to moderate vector of WNV in a laboratory study, its abundance and preference to feed on both birds and mammals make it a competent vector for WNV in the southern U. S. (Turell 2005). *Culex quinquefasciatus* has also been found to undergo non-viremic transmission between infected and non-infected mosquitoes feeding simultaneously on naïve mice, with infection rates as high as 5.8% (Higgs et al. 2005). No detectable viremia was found in the host mice after feeding, and transmission was thought to be through high virus titers secreted in mosquito saliva while feeding at high densities. This phenomenon has not been described in the field or in other vector species of mosquitoes in North America. Non-viremic transmission may however explain high WNV infection rates within the *Cx. quinquefasciatus* geographical range, as the mosquito infection rate could increase much faster if mosquitoes are able to obtain WNV infections by feeding adjacent to an infected mosquito rather than having to obtain an infected bloodmeal from a viremic host.

Other species of mosquitoes that may be important vectors of WNV in the United States include *Culex restuans* Theobald, *Culex nigripalpus* Theobald and *Culex salinarius* Coquillett (Turell 2005). These species are all found in the eastern United States, and have been found to be competent WNV vectors under laboratory conditions.

The most common mosquitoes in the PRB of Wyoming and Montana include the floodwater mosquitoes *Aedes vexans* Meigen, *Aedes melanimon* Dyar, and *Aedes dorsalis* Meigan, and *Cx. tarsalis*, a species which colonizes newly-created surface pools. Each of these species has a unique life history as both immature and adults which allow them to survive in this region. I will first discuss basic mosquito biology, and then describe species-specific characteristics.

Larval Distribution

Immature mosquitoes pass through four larval stages in aquatic habitats before pupating and emerging as adult mosquitoes. Each species of mosquito has different habitat requirements for optimal development ranging from flooded grasses to stagnant wastewater treatment plants. Within a given body of water, microhabitats may exist that support different species of mosquitoes. A study in Iowa found that temporary pools supported *Cx. tarsalis*, *Cx. pipiens* and *Ae. vexans*, while intermittently flooded vegetation areas around the perimeter of their study site included species such as *Anopheles punctipennis* Say, *Culiseta inornata* Williston and *Cx. pipiens* (Mercer et al. 2005). Of the total larval mosquito population within their study areas, 65.7% of mosquitoes were found in temporary pools with intermittently flooded and permanently flooded areas providing habitat for the remaining 34.3%. Open-water habitats contained no mosquito larvae in this study, and generally provide habitat for very few mosquitoes in wetland areas (Thullen et al. 2002). Factors such as vegetation density, dissolved nitrogen content, organic matter, and phosphate availability contribute to the productivity of a wetland for mosquito development, and the availability of these resources in any given microhabitat may be the determining factor on the species that will live in that habitat (Lawler and Dritz 2005; Jiannino and Walton 2004).

Laboratory results show that mortality among larvae at densities greater than 500 per mosquito rearing pan was increased by 60% in *Cx. tarsalis, Cx. restuans* and *Cs. inornata* (Buth et al. 1990). A shorter development time due to warmer water temperatures reduced mortality under laboratory conditions, but was not seen in the field, likely due to fluctuating ambient temperatures. *Culex tarsalis* and *Cs. inornata* occurring concurrently under natural conditions can have higher densities than single species populations, indicating that these two species may fill different niches within the same aquatic environment (Fanara and Mulla 1974).

Adult Dispersal Patterns

Distribution of adult mosquitoes after eclosion vary both among species and environmental conditions. Mosquito flights have been classified as migratory, appetential and consummatory, and commence for one of five reasons: (1) resting sites, (2) carbohydrate sources, (3) blood meals, (4) ovipositional sites, or (5) mates (Bidlingmayer 1985, Service 1997). Migratory flights have been observed in *Cx. tarsalis* in southern California in pre-diapausal insects including unidirectional flights of up to 17.7 km (Bailey et al. 1965). This type of dispersal may be common in the Powder River basin where overwintering habitat is sparse. Appetential flights are upwind searching flights for olfactory host clues, mates or carbohydrate sources (Bidlingmayer 1985). Once a food source or mate is detected, consummatory flight begins in which a food source is sought and consumed. In cases where food sources are sparse, adult mosquitoes may fly several kilometers in the appentential flight mode, often moving long distances from their original larval habitat. Cases have been observed where high larval densities have also increased dispersal distances by newly emerged adults spiraling several meters upwards in an attempt to catch wind currents (Bailey et al. 1965). In any case, once a mate and or blood meal is found, appentential flight mode begins again in search of a suitable oviposition site based on a species individual needs.

One of the main reasons that *Cx. tarsalis* is such an efficient vector of WNV in the western United States is that it feeds on both birds and mammals. A study conducted in central California indicates 97.2% of all blood-fed mosquitoes in the spring fed on host birds, whereas between May and October, 58.5% of blood meals were from avian hosts, and 41.4% were from mammals (Tempelis and Washino 1967). This shift in feeding habits is most likely due to avoidance behavior by avian host species or the relatively high availability of mammalian over avian hosts in late summer when altricial nestling birds have fledged (Kilpatrick et al. 2006). A shift in feeding hosts may contribute to the spread of WNV among mammals (Kilpatrick et al. 2006).

After a female mosquito takes an infected blood meal, a specific amount of time called the extrinsic incubation period (EIP) is required before that insect is capable of transmitting the virus. The EIP is dependent on the species of vector mosquito, virus replication rate and ambient weather temperatures. The movement of adult mosquitoes to cool, shaded resting places during the day, and subsequent host-seeking behaviors at night allows them to maintain themselves in a thermal environment with lower temperature variation than in the surrounding habitat (Meyer et al. 1990). This may reduce the EIP in insects that occupy environments with a wide range of maximum and minimum temperatures. *Culex tarsalis* in southern California had an estimated EIP of 5-7 days at 28ºC, which would allow for virus transmission within 1 – 2 gonotrophic cycles (Riesen et al. 2006). Reisen indicates that virus activities in the western United States were closely linked to above-average temperatures in 2004 and 2005, where EIP's were likely reduced to a point where transmission could occur after two gonotrophic cycles and viremic mosquitoes were more prevalent in the environment.

Information regarding EIP and temperature relationships has been used to create a predictive model for WNV outbreaks based on degree-day accumulations over time. In a hot year (2003), this model predicted the WNV cases in Wyoming with a 91.3% total accuracy, and was 65.2% accurate in 2004, which was relatively cool and dry (Zou et al. In press). Predictive modeling such as the proceeding degree-day model may be useful in the future to forecast WNV outbreak in high risk areas along with proper surveillance.

Mosquitoes have several different survival strategies for overwintering in cool climates. Some species over-winter as adults in diapause, others lay eggs that remain viable over the winter, and several species survive the winter as larvae (Clements 1992). Mosquitoes that over-winter as adults have a higher rate of survival if they enter diapause directly, rather than taking a blood meal first. Female mosquitoes are stimulated to enter diapause by short day lengths and low water temperatures as early instar larvae (Tauber and Tauber 1976). As these mosquitoes prepare for dormancy the development of the primary ovarian follicles stops and production of trypsin and chymotrypsin-like proteases that are used for digesting bloodmeals are reduced (Tauber and Tauber 1976; Robich and Denlinger 2005). These females switch from blood meals to sugar gluttony shortly before entering diapause as a way to increase hypertrophy of the fat bodies before winter (Robich and Denlinger 2005). The only exception to this is when females take a blood meal and develops fat body rather than eggs, a process called gonotrophic disassociation. This is the only known way that an adult mosquito can over-winter WNV without undergoing vertical transmission of the disease (Turell et al. 2002).

Species Specific Biology

Culex tarsalis. *Culex tarsalis* is a widely distributed mosquito species preferring rural areas west of the Mississippi River from Canada into Mexico. This species is a highly efficient vector of WNV, and it has remained one of the top four species of mosquitoes in the United States for total positive pools since WNV spread west of the Mississippi River in 2002 (Hayes 2005, Turell 2005). This species of mosquito has been widely studied throughout its range because of its ability to transmit pathogens such as WNV, St. Louis encephalitis, and western equine encephalitis between birds and mammals. *Culex tarsalis* was the only species of mosquito collected in abundance in the PRB that regularly takes both avian and mammalian blood meals, and thus it has the most veterinary and medical importance.

Culex tarsalis populations have been reported to have high numbers of host-seeking females in August and September in northern climates, as their populations build though the summer from over-wintered females (Knight et al. 2003). *Culex tarsalis* emerges from diapause during the spring, seeks a bloodmeal and completes a gonotrophic cycle. Adults mate in large swarms at dusk, with males copulating each evening, and most females mating 1-2 days post emergence (Riesen et al. 2002). Females lay eggs on the surface of freshwater pools in rafts of 100 eggs or more, seeking out suitable ovipositional habitats by using non-volatile chemical cues (Isoe et al. 1995). Some of the ovipositional cues that female *Cx. tarsalis* use include flooded and decomposing grasses, cattle manure and aquatic bacterial composition. *Culex tarsalis* larvae have been observed at highest densities in vegetation cover dominated by cattails (*Typhia* spp.) root masses and high stem density (Walton et al. 1990). The eggs that are laid are not drought resistant and will hatch several days after being deposited depending on environmental conditions. (Clements 1992)

Larvae of *Cx. tarsalis* are found in newly flooded habitats, and are often the first species of mosquito to colonize a water source (Fanara and Mulla 1974). Flooded areas with high percentages of plant cover, like saltgrass, have the highest larval populations of *Cx. tarsalis* in California, and this affinity for colonizing freshly flooded grasslands probably is true for this species throughout its range (De Szalay and Resh 2000). The two factors that were found to be most significant in predicting larval abundance of this mosquito in California include maximum water temperature and pond age with newly flooded habitats as the most productive. In this system, duck ponds are flooded annually to provide waterfowl with winter habitat, and gravid *Cx. tarsalis* females are the first mosquito species to utilize this resource. This behavior may be initiated to avoid predators who take 3-4 weeks to reach abundance levels that have a significant effect on larval mosquito populations (Walton et al. 1990). The range of temperatures that are optimal for larval *Cx. tarsalis* development in the laboratory is between 10°C and 37°C, with a mean of 32°C (Fanara and Mulla 1974). The development time for *Cx. tarsalis* larvae under natural conditions ranges from 19.8 to 25.3 days in Southern Manitoba, and may be shorter in warmer climates (Buth et al. 1990).

Adult females are opportunistic feeders, taking bloodmeals from either birds or mammals (Gunstream et al. 1971). *Culex tarsalis* are crepuscular/ night feeders, and spend most of their days resting under vegetation (Turell et al. 2005). The highest activity levels of host seeking females occurs between 10 PM and 1 AM (Bast 1961; Knight et al. 2003; Riesen et al. 1997). In the spring and early summer, females preferentially seek avian blood meals, many of which are from nestlings (Blackmore and

Dow 1958). Catches of host-seeking *Cx. tarsalis* are found at highest densities in traps surrounded by elevated vegetation, and lowest over tree snags, open water, sandbars and in urban areas. In areas of southern California surrounding the Salton sea, proportions of blood meals taken from avian hosts were directly related to the density of host seeking females. Abundances of host seeking females may preferentially feed on young altricial birds in the nest, which have few defensive behaviors. These birds however quickly mature and develop defensive behaviors to reduce insect feeding (Lothrop and Riesen 2001; Bast 1961). This leads to a change in feeding behavior by *Cx. tarsalis* from birds to mammals in the late summer and fall (Gunstream et al. 1971). Those insects that have been infected with WNV in the early summer may transmit the virus to humans and horses by this shift in feeding.

Laboratory studies indicate that 74-100 of *Cx. tarsalis* become infected with WNV after taking blood meals with $10^{7.1}$ PFU/ml, which is a common virus titer in many North American birds (Goddard et al. 2002). These infected mosquitoes have an estimated WNV transmission rate of 81 and 91% after ingesting blood-meals containing $10^{6.5}$ and $10^{7.3}$ PFU/ml respectively (Turell et al. 2002b). A female *Cx. tarsalis* requires 35-40 days between egg cycles, and in northern climates they average 2.6-2.9 generations per season (Buth et al. 1990). This requires female mosquitoes to acquire an infected blood meal in her first gonotrophic cycle, survive at least 35 days, and then probe a susceptible host such as a human, horse or sage-grouse to transmit virus.

Culex tarsalis must either be re-infected with WNV each spring while taking a bloodmeal, undergo diapause as an infected adult or vertically transmit virus from gravid female to egg. Laboratory studies have shown vertical transmission from infected females to F_1 progeny with a minimum mosquito infection rate of 6.9 per thousand; however, this mechanism was not seen in all *Cx. tarsalis* samples tested, and may change between local populations (Goddard et al. 2003). This overwintering mechanism is most likely coupled with others such as reservoir hosts and infectious migratory birds, with variations in composition between regions.

Culex tarsalis is the primary vector for several encephalitic diseases including western equine encephalitis, Saint Louis encephalitis in the western United States, and West Nile virus (Knight et al. 2003). These pathogens are amplified in the enzootic cycle between birds and mosquitoes, most likely among passeriform birds. Encephalitic diseases can affect humans and domestic mammals; however, they are dead end hosts to the pathogen, not developing high enough viremias to infect subsequent feeding mosquitoes.

Aedes vexans. *Aedes vexans* is a floodwater mosquito commonly found around flood irrigation systems and spring snowmelt locations across North America (Knight et al. 2003). This species of mosquito is a crepuscular/ night feeder that prefers to take blood meals on large mammals such as cattle and white-tailed deer, and is rarely collected with evidence of an avian blood meal (Gunstream et al. 1971; Turell 2005). Females of this species lay individual eggs in moist soils subject to flooding. Floodwater mosquitoes, such as *Ae. vexans*, have desiccation-proof egg shells that allow an embryo to survive long periods in a dry environment. Eggs with this adaptation can remain viable for several years and will be stimulated to hatch when the right environmental and physical conditions such as flooding and snowmelt occur (Clements 1992). These eggs must undergo a period of desiccation prior to inundation in a low oxygen environment as well as exposure to cold to stimulate hatching (Bates 1970).

Laboratory and field-testing indicate the *Ae. vexans* is not a primary vector of WNV in North America although studies indicate that they do transmit the pathogen at low rates (Turell et al, 2001). *Aedes vexans* is not an ornithophagic mosquito, and thus is unlikely to obtain WNV from a viremic bird. Laboratory testing has shown that even after being orally challenged with an infected blood meal, these insects were refractory to infection with dissemination rates of 8%. Of those insects where virus passes through the midgut, 100% were able to transmit virus to a new host, and would be a potential vector in the field (Turell et al. 2001). *Aedes vexans* can transmit western equine encephalitis virus in the western United States. These cases are also incidental as WEE is amplified by avian hosts in the same manner as WNV except when secondary amplification cycles occur involving small mammals such as hares (*Lepus americanus* Erxleben), and ground squirrels (*Spermophilus richardsoni* Elegans) (Knight et al. 2003).

*Aedes dorsalis.* *Aedes dorsalis* is a floodwater mosquito that is often attracted to ephemeral areas with high salt contents for oviposition (Knight et al. 2003). This species of mosquito is found as adults throughout the summer in the western and northeastern United States and southern Canada (Darcie and Ward 1981). *Aedes dorsalis* requires habitat that is relatively wet, and is common in areas flooded by snowmelt and irrigation events in dryer climates. Host-seeking females are considered opportunistic blood feeders, and take a majority of their blood meals from large mammals. They prefer to feed at night, but they will feed during the day if a suitable host enters their resting area (Turell et al. 2005).

Aedes dorsalis is not considered a primary vector of WNV in North America but is involved in WEE transmission in some parts of their range (Gunstream et al. 1971; Turell et al. 2005). Research in California indicates that *Ae. dorsalis* as well as *Ae. melanimon* and *Ae. campestris* can perpetuate a secondary transmission cycle of WEE among mammals, especially lagomorphs (Riesen et al. 1998). Larvae of *Aedes dorsalis* have tested positive for WEE in the lab at low rates, indicating vertical transmission which would allow for virus overwintering.

<u>*Aedes melanimon*</u>. *Aedes melanimon* is a floodwater mosquito found across the western United States and southwestern Canada (Darsie and Ward 1981). This species lays eggs in areas of flooded vegetation with gonotrophic cycle, varying from 4 to 5 days (Jensen and Washino 1991). Female *Ae. melanimon* feed on mammals including cattle and humans, seeking hosts at dusk. This species of mosquito has high adult survivorship and abundance across the summer, along with a short gonotrophic cycle length all of which contribute to the increased probability of obtaining and disseminating a pathogen by an individual vector (Goddard et al. 2002).

The CDC considered *Ae. melanimon* a competent vector for WNV in the United States although it is not considered a primary vector (CDC 2006; Goddard et al. 2002). *Aedes melanimon* has been implicated as a secondary vector of WEE in parts of California because of its contribution to the amplification and transmission of a secondary virus cycle in cottontail rabbits (*Sylvilagus floridanus*) in WEE outbreak years

(Jensen and Washino 1991). The primary vector for WEE in the western U. S. is *Culex tarsalis*, with wild bird populations serving as the basic viral reservoir (CDC 2006). *Culex tarsalis* may also feed on mammalian hosts and transmit WEE, providing an opportunity for *Ae. melanimon* to acquire the WEE pathogen. *Ae. melanimon* that obtain a bloodmeal on WEE infected mammalian hosts can quickly transmit the WEE pathogen through the susceptible host population including horses and humans, thus creating a secondary transmission cycle absent of primary vectors and hosts.

Mosquito Control Strategies

Tactics used for mosquito control in the United States include chemical, biological and physical control mechanisms. Each of these tactics has positive and negative attributes that should be assessed on a case by case basis before being implemented. These attributes are cost, environmental effects, duration of control, and ease of use.

Biological control includes the introduction and conservation of natural mosquito predators to maintain mosquito populations at a reduced level. This incorperates the introduction of invertebrate and vertebrate predators such as Coleoptera adults and larvae, Odonata adults and larvae as well as several predatory fish species. Invertebrate predators such as naiad Odonata and Notonectidea can significantly reduce larval mosquito populations in habitats that are greater than 1 month old, and become increasingly effective at controlling mosquito populations in mature ponds (Riesen et al. 1989; Walton et al. 1990). *Mesocyclops longisetus* Thiebaud and *Macrocyclops albidus* Jurine have been introduced in Louisiana rice fields, marshes and ditches to effectively control

Anopheles spp. and *Culex quinquefasciatus* (Marten et al. 1994). Although these invertebrates may not eliminate mosquito populations, they may be used to suppress populations in small aquatic habitats.

Vegetation management in larval mosquito habitats is also a viable mosquito control strategy in some situations, especially in man-made or intensively managed aquatic habitats. Methods used in vegetation management include burning aboveground plant material, intermittently thinning, deepening of shallow areas to reduce emergent vegetation and turning soils of ephemeral habitats during dry seasons. In general, opening densely vegetated areas reduces mosquito habitat while increasing the habitats of mosquito predators and wildlife species (De Szalay and Resh 2000; Batzer and Resh 1992; Jiannino and Walton 2004). Specifically, if densely vegetated areas are modified to contain small hummocks of emergent vegetation dispersed within deepened open water, mosquito refuge is decreased while predator habitat is increased. This results in adult mosquito emergence 100- and ten-fold lower in hummock and thinned treatments than in densely vegetated control treatments (Thullen et al. 2000). This practice allows for mosquito management while maintaining wildlife habitat without the use of pesticides or labor-intensive annual treatments.

Fish have been used extensively across the United States for mosquito larval control purposes for more than 50 years with varying effects (Walton 2007). The most commonly stocked fish is the mosquitofish (*Gambusia affinis* Baird and Girard and *Gambusia halbrooki* Girard), but there has been some interest in the use of native fishes for mosquito control purposes (Knight et al. 2003). Mosquitofish are effective predators in man-made environments, however they do not over-winter well in cool climates making them difficult to maintain in some areas (Cech and Linden 1987). Where mosquitofish are stocked they are efficient predators of mosquito larvae in habitats that contain little or no vegetation, however both fry and adults have a higher survival rate in areas with vegetation to act as shelter from predators (Walton 2007). Dense floating vegetation, as well as decaying emergent vegetation provides cover for mosquito larvae, and reduces the efficacy of the mosquitofishes biocontrol abilities (Berkelhamer and Bradley 1989). Other fishes that have been tested for larvivorous activity include the Sacramento blackfish (*Orthodon microlepidotus* Ayres), Pacific blue-eye (*Pseudomugil signifier* Knar), and the killifish (*Rivulus marmoratus* Poey) with varied results (Taylor et al. 1992; Willems et al. 2005). Many of these fishes are effective predators at the juvenile stage, and then move on to larger prey as they grow. These species may be valuable in an integrated pest management program where the juveniles are allowed to control mosquito populations at a given period of their development, and then other control measures are used for the subsequent portion of the mosquito season.

Pesticide use, including adulticides and larvicides, is common in urban areas with high mosquito populations, and has been used as a preventative measure in parts of the PRB. Larvicides are more effective at controlling mosquito populations because larvae are in a confined area compared to widely dispersed like adults. Products such as *Bacillus thuringiensis* var. *israelensis* (Bti) are microbial larvicides that disrupt the insect's digestive system, and provide a 90-100% reduction in *Ae. vexans* and *Culex* spp.(Berry et al. 1987, Russel et al. 2003). Larviciding oils are also used as a larviciding material, controlling mosquito larvae and pupae by creating a thin film on the water surface that disrupts the insect's ability to obtain atmospheric oxygen through its siphon. Larviciding oils are most effective in habitats with little emergent vegetation and little wind (Lampman et al. 2000). Products such as Golden bear have a LD_{50} activity of 3.6 µl/ 54 cm^2 and have an activity time of more than 16 hours in the field (Lampman et al. 2000).

Mosquito adulticides are often distributed as a mist or aerosol, using aerial application, truck foggers, or backpack foggers in areas of high adult mosquito density (CDC 2006). Some products that are commonly used by the mosquito control industry are pyrethrins and 5% malathion (AMCA 2006). These products can be very effective, but require specific environmental conditions for proper use including wind speed, temperature and humidity and do not have long term treatment effects. These conditions often make adulticides less effective than larval treatments, and many mosquito abatement districts choose to use these products as a back-up to larval treatments.

Ponds from coal bed natural gas development in the Powder River basin vary in shape, size, vegetation cover and maturity. Regardless of their individual mosquito production, as a whole they greatly increase the potential for mosquito abundance in this region. Recent research comparing the mosquito abundance of various pond types in Delaware indicate that shallow sided, highly vegetated habitats produce the largest number of mosquito larvae overall (Gingrich et al. 2006). Mosquito abundance in the PRB will most likely be highest in those habitats that remain wet throughout the season, and have a high density of vegetation around the shorelines. Those CBNG ponds that fit this description may be very productive, while newer ponds may take time to develop these mosquito production characteristics. Finding ways to reduce mosquito production in existing ponds, and modify the design of future ponds to reduce their utility as larval mosquito habitat may greatly decrease the overall mosquito production of the PRB, and reduce the risk of WNV transmission among humans, livestock and wildlife in this region.

CHAPTER 2

ADULT MOSQUITO ABUNDANCE AND WEST NILE VIRUS INFECTION RATES IN NATURAL, AGRICULTURAL AND COALBED NATURAL GAS PONDS

Introduction

West Nile virus was first detected in Wyoming on 18 August 2002, resulting in 96 equine, 2 human and 17 avian cases across the state by the end of the year. An epidemic occurred in 2003, with 393 human cases and 9 fatalities, 230 positive horses, and 182 confirmed bird deaths (Table 1) (Wyoming Department of Health 2006). Of those cases, 23.4% of the human and 19.5% of the equine reports in Wyoming were from Sheridan, Johnson and Campbell counties, all within the geographic boundaries of the Powder River Basin (PRB). The PRB has been under development for coal bed natural gas (CBNG) extraction for the past 16 years, with the majority of development taking place after 1996. This development includes the creation of effluent CBNG ponds. Prior to 2003 no quantitative or qualitative data regarding mosquito production had been collected from these ponds. However there is concern over the potential they may produce putative vectors of WNV and have a negative impact on human, equine, and wildlife health.

The 2003 WNV outbreak included the first reported case of WNV in a greater sage-grouse (*Centrocercus urophasianus*; “sage-grouse”) near Spotted Horse,

Table 1. 2002 and 2003 West Nile Virus infections in Wyoming by County. The counties of the Powder River Basin (*italics*) account for 30% of the human WNV cases in Wyoming in 2002, and 70% in 2003 (Wyoming Department of Health 2006).

County	Human Infections		Human Deaths		Horse Infections		Avian Infections		Total Infections	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Albany	0	5	0	0	0	5	0	19	0	29
Big Horn	0	4	0	0	8	22	0	1	8	27
Campbell	***0***	***71***	***0***	***1***	***9***	***15***	***1***	***16***	***10***	***102***
Carbon	0	1	0	0	2	3	0	2	2	6
Converse	0	19	0	0	0	16	0	2	0	37
Crook	0	9	0	0	1	2	0	0	1	11
Fremont	0	24	0	1	4	54	0	7	4	85
Goshen	2	89	0	3	41	3	13	64	56	156
Hot Springs	0	4	0	0	0	4	0	1	0	9
Johnson	***0***	***8***	***0***	***0***	***1***	***13***	***2***	***2***	***3***	***23***
Laramie	0	31	0	1	11	15	0	26	11	72
Lincoln	0	0	0	0	0	0	0	0	0	0
Natrona	0	28	0	0	4	11	0	24	4	63
Niobrara	0	4	0	0	1	2	0	0	1	6
Park	0	6	0	0	4	27	0	6	4	39
Platte	0	62	0	2	4	7	1	10	5	79
Sheridan	***0***	***13***	***0***	***0***	***4***	***17***	***0***	***5***	***4***	***35***
Sublette	0	1	0	0	0	2	0	0	0	3
Sweetwater	0	0	0	0	0	2	0	3	0	5
Teton	0	0	0	0	1	0	0	0	1	0
Uinta	0	0	0	0	0	0	0	0	0	0
Washakie	0	2	0	0	0	4	0	1	0	7
Weston	0	12	0	1	1	6	0	0	1	18
Total	2	393	0	9	96	230	17	189	115	812

Wyoming, causing a 75% decline in the local radio collared population (Naugle et al. 2004). These mortalities were closely associated with sage-grouse habitats undergoing development for CBNG extraction, including the development of holding ponds for effluent water extracted in the drilling process. This research project was developed to quantify the differences in mosquito populations when aquatic habitats (e.g., CBNG ponds) are increased on the landscape, and the infection rates of WNV vectors in this region. I hypothesized that the presence of CBNG impoundments in the PRB will be associated with a greater abundance of larval and adult mosquitoes, specifically *Culex tarsalis*.

My primary objective in 2004 was to quantify the adult mosquito populations in five different types of aquatic habitats that were suspected of producing mosquitoes in the PRB, Wyoming. In 2005, I continued to sample adult mosquito populations in four of the 2004 study sites. I also compared larval mosquito production and vegetation habitat characteristics in each of these study sites to test for differences in larval mosquito production in the available aquatic habitats in the PRB (Chapter 3).

Materials and Methods

Field Methods

Experimental Design. In 2004 and 2005 adult mosquitoes were collected using battery operated CO_2-baited CDC miniature black light traps (John W. Hock Company, Gainsville, FL). Lights were removed from the traps to exclude non-mosquito fauna. Traps with approximately 1 kg dry ice were set out in the evening and programmed to turn on at dusk and operate until collection the next morning. Upon retrieval, adult mosquito samples were transported on wet ice until they could be euthanized with tri-ethylamine and stored at -10°C for later processing (identification and virus assay).

Individual trap sites were randomly selected from aquatic habitats identified using hardcopy USGS EROS data center landsat telocomposit 7,4,3 band combinations (red, green, blue) for each study area. These color bands highlight riparian habitats when viewing satellite imagery maps (Randy McKinley USGS, personal communications). Forty- five trap sites were selected in 2004 between five different study areas in Campbell and Johnson counties, Wyoming. These sites included natural (7 sites), and irrigated agriculture water sources (8 sites), sagebrush steppe (2 study areas, 20 sites) and a combination of mature and new coal bed natural gas ponds (10 traps). Adult mosquitoes were sampled twice weekly from 11 July – 9 September (Julian dates 193 – 253). Some missing samples were due to weather and landowner restrictions.

Adult mosquitoes were sampled from 20 trap locations in 2005 in Campbell and Johnson Counties, Wyoming. The total number of trap sites was reduced in 2005 because sagebrush steppe study areas were omitted to allow time for larval sampling, and adult collections in 2004 were very low. These trap locations were in four different study areas including natural water sources, irrigated agriculture, mature CBNG ponds, and new CBNG ponds. Each site was randomly selected from those sampled in 2004 for a total of 5 ponds per study site. Light traps were placed in habitats between emergent aquatic vegetation and flooded grasses whenever possible based on the vegetation characteristics at each individual pond. When these habitats were not available, light traps were placed within 2 m of the shoreline near shallow water. Light traps were set bi-weekly in each study area from 15 May - 23 August (Julian dates 134 – 246). Larval samples were taken the day adult traps were set.

Study Sites

The research area was split into five blocks in 2004, each representing a unique aquatic habitat in the PRB. These sites included; 1) developed CBNG, 2) irrigated agriculture, 3) undeveloped sagebrush steppe, 4 and 5) (Figure 1). In 2005, I modified the design and selected 1) mature CBNG ponds, 2) new CBNG ponds, 3) irrigated agriculture and 4) sagebrush steppe under CBNG development. These study areas were chosen for their current land use, proximity to radio-collared sage-grouse habitats, landowner cooperation and aquatic habitat resources. A detailed description of each site follows:

Sagebrush Steppe under CBNG Development. Sagebrush steppe under CBNG development (natural water sources) was sampled in 2004 and 2005 and included springs, drying river beds, oxbow lakes, and stock ponds. Qualifying stock ponds were not artificially filled from anthropogenic sources (e.g., CBNG water). These natural ponds were part of the PRB landscape prior to CBNG development in northeastern Wyoming. The ponds used in this block were in a study area located 24 km south of Buffalo, Wyoming off Interstate 90 (13T 0390639, 4917115, elevation 1220 m) in land grazed by cattle during the course of the study. Water sources in this area are ephemeral. They are filled with runoff from snowmelt and rain water early in the season and then become dry in mid to late summer. Several small rainstorms occurred throughout the summer, allowing these aquatic habitats to stay wet into August in 2005, but precipitation was insufficient either field season to fill natural depressions to early spring levels.

Aquatic vegetation was sparse around natural water sources in northeastern WY due to the ephemeral nature of natural springs in this dry environment. Average vegetation cover around the natural water sources sampled was 63% (n=5), which included bluebunch wheatgrass (*Pseudoroegneria spicata* Pursh), western wheatgrass (*Agropyron smithii* Rydb), prairie junegrass (*Koeleria macrantha* Ledeb), blue grama (*Bouteloua gracilis* Vasey), Japanese brome (*Bromus japonicus* Thunb.), cheatgrass (*Bromus tectorum* L.), crested wheatgrass (*Agropyron cristatum* L.), sage brush (*Artemisia* spp.) and cattail (*Typha* spp.).

Sagebrush Steppe with Limited CBNG Development: CX Ranch. This site was north of Sheridan, Wyoming on the Montana/ Wyoming border (13T 0348842, 4990002, elevation 1120 m). Upland sagebrush-steppe habitat in the PRB was dominated by Wyoming big sagebrush (*Artemisia tridentata wyomingensis* Beetle) and intermixed native and non-native grasses such as bluebunch wheatgrass (*Pseudoroegneria spicata* Pursh), western wheatgrass (*Agropyron smithii* Rydb), prairie junegrass (*Koeleria macrantha* Ledeb), blue grama (*Bouteloua gracilis* Vasey), Japanese brome (*Bromus japonicus* Thunb), cheatgrass (*Bromus tectorum* L.) and crested wheatgrass (*A. cristatum* L.). Plains silver sagebrush (*Artemisia cana cana* Pursh) was also present in drainages but at much lower abundance. This sagebrush-steppe habitat has limited CBNG development. The few CBNG ponds that are present are approximately 1 acre in size, shallow, and subject to heavy cattle use. Light traps were set in 2004 near naturally occurring water sources (5 traps), and in upland sage areas (3 traps) where sage-grouse were radio-tracked in high densities in 2003 and 2004. This area was not sampled in 2005.

Sagebrush Steppe with Limited CBNG Development: Padlock Ranch. This study area is north of Sheridan Wyoming on the Montana/ Wyoming border and east of the CX ranch (13T 0380795, 4984181, elevation 1160 m). No CBNG ponds are currently filled in this area. Naturally occurring water sources include man-made stock ponds, overflowing stock tanks and one naturally occurring ephemeral pool. The sites of proposed CBNG ponds are known in this study area, and several of our 2004 light traps were placed where CBNG ponds will be located once gas extraction starts. This area was not sampled in 2005.

Irrigated Agricultural Water Sources. Agricultural water sources included small ponds and ditches from flood irrigated agricultural such as hay and alfalfa. Study locations were (1) 32 km south of Buffalo, Wyoming on interstate 25 (13T 0361201, 4897075, elevation 1550 m), (2004 and 2005) and (2) 8 km east of Buffalo, Wyoming on Wyoming highway 16 (2005 only). Water sources for flood irrigation included Upper Crazy Woman Creek, and Clear Creek in privately managed fields. In 2004, two flood irrigation events occurred the weeks of May 27th and June 25th (Julian dates 147, 176). In 2005, one flooding event occurred from June 8th – June 10th, based on the regular irrigation practices of the landowner (Julian date 159 – 161). After each irrigation event, water persisted in 3 of 5 impoundments throughout the season, while the remaining 2 evaporated within two weeks (personal observational). Aquatic vegetation in agricultural water sources (n=5) were predominately cattails (*Typha* spp.) with various rushes (*Juncaceae* spp.).

Mature Coal Bed Natural Gas Ponds. Mature coal bed natural gas ponds were located around Spotted Horse Wyoming, on Wyoming highway 16 (13T 0436498, 4948103, elevation 1.23 km). Mature CBNG ponds received effluent CBNG water for ≥ 5 years and vegetation covered more than 50% of the shoreline. Many of these ponds were previously used as livestock watering ponds by private landowners and were excavated and enlarged to accommodate larger water influxes from CBNG development. Effluent water from CBNG development was added to these ponds at various rates, maintaining relatively stable water levels throughout the field season. Vegetation cover ranged from 45.6% to 89% between ponds, including sedges, rushes, forbs and flooded upland grasses, with an average vegetation cover of 54.5%.

New Coal Bed Natural Gas Ponds. New CBNG ponds were also located near Spotted Horse Wyoming, on Wyoming highway 16 (13T 0433045, 4949482, elevation 1.2 km). These ponds received effluent CBNG water for ≤ 5 years and vegetation covered less than 50% of the shoreline. Several of these ponds were also former stock ponds, and were recently excavated for effluent CBNG water storage. Other ponds were constructed specifically for CBNG water use and were occasionally used for livestock watering. Many of these ponds are continuously filled with water from CBNG wells and maintained relatively constant water levels with the exception of one pond (Smith pond) where water level fluctuated several feet over the course of the summer. Average vegetation cover per sampling point was 21%, and was predominately flooded upland grasses, algae and forbs.

The CX upland sagebrush-steppe and padlock upland sagebrush-steppe study sites were combined to represent one upland sagebrush habitat block in the final statistical analysis after preliminary statistical tests indicated no significant differences between these study sites for variables tested.

Laboratory Methods

Mosquito samples were stored at -10°C and sorted on a laboratory chill table (BioQuip 1431) using a 63–500x stereomicroscope. All mosquito specimens collected in 2004 were identified to genus using the key of Darcie and Ward (1981), with putative WNV vectors in the *Culex* or *Aedes* genera identified to species for Padlock and CX Ranch upland sagebrush-steppe areas by members of USDA ARS Arthropod-Borne Animal Disease Research Laboratory (ABADRL) in Laramie, Wyoming. *Aedes* and *Culex* mosquitoes captured from other study areas in 2004 and all study areas in 2005 were sorted to species.

RNA extractions for WNV were conducted on pools of female mosquitoes in 2004 and 2005 by USDA ARS ABADRL. A maximum of 50 and minimum of 20 specimens were tested per pool with a total of 923 pools in 2004 and 244 in 2005. Those light trap collections that contained < 20 mosquitoes of the same species were pooled with other samples for the same trapping location in a given month. If 20 insects were not collected from a trap site in a month, the pool was run with < 20 specimens, and is later noted as such.

RNA extraction was conducted with the RNeasy 96 kit (Qiagen, Valencia, CA). Samples were ground in liquid nitrogen, mixed with 1 mL buffer RLT and centrifuged at 8000 x *g* for 10 minutes. Half of the supernatant was stored at -80 °C, and the remaining was used in the extraction according to manufacturer's specifications. Approximately 50 µL of eluate was recovered per sample and stored at -20 °C until used in the TaqMan assay. RT-PCR was run (Lanciotti et al. 2000) on the ABI Prism 7000 sequence detection system with TaqMan one step RT-PCR master mix reagents (Applied Biosystems, Foster City, CA, USA). Primer and probe combinations (DNA Technologies Inc., Coralville, IA, USA) were then synthesized (Lanciotti et al. 2000; Lanciotti and Kerst 2001). Positive samples from the WNENV primer/ probe were tested with the WN3'NC primer/ probe set. Pools were considered positive when CT values were <37, and the normalized fluorescent signal (Rn) was 2x greater than the average of eight non-template controls for both primer/ probe sets.

Statistical Methods

Data from the 2004 and 2005 field seasons were analyzed separately due to differences in study designs and data collection protocols. Differences in adult mosquito abundance between habitat types were analyzed in SAS PROC MIXED by species with a generalized mixed effect linear model. In 2004, the sagebrush-steppe study areas were combined to represent one upland sagebrush steppe habitat after an initial PROC MIXED model was run and no significant differences in mosquito populations were found between sampling sites. Because sequential mosquito counts can be serially-correlated and mosquito counts estimated for the same habitat closer in time are more likely to be correlated than measures more distant in time, I modeled the appropriate covariance structure that best represented the data in SAS PROC MIXED (Littell et al. 1996, 1998). The covariance structure is derived from variances at individual times and correlations between measures at different times on the same habitat (Littell et al. 1998). I used a compound symmetry (CS) error structure where all measures at all times have the same variance and all pairs of measures on the habitat have the same correlation (Littell et al. 1996). SAS PROC MIXED is a generalization of a standard linear model and data are permitted to exhibit correlation and nonconstant variability (SAS 8.2 online doc.). I used the REPEATED statement in PROC MIXED to model the covariation within habitats, which accounts for the violation of independence of the observations on the same pond at different times (Littell et al. 1998). The RANDOM statement was used to model the variation between habitats, which accounts for heterogeneity of variances from individual ponds (Littell et al. 1998). The random effects factor was the sub-sample of ponds within treatment group that were randomly chosen from all available ponds in the study area. In this manner, my results are able be to extrapolated to all ponds in the study area. All other factors in the model were fixed effects. Maximum likelihood methods were then used to fit a mixed-effects (both random and fixed effects) general linear model in SAS PROC MIXED.

Minimum infection rates of mosquito pools were calculated using the Pooled Infection Rate add-in for Microsoft Excel® (Biggerstaff 2006). Infection rates were first calculated for each species, and then re-grouped and analyzed by study area and study site for those species found to have positive pools in a given year.

Weather data were obtained from the United States National Weather Service archival climatological data for Sheridan, Wyoming (National Weather Service 2006). Average monthly temperatures from May-August were recorded, including the departure from normal. Precipitation data were recorded as monthly totals including the departure from normal, as well as the number of days with 0.02, 0.3, 1.3, and 2.5 centimeters or more of rainfall.

Results

2004 Mosquito Collections

A total of 38,543 adult mosquitoes representing 10 taxonomic groups were sorted from 554 trap nights in 2004. *Culex tarsalis* accounted for 37% of the total catches, followed by *Ae. dorsalis* (31.4%), *Ae. vexans* (16.7%), *Ae. melanimon* (10.9%), *Psorophora* spp. (1.6%) and *Ochleratatus* spp, (1.9%). *Cu. inornata*, *Cx. pipiens*, *Culiseta* spp., *Anopheles* spp. each comprised ≤ 1% of the catches (Figure 2).

Total mosquito collections in 2004 varied by site (DF = 3, 587, F = 3.00, *P* = 0.03), and weeks (*P* = 0.0001), with highest weekly collections in the months of May and June. Overall, more mosquitoes were collected from irrigated agriculture sites in 2004 than any other study area with an average of 171.6 (SE = 27.0) specimens collected per trap night. CBNG and natural areas averaged 109.0 (SE = 24.4) and 163.1 (SE = 27.2)

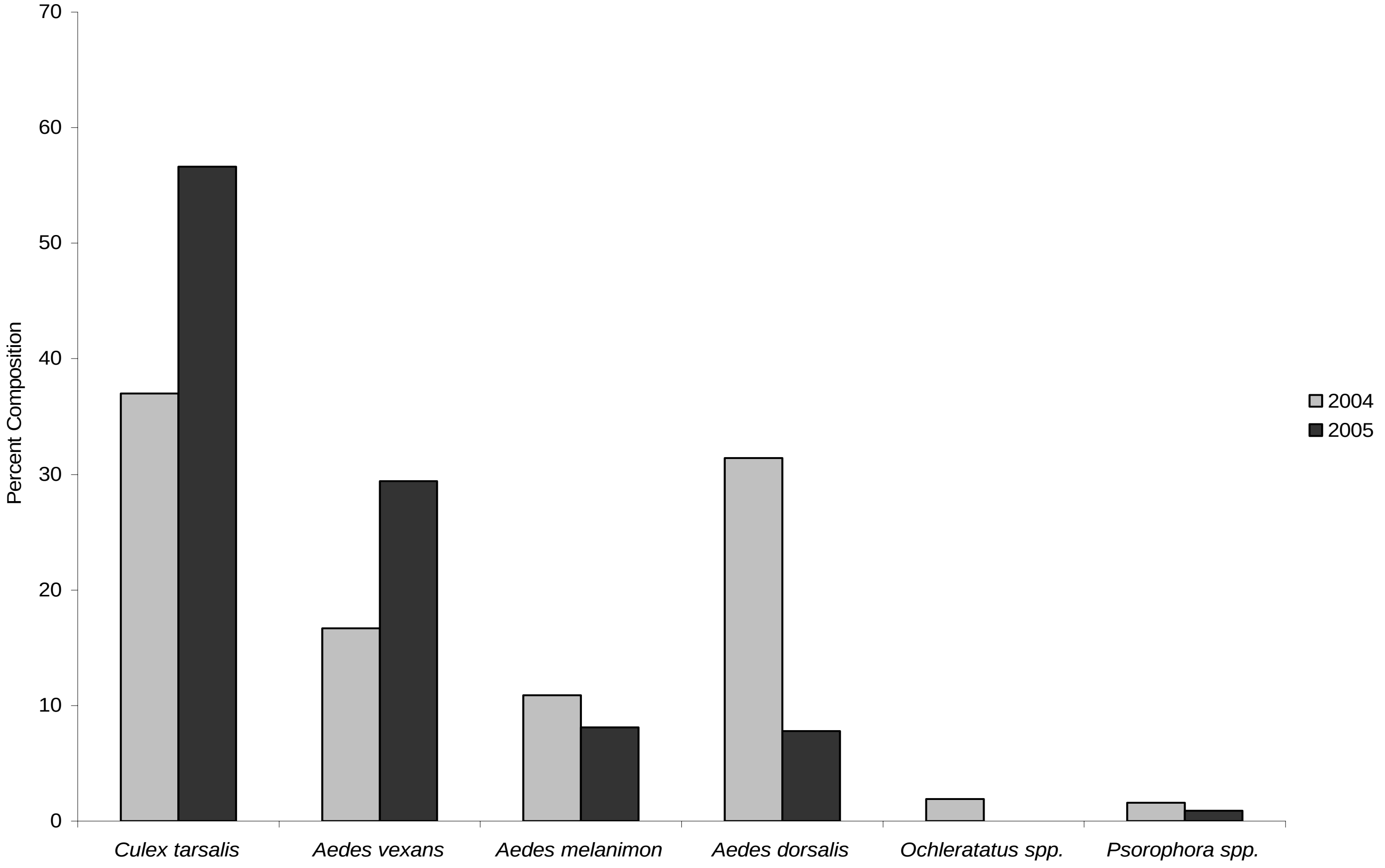

Figure 2. Percent composition of adult mosquito species collected by CDC black light traps, Powder River Basin, Wyoming 2004 and 2005.

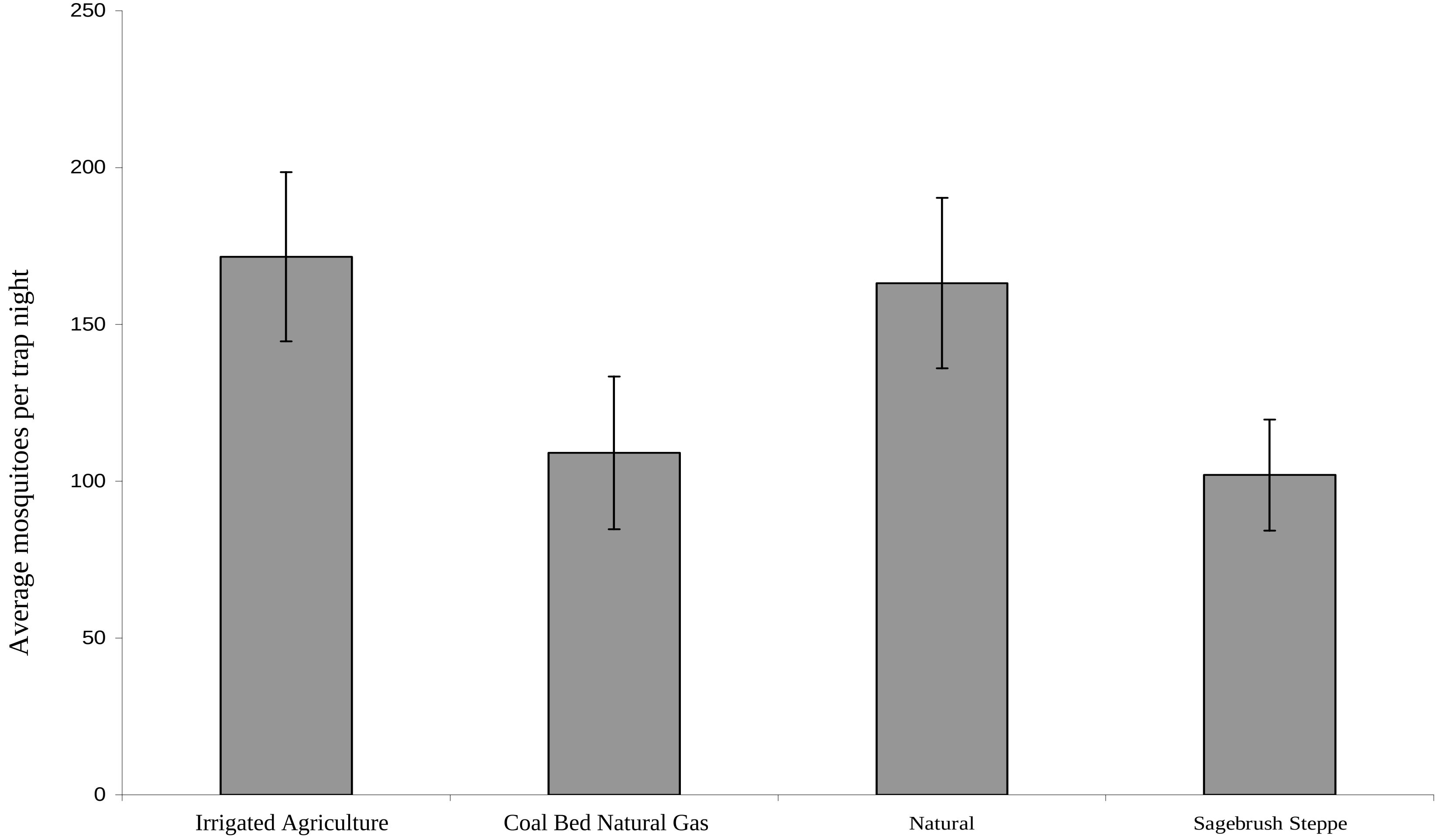

Figure 3. Average mosquitoes collected per trap night by study area with standard errors, Powder River Basin, Wyoming 2004.

mosquitoes per trap night, respectively (Figure 3). Sagebrush-steppe study sites had the lowest average mosquito counts of all study sites, with a mean of 102.0 (SE = 17.7) and were significantly lower than mosquito populations from natural ($P = 0.013$) and irrigated agricultural sites ($P = 0.03$).

Culex tarsalis collections in 2004 differed (3, 587 df, F = 10.3, $P < 0.0001$) between the five study areas sampled. They were significantly higher in irrigated agricultural sites than natural or sage-steppe study areas (mean ± SE 44.3 ± 6.9, $P \leq 0.007$) (Figure 4, Figure 5). *Culex tarsalis* populations were the lowest in sagebrush steppe sites (10.1 ± 4.9). Sagebrush steppe populations were significantly lower than all other populations sampled ($P \leq 0.05$), though the presence of adult mosquitoes in this area is perhaps unusual considering that these traps were not near aquatic habitats.

Culex tarsalis collections in 2004 varied by week (DF = 8, F = 4.8, $P < 0.0001$). The highest mean estimates for the entire PRB were found at week 7 (Julian date 176) (48.2 ± 6.6, $P = 0.0001$), and the lowest estimate were found at week 12 (Julian date 246) (2.5 ± 8.5, $P = 0.77$). Differences in least square means indicate a significant difference between weeks 4 and 7 ($P = 0.001$), 6 and 7 ($P = 0.006$), and 8 - 12 and 7 ($P \leq 0.01$) (Table 2). No differences were found between other weeks sampled.

Aedes vexans was most abundant in irrigated agriculture areas (3, 586 df, F = 10.13, $P < 0.0001$) with significantly higher collections than any other sampled habitat (Figure 5). Mean collection sizes in agricultural areas were 58.1 mosquitoes per trap night (SE = 10.1). There were no significant differences by week found for this species

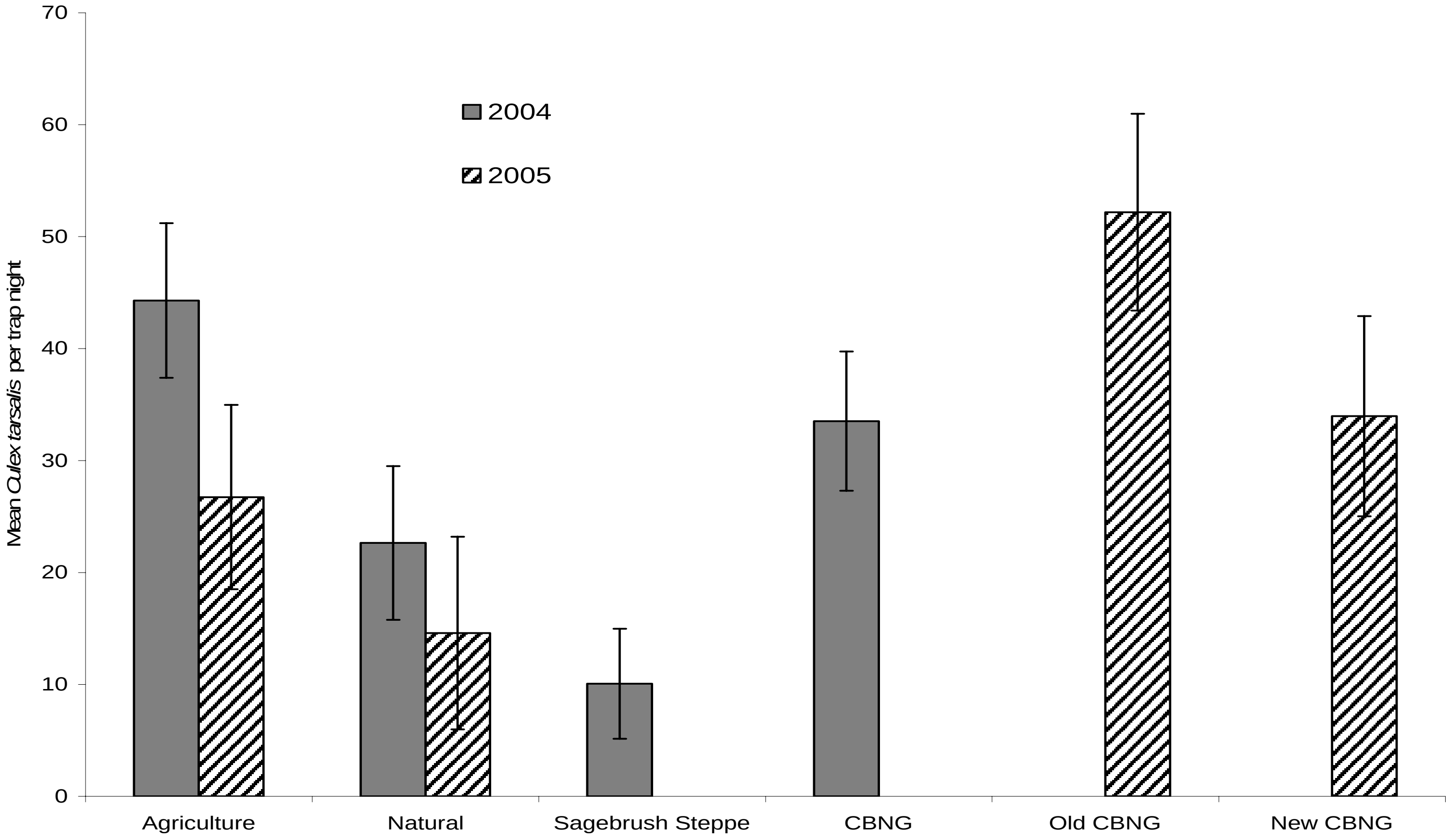

Figure 4. Means and standard errors for *Culex tarsalis* per trap night by study site in the Powder River basin, Wyoming, 2004 and 2005.

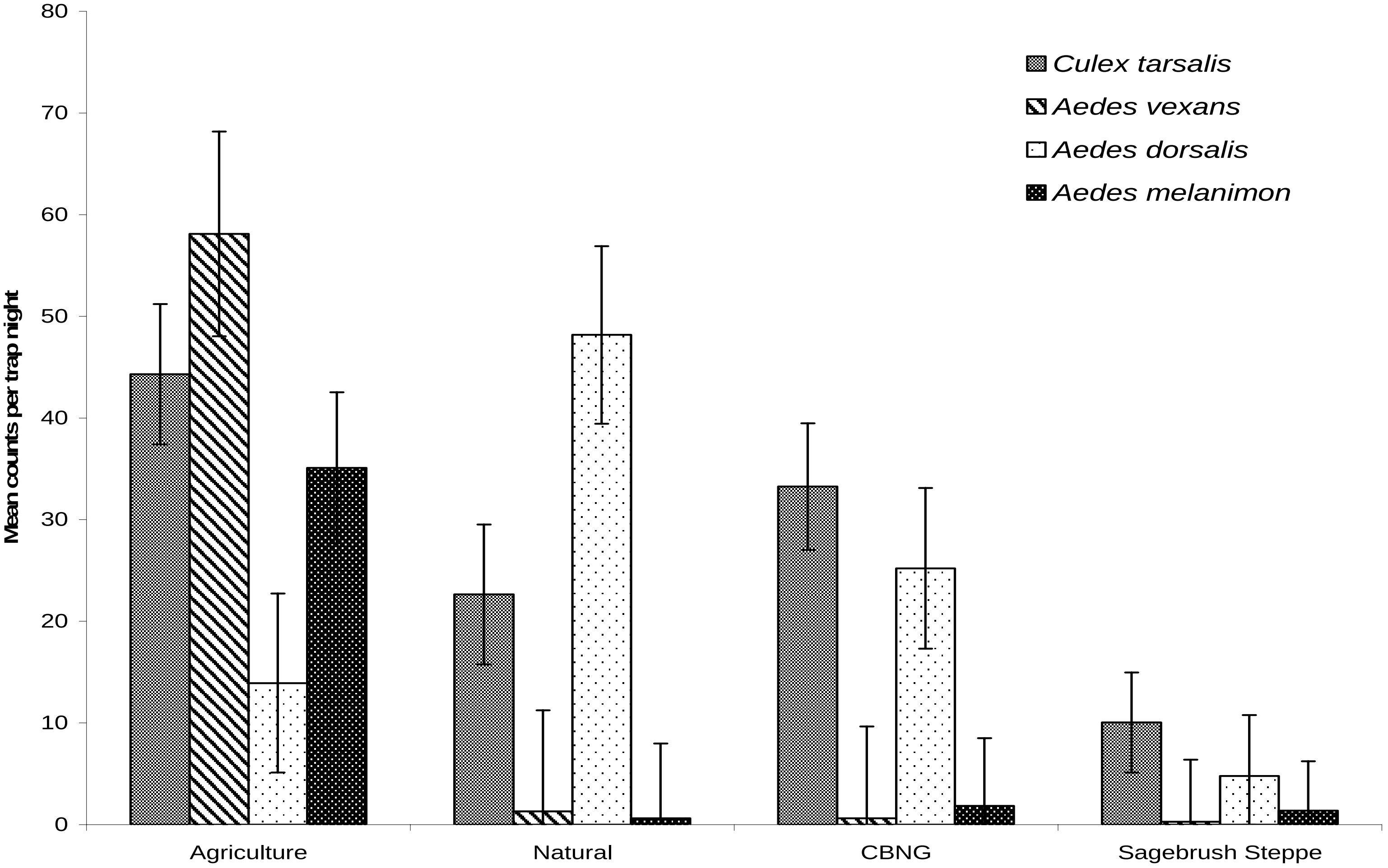

Figure 5. Means and standard errors by study area for the four most abundant mosquito species collected in the Powder River basin, Wyoming, 2004.

Table 2. Mean counts of 4 species of adult mosquitoes by week in the Powder River Basin of Montana and Wyoming 2004.

	Julian date and week of sampling								
Species and habitat type	134 Week 4	148 Week 5	162 Week 6	176 Week 7	190 Week 8	204 Week 9	218 Week 10	232 Week 11	246 Week 12
Culex tarsalis									
CBNG	N/A	5.50	N/A	66.50	30.30	22.38	37.81	56.25	101.69
Agriculture	0.67	1.37	13.67	35.70	54.12	N/A	77.90	7.70	12.10
Natural	0.75	0.50	3.50	9.00	17.07	20.86	75.21	9.71	17.50
Sagebrush	0.00	0.34	13.25	4.11	14.22	4.68	25.25	6.99	10.35
Aedes melanimon									
CBNG	N/A	0.00	N/A	56.00	40.90	19.88	104.44	32.88	12.25
Agriculture	1.22	0.00	0.00	2.10	4.06	N/A	0.75	0.80	0.10
Natural	1.25	1.14	0.07	0.00	1.43	0.14	5.57	1.86	0.43
Sagebrush	1.13	0.44	0.25	1.11	0.55	0.08	0.35	0.20	2.88
Aedes vexans									
CBNG	N/A	0.00	N/A	485.50	41.50	77.88	79.44	24.50	39.88
Agriculture	0.00	0.00	0.00	1.50	5.35	N/A	0.45	0.10	0.30
Natural	0.00	0.00	0.29	0.29	0.21	0.00	1.86	3.86	5.93
Sagebrush	0.00	0.00	0.00	0.23	0.30	0.03	0.20	0.15	0.30
Aedes dorsalis									
CBNG	N/A	0.25	N/A	13.25	1.10	4.88	4.25	16.88	36.19
Agriculture	1.11	10.42	37.83	47.80	92.88	N/A	25.15	5.45	2.15
Natural	1.25	0.14	18.64	5.71	10.29	3.29	183.86	28.14	92.29
Sagebrush	39.50	1.10	0.25	4.40	4.58	0.50	0.90	1.90	15.40

of mosquito across the PRB (*P* = 0.48), likely due to low *Ae. vexans* collections in CBNG, sagebrush steppe and natural areas (Table 2).

Abundance of *Ae. dorsalis* was significantly higher in natural aquatic habitats (48.2 ± 8.7, $P \leq 0.04$) than any other study area (Figure 5). *Aedes dorsalis* collections indicated no difference between irrigated agriculture and CBNG (3, 587 df, F = 8.59, *P* = 0.32). Sagebrush steppe areas supported the lowest catches of *Ae. dorsalis* (4.8 ± 6.0) which was significantly lower than natural or CBNG sites (*P* = 0.03, $P < 0.0001$) (Table 2). Weekly collections of *Ae. dorsalis* across the PRB were highest in mid-summer (*P* = 0.043) (Julian date 213), with abundances decreasing in late August and September likely due to ephemeral larval habitats in natural areas, decreased photoperiod and cool summer temperatures.

The majority of the *Ae. melanimon* collected in 2004 was found in the agricultural sites, with an average of 33.6 specimens per trap night (SE = 5.79, 3, 587 df, F = 7.08, *P* = 0.0001). All other study sites averaged less than 1.2 specimens per trap night and were not found to be a significant source for this species. No weekly significant differences were found for *Ae. melanimon* in the 2004 field season (Table 2).

Culex pipiens was rarely caught in 2004, with no significant difference between study areas, and a maximum average collection of 0.04 in the agricultural study site (SE = 0.02). Other species of mosquitoes captured representing <1% of the total population included *Ae. campestris* Dyar, *Ae. implicatus* Vockeroth, *Ae. trivittatus* Coquillet, *Ae. nigromaculus* Ludlow, *Ae. c. canadensis* Theobald, *Ae. provocans* Walker, *Ae.*

cataphylla Dyar*, Ae. idahoensis* Theobald*, Ae. hendersoni* Cockerell*, Cu. inornata* Williston *Culiseta* spp,. and *Anopheles* spp.

2005 Mosquito Collections

Overall, 6,469 adult mosquitoes representing 16 taxonomic groups were sorted and pooled for WNV testing in 2005 from 160 trap nights. From these samples *Cx. tarsalis* was the most abundant mosquito collected, representing 56.6% of the total mosquito population. Other species that were identified include *Ae. vexans* (29.4%), *Ae. melanimon* (8.1%) and *Ae. dorsalis* (7.8%). *Ae. campestris, Ae. implicates, Anopheles* spp., *Psorophera* spp.*, Ae. trivittatus, Ae. nigromaculus, Ae. c. canadensis, Cx. pipiens, Ae. provocans*, *Ae. cataphylla*, *Ae. idahoensis,* and *Ae. hendersoni* all comprised ≤ 1% of the total collection in 2005.

Total mosquito populations were significantly different from one another at the *P* = 0.10 level in 2005 (3, 129 df, F = 2.68, *P* = 0.049), with irrigated agriculture areas producing the highest total mosquito counts over the field season (107.6 ± 23.3). These irrigated sites were significantly different from natural (*P* = 0.05) and old CBNG (*P* = 0.02) sites, with most of the specimens in this area identified as *Ae. vexans* followed by *Cx. tarsalis, Ae. melanimon* and *Ae. dorsalis* (Figure 6). Significant differences were found between weekly total mosquito production (8, 129 df, F = 3.03, *P* = 0.004), with week 5–7 having higher total mosquito counts than any other week sampled (Julian date 162–178) (Figure 7).

Table 3. Mean counts of adults of 4 species of mosquitoes by week in the Powder River Basin of Montana and Wyoming 2005.

	Julian date and week of sampling								
Species and habitat type	134 Week 1	148 Week 2	162 Week 3	176 Week 4	190 Week 5	204 Week 6	218 Week 7	232 Week 8	246 Week 9
Culex tarsalis									
Old CBM	N/A	0.00	0.00	5.40	66.60	103.00	121.50	55.20	54.50
New CBM	N/A	0.00	0.00	3.60	75.60	66.00	52.40	41.80	24.00
Natural	0.00	0.00	0.00	2.20	11.00	31.40	64.60	5.75	N/A
Agriculture	0.00	0.20	0.00	22.00	20.60	145.40	34.00	2.67	0.00
Aedes melanimon									
Old CBM	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New CBM	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural	0.00	0.00	0.00	0.60	0.20	0.00	0.00	0.25	N/A
Agriculture	0.00	0.00	0.00	7.00	21.00	108.60	4.00	0.00	0.00
Aedes vexans									
Old CBM	N/A	0.00	0.00	0.00	0.80	2.40	0.67	0.60	18.00
New CBM	N/A	0.00	0.00	3.60	75.60	66.00	52.40	41.80	24.00
Natural	0.00	0.00	0.00	2.20	11.00	31.40	64.60	5.75	N/A
Agriculture	0.00	0.20	0.00	22.00	20.60	145.40	34.00	2.67	0.00
Aedes dorsalis									
Old CBM	N/A	0.00	0.00	0.40	5.80	3.20	2.67	3.20	4.50
New CBM	N/A	0.00	0.00	4.60	12.20	8.60	1.20	7.60	0.00
Natural	0.00	0.40	0.00	48.00	2.60	5.80	3.20	12.00	N/A
Agriculture	0.00	2.20	0.00	8.00	2.40	0.00	0.40	0.50	1.00

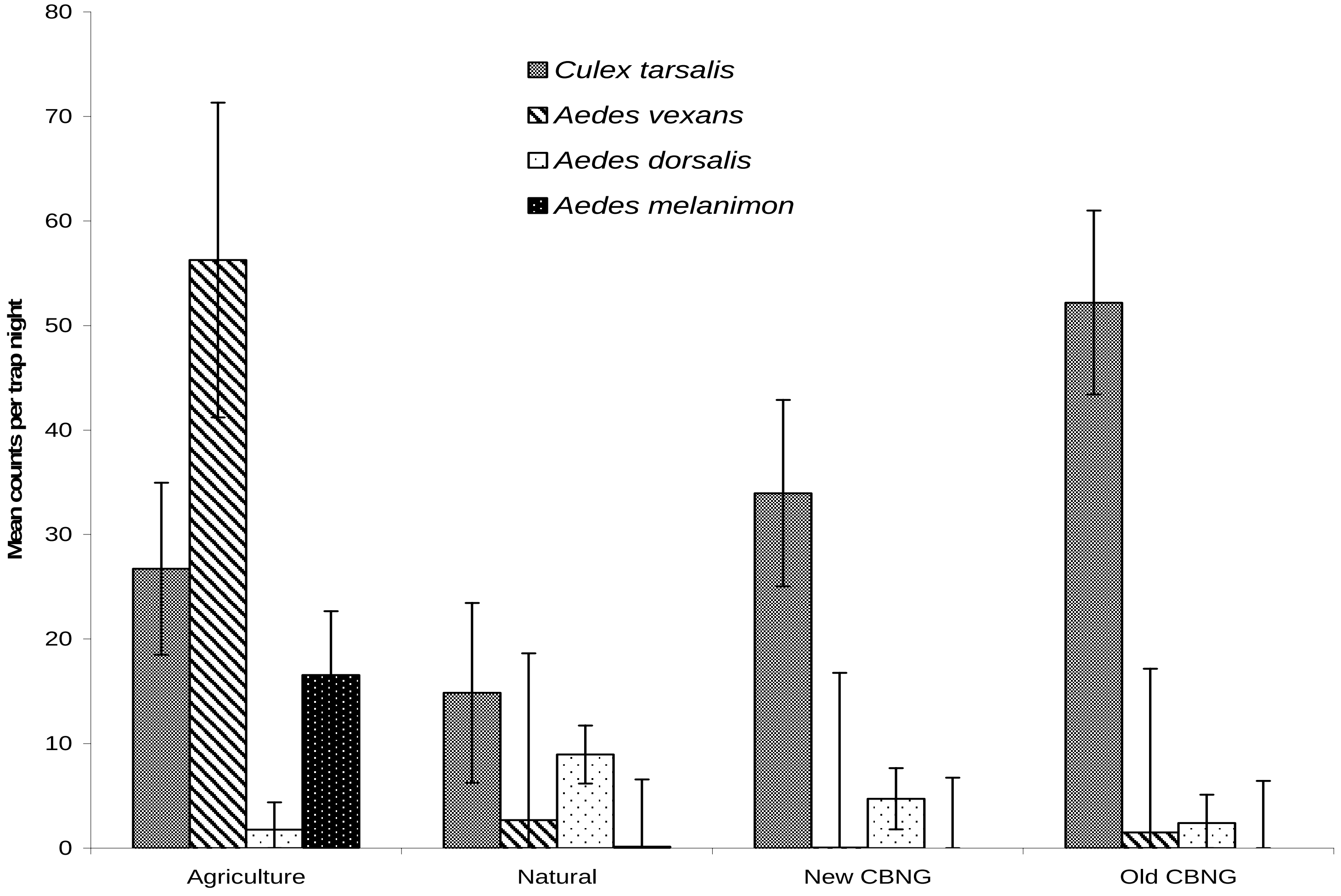

Figure 6. Means and standard errors by study area for the four most abundant mosquito species collect in the Powder River Basin, Wyoming, 2005.

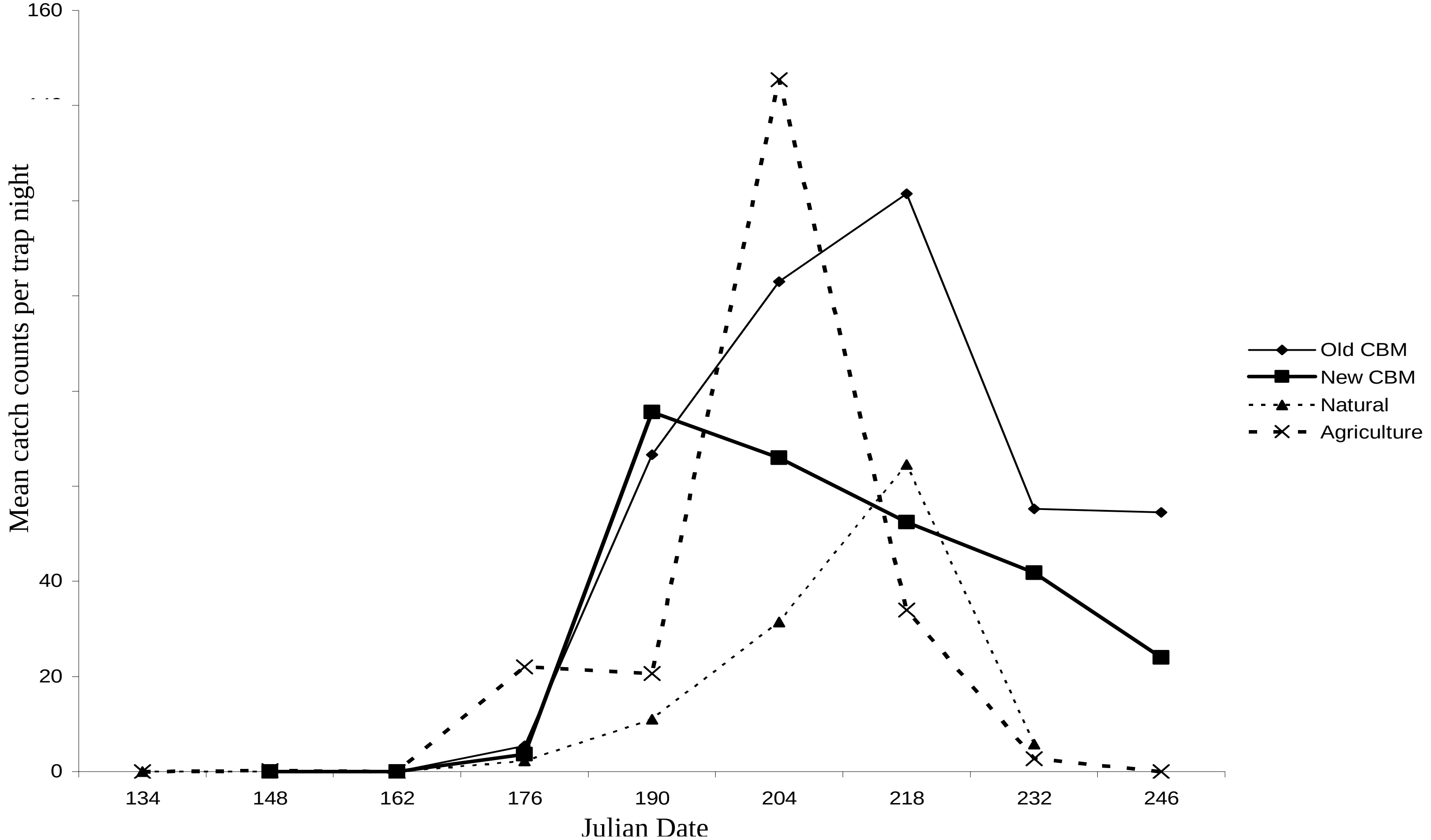

Figure 7. *Culex tarsalis* mean catch counts over time by study area, Powder River basin, Wyoming, 2005.

Culex tarsalis was the most abundant mosquito collected during 2005 (Figure 2), with old CBNG sites producing significantly more mosquitoes than irrigated agriculture or natural water sources (33.9 ± 8.9, 3, 129 df, F = 2.41, $P \leq 0.03$) (Figure 6). Weekly population counts were significant for *Cx. tarsalis* in 2005, with weeks 5–8 (Julian date 162–188) producing more mosquitoes than all other weeks sampled (8, 129 df, F = 11.3, $P \leq 0.008$) (Figure 7, Table 3). Week six had the largest average catch of all weeks sampled, with mean counts of 86.3 *Cx. tarsalis* per trap night (SE = 9.5).

Aedes vexans were most abundant in irrigated agricultural areas in 2005, similar to 2004 sampling (3,129 df, F = 3.43, $P = 0.019$). Mean counts of *Ae. vexans* in agricultural areas were 56.3 mosquitoes per trap night, which was significantly higher than all other study sites sampled (Figure 6) ($P \leq 0.015$). While irrigated agricultural areas were significantly more productive for *Ae. vexans* than other study site there was no significant weekly population trend seen in 2005 (8, 129 df, F = 1.04, $P = 0.41$) (Table 3). Abundances of *Ae. dorsalis* in 2005 were much lower than 2004 samples, with no significant differences between study areas (Figure 6) (3, 129 df, F = 1.54, $P = 0.20$). The highest abundances were around natural water sources, as in 2004, however mean catches were much lower (8.9 ± 2.8), with no significant differences from other study areas. No significant weekly trends were seen in *Ae. dorsalis* populations in 2005 (8, 129, F = 1.28, $P = 0.26$) (Table 3).

Aedes melanimon population trends were similar in 2005 to the previous year samples, with abundances higher in irrigated agriculture than other sampled water sources (Figure 6). In 2005 these differences were not significant (3, 129 df, F = 1.9, $P =$

0.13). There were no significant weekly trends for *Ae. melanimon* in 2005 (8, 128 df, F = 0.96, *P* = 0.47) (Table 3), likely due to the reduced irrigation practices in 2005 from that seen in 2004.

Mosquito Infection Rates

A total of 923 and 244 pools of insects were tested for WNV using PCR assays in 2004 and 2005 respectively, with WNV isolation from 16 pools between both years. Species that were tested for WNV included *Cx. tarsalis* (241, 125 mosquitoes tested in 2004 and 2005 respectively), *Ae. vexans* (52, 22), *Ae. provocans* (1- 2005), *Ae. nigromaculus* (2, 1), *Ae. melanimon* (38, 8), *Psorophera* spp. (10- 2004), *Ochleratatus* spp. (21- 2004), *Culiseta* spp. (8- 2004), *Ae. implicates* (1- 2005), *Ae. dorsalis* (124, 11), *Ae. campestris* (1- 2005) and the biting midge *C. sonorensis* (428, 75). All the positive pools detected were from *Cx. tarsalis* samples, with minimum infection rate of 1.22 per thousand from 2004, and 0.84 per thousand from 2005 (Table 4).

Infected pools of mosquitoes were collected in different study areas in 2004 and 2005. Of the 12 infected pools found in 2004, 8 were from agricultural areas, 2 were from CBNG and 2 were from CX sagebrush steppe with minimum infection rates of 2.90, 0.60 and 1.48 per thousand respectively. In 2005, all the positive pools detected were from CBNG areas. Two infected pools were found at old CBNG ponds with an infection rate of 0.99, and 2 infected pools were detected in new CBNG areas with an infection rate of 1.96.

Table 4. Mosquito infection rates for *Culex tarsalis* collected in the Powder River basin, Wyoming in 2004 and 2005.

Year	Species	Infection Rate	Lower Limit	Upper Limit	Number Pools	Number Positive Pools	Number Individuals
2004	*Cx. tarsalis*	1.22	0.66	2.07	239	12	10,120
2005	*Cx. tarsalis*	0.84	0.27	2.03	123	4	4,804

Culex tarsalis infection rates

	Group	Infection rate	Lower Limit	Upper Limit	Number Pools	Number Positive Pools	Number Individuals
2004	Agriculture	2.90	1.36	5.52	63	8	2,936
	Natural	0.00	0.00	2.23	38	0	1,637
	CBNG	0.60	0.11	1.98	79	2	3,338
	CX Sagebrush steppe	1.48	0.27	4.87	36	2	1,372
	Padlock Sagebrush steppe	0.00	0.00	4.21	23	0	837
2005	Agriculture	0.00	0.00	3.35	29	0	1,065
	Natural	0.00	0.00	5.17	18	0	663
	Old CBNG	1.96	0.36	6.43	29	2	1,030
	New CBNG	0.99	0.18	3.26	47	2	2,043

Table 5. Average monthly temperature and rainfall data for Sheridan, WY, May - August 2004 and 2005 (National Weather Service 2006).

Month	Year	Average Monthly Temperature (°C)	Departure from Normal (°C)	Total Monthly Precipitation (centimeters)	Departure from Normal (centimeters)	Days with total rainfall ≥ (inches)			
						0.01	0.10	0.50	1.00
May	2004	11.6	0.4	1.8	-4.3	11	2	0	0
	2005	10.6	-1.1	15.7	9.6	12	6	3	3
June	2004	15.9	-0.9	2.9	-2.2	9	3	1	0
	2005	16.8	0.6	7.5	2.3	10	4	3	0
July	2004	20.4	-0.1	4.4	1.5	11	6	1	0
	2005	22.2	3.0	2.6	-0.3	4	2	1	0
August	2004	18.7	-2.2	1.4	-0.6	7	1	0	0
	2005	18.8	-2.2	3.0	1.0	11	5	0	0

Weather Data

Average monthly temperature and rainfall data for Sheridan, WY, May-August 2004 and 2005 indicate normal to below average temperatures in 2004 and 2005 (National Weather Service 2006). 2004 average temperatures ranged from 11 - 20 °C in 2004, and 11 - 22 °C in 2005 (Table 5). Departures from normal temperatures were -3 °C in 2004 and -0.1 °C in 2005. Average monthly rainfall in 2004 ranged from 1.4 – 4.4 centimeters in 2004 and 2.6 – 15.7 centimeters in 2005. Departures from normal rainfall was -5.5 centimeters in 2004 and +12.7 centimeters in 2005, indicating major changes in total rainfall between 2004 and 2005 field seasons. A total of 52 days accumulated > 0.25 centimeters of total rainfall between May and August 2004, with zero days accumulating >2.54 centimeters total rainfall. The 2005 field season included 64 days with > 0.25 centimeters total rainfall, with three days accumulating >2.54 centimeters total rainfall in May 2005.

Discussion

The Powder River Basin of Wyoming is currently undergoing both local and landscape scale changes in land use and development due to the production of coal bed natural gas. Satellite imagery shows that CBNG development has had a 2-fold increase in road, 2-3x increase in powerlines, 5x increase in number of total ponds in ranching areas with a 9x increase in total area of water, and a 2x increase in area of ponds and water in agricultural areas (Naugle et al. in press). Further imagery indicates that these ponds have contributed to a 75% increase in potential *Cx. tarsalis* habitat area across this region

(Zou et al. 2006). *Culex tarsalis*, the vector responsible for transmitting WNV in northeastern Wyoming, is a species of mosquito native to the PRB (Hayes 2005, Turell et al. 2005); however, their population levels have increased in some areas due to human development in both agriculture and CBNG fields. This in combination with my research data allows me to reject my hypothesis that CBNG development has not increased mosquito production in the PRB including the WNV vector *Cx. tarsalis*.

In 2004 *Cx. tarsalis* was the most abundant mosquito collected across the PRB and was second in abundance to *Ae. vexans* in 2005. *Culex tarsalis* populations were highest in irrigated agriculture and CBNG sites, both of which are artificially supplemented with water throughout the summer. These sites were vegetated by sedges, rushes, forbs and flooded upland grasses. Many of these ponds also included inlets and outlets, which were significant production areas for *Cx. tarsalis* larvae in 2005 (Chapter 3). *Culex tarsalis* populations have been observed in southern California with high densities around irrigated agriculture (Riesen et al. 1992), and are known to be one of the first mosquito species to colonize wastewater ponds in the southwestern United States (Walton et al. 1990; Fanara and Mulla 1974). Our *Cx. tarsalis* collections show similar patterns to those observed in anthropogenic water sources in California, with the highest catch counts in Wyoming observed around irrigated and CBNG habitats.

In 2004 high populations of *Cx. tarsalis* were observed in agricultural sites, followed by sites under CBNG development. That summer had below average precipitation in northeastern Wyoming (-41.7% average, National Weather Service 2006) and subsequently our study sites had a 2-fold increase in irrigation of hay fields (Sparo

Zezas, personal communications). In contrast, rainfall in 2005 was 12.7 centimeters above the seasonal average, with normal seasonal temperatures and irrigation practices. This was reflected in adult mosquito populations with total mosquito production in irrigated agricultural areas increasing by 27% above average under drought conditions, and *Cx. tarsalis* production increasing by 39%. In comparison, natural sites saw a 10% decrease in *Cx. tarsalis* production from 2005 to 2004. These mosquitoes have been observed under drought conditions in California, and have demonstrated similar trends, with increased populations in irrigated agriculture during a dry year (1990) (Riesen et al. 1992). Overall, drought conditions may facilitate increased mosquito production in agricultural areas by increasing flood irrigation habitats when naturally occurring habitats are drying down due to lower precipitation.

Seasonal trends in mosquito populations for both the 2004 and 2005 field season were strongest in *Cx. tarsalis* populations across the PRB. These populations increased over the course of the spring and summer, with peak population the week of 22 July (x = 86.3 per trap). Similar population trends have been observed in California with peak *Cx. tarsalis* populations the first week of July (Isoe and Millar 1995, Knight et al. 2003). No other strong weekly trends were seen in other species of mosquitoes collected in the PRB. *Aedes vexans* were slightly more abundant in the early spring, with no significant differences found between sampling weeks in 2004 or 2005.

West Nile virus mosquito infection rates varied between study years and study sites across the Powder River basin. In 2003, female *Cx. tarsalis* caught in CDC light traps tested positive for WNV with an infection rate of 7.16 per thousand, and *Culicoides* *sonorensis* were found with a WNV infection rate of 2.31 per thousand (Naugle et al. 2004). In 2004 and 2005, study areas with the highest adult *Cx. tarsalis* population also had the highest mosquito infection rates, with agricultural sites having infection rates of 2.90 in 2004, and old CBNG sites had infection rates of 1.96 in 2005. *Culex tarsalis* average 2.6- 2.9 generations per season in northern climates, with infected females needing to survive a minimum of 2 gonotrophic cycles in warm years to infect a susceptible host and continue amplifying WNV in the environment (Riesen et al. 2006). Because this is a relatively long time for adult mosquito survival, population levels may need to be above a given threshold to maintain WNV primary infection cycles within an ecosystem. Threshold modeling of local mosquito populations including regional temperature data may be a potential predictive tool for WNV monitoring in the future.

Landscape changes due to CBNG development and irrigated agriculture in the PRB have created habitats with significantly higher mosquito populations than natural landscapes of northeastern Wyoming. CBNG ponds placed in upland sagebrush steppe habitat have created areas with significantly more mosquitoes than the original landscape, including the WNV vector *Cx. tarsalis*. These mosquitoes have been detected with WNV in 2003, 2004 and 2005 and WNV has been documented in greater sage grouse in CBNG fields. Modifications to current water usage practices will likely be required to mitigate the potential threat of WNV to human health and wildlife.

CHAPTER 3

COMPARITIVE LARVAL MOSQUITO ABUNDANCE IN NATURAL, AGRICULTURAL AND COAL BED NATURAL GAS PONDS

Introduction

The effects of energy development on the economy, environment, and wildlife populations of western North America is an issue of concern as new energy resources are explored across the west. The PRB coal seam boundary which spatially defines where CBNG development occurs is ~ 2.4 million ha; roughly the size of New Hampshire. Within this area the Bureau of Land Management (BLM) has already authorized plans to drill 51,000 CBNG wells on federal mineral holdings in the PRB of Wyoming and the potential exists for another 15,000 in Montana (BLM 2003 a, b). Coal bed natural gas is currently being extracted for commercial use in the Powder River basin by the natural gas industry at the rate of 23 million m^3 per day (Department of Energy 2002). Methane extraction includes the removal of groundwater to allow confined gases to flow to well heads. This groundwater is discharged into existing cattle ponds, newly constructed ponds, or surface drainages (Clark et al. 2001). Coal bed natural gas development and associated infrastructure in the PRB has caused rapid, large-scale changes to sagebrush habitats of Montana and Wyoming. The potential impacts that could result from the high density of wells, power lines, roads, increased vehicle traffic, pipelines, compressor stations, and water storage ponds within a gas field this size is of concern to wildlife managers tasked with conservation of sensitive species. Since 1999, an estimated 19,000

CBNG well heads have been constructed in the PRB, with 20,000 more projected in the future, each of which will produce discharge water that must be held in CBNG ponds, re-injected into the aquifer, or otherwise dispersed (Department of Energy 2002).

Coal bed natural gas ponds vary in shape, age and structure creating varied types of aquatic habitats in a region that has previously been considered semi-arid (Hemstrom et al. 2002; Walker et al. 2004). These ponds are potential habitats for mosquito production, including the mosquito *Culex tarsalis*, the main vector for West Nile virus (WNV) in the western United States (Hayes 2005; Turell et al. 2005; Zou et al. 2006).

Coal bed natural gas development has affected several species of wildlife native to the PRB (Daszak et al. 2000; Marra et al. 2004), including the greater sage-grouse (*Centrocercus urophasianus*) (Naugle et al. 2004, 2005; Walker et al. 2004). The new networks of roads, power lines, pipelines, compressor stations and wellheads from energy development result in cumulative impacts that are detrimental to sage-grouse survival (Holloran 2005; Aldridge and Boyce In Press). Along with these habitat changes, the introduction of new pathogens to the sage-grouses native range may cause population declines that, when compounded, are beyond the scope of recovery for this species. The introduction of WNV to the PRB reduced late summer survival of female sage grouse by 75% in some areas in 2003. Additional vectors of WNV in the PRB from CBNG ponds may increase WNV sage grouse mortality in this region.

Populations of adult *Cx. tarsalis* mosquitoes have been found throughout the PRB including in natural, agricultural and CBNG habitats. This species was positive for WNV in select areas of the PRB and is the likely vector of this pathogen to human, equine, and wildlife species (Hayes 2005, Turell 2005). Migratory flights of host-seeking or ovipositional-site-seeking female *Cx. tarsalis* have been found to travel up to 17.7 km in California (Bailey et al. 1965), indicating that females caught in a CO_2 baited light trap may have emerged in a different aquatic habitat than where they were collected as adults. To identify where mosquitoes are being produced in the PRB and the specific habitats preferred for larval mosquitoes, I sampled four different types of aquatic habitats including CBNG, natural and irrigated agriculture. I hypothesized that the type of habitat created by CBNG development would have larger populations of mosquitoes than are present in natural and agricultural water sources in the same region.

Materials and Methods

Study Sites

Aquatic habitats sampled for adult mosquitoes were also sampled for mosquito larvae production. A complete description of these study sites is found in Chapter 2. Five habitats were sampled; these included sagebrush steppe under CBNG development (natural water sources), irrigated agricultural water, new CBNG ponds, mature CBNG ponds and CBNG pond outlets.

Coal bed natural gas outlets were also sampled for larval production separately from the CBNG ponds. These areas were not sampled for adult mosquitoes because they are contiguous with the ponds. These outlets are a result of water seeping under the earthen dam created to hold CBNG water. Neither age nor vegetation type of the contributing CBNG pond was included in the classification of CBNG outlets. Outlets were treated as a separate block in the analysis, as they had different vegetation and shoreline characteristics, and they produced mosquitoes independently of their contributing CBNG pond. These outlets were small areas, generally less than 50 m in length and 3 m in width and no more than 46 cm in depth. Water levels were relatively stable throughout the 2005 field season, although outlet lengths were often reduced during hot, dry weather. Average vegetation cover was 40% in late August, predominately covered by rushes, sedges, flooded upland grasses and emergent wetland grasses.

Field Methods

Mosquito larvae were collected bi-weekly from 13 May–24 August (Julian date 114-226), 2005 in each of the five habitat blocks. Each block contained five randomly selected aquatic habitats which were sampled at 20 points along a transect at 5 m intervals. Each point was sampled four times using a 350 ml standard dipper. A sample was taken at 0.5 m intervals in each of the cardinal directions while I stood in the water and faced the body of the pond to be sampled with the shoreline behind me. All larvae collected from a sampling points were pooled and concentrated into 20 ml vials and preserved in 95% alcohol for processing.

I characterized pond vegetation on 3-17 August 2005 when vegetation had matured enough to be accurately identified to major groups (e.g., rushes, sedges, flooded upland grasses and forbs). I used a standard 46 x 46 cm Daubenmire (1959) frames to sample each larval sampling point for vegetation variables including plant cover (%), cover type and plant type. Cover variables included emergent, submergent, open water, and flooded upland vegetation. Plant type variables included algae, forbs, grasses, rushes, sedges woody plants, and open water. I converted categorical estimates of plant cover to percentages using methods developed by Daubenmire (1959) (1 = 2.5%, 2 = 15%, 3 = 37.5%, 4 = 62.5%, 5 = 85%, 6 = 97.5%) for each larval sampling point, and averaged these values for each pond, and for each study site.

Weather data obtained from the United States National Weather Service archival climatological data for Sheridan, Wyoming (National Weather Service 2006). Average monthly temperatures from May - August were recorded, including the departure from normal. Precipitation data were recorded as monthly totals including the departure from normal, as well as the number of days with 0.02, 0.25, 1.27 and 2.54 centimeters or more of rainfall.

Laboratory Methods

Second, third and fourth stage larvae were counted and identified to genus and/ or species (Darsie and Ward 1981). *Aedes* and *Culex* larvae were identified to species; *Culiseta* and *Anopheles* were identified to genus. First instar and pupae were recorded but were not identified due to lack of appropriate morphological characteristics for species keys in this region. All specimens were stored in 70% ethanol for future reference.

Statistical Methods

For data analysis comparing mosquito abundance among aquatic habitats, mean values were calculated for each mosquito species from the 20 points sampled per pond to avoid pseudoreplication (Hulbert 1984). Data analysis conducted to assess the impact of different aquatic vegetation characteristics among pond types used each larval sampling point individually, as vegetation characteristics could vary from point to point within a pond.

Larval abundance of mosquitoes between pond types was analyzed in SAS PROC MIXED with a generalized mixed effect linear model (Littell et al. 1996). Number of mosquito larvae per time period was transformed as ln $(x + 1)$ to meet the assumption of normality. Because sequential larval counts can be serially-correlated and larval counts estimated for the same pond closer in time are more likely to be correlated than measures more distant in time, I modeled the appropriate covariance structure that best represented the data in SAS PROC MIXED (Littell et al. 1996, 1998). The covariance structure is derived from variances at individual times and correlations between measures at different times on the same pond (Littell et al. 1998). I used a compound symmetry (CS) error structure where all measures at all times have the same variance and all pairs of measures on the pond have the same correlation (Littell et al. 1996). SAS PROC MIXED is a generalization of a standard linear model and data are permitted to exhibit correlation and non-constant variability (SAS 8.2 online doc.). I used the REPEATED statement in PROC MIXED to model the covariation within ponds, which accounts for the violation of independence of the observations on the same pond at different times (Littell et al. 1998). The RANDOM statement was used to model the variation among ponds, which accounts for heterogeneity of variances from individual ponds (Littell et al. 1998). The random effects factor was the sub-sample of ponds within treatment group that were randomly chosen from all available ponds in the study area. All other factors in the model were treated as fixed effects. Maximum likelihood methods were then used to fit a mixed-effects (both random and fixed effects) general linear model in SAS PROC MIXED.

Timing of larval production between aquatic habitats for each of the four most abundant species was assessed using a 1-way ANOVA blocked by week. I used a 1-way ANOVA to assess differences in larval populations on a week-by-week basis because these were only within week comparisons, and ponds were not repeatedly sampled within weeks.

I also used a 1-way ANOVA to assess whether the production of *Cx. tarsalis* was related to vegetation characteristics in the four habitat types that were sampled. I used *Cx. tarsalis* because it is the most abundant mosquito species in the PRB and is known to vector WNV in the western U.S. Only larval counts taken the week that vegetation characteristics were measured were used in analyses.

Results

Mosquito Populations

A total of 6,483 mosquito larvae was captured and identified from 12,636 individual dips. The dominant species identified across all study sites was *Cx. tarsalis,* which accounted for 47.8% of the individual larvae collected (Figure 7). *Culiseta* spp. represented 20.8% of the collections, followed by *Ae. vexans* (4.2%), *Ae. dorsalis* (3.1%), *Ae. melanimon* (2.3%) and *Ae. campestris* (0.1%). Unidentified 1st instar larvae and pupae accounted for 20.9% and 0.08% of the total collection, respectively.

Culex tarsalis abundance was significantly different at the 90% level (df = 4, *P* = 0.09) between the five sampled aquatic habitats. Post-hoc tests showed that *Cx. tarsalis* abundance was similar across all types of CBNG and natural sites ($P \geq 0.41$, Figure 8). *Culex tarsalis* abundance was lowest in agricultural sites, with a mean count of 0.47 larvae per sampling point (post hoc *P* = 0.03) (Table 6). *Culex tarsalis* showed strong seasonal differences ($P < 0.0001$) with a peak in larval populations the week of 18 July (Julian date 184) (Figure 9). *Culex tarsalis* abundance increased precipitously from mid-June to mid-July, (Julian date 142–184) and sustained high production through mid-August (Figure 9). The habitat type that contributed most to this peak was CBNG outlet ponds (141.6 ± 1.7, *P* = 0.03; Figure 10). *Culex tarsalis* abundance in new CBNG, old CBNG and natural sites also increased the week of 18 July, but with no significant differences between group means ($P \geq 0.95$), and to a lesser extent when compared to CBNG outlet ponds (*P* = 0.03).

Abundance of *Culiseta* differed (*P* = 0.05) between the five sampled aquatic habitats. *Culiseta* abundance was similar in agricultural, natural and CBNG outlets ($P \geq 0.001$), and was lowest in new and old CBNG sites (*P* = 0.196 and *P* = 0.053, Table 6). Unlike other species, *Culiseta* did not show strong seasonal differences in 2005, but timing of abundance peaks was variable between aquatic habitats (*P* = 0.09). *Culiseta* populations in CBNG outlets and natural sites peaked in mid-summer (Julian date 142-184; Figure 8).

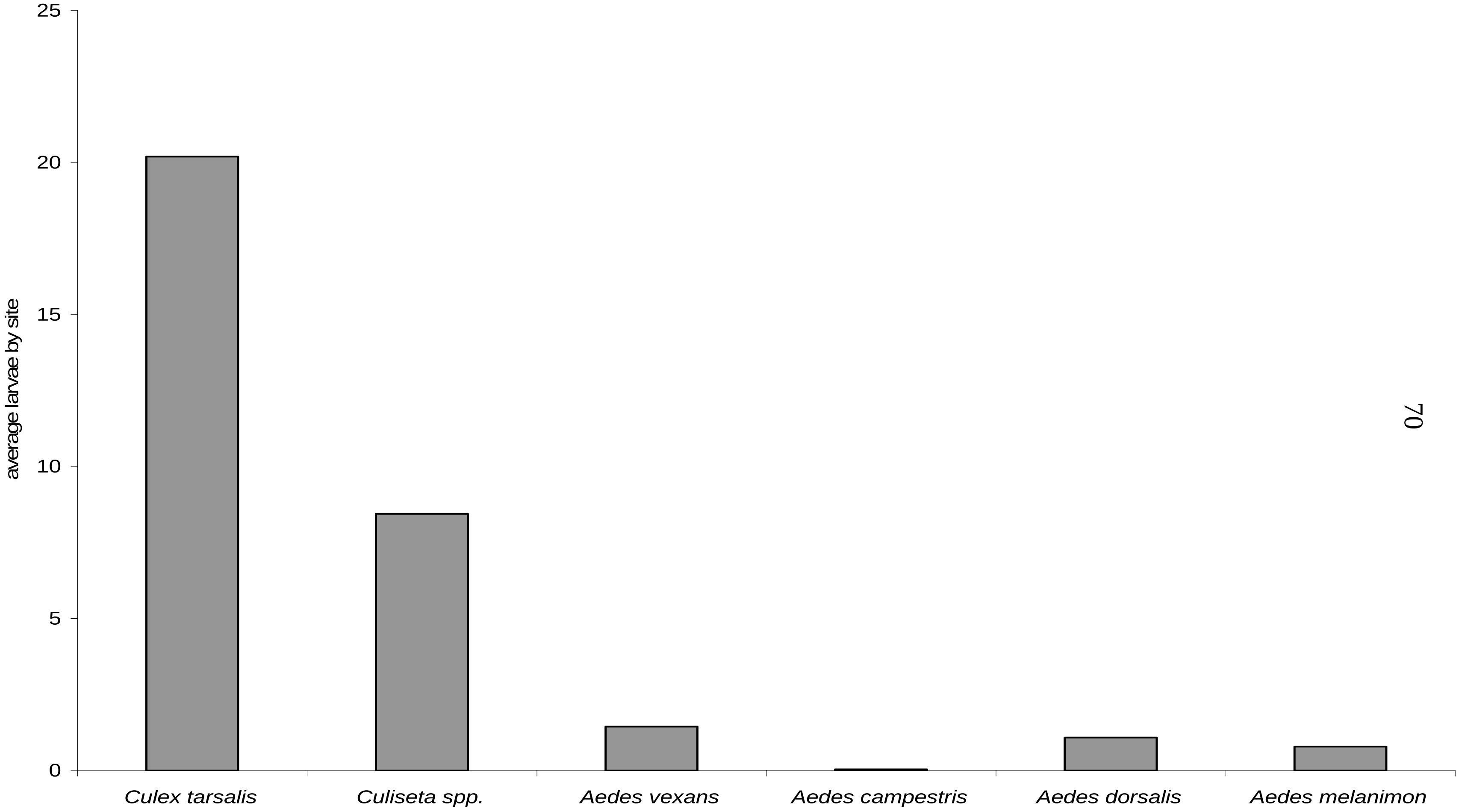

Figure 8. Mosquito larvae collected by taxon in the Powder River Basin, Wyoming, 2005.

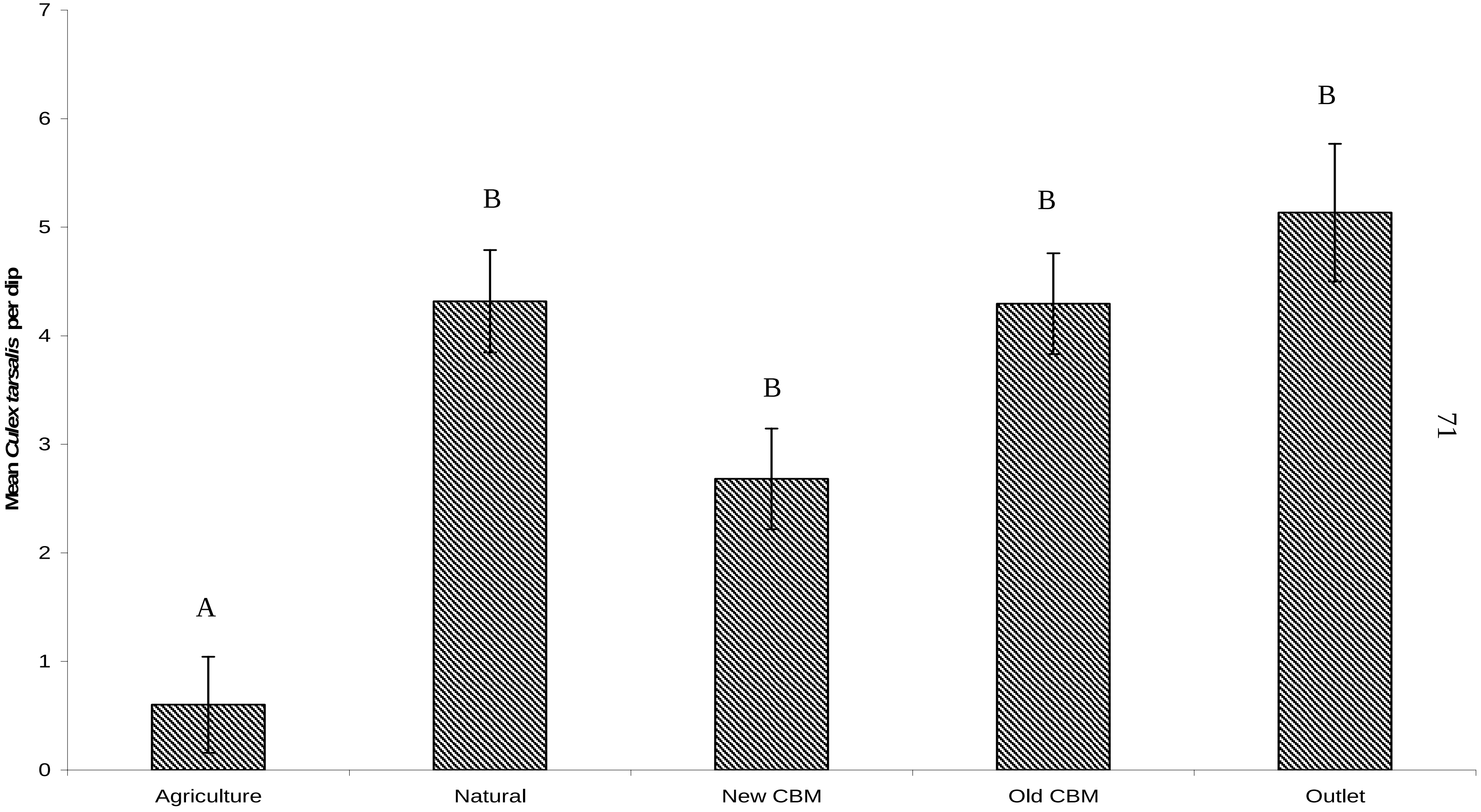

Figure 9. Mean larval production (SE bars) of *Culex tarsalis* per dip from
5 aquatic habitats types in the Powder River Basin, Wyoming, 2005. (Statistical differences > 0.05 denoted by letters).

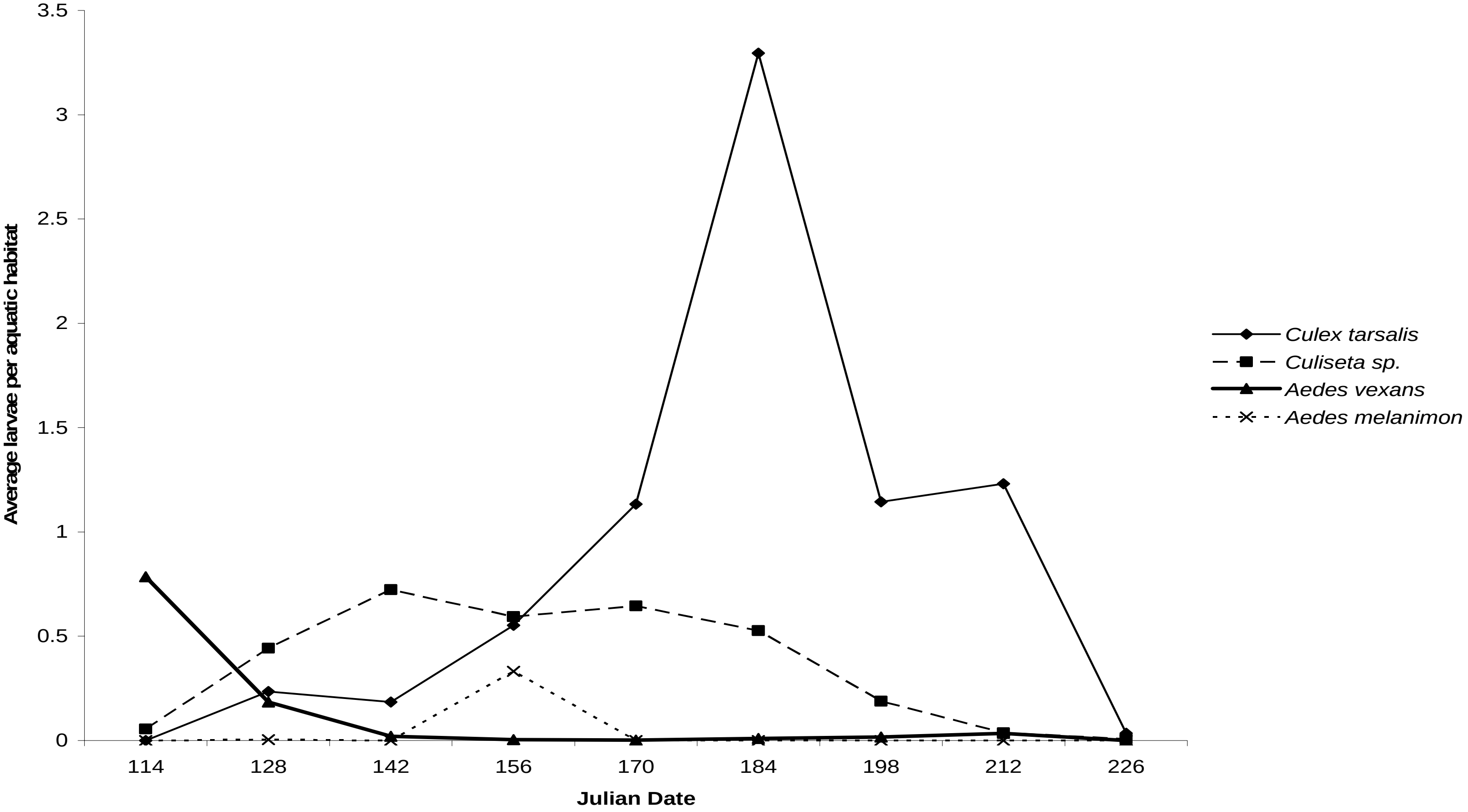

Figure 10. Timing of larval production for four species of mosquitoes in the Powder River Basin, WY, 13 May – 24 August, 2005.

Table 6. Weekly larval mosquito mean counts per dip (SE) by study area for the four most abundant larval species collected, Powder River basin Wyoming, 2005.

Julian date and week of sampling									
Species and habitat type	128 Week 1	142 Week 2	156 Week 3	170 Week 4	184 Week 5	198 Week 6	212 Week 7	226 Week 8	Season Total
Culex tarsalis									
Agriculture	0.00(0)	0.38(.71)	0.25(.67)	0.38(1.01)	1.13(1.32)	1.07(1.16)	1.43(1.21)	0.37(.85)	.47(.33)
Natural	0.00(0)	2.84(.71)	1.06(.67)	5.07(1.01)	7.32(1.57)	32.55(1.37)	29.45(1.43)	1.45(2.17)	4.28(.43)
New CBNG	N/A	0.64(.71)	0.32(.67)	0.78(1.01)	5.48(1.32)	13.97(1.16)	7.01(1.21)	2.06(1.07)	2.97(.43)
Old CBNG	N/A	2.93(.71)	2.33(.67)	2.76(1.01)	1.96(1.32)	23.85(1.16)	1.30(1.21)	13.01(1.07)	4.12(.43)
CBNG Outlet	N/A	0.00(1.00)	0(.94)	1.72(1.47)	10.87(1.97)	141.59(1.71)	3.85(1.78)	13.67(1.57)	5.18(.51)
Aedes vexans									
Agriculture	0.80(1.25)	0.64(.60)	0.00(.25)	0.00(.10)	0.15(.07)	0.43(.14)	0.43(.21)	0.53(.21)	.36(.12)
Natural	1.69(1.25)	4.44(.60)	0.48(.25)	0.25(10)	0(.07)	0.15(.15)	0.19(.24)	0.00(.43)	.70(.12)
New CBNG	N/A	0.38(.60)	0.15(.25)	0(.10)	0(.07)	0(.14)	0.15(.21)	0(.25)	.09(.12)
Old CBNG	N/A	1.65(.60)	0.25(.25)	0(.10)	0(.07)	0(.14)	0(.21)	0(.25)	.20(.12)
CBNG Outlet	N/A	0(.84)	0(.32)	0(.14)	0(.07)	0(.18)	0(.29)	0(.34)	0(0)
Aedes melanimon									
Agriculture	0(0)	0(0)	0(0)	1.54(.59)	0(0)	0(0)	0(0)	0(0)	.20(.07)
Natural	0(0)	0.22(.10)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	.03(.07)
New CBNG	N/A	0(.10)	0(0)	0(.59)	0(0)	0(0)	0(0)	0(0)	0(0)
Old CBNG	N/A	0(.10)	0(0)	0(.59)	0(0)	0(0)	0(0)	0(0)	0(0)
CBNG Outlet	N/A	0(.10)	0(0)	0(.83)	0(0)	0(0)	0(0)	0(0)	0(0)
Culiseta spp.									
Agriculture	0.59(.43)	1.90(1.02)	4.99(1.18)	2.96(.97)	3.23(.90)	0.78(.87)	5.61(.51)	0.63(.22)	2.02(.32)
Natural	0.25(.43)	2.23(1.02)	0.97(1.18)	2.10(.97)	6.46(1.06)	6.55(1.01)	0.57(.59)	0(.45)	1.67(.36)
New CBNG	N/A	1.31(1.02)	1.56(1.18)	0.15(.97)	0(.90)	0.15(.87)	0(.51)	0(.26)	.38(.32)
Old CBNG	N/A	2.80(1.02)	2.61(1.18)	0(.97)	0(.90)	0.59(.87)	0(.51)	0(.26)	.54(.32)
CBNG Outlet	N/A	0(1.48)	0(1.74)	3.60(1.41)	10.20(1.30)	6.63(1.24)	0(.71)	0.82(.35)	1.56(.39)

Agricultural sites produced two population peaks, one in early summer and another later in the year; both peaks coincided with the release of irrigation water on fields. The second peak produced more larvae of *Culiseta* in agricultural sites (*P* = 0.02) than in any other habitat type at that time of the year (Table 6).

Abundance of *Aedes vexans* differed (*P* = 0.030) between the five sampled aquatic habitats, being highest in natural habitats (*P* = 0.030), intermediate in agricultural and new and old CBNG sites, and absent from CNBG outlets (Table 6). Timing of production varied seasonally (*P* = 0.0005) and was highest across all habitat types in late May (Table 6). Natural water sources produced the highest mean *Ae. vexans* counts per dip on 22 May, 2005 (Julian date 142), likely due to flooding from snowmelt and spring rain events.

Abundance of *Aedes melanimon* was similar in agricultural and natural sites (*P* = 0.27); no larvae were captured in CBNG habitats of any type (Figure 6). Abundance of *Ae. melanimon* varied seasonally (*P* = 0.085) with a peak in early summer (26 June, Julian date 177) (Table 6).

Larval Use of Vegetative Cover Types

Abundance of *Cx. tarsalis* differed (*P* = 0.056) between the four vegetative cover types (Figure 12). Abundance was greater in flooded upland vegetation than in open water, emergent, or submergent cover types (*P* < 0.00001); very few larvae were collected from open water habitats that lacked vegetative cover (0.0 ± 0.1) (Figure 12).

Abundace of *Cx. tarsalis* also differed (*P* = 0.01) between plant types encountered during larval sampling (Figure 11). *Culex tarsalis* abundance was highest in forbs (1.0 ±

0.1) followed by flooded upland grasses (0.9 ± 0.1). Open shoreline with no vegetation, non-vegetated sampling points and those with woody plant cover harbored almost no larvae over the 2005 sampling season, and were not good predictors for *Cx. tarsalis* larval habitats.

Weather Data

Average monthly temperature and rainfall data for Sheridan, WY, May - August 2005 indicate normal to below average temperatures (National Weather Service 2006). 2005 average temperatures ranged from 11 - 22 °C (Table 3). Departures from normal temperatures were -0.1 °C in 2005, and average monthly rainfall 2.6 – 15.7 centimeters. Departures from normal rainfall in 2005 was +12.7 centimeters. The 2005 field season included 64 days with > 0.02 inch total rainfall, with three days accumulating >2.54 inch total rainfall in May 2005.

Discussion

New and mature CBNG ponds are producing *Cx. tarsalis* larvae similar to or above levels occurring in natural water sources in northeastern Wyoming. These sites also produce *Cx. tarsalis* over longer intervals than natural sites with peak larval production the week of 18 July (Julian date 198). This is comparable to *Cx. tarsalis* production in Nebraska, where the first larvae were found on 25 May, with peak production the week of 11 July (Julian date 191) (Edmunds 1955). The most productive areas for *Cx. tarsalis* larvae were CBNG pond outlets, which have been observed to fluctuate in water level in 2005 (personal observation).

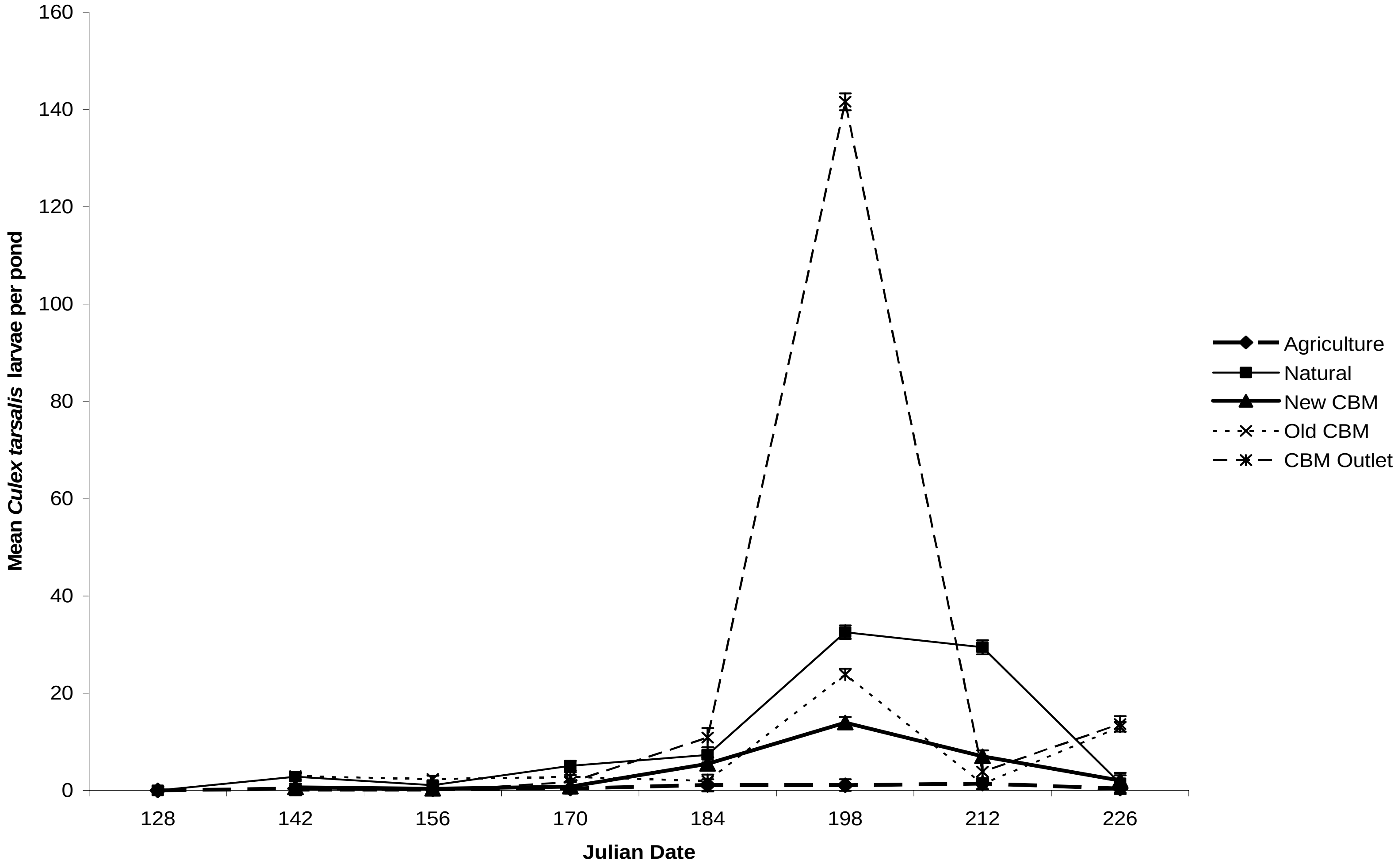

Figure 11. *Culex tarsalis* production over time by aquatic habitat in the Powder River basin, Wyoming, 2005.

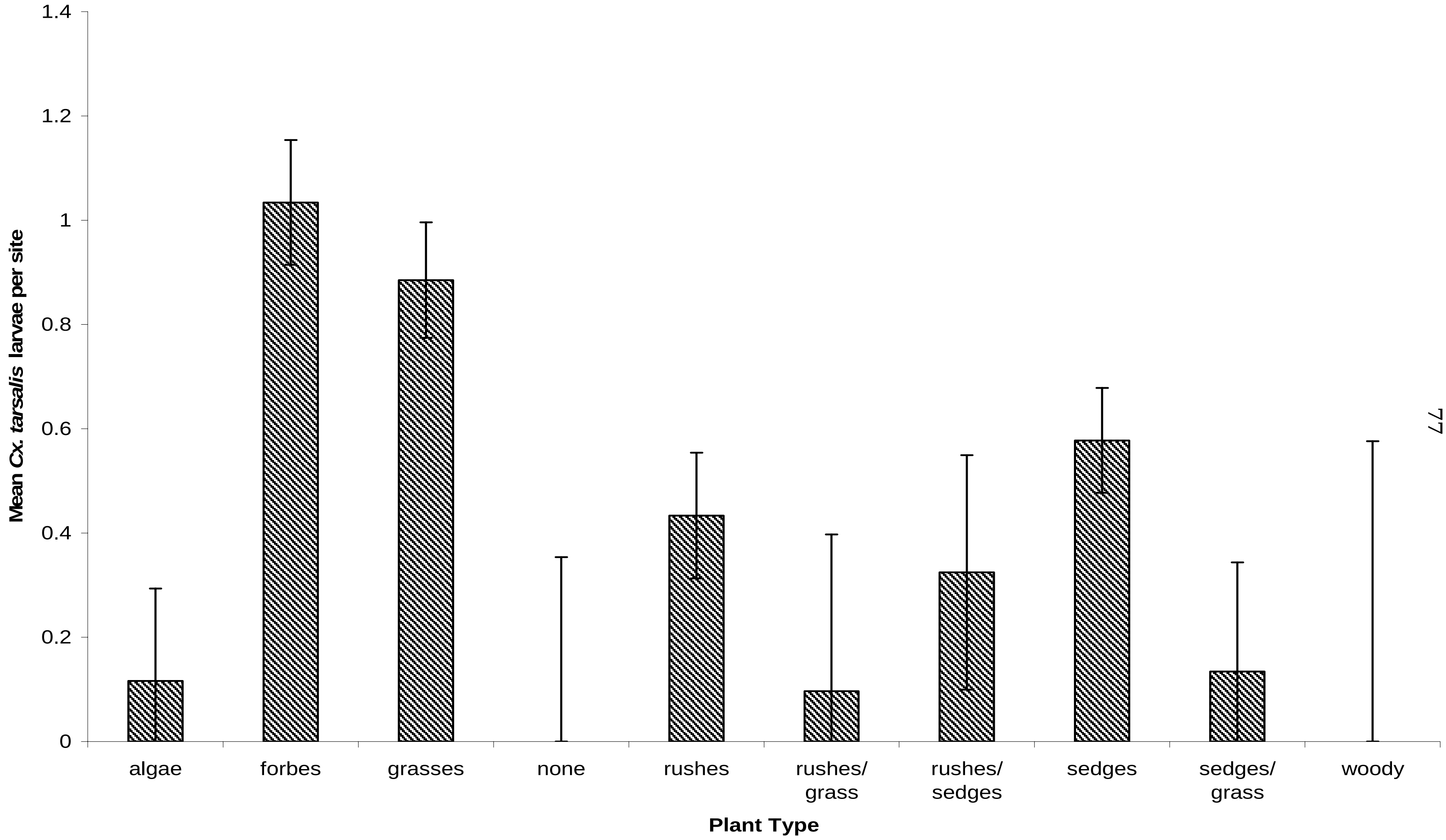

Figure 12. *Culex tarsalis* production by local habitat plant type across the Powder River basin, Wyoming for the week of 4 August 2005 (Julian date 216).

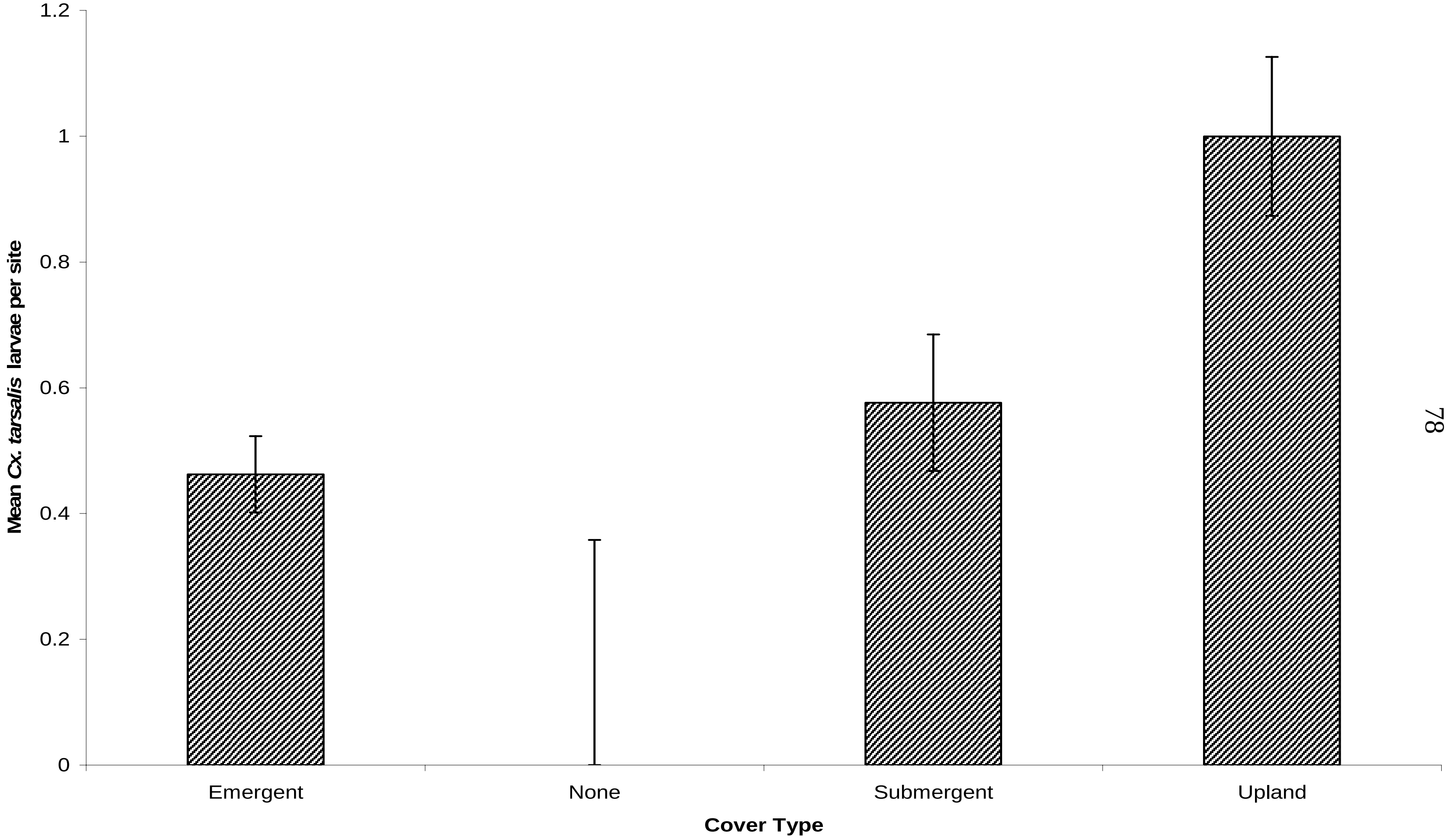

Figure 13. *Culex tarsalis* production by local habitat cover type across the Powder River basin, Wyoming for the week of 4 August 2005.

In other areas *Cx. tarsalis* have been found in high abundances in freshly flooded ponds in Southern California, with peak populations several days after flooding (x = 7) (Beehler and Mulla 1995). Fluctuating water levels of CBNG ponds and pond outlets are similar to the flooded habitats studied in California, and provide more oviposition sites for *Cx. tarsalis* than other aquatic habitats in this region.

High larval production of *Cx. tarsalis* in CBNG sites is consistent with high capture rates of adult *Cx. tarsalis* in light traps in 2005, showing that increased larval populations equate to an increased abundance of host-seeking vectors that can potentially spread WNV. Study areas with the highest adult *Cx. tarsalis* population also had the highest mosquito infection rates in 2004 and 2005, with mature CBNG sites having infection rates of 1.96 infected mosquitoes per 1000 in our 2005 study. In 2003, the U. S. Geological Survey indicated that 70% of WNV cases in humans in Wyoming were from the PRB, which accounts for approximately 11% of the counties in the state (3 counties). That same year, survival of sage-grouse in natural gas fields in the Spotted Horse area of the PRB showed a 75% decline due to WNV infection, and demonstrated little ability to develop antibodies to this pathogen (Naugle et al. 2004, 2005; Walker et al. 2004).

Coal bed natural gas ponds do not currently produce many *Ae. vexans*, which are known vectors for Rift Valley Fever (RVF) in Eurasia and Africa (Ba et al. 2005). They also do not produce significant *Ae. melanimon,* which vector Western Equine Encephalitis (WEE) and Saint Louis Encephalitis (SLE) in the western hemisphere (Jensen and Washino 1991). Larvae of *Ae. vexans* or *Ae. melanimon* were most abundant in natural and irrigated agricultural sites, likely because these sites are ephemeral, providing muddy substrate for oviposition. I recommend that these habitats be closely monitored if the risk of RVF, WEE, or SLE increases regionally.

Field studies in southern California indicated that *Cx. tarsalis* prefer aquatic habitats surrounded by grasses and annual vegetation with large populations of protozoans, and bacteria, as well as decay of elevated vegetation (Beehler and Mulla 1995; Fanara and Mulla 1974). Vegetation and high primary productivity provide food and cover for larval mosquitoes, making them an important component for oviposition sites. My vegetation assessment indicates that both new and mature CBNG ponds as well as natural water sources are fulfilling these requirements for *Cx. tarsalis* habitats. Recent research using Landsat satellite imagery from the PRB found that CBNG development has resulted in a 75% increase of potential larval habitat for *Cx. tarsalis* (Zou et al. 2006). My larval sampling indicates that CBNG sites are good larval habitats for *Cx. tarsalis*, especially those with flooded grasses and vegetation. As such CBNG ponds are producing mosquitoes at a rate at or above natural water sources in this region.

Culex tarsalis do not prefer open water habitats as oviposition sites throughout their range (Jiannino and Walton 2004). In the PRB, I found no *Cx. tarsalis* larvae in open water habitats throughout the 2005 field season. Modifying existing CBNG ponds by reducing aquatic vegetation and making shorelines steeper may reduce *Cx. tarsalis* production in this region without providing habitats for other disease vectors such as *C. sonorensis*. Habitat modifications for *Cx. tarsalis* production have been used with some success in wastewater treatment ponds in southern California (Batzer and Resh 1992; DeSzalay and Resh 2000; Thullen et al. 2002). Coal bed natural gas ponds provide us an opportunity to experiment with habitat manipulation practices as vegetation can be completely removed from these areas without reducing the efficiency of the site as in a wastewater treatment facility.

Management Recommendations

Based on available information that I obtained in this study, I recommend a multi-dimensional approach (AMCA 2006) to reduce mosquito production from CBNG ponds across the PRB. A three-pronged approach for mosquito control of *Cx. tarsalis* at CBNG sites would include 1) modifying new CBNG ponds for primary source reduction, 2) site modifications to new CBNG sites and retro-fitting existing ponds to reduce larval production, and 3) initiating mandatory use of larval control methods at existing CBNG sites.

The most effective way to reduce future mosquito production is to limit construction of additional CBNG ponds. One way to limit the number of newly created CBNG ponds is to re-inject water produced during the extraction process into sub-surface voids after gas is removed (USGS 2000; Department of Energy 2002). A new technology for water re-injection is currently being tested in the PRB where no treatment chemicals are needed, and approximately 75% of CBNG production water is capable of being received by the aquifer (Society of Petrolium Engineers 2007). This technology, called the Aquifer Recharge Injection Device (ARID), is currently being tested by Marathon Oil in eleven wells in the PRB with permits for more to come. If new CBNG ponds are not eliminated, then modifications such as the ones listed below to new and existing ponds would likely reduce mosquito production from these habitats.

The following are seven distinct site modifications that if adhered to, would minimize exploitation of CBNG ponds by *Cx. tarsalis:*

1. Increase the size of ponds to accommodate a greater volume of water than is discharged. This will result in un-vegetated and muddy shorelines that breeding *Cx. tarsalis* avoid (De Szalay and Resh 2000). This modification may reduce *Cx. tarsalis* habitat but could create larval habitat for *Culicoides sonorensis*, a vector of blue tongue disease, and should be used sparingly (Schmidtmann et al. 2000). Steep shorelines should be used in combination with this technique whenever possible (Knight et al. 2003).
2. Build steep shorelines to reduce shallow water (>60 cm) and aquatic vegetation around the perimeter of impoundments (Knight et al. 2003). Construction of steep shorelines also will create more permanent ponds that are a deterrent to colonizing mosquito species like *Cx. tarsalis* which prefer newly flooded sites with high primary productivity (Knight et al. 2003).
3. Maintain the water level below that of rooted vegetation for a muddy shoreline that is unfavorable habitat for mosquito larvae. Rooted vegetation includes both aquatic and upland vegetative types. Avoid flooding terrestrial vegetation in flat terrain or low lying areas. Aquatic habitats with a vegetated inflow and outflow separated by open water produce 5-10 fold fewer *Culex* mosquitoes than completely vegetated wetlands (Walton and Workman 1998). Wetlands with

open water also had significantly fewer stage III and IV instars which may be attributed to increased predator abundances in open water habitats (Walton and Workman 1998).

4. Construct dams or impoundments that restrict down slope seepage or overflow by digging ponds in flat areas rather than damming natural draws for effluent water storage, or lining constructed ponds in areas where seepage is anticipated (Knight et al. 2003).
5. Line the channel where discharge water flows into the pond with crushed rock, or use a horizontal pipe to discharge inflow directly into existing open water, thus precluding shallow surface inflow and accumulation of sediment that promotes aquatic vegetation.
6. Line the overflow spillway with crushed rock, and construct the spillway with steep sides to preclude the accumulation of shallow water and vegetation.
7. Fence pond site to restrict access by livestock and other wild ungulates that trample and disturb shorelines, enrich sediments with manure and create hoof print pockets of water that are attractive to breeding mosquitoes.

The third and final part of my suggested three-pronged approach is to initiate the use of larval control methods at CBNG ponds that have been sampled and are positive for mosquito larvae. Treating CBNG ponds with larvicides such as *Bacillus thuringiensis* var. *israelensis* (Bti) have been shown to provide a 90-100% reduction in *Ae. vexans* and *Culex* spp. larvae in California, and these materials could be used in CBNG ponds to control larvae during weeks of peak densities (Berry et al. 1987; Russel et al. 2003).

Larvicide treatments of CBNG ponds should be conducted by certified pesticide applicators that have been trained to identify mosquito breeding habitats in the field, and can efficiently distribute larviciding materials according to product guidelines. The key to managing mosquito production with larvicide materials is to place the product in areas of high larval densities (Berry et al. 1987). Trained field personnel will need to visit potential mosquito production areas on a weekly or bi-weekly basis during the growing season to check for mosquito production. Treatment will then need to be administered when 1) appropriate larval densities are found (e.g., 5 larvae per dip) and 2) when larvae sampled are in a target genus (e.g., *Culex* spp.). When larvicides are applied they should be used in concentrations according to product guidelines, and only in aquatic areas that are known larval mosquito habitats including flooded upland grasses and emergent aquatic vegetation.

Lastly, additional research is being conducted to assess the efficacy of using native larvivorous fishes to control mosquito population CBNG ponds. It is possible that a combination of water re-injection, CBNG pond modification and larvivorous fishes could be used to reduce the overall mosquito production without the need for a long-term labor-intensive mosquito management programs surrounding CBNG development. Until this is known, this three-pronged approach to managing mosquito production is prudent to reducing the risk of disease to humans and wildlife in the PRB.

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Linking conservation actions to demography: grass height explains variation in greater sage-grouse nest survival

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Conservation success often hinges on our ability to link demography with implementable management actions to influence population growth (λ). Nest success is demonstrated to be important to λ in greater sage-grouse *Centrocercus urophasianus*, an imperiled species in the North American sagebrush-steppe. Enhancing this vital rate through management represents an opportunity to increase bird numbers inside population strongholds. We identified management for grass height as an action that can improve nest success in an analysis of sage-grouse nests ($n = 529$) from a long-term study (2003–2007) in the Powder River Basin, southeast Montana and northeast Wyoming, USA. Average grass height by study area and year varied (11.4–29.2 cm) but its positive effects on nest survival were consistent among study years and study areas that differed in absolute rates of nest success. We tested the predictive ability of models by grouping output from log-link analyses (2004–2006) into two bins with nest success probabilities < 0.45 and > 0.55, and validated the relationship with additional data from 2003 and 2007. Nests with probabilities > 0.55 were 1.64 (2004–2006) to 3.11 (2007) times more likely to hatch than those < 0.45, except in 2003 when an early wet spring resulted in universally high grass height at nest sites (29.2 cm) and high predicted nest success (64%). The high predictive power of grass height illustrates its utility as a management tool to increase nest success within priority landscapes. Relationships suggest that managing grass height during drought may benefit sage-grouse populations.

Achieving desired conservation outcomes requires planning at scales that match the biological needs of wide-ranging focal species (Nicholson et al. 2013). Inherent in conservation success is our ability to link demography to implementable management actions that influence population growth (λ; Mills 2012). Implementing locally beneficial conservation practices inside intact ecosystems maximally benefits species for which landscape context matters (Wilson et al. 2007, Schultz 2010). Advances in spatial ecology make landscape prioritization more feasible (Millspaugh and Thompson 2009), but identifying intact targets is only a first step (Knight et al. 2008). Still missing in most plans is a demographic link between a conservation action and its ability to influence demographic traits influencing λ (Wisdom et al. 2000, Caswell 2001).

Greater sage-grouse *Centrocercus urophasianus* (hereafter sage-grouse) are native only to western arid and semiarid sagebrush *Artemisia* spp. landscapes (Schroeder et al. 1999), and extirpated from half their range (Schroeder et al. 2004), the species is a candidate for listing under the federal Endangered Species Act (US Fish and Wildlife Service 2010). Major fragmenting threats include energy development (Naugle 2012), wildfire (Bukowski and Baker 2013, Murphy et al. 2013), cultivation for row crop production (Foley et al. 2011) and others (Knick et al. 2013). The current sage-grouse distribution encompasses 76 million hectares, yet population densities are highly clumped across their range (Doherty et al. 2010a). In efforts to focus conservation actions, the US Fish and Wildlife Service identified “Priority Areas for Conservation” (PACs; US Fish and Wildlife Service 2013) by consulting US states to incorporate the best available population and habitat data into site delineation. Research has focused on reducing threats to populations within PACs (Baruch-Mordo et al. 2013, Copeland et al. 2013), yet management actions that aim to bolster populations within priority areas will be critical for a species with declining distribution.

The purpose of our paper is to increase conservation effectiveness by exploring linkages between demography and implementable actions to benefit populations. Nest success is demonstrably important to λ, and enhancing this vital rate through management may benefit populations (Taylor et al. 2012). Variation in nest survival may in part be explained by grass height (DeLong et al. 1995), a feature influenced by grazing (Rickard et al. 1975), and a preeminent landuse in sagebrush systems. We used generalized linear models to estimate the influence of vegetation and nest characteristics on sage-grouse nest survival within a landscape context (Dinsmore et al. 2002, Rotella et al. 2004). Findings will help guide the US Dept of Agriculture's Sage Grouse Initiative (SGI) in implementing rotational grazing systems designed to increase hiding cover for nesting grouse inside PACs on 847 000 ha of privately-owned rangelands (<www.sagegrouseinitiative.com/our-work/proactive-conservation/> under Grazing Systems).

Material and methods

Study area

We sampled sage-grouse in two distinct study areas in Johnson and Sheridan Counties in northeast Wyoming (southern region), and Bighorn, Rosebud, and Powder River Counties in southeast Montana (northern region), USA. Northern study areas were dominated by sagebrush, with conifer encroachment in more rugged landscapes and overall larger grassland areas. Southern study areas were also dominated by sagebrush, but had no conifers and exhibited smaller grassland areas. Shrub–steppe habitats were dominated by Wyoming big sagebrush *A. tridentata wyomingensis* with an understory of native and non-native grasses. Land use in both study areas was dominated by cattle ranching and land tenure was a mix of federal, state and private. Doherty et al. (2008) provides detailed descriptions of study areas. Because of the differences in landscape context, study area was included as a categorical blocking variable.

Capture, radio-tracking and predictor variables

We captured sage-grouse in rocket-nets and walk-in traps (Giesen et al. 1982) and by spotlighting (Wakkinen et al. 1992) March–April and July–October in 2003–2007. We aged females, fitted them with necklace style VHF radio collars, and relocated sage-grouse to monitor nests by ground based radio-tracking throughout the breeding season. We used established protocols (Connelly et al. 2003) to quantify local vegetative features known to influence habitat selection within ≤15 m of nests (Connelly et al. 2000, Hagen et al. 2007; Table 1). Doherty et al. (2010b) provides a full description of nest monitoring.

Statistical analyses and model selection

We used generalized linear models with a binomial likelihood and a log-link to estimate the influence nest age, study area and grass height on the daily survival rates (DSR) of nests (Dinsmore et al. 2002, Rotella et al. 2004). We derived nest survival rates by multiplying DSR together over the 28 day predicted incubation time for sage-grouse. We divided samples into nests used to build the model ($n = 383$ nests in 2004–2006) and those used to test model stability and predictive capability ($n = 146$ in 2003 and 2007).

We followed an iterative system for model selection. We first included a variable that controlled for the known effect of a spring snow storm in 2005 on DSR in all variable screenings and final model selection (Walker 2008).

Table 1. List of variables used in model selection explaining sage-grouse nest survival, Powder River Basin, Montana and Wyoming, USA, 2004–2006.

Candidate variables	Description
Local scale habitat variables	
Shrub canopy cover	using the line-intercept method along two 30 m perpendicular transects centered at nest or random locations (Canfield 1941)
Shrub density	all shrubs > 15 cm within 1 m of transect line were counted, total /120 m^2
Quadratic shrub canopy cover	shrub canopy cover + (shrub canopy cover × shrub canopy cover)
Nearest shrub height	height of nearest shrub to Daubenmire quadrant location. There were 10 Daubenmire quads on each of the two 30 m transects for a total of 20 Daubenmire quads. They were spaced 3 m apart and started at 0 m
Visual obstruction at nest	height density readings at 0, 1, 3 and 5 m from nest or available shrub in each cardinal direction (Robel et al. 1970)
Nearest grass height	average of the vegetative droop height for the nearest grass from the 20 Daubenmire quadrants
Tallest grass height	average of the vegetative droop height for the tallest grass from the 20 Daubenmire quadrants
Average grass height	(nearest grass height + tallest grass height)/2
Nest characteristic variables	
Hen age	yearling or adult (Walker 2008)
Nest age	(nest age in days + nest age in days^2) (Walker 2008)
Snowstormmarker	grouped 7 nests that were abandoned following major snow event in May 2005
Abiotic site variables	
Study area	north or south Powder River Basin
Year	year of observation

We assigned predictor variables into 1 of 3 model categories: 1) habitat, 2) nest characteristic, and 3) site variables (Table 1). We first examined univariate selection for study area and the 8 habitat variables, and removed variables if 95% confidence intervals overlapped zero. If predictor variables were highly correlated ($r \geq |0.7|$), only the variable with the greatest biological merit was included in the model (Chatfield 1995). When variables were moderately correlated (i.e. $|0.3| \leq r < |0.7|$), we checked for stability and consistency of parameter estimates as predictor variables were added.

We allowed each variable that made it past variable screening to compete with all other combinations of variables to identify the most parsimonious model for habitat and study area. If variables made it past screening we determined if their addition improved model fit via Akaike's information criterion with a small sample size correction factor (AIC_c; Burnham and Anderson 2002). After obtaining the best habitat model using AIC_c values, we then tested if inclusion of nest characteristic variables (Table 1) and an additional abiotic site variable (year effect) documented in Walker (2008) were still important predictor variables when included with habitat covariates. We followed the exact variable screening and AIC methods described above to test if these variables improved model fit.

We tested the predictive strength of the final habitat model by grouping predicted nest survival probability from log-link analyses (2004–2006) into two bins with probabilities of nest survival, <0.45 and >0.55, generically representing low and high nest survival probabilities, respectively. We then compared observed nest success from independent data sets (2003 and 2007) between low and high validation bins, and calculated the ratio of observed nest success between the high and low bins. We reasoned that observed nest success should be higher in the top validation bin if the final model predicted nest success well across years, demonstrated by a ratio of observed nest success >1 between bins. We further evaluated the predictive model by comparing predicted nest success from our top model to observed nest success by year. Average grass height around nesting sage-grouse in a given year (Table 1) was the only continuous predictor variable included in our top model, thus we evaluated how well one variable served as an indicator of nest success. Statistical analyses were performed in program SAS ver. 8.0 (SAS Inst. <http://v8doc.sascom/sashtml/>).

We performed a bootstrap analysis to quantify precision and the effect size of grass height on nest survival, using beta coefficients from the best approximating model (Burnham and Anderson 2002). We used the logistic exposure equation (Rotella et al. 2004) to generate the predicted probability of successfully hatching a nest for each bootstrap dataset ($n = 5000$) by systematically varying grass height within the observed range of variation. We computed at each percentage the probability of successfully hatching a nest for each of 5000 simulations. We ordered these probabilities and used a rankit adjustment (Chambers et al. 1983) to estimate upper and lower 95% confidence intervals.

Results

Nearest, tallest and average grass height were the only variables with significant coefficients when tested univariately. Nearest, tallest and average grass height were all positively associated with nest success, but were highly correlated and could not be included in the same model. Average and nearest grass height had virtually identical univariate coefficient estimates, however average grass height showed less variation around the estimate (average grass height $\beta = 0.034$, $SE = 0.013$, 95% CI = 0.008–0.060 vs nearest grass height $\beta = 0.039$, $SE = 0.019$, 95% CI = 0.001–0.076). Further, average grass height outcompeted nearest and tallest grass measures based on AIC_c values, thus it was retained for additional modeling.

The addition of study area increased model fit, while hen age and year effects were removed from the model because they explained no additional variation in nest survival when included with habitat variables and confidence intervals around effect estimates overlapped zero. The inclusion of nest age increased model fit ($w_i = 0.974$; Table 2). Our final model included average grass height, nest age, study area and the variable that controlled for the known effect of a spring snow storm in 2005 on DSR.

Table 2. Comparisons of grass height, study area and nest age variables to identify the AICc best model explaining sage-grouse nest survival, Powder River Basin, Montana and Wyoming, 2004–2006[a].

Model	K	AIC_c	ΔAIC_c	w_i
Average grass height + study area + nest age	6	834.418	0.000	0.974
Average grass height + study area	4	841.634	7.216	0.026
Average grass height	3	866.099	31.681	0.000
Study area	3	927.881	93.463	0.000

[a] all models included a categorical blocking variable which controlled for nests abandoned in a heavy spring storm in 2005 (Walker 2008).

Estimates of average grass height tracked annual trends in nest success (Fig. 1; northern region 2003–2007, beta estimate = 0.036, $p = 0.023$; southern region 2004–2007, beta estimate = 0.079, $p = 0.001$). Bootstrap analyses showed the positive relationship between average grass height and nest success (Fig. 2). Our final model including grass height and study area demonstrated large effect sizes (Fig. 2). Nests with probabilities >0.55 were 1.64 (2004–2006) to 3.11 (2007) times more likely to hatch than those <0.45 (Table 3), except in 2003 when average grass height (29.2 cm) and apparent nest success reached their highest recorded levels (68%, Fig. 1).

Discussion

High predictive power of grass height illustrates its utility as a management tool to benefit sage-grouse populations. Findings show grass height is a strong predictor of nest survival inside intact landscapes, and increasing hiding cover can increase nest success, a demographic rate that explains a

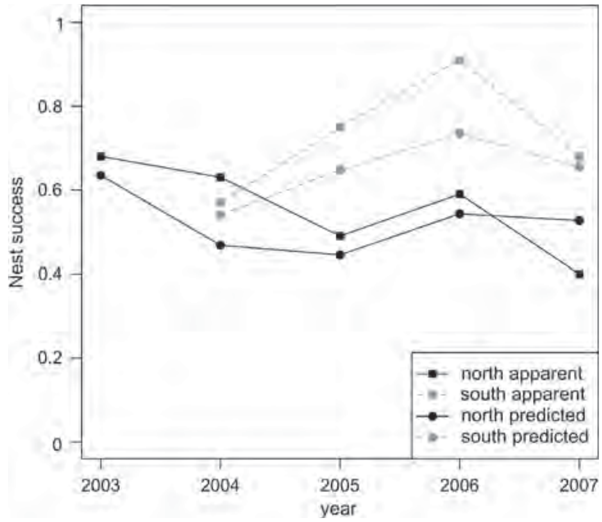

Figure 1. Apparent and predicted annual nest survival by year for sage-grouse in the Powder River Basin, Montana and Wyoming, US, 2003–2007. The final model included the effects of grass height, nest age, study area, and 2005 spring snow storm. Grass height measurements were averaged across nests within years to make annual predictions.

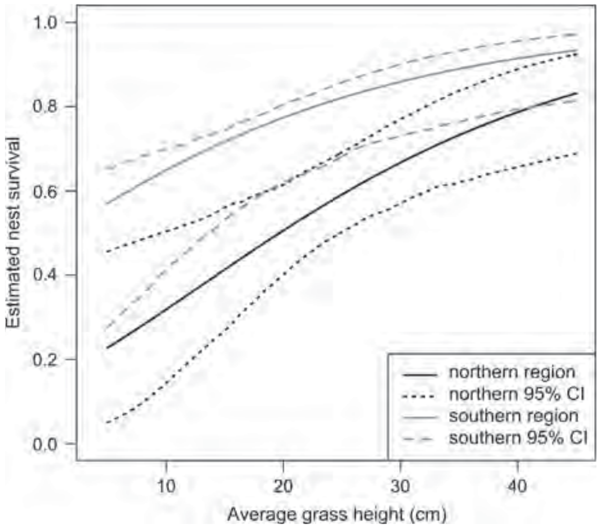

Figure 2. Relationship between average grass height and sage-grouse nest survival, Powder River Basin, Montana and Wyoming, USA, 2004–2006. Estimates of nest survival (95% confidence intervals [CIs]) in both study areas are based on 5000 bootstrap samples.

third of variation in λ (Taylor et al. 2012). Moreover, grass height is a reliable management tool because it explained variation (Fig. 2) despite variability in absolute rates of nest success between study areas. Positive effects of grass height should be evaluated on other important demographic rates including adult female and chick survival (Taylor et al. 2012) to see if benefits extend beyond what is now known.

Managing grass height in large and intact landscapes with grazing is a tool that may benefit populations in eastern Montana and northeast Wyoming. Positive effects of grass height in our study areas explained variation in nest success between years with large and precise effect sizes. Differing intercepts prohibit extrapolating of results to novel sagebrush systems because absolute effects likely depend upon regional conditions that influence grass and shrub composition. South and west of our study areas where sagebrush rather than grass provides most hiding cover, grass height had only a weak effect on nest success, and nest fates were dominated by year and site effects (Holloran et al. 2005). Grass height is positively related to nest success for other prairie grouse species and subspecies (Attwater's prairie-chickens *Tympanuchus cupido attwateri*, Lehmann 1941; plains sharp-tailed grouse *T. phasianellus jamesi*, Hillman and Jackson 1973; greater prairie-chicken *T. cupido pinnatus*, McKee et al. 1998).

Table 3. Validation of grass height as a predictor for sage-grouse nest success, Powder River Basin, Montana and Wyoming, 2003–2007. We tested the AICc best model (Table 2) by calculating the predicted probability of hatching for each nest by applying grass height and region coefficients from log-link analysis (2004–2006) to observed grass heights at nests. We used the predicted probability (n is number of nests in each category) of hatching to group nests with probabilities of <0.45 and >0.55 and then compared apparent nest success ratios. We also validated the relationship with independent data sets (2003 and 2007). Nest age was excluded because we exponentiated daily survival rate for nests across the 28-day incubation period.

Predicted probability	Observed nest success		
	2003	2004–2006	2007
$p<0.45$ (low)	0.714 (n = 7)	0.486 (n = 70)	0.200 (n = 5)
$p>0.55$ (high)	0.667 (n = 30)	0.796 (n = 184)	0.623 (n = 52)
Ratio (high/low)	0.93	1.64	3.11

Findings suggest that maintaining grass height during drought may provide the greatest benefits to populations. Average grass height and predicted nest success in this study is within the range of published literature (Schroeder et al. 1999, Connelly et al. 2000). Benefits may be negligible in years resembling 2003 when spring rains provided abundant grass and the correspondingly highest predicted nest success for the northern study area. High variation in pooled grass height by study area and years (11.4–29.2 cm) also suggested that modifying grazing practices to maintain nesting cover could improve a habitat feature that otherwise limits λ. We have identified a strong corollary of nest success in the Powder River Basin (PRB). If this relationship is validated in new study areas across different parts of the sage-grouse range, and if the relationship between grass height and nest success can be calibrated within these new areas, grass height may be useful as a surrogate to monitor nest success.

Findings emphasize the importance of an indirect effect of grazing on sage-grouse nest success. Results have broad implications because livestock grazing is the most widespread land use in the world (Holechek et al. 2003), affecting 70% of land area in the western US (Fleischner 1994). Effects of grazing on sage-grouse habitat may be wide-ranging depending upon current and historic timing and intensity of grazing, soil conditions, precipitation, plant communities and habitat features under consideration (Beck and Mitchell 2000, Connelly et al. 2000, 2004, Crawford et al. 2004). However, adjustments to duration and timing of grazing also may increase residual cover with the added benefit of increasing long-term rangeland health on which birds depend. For example, reducing the short-term stocking rate of sheep increased black grouse *Tetrao tetrix* numbers by 6% annually in Europe by increasing residual cover (Calladine et al. 2002). Replicated experiments to document sage-grouse response to different grazing systems are needed to help guide land managers to practices that are beneficial to sage-grouse and economically viable to producers (Krausman et al. 2011).

Habitat management within a PAC-based conservation strategy may benefit populations, but sage-grouse are a wildland species, and grass height is of little consequence if sagebrush systems continue to be replaced by anthropogenic land uses (Knick et al. 2013). Viability of ranching as a predominant land use may in part determine the future of sage-grouse conservation in the West. The SGI has increased by four-fold their implementation of rotational grazing systems by resting for up to 17 months the pastures used by nesting sage-grouse grouse within 488 000 ha inside Montana's PACs (J. Siddoway pers. comm.). Our findings suggest that these types of grazing systems that promote nest success may provide one mechanism to offset population losses by increasing bird numbers.

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Research Article

Male Greater Sage-Grouse Detectability on Leks

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ABSTRACT It is unlikely all male sage-grouse are detected during lek counts, which could complicate the use of lek counts as an index to population abundance. Understanding factors that influence detection probabilities will allow managers to more accurately estimate the number of males present on leks. We fitted 410 males with global positioning system and very high frequency transmitters, and uniquely identifiable leg-bands over 4 years in Carbon County, Wyoming. We counted male sage-grouse using commonly used lek-count protocols and evaluated variables associated with our ability to detect marked males using sightability surveys on 22 leks. We evaluated detection probabilities of male sage-grouse based on factors related to bird characteristics such as age or posture, lek and group size, lek characteristics such as vegetation cover or aspect, light conditions, weather, and observer. We then applied the detection probabilities to more accurately estimate male counts on leks. Detection probabilities were generally high ($\bar{x} = 0.87$) but varied among leks from 0.77 to 0.93. Male sage-grouse detection declined with increasing sagebrush height and bare ground and increased with more snow cover. Detection probabilities were also lower when observers counted from a higher elevation than the lek. Our sightability models predicted detection well and can be used to accurately estimate male abundance on leks from lek counts, which is especially useful where accurate abundance estimates are required or inference about population status is based on only 1 count. Further, it is important to consider lek attendance as a component of counts on leks because it affects availability of male sage-grouse for detection during lek counts. Detection can be maximized by conducting lek counts from 30 minutes before sunrise to 30 minutes after sunrise, although current protocols recommend lek counts can be performed up to 1 hour after sunrise. Detection can also be maximized by conducting lek counts ≥ 2 days after snowfall, which maximizes attendance and detection. © 2015 The Wildlife Society.

KEY WORDS abundance, *Centrocercus urophasianus*, detectability, detection, greater sage-grouse, index, lek counts, sightability, Wyoming.

Biologists and managers must be able to accurately monitor the status and trends of species that are declining in abundance, or under consideration for listing as endangered. For many species, detectability during surveys is an important factor affecting the accuracy and reliability of monitoring programs. When detection rates differ over time and space, observed trends in abundance may be biased unless they are corrected (Johnson 2008, Kéry and Schmidt 2008, Schmidt et al. 2013). Consequently, attempts have been made to identify factors affecting detectability of large mammals (Samuel et al. 1987, Bodie et al. 1995, Rice et al. 2009, Vander Wal et al. 2011, Walsh et al. 2011), songbirds (Farnsworth et al. 2002, Alldredge et al. 2007, Diefenbach et al. 2007, Kéry and Schmidt 2008, Schmidt et al. 2013), and other species to avoid bias in assessments of trends. Problems with detectability are a primary reason new analytical approaches, such as occupancy modeling (MacKenzie et al. 2003), have become so popular in recent years. For species such as the greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse), which was previously designated as warranted but precluded from listing as endangered under the Endangered Species Act of 1973 (U.S. Fish and Wildlife Service [USFWS] 2010), careful monitoring is necessary to aid conservation efforts.

State and federal management agencies have been counting male sage-grouse on leks since the 1940s to evaluate sage-grouse population status and trends, and these data represent the only long-term data set available for sage-grouse abundance assessments (Connelly and Schroeder 2007, Johnson and Rowland 2007). Lek counts are also valuable because leks are relatively high concentrations of the population that can be easily and inexpensively surveyed every year in the same location (Patterson 1952, Dalke et al. 1963, Beck and Braun 1980, Walsh et al. 2004, Sedinger

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2007). Lek locations and the timing of the breeding season are predictable because sage-grouse have high site fidelity to leks annually (Patterson 1952, Jenni and Hartzler 1978, Connelly et al. 2003) and within a breeding season (Campbell 1972, Dunn and Braun 1985, Schroeder and Braun 1992, Schroeder and Robb 2003, Walsh et al. 2010).

Although lek counts are used to survey male sage-grouse populations and may be useful to monitor relative abundance annually, lek counts may not provide a reliable index to population size if imperfect detection and variability in detection exist among leks or through time (Samuel et al. 1987, Anderson 2001, Johnson 2008). Lek counts may be unreliable estimates of relative abundance as well, if detection varies among survey events within a year. Birds that are not easily observed but are still present on the lek, such as foraging males or yearlings that do not actively display (Garton et al. 2007), may not be counted during a lek survey, and thus bias male abundance estimates. When detection is imperfect, detection probabilities can be used to estimate the number of males missed during a lek survey, and more accurately estimate the number of males present (White and Shenk 2001, White 2005). So-called sightability studies have been extensively applied to ungulates and other large game species (Samuel et al. 1987, Steinhorst and Samuel 1989, Bodie et al. 1995, Udevitz et al. 2006, Vander Wal et al. 2011) but have only recently been proposed for use on upland game birds (Walsh et al. 2004, Clifton and Krementz 2006, Baumgardt 2011). Sightability studies can be used with marked animals to determine factors influencing detection, including variables related to the marked animal and its immediate surroundings.

Factors that may affect sage-grouse sightability include light conditions (Vander Wal et al. 2011), bird behavior, bird location within the lek and in relation to other birds, observer experience and location in relation to the bird, and vegetative cover (Samuel et al. 1987, Vander Wal et al. 2011, Walsh et al. 2011). The physical size of the lek and group size of displaying birds on the lek may also affect an observer's ability to effectively search the area, and observers may have difficulty accurately counting males on leks with many birds (Samuel et al. 1987, Rice et al. 2009). Movement or posture of birds can increase an observer's ability to notice them (Bodie et al. 1995, Garton et al. 2007). Topography and vegetation at leks, or an observer's location in relation to the bird, could also influence detection (Bodie et al. 1995). Sightability studies determine the degree to which various factors influence detection, and can be used to estimate a detection probability for each lek based on characteristics of a lek, conditions of the count, and characteristics of male sage-grouse.

This research was part of a larger, long-term study using a before–after, control-impact design to assess relationships between wind energy development and sage-grouse ecology in Carbon County, Wyoming. We estimated detection probabilities on leks in the pre-construction phase of a wind energy development. Our objectives were to 1) evaluate how bird characteristics and activity, lek size, lek characteristics, vegetation, light conditions, and observer affected detection probabilities, 2) apply estimated detection probabilities to lek count data for an accurate estimate of male abundance on leks, and 3) determine optimal conditions for lek counts to maximize detectability of male sage-grouse on leks.

STUDY AREA

The wind energy development was proposed on The Overland Trail Ranch (OTR), an approximately 1,295-km^2 mix of private and public land (Bureau of Land Management and Wyoming Office of State Lands and Investments) south of Rawlins, Wyoming. The OTR is a sagebrush steppe basin with foothills to the south and southwest and rocky ridges to the north and northeast with elevation ranging from 1,890 m to 2,590 m.

The climate is semiarid, with long, cold winters and short, hot summers (Bailey 1995). Highest temperatures are in July ($\bar{x}$ max. = 31° C) and lowest temperatures in December and January ($\bar{x}$ max. = −1° C; Western Regional Climate Center [WRCC] 2008). Annual precipitation is typically between 19 cm and 26 cm, with most precipitation occurring between April and October (WRCC 2008).

Vegetation in our study area was classified as intermountain semidesert province (Bailey 1995). Vegetation predominantly consisted of sagebrush or shadscale (*Atriplex confertifolia*) with short grasses (Bailey 1995). Greasewood (*Sarcobatus vermiculatus*) grew in moist alkaline flats, and willows (*Salix* spp.) and sedges (*Carex* spp.) lined streams and valley bottoms (Bailey 1995). Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) dominated lower elevations and mountain big sagebrush (*A. t. vaseyana*) dominated higher elevations, with silver sagebrush (*A. cana*) in lowlands and black sagebrush (*A. nova*) in rocky, exposed soils (Thatcher 1959, Chapman et al. 2004, Connelly et al. 2004, Welch 2005).

METHODS

Trapping and Marking

We trapped birds and distributed transmitters among active leks on and around the OTR. To avoid bias for dominant males roosting near leks (Walsh et al. 2004), we captured male sage-grouse in late fall and early spring to supplement the number of marked individuals and account for overwinter mortality. We captured male sage-grouse using spotlighting and hoop-netting techniques (Giesen et al. 1982, Wakkinen et al. 1992) facilitated by all-terrain vehicles. We weighed captured males and classified them based upon primary wing feather characteristics (Eng 1955, Crunden 1963) as adults ($\geq$2 years old) or yearlings (1–1.5 years old). Each bird received uniquely identifiable colored leg band combinations to facilitate resighting on leks (Walsh 2002; National Band and Tag Company, Newport, KY).

We deployed 20 transmitters in 2011, 20 in 2012, and 10 in 2013 using 30-g solar-powered platform transmitter terminal (PTT-100) global positioning system (GPS) transmitters (accuracy ± 18 m, Microwave Telemetry, Columbia, MD). The GPS–PTT transmitters had ultra high frequency (UHF) tracking. We marked an additional 50 males in

2011 with very high frequency (VHF) transmitters and attempted to maintain a sample size of 50 males with VHF transmitters every year by replacing expired transmitters and tagging new birds. Adult and yearling males tagged in spring with VHF transmitters usually received 30-g transmitters (Model A1150, Advanced Telemetry Systems [ATS], Isanti, MN), whereas juveniles tagged in fall with VHF transmitters received 15-g ATS transmitters (Model A1260, ATS) or 15-g Telonics (LB-35, Telonics, Mesa, AZ) transmitters. All GPS-PTT and VHF transmitters were <2% of grouse body weight and were attached using the Rappole and Tipton (1991) method. Trapping and handling procedures were approved through the University of Missouri Institutional Animal Care and Use Committee (Protocol #6750) and Wyoming Game and Fish Department (WGFD) Chapter 33 Permit (Permit #752).

Sightability Surveys

We monitored 58 leks throughout the study area (Fig. 1). Twenty-four to 33 leks were active each year of the study (2012–2014). We completed 2.65 ± 0.06 ($\bar{x} \pm$ SE) sightability surveys per lek on 20–22 active leks each spring (surveys per lek from 2012 to 2014 range = 1–11). Sightability surveys began 2 April 2012, 28 March 2013, and 19 March 2014 and continued until most leks were inactive or 3 lek counts were completed on each lek (22 May each year). We set up ground blinds at an observation point roughly 20–150 m from displaying males 1 week prior to lek counts to allow sage-grouse to habituate to its presence.

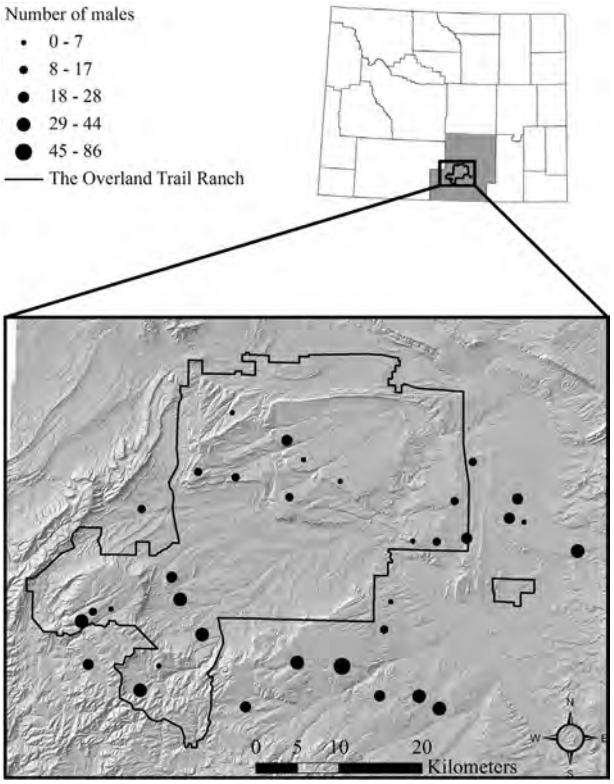

Figure 1. The Overland Trail Ranch in Carbon County, Wyoming, with all active greater sage-grouse leks in the study area. Active leks had ≥1 male from 2012 to 2014. Symbol size represents relative lek size based on 2013 count data. Because leks were active and inactive different years, we had 34 active leks total throughout the study.

We used a protocol with 2 observers to conduct sightability surveys. One observer (observer 1) recorded numbers of displaying males on leks and noted the occurrence and location of marked birds on the lek, facilitated by telemetry. Observer 1 was in a blind on the lek perimeter, able to observe marked birds and use telemetry to locate unseen marked birds. Observer 1 entered the blind 2 hours before sunrise and counted sage-grouse at 15-minute intervals starting as soon as light was sufficient, approximately 30 minutes before sunrise, until all birds left the lek (usually before 1000 hours). Between counts, observer 1 used telemetry equipment to scan UHF and VHF radio frequencies and detect unseen radio-marked birds on the lek. Once a male was visually confirmed to be present on the lek, observer 1 would note the marked male's location. Once a bird was detected by observer 1, it was not considered again.

A second observer (observer 2) independently recorded numbers of displaying males and the occurrence and location of marked individuals with no prior knowledge of marked individuals on the lek. Observer 2 counted sage-grouse on foot, using WGFD protocols for lek surveys simultaneously with observer 1. Observer 2 conducted lek counts from a location approximately 50–200 m from the lek boundary, and the location was independently chosen by observer 2 on the observation morning to imitate a WGFD observer's location choice during conventional lek counts. Observer 2 recorded male and female birds on the lek, color band identities, locations, and associated covariates for marked males. Observer 2 noted time spent surveying for marked individuals and total time observers were present at the lek.

Once the survey was complete, observers immediately compared data. We considered grouse that observer 2 located to be detected. We considered grouse that observer 1 noted, but observer 2 failed to detect as undetected. We used covariates recorded by observer 2 when the marked male was detected by observer 2, and covariates recorded by observer 1 when the marked male was not detected by observer 2.

For lek counts, we recorded date, observer location (Universal Transverse Mercator), time, wind speed, and sky condition. We recorded sky conditions as a code including clear or a few clouds (0), partly cloudy (1), cloudy or overcast (2), fog or haze (3), drizzle (4), showers (5), flurries (6), or snow showers (7). For each marked bird, observers recorded the bird's activity (sitting, foraging or standing without strutting, or strutting), time the bird was observed, group size (no. grouse within 5 m of the marked bird), number of males present on the lek at the time of detection, and time spent searching for the marked male (i.e., sampling intensity). We determined marked bird locations using a compass and rangefinder (accuracy ± 1 m from 5 m to 686 m away, Leupold RX-750, Beaverton, OR) to determine an azimuth and distance from a known location of the observer.

After grouse left the lek, we recorded microsite vegetation measurements on the day of the sightability survey at the location where the grouse was detected. We established 2, 10-m perpendicular bisecting transects in cardinal directions that were centered over the sage-grouse's location. We measured visual obstruction (VOR) using a modified Robel pole with 1.27-cm increments (Robel et al. 1970, Benkobi et al. 2000) at the plot center and every meter up to 5 m from the plot center, with a VOR reading in each cardinal direction ($n = 84$). We recorded the lowest height at which an increment on the Robel pole was completely obscured. We estimated canopy cover using a 0.1-m^2 quadrat placed parallel to the transect (Daubenmire 1959, Hanley 1978) at 1-m intervals out to 5 m along each transect and plot center ($n = 24$). Observers estimated canopy cover classes (1 = 0–5%, 2 = 5–25%, 3 = 25–50%, 4 = 50–75%, 5 = 75–95%, 6 = 95–100%) for sagebrush, other non-sagebrush shrubs, grasses and forbs, snow, and bare ground in each quadrat (Daubenmire 1959). We measured natural droop height (cm) of sagebrush, other shrubs, and grasses or forbs by selecting the plant in each category closest to the corner of the frame. We averaged Robel pole and vegetation height measurements for each sage-grouse location, and recoded canopy cover classes to the midpoints of the intervals and calculated average percent coverage for all cover classes at each sage-grouse location.

We calculated lek attendance rates, surrounding sagebrush cover, and elevation differences from observer to grouse as additional covariates. We calculated a seasonal lek attendance rate for each male sage-grouse by dividing the number of days the bird attended a lek by the number of days he was available to attend the lek throughout the season (Walsh et al. 2004, Fremgen 2014). We used ArcMap 10.0 (Environmental Systems Research Institute, Redlands, CA) with a 30 × 30-m categorical land cover layer based on Landsat ETM+ data (Driese and Nibbelink 2004), which we reclassified as sagebrush or other cover to calculate the percent of sagebrush within 50 m of the marked male. The 50-m radius provided a larger-scale representation of surrounding sagebrush cover on the lek, whereas the 5-m microsite vegetation measurements characterized sagebrush cover surrounding the male. We used a 30 × 30-m digital elevation model (DEM) to determine elevation for observation points and marked males, and we subtracted the elevation of the marked male's location from observer 2's elevation to model effects of the observer's position in relation to the lek. After the lek season ended, observers mapped leks using known locations of marked and unmarked birds noted during lek counts, and sign such as feathers, cecal tar, and droppings (Fremgen 2014). We calculated lek area (m^2) in ArcMap 10.0 using mapped lek perimeters.

Sightability Model Data Analysis

We created a priori models related to observer characteristics, lek size, vegetation characteristics, environmental conditions, and bird characteristics. We created models using biologically reasonable combinations of variables (Fremgen 2014: appendix D). We tested for correlation among covariates using PROC CORR in SAS 9.3 (SAS Institute, Cary, NC) and eliminated 1 variable of the pair when they were correlated ($r > 0.8$); we kept the variable that was most biologically meaningful. We evaluated whether data could be combined across years by comparing model rank with and without year as a covariate for multiple models; because year did not influence detection, we analyzed data pooled across years.

We modeled sightability of male sage-grouse using covariates for birds that were and were not detected using logistic regression in a generalized linear mixed model with observers modeled as a random effect using PROC GLIMMIX in SAS 9.3. We used second-order small sample size Akaike's Information Criterion (AIC_c; Burnham and Anderson 2002) to identify the most parsimonious model. Our model selection process involved 2 stages, including a screening process first to select the structural form of each variable that best represented its effect on detection, and then fitting a priori models using the best structural form (Franklin et al. 2000, Washburn et al. 2004). We tested structural forms of each variable using AIC_c to rank linear, quadratic, and pseudothreshold forms with the quadratic term centered on its mean to avoid multicollinearity between linear and quadratic terms in the polynomial (Bonnot et al. 2011). For simplicity we selected linear structural forms unless a nonlinear form was >2 ΔAIC_c units less than the linear form for that variable. We fit our a priori model set and averaged parameter estimates for all models with an Akaike weight (w_i) >12.5% the weight of the top model (Burnham and Anderson 2002). We did not consider interactions among variables because it would be complex for our many categorical variables. Initially, top models included sampling intensity and time since 30 minutes before sunrise, but those variables were not interpretable because they were strongly related to their sample distribution, with most males being recorded early in the morning. We removed models including those variables from analysis.

We evaluated goodness-of-fit using the Pearson χ^2 statistic divided by degrees of freedom (Pearson χ^2/DF). We evaluated the predictive ability of the most-supported model using 10-fold cross validation (Boyce et al. 2002) by dividing data into 10 random subsets and removing 1 subset for testing data, and refitting the model set using the remaining 9 subsets as training data. We estimated detection probabilities for testing sets based on model parameter estimates from the corresponding training set, and found the average difference between predicted probability of detection and observed detection. We also evaluated predictive ability using the Spearman-rank correlation coefficient by dividing our observations of detected males into 10 equal size bins based on the range of predicted probability of detection, and calculated the Spearman-rank correlation between the predicted probability and frequency of observed detections in each bin.

We used averaged model parameter estimates, weighted by model probability, to calculate detection probabilities at each lek using characteristics of the lek observed during the lek count with the highest male count, and we estimated an average detection probability by averaging characteristics across leks. Once we calculated the detection probability ($\hat{y}$) for each lek, we used it to obtain an accurate estimate of males present on the lek from count data. The estimated number of males on the lek ($\widehat{N}$) was:

$$\widehat{N} = \sum_{1}^{t} \frac{l_i}{\widehat{y}_i}$$

where l_i is the maximum number of birds counted on lek i throughout the season by any observer, and $\hat{y}_i$ is the detection probability on lek i. We calculated variance for the corrected abundance using bootstrap methods. At each active lek, we sampled from the estimated detection probability and used the male high count to calculate abundance for 1,000 iterations. We summed the estimated numbers of males at each lek for the corrected male abundance at all leks. Male sage-grouse move among leks, but the probability that a male would move to a new lek and be double counted during lek counts was low because lek counts were completed near the peak of attendance, when interlek movements are less likely (Fremgen 2014). Therefore, lek counts are not likely to overestimate total male abundance from double counting males if counts are completed at an appropriate time of year, near the peak of male attendance.

RESULTS

We deployed an average of 85 ± 27 ($\bar{x} \pm$ SE) transmitters each year (37 ± 9 GPS-PTT transmitters and 48 ± 19 VHF transmitters) to assist with lek counts and sightability survey effort (Table 1). From 2012 to 2014, we detected 222 marked birds; 44 birds were not detected by observer 2 but present on the lek. Most of the marked male sage-grouse were recorded as detected between 30 minutes before sunrise to 1 hour after sunrise (Fig. 2). Only 12 (5%) marked individuals were detected >1 hour after sunrise.

The top sightability model included sagebrush height and snow cover, which were the most important factors for detection, but we model-averaged parameter estimates across the top 3 models because of model uncertainty (Table 2). Detection of marked males increased with greater snow cover and lower sagebrush height (Fig. 3). Although detection also had a negative relationship with bare ground and elevation difference between observer and the observed grouse, the effects were not as strong, with little change in predicted detection across the range of data we observed (Table 3; Fig. 3).

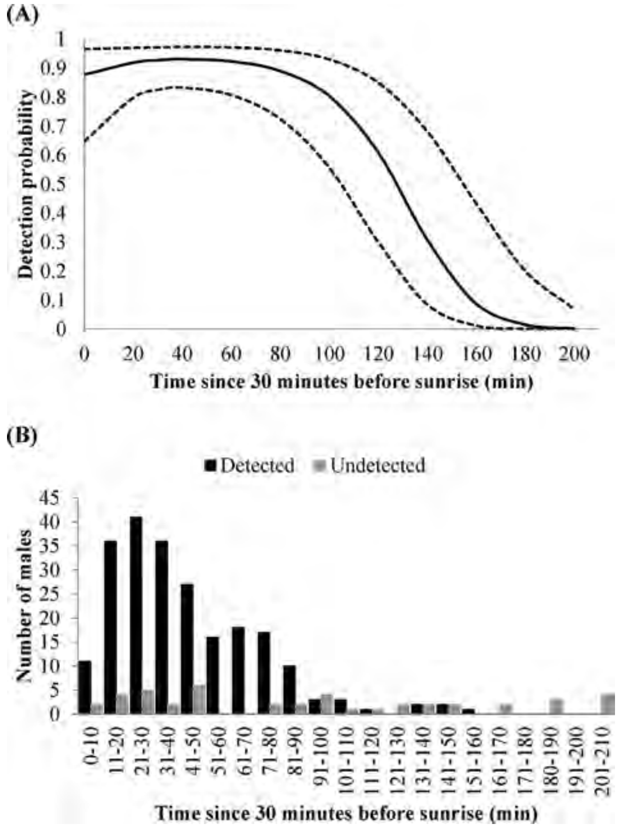

Figure 2. Detection of greater-sage grouse across time (since 30 min before sunrise) during sightability surveys in Carbon County, Wyoming from 2012 to 2014 including A) the probability of detection (with 95% CI) predicted from logistic regression with a random effect for observer identity, modeled across the range of times we observed and B) counts of males that were detected or undetected through different time intervals. We calculated time since 30 minutes before sunrise for males that were not detected by observer 2 (undetected) as time spent searching the lek without finding the marked male. Time since 30 minutes before sunrise was initially the top model, and the effect is shown in panel A, but we removed the variable from model selection because it was highly correlated with the rate at which we recorded marked males.

The model-averaged probability of bird detection across all leks was generally high (0.87 [95% CL: 0.78, 0.93]), but the model-predicted, lek-specific detection probabilities varied

Table 1. Lek sizes and sightability survey effort to assess male greater sage-grouse detectability in Carbon County, Wyoming in 2012–2014.

	2012	2013	2014
Start date of sightability surveys	2 Apr	28 Mar	19 Mar
End date of sightability surveys	22 May	22 May	22 May
No. leks counted	49	56	58
No. occupied leks	24	29	33
High count of males on occupied leks ($\bar{x} \pm$ SE)	20 ± 3.09	17 ± 2.35	23 ± 3.03
Range of number of males on an occupied lek	1–63	1–48	1–86
Lek high counts (total for leks with sightability surveys)	408	428	540
No. sightability surveys completed	48	56	60
Leks with sightability surveys	20	20	22
No. observations of marked males	33	112	121
No. marked males that were detected by observer 2 (without telemetry equipment)	23 (70%)	99 (88%)	100 (83%)
No. unique marked males observed	28	67	67

Table 2. Top 3 sightability models, ranked by second order Akaike's Information Criterion (AIC_c) predicting male sage-grouse detectability in Carbon County, Wyoming, 2012–2014. All other models had a model weight (w_i) <12.5% of the top model.

Model[a]	−2 LL[b]	K[c]	AIC_c	ΔAIC_c	w_i[d]
ln(sagebrush height + 0.05) + snow cover	221.8	4	229.9	0.0	0.420
ln(elevation difference + 0.05)	226.9	3	233.0	3.1	0.089
ln(sagebrush height + 0.05) + *ln*(bare ground + 0.05)	225.1	4	233.3	3.3	0.079
Null model	233.0	2	237.0	49.2	0.000

[a] Parameters with +0.05 indicate we added 0.05 to linear structural forms to make values non-zero before natural logarithm transformation into the pseudo-threshold structural form. Elevation difference is between the observer and the grouse detected (i.e., observer elevation − grouse elevation).

[b] LL, log likelihood.

[c] No. parameters in model.

[d] Model weight.

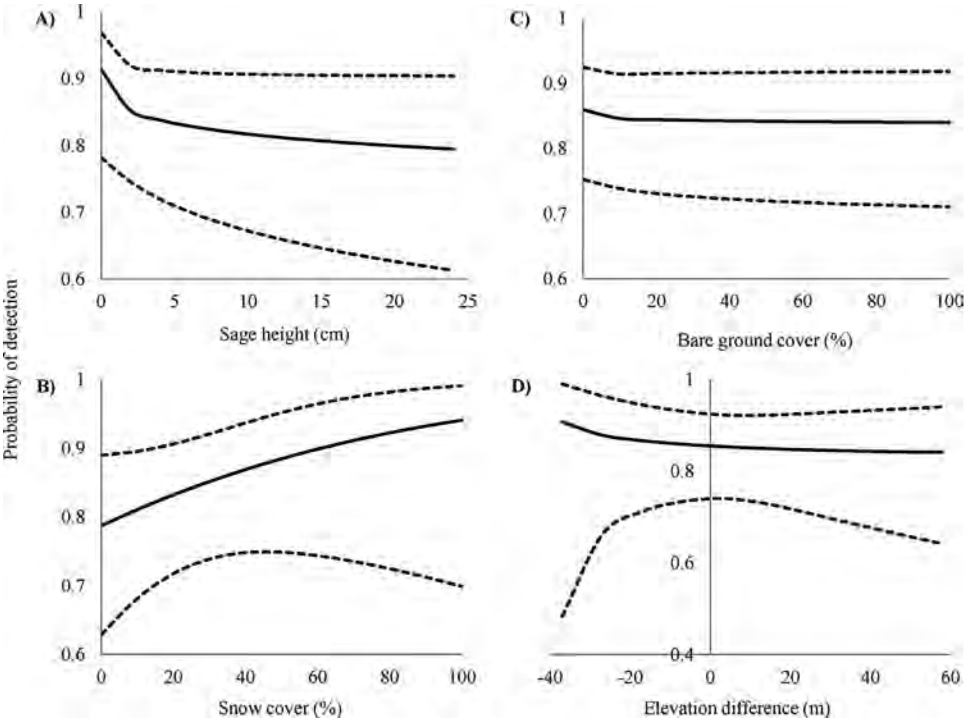

Figure 3. Variables included in the model-averaged top models for male greater sage-grouse detectability in Carbon County, Wyoming from 2012 to 2014. Variables are graphed across the range observed throughout the study, and include 95% upper and lower confidence limits as dotted lines. Detection was influenced by A) sagebrush height, B) snow cover, C) bare ground cover, and D) elevation difference between the observer and the bird (i.e., observer elevation − grouse elevation).

from 0.77 (95% CL: 0.58, 0.89) to 0.93 (95% CL: 0.73, 0.98). The Pearson χ^2/DF statistic indicated adequate model fit for the top 3 models, ranging from 0.81 ($\chi^2_{266} = 216.15$) to 0.83 ($\chi^2_{266} = 220.05$). The difference between observed detection and predicted detection probabilities averaged 0.27 ± 0.28 ($\bar{x} \pm$ SE) and the Spearman rank correlation coefficient indicated the model predicted well ($\rho_{10} = 0.96$, $P \leq 0.001$).

Table 3. Model-averaged parameter estimates with unconditional standard errors (SE), odds ratios, and 95% confidence intervals (LCL, UCL) for detection probabilities of male greater sage-grouse on leks in Carbon County, Wyoming, 2012–2014.

Parameter[a]	Estimate	SE	Odds ratio	LCL	UCL
ln(bare ground + 0.05)	−0.0202	0.0375	0.9800	−0.0937	0.0533
ln(elevation difference + 0.05)	−0.2174	0.3967	0.8046	−0.9949	0.5600
Intercept	2.3693	1.6479	10.6902	−0.8606	5.5993
ln(sagebrush height + 0.05)	−0.1639	0.1145	0.8488	−0.3883	0.0605
Snow cover	0.0146	0.0112	1.0147	−0.0074	0.0366

[a] Parameters with +0.05 indicate we added 0.05 to linear structural forms to make values non-zero before natural logarithm transformation into the pseudo-threshold structural form. Elevation difference = observer elevation − grouse elevation.

Detection probabilities and associated male population estimates varied throughout the study area. When accounting for undetected males during lek counts on leks with sightability surveys, abundance in 2012 differed by 17% between the raw count (408) and estimated (478 ± 6.31, $\bar{x} \pm \mathrm{SD}$) number of males; the male population in 2013 differed by 18% between raw (428) and estimated (503 ± 5.79) abundance; and the male abundance in 2014 differed by 19% between raw (540) and estimated (644 ± 6.75) number of male sage-grouse. Counts were corrected by as much as 14 males on a relatively large lek with tall and dense sagebrush where the detection probability was 0.79.

DISCUSSION

Detection probabilities for male sage-grouse on leks in Carbon County, Wyoming were generally high and the most important factors affecting detection were sagebrush height and snow cover, although bare ground and the elevation difference between the observer and sage-grouse were also included in supported models. Our hypothesis that vegetation cover inhibits detection of male sage-grouse on leks was corroborated by the most strongly supported model. Vegetation is consistently an important variable influencing detection of wildlife during surveys because increasing vegetative cover can conceal animals and decrease detection (Samuel et al. 1987, Anderson and Lindzey 1996, Rice et al. 2009, Vander Wal et al. 2011). Less bare ground and shorter sagebrush predicted higher detection probabilities for male sage-grouse. However, bare ground may have been a spurious variable because it had wide confidence intervals, and although bare ground was never included in a priori models with snow cover because they were negatively correlated, they were in the same model after model averaging (Cade 2015). Higher snow cover increased our ability to observe male sage-grouse on leks. Most snowfall during our study occurred as several heavy storms, creating a white background on the lek that contrasted the male's dark plumage, making them more easily visible. Samuel et al. (1987) also reported snow cover increased contrast and detection rates of animals in surveys. There was a slight trend toward low detection when observers were higher than the lek, possibly because some males were obscured in small depressions in the landscape such as drainages.

Sage-grouse behavior, lek size, topographic characteristics of the lek, light conditions, and number of birds on the lek did not affect our ability to detect marked individuals in our study. Movement by animals or posture increased an observer's ability to detect some animals (Samuel et al. 1987, Bodie et al. 1995). In our study, observers had similar resight probabilities for all sage-grouse postures, possibly because male sage-grouse can be completely obscured by vegetation irrespective of activity. We expected better light conditions, with clear skies and direct sunlight later in the morning, to yield higher detection probabilities (Bodie et al. 1995, Baumgardt 2011, Vander Wal et al. 2011). However, this expectation was not supported in our data and we did not conduct lek counts during heavy precipitation (Connelly et al. 2003) that would have resulted in low-light and high-cloud cover and likely low detection probabilities. During light precipitation, few males were present on leks and observers often located marked males within 30 minutes before or after sunrise. We also anticipated males would be difficult to detect at larger leks resulting in lower detection probabilities (Baumgardt 2011), but marked males were visible regardless of the number of birds present or the lek's physical area. High detection rates for sage-grouse on leks resulted from the relatively flat, open landscapes (Patterson 1952) with less habitat diversity and landscape diversity than areas surveyed for other wildlife.

Several factors complicate use of lek counts as a population index and should be quantified, because lek counts are the only long-term population trend data available for sage-grouse across their range. Not all leks are known and those that are known may not be a representative sample of all leks (Anderson 2001, Johnson and Rowland 2007). Further, not all leks are counted every year because of logistical constraints (Johnson and Rowland 2007), although some state agencies monitor male abundance trends using only leks that have been surveyed consistently through time (R. S. Gamo, Wyoming Game and Fish, personal observation). Often, not all males will be present on the lek during counts because date, time of day, weather, and predators affect lek attendance (Jenni and Hartzler 1978, Emmons and Braun 1984, Walsh et al. 2004, Johnson and Rowland 2007, Fremgen 2014), and occasionally birds visit different leks (Emmons and Braun 1984, Schroeder and Robb 2003, Fremgen 2014). Most bird surveys, including lek counts, have issues with availability of birds for counting such as lek attendance or interlek movements, which should be considered in addition to detectability (Farnsworth et al. 2002, Alldredge et al. 2007, Diefenbach et al. 2007, Kéry and Schmidt 2008, Schmidt et al. 2013). Finally, despite being present, not all males are accurately counted (Walsh et al. 2004). We quantified accuracy of counts given birds were present on the lek, but other aspects of lek counts should be assessed for their influence on the validity of lek counts.

Because sage-grouse population estimates are often based on the highest count observed on a lek during a season (Walsh et al. 2004, Johnson and Rowland 2007, Garton et al. 2011), accurate estimates of abundance should maximize detection and attendance by males. Many bird species are less active during high winds and precipitation, and, therefore, not available for detection during count-based surveys (Robbins 1981). Male sage-grouse attendance rates are lower on days with precipitation and increasing wind speeds and can remain low for an additional day (Bradbury et al. 1989, Fremgen 2014). Precipitation in our study had a stronger effect on attendance than high winds, with substantial declines in attendance the day of a precipitation event and the subsequent day (Fremgen 2014). However, detection on leks increased with increasing snow cover immediately after precipitation, creating a challenge to balance maximum detection and availability. To accurately estimate population abundance, managers must identify the highest count of males available on the lek, which should be done by maximizing detectability and availability for detection and performing at least 3 lek counts on active leks (Connelly et al. 2003).

Counts are a good index to the population when detection is constant through time and space and independent of population size (Johnson 2008). In our preliminary data analysis, we found that detectability on leks did not vary annually and substantially from one lek to another. Therefore, lek counts can be a reasonable index to population abundance assuming all other components of detection listed above are also constant. Additionally, we found detectability on leks was independent of the lek size and number of males present on the lek, indicating lek counts may be adequate indices to population abundance at a larger scale.

MANAGEMENT IMPLICATIONS

If accurate estimates of male abundance on leks are desirable for small regional populations, especially if there is great variation in vegetation or snow cover among leks or surveys within a year, we recommend concurrent sightability surveys to estimate and correct for detection probabilities. If detection on leks is not accounted for, lek counts can underestimate regional abundance of males on leks by 17–19%. However, because detectability on leks is constant spatially and temporally, and independent of population size, lek counts may be an adequate index for broader scale population trends unless other components of detection vary. Current lek count protocols recommend avoiding lek counts during precipitation or high winds but do not incorporate any lag effect after precipitation (Connelly et al. 2003). We found snow cover increased detection, but we recommend waiting to perform lek counts until 2 days after snow storms in areas with severe storms to maximize availability of grouse (Fremgen 2014). Current lek count protocols recommend performing lek counts 30 minutes before sunrise to 1 hour after sunrise (Connelly et al. 2003). We found the rate of recording marked males was highest within the recommended time frame but most efficient in the first hour. We do not advocate observers performing lek counts from a lower elevation than the birds; rather we suggest counters consider visibility of birds in relation to landscape features such as drainages. Although we were able to determine variables that can be manipulated to maximize detection probabilities during lek counts, other factors contributing to detection may be beyond the control of observers. For example, detection improved with shorter sagebrush near males on the lek, but vegetation cannot be controlled during lek counts. Modeling detection probabilities based on sightability surveys are critical to accounting for these factors when estimating abundance.

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Greater Sage-Grouse Population Dynamics and Probability of Persistence

Final Report to Pew Charitable Trusts
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Abstract. We updated our earlier comprehensive analysis of Greater Sage-Grouse (*Centrocercus urophasianus*) population dynamics and probability of persistence from 1965 to 2007 throughout the species range by accumulating and analyzing additional counts of males from 2008 to 2013. A total of 89,749 counts were conducted by biologists and volunteers at 10,060 leks from 1965 through 2013 in 11 states occupied by Greater Sage-Grouse. In spite of survey effort increasing substantially (12.6%) between 2007 and 2013 in 10 of the 11 states, the reconstructed estimate for minimum number of breeding males in the population fell by 55% from 98,616 (SE 3,736) to 44,297 (SE 1,019). Using standard approximations for missing values from Colorado suggests that the range-wide population fell 56% from109,990 breeding males in 2007 to 48,641 breeding males in 2013. The best model of annual rates of change of populations estimated across the Sage-Grouse Management Zones was a stochastic density dependent Gompertz model with 1-year time lags and declining carrying capacities through time. Weighted mean estimates of carrying capacity for the minimum number of males counted at leks for the entire range-wide distribution, excepting Colorado, were 40,505 (SE 6,444) in 2013 declining to 19,517 (SE 3,269) in 30 years and 8,154 (SE 1,704) in 100 years. Starting with the estimated abundance of males counted at leks in 2007 a simple effort to evaluate the validity of future forecasts of abundance was conducted by forecasting abundance in 2013 from Gompertz density dependent models with 1-year time lag and declining carrying capacity models of 6 of the 7 management zone populations. Estimated mean abundance in 2013 predicted 97.8% of the variation in true abundance in management zones. Concerted efforts across both public and private land ownerships that are intended to benefit Greater Sage-Grouse show little current evidence of success but more will be required to stabilize these declining populations and ensure their continued persistence in the face of ongoing development and habitat modification in the broad sagebrush region of western North America.

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Introduction

The Greater Sage-Grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) is considered a "landscape species" with annual ranges that can encompass > 2,700 km^2 (Leonard et al. 2000, Holloran and Anderson 2005, Knick and Connelly 2011). Movements within breeding habitat can exceed 25 km, and seasonal ranges can be > 80 km apart (Connelly et al. 1988, Holloran and Anderson 2005). Populations throughout the species' range have been negatively affected by loss and fragmentation of habitat largely due to wildfire, invasive species and energy development (Doherty et al. 2008, Miller et al. 2011). Moreover, some populations have declined as a result of west Nile virus (Walker et al. 2004, 2007). Schroeder et al. (2004) estimated that sage-grouse have been extirpated from 44% of the species' likely historic range.

Despite substantial evidence indicating population declines and habitat loss (Braun 1998, Connelly et al. 2004, Schroeder et al. 2004), in 2005, the U.S. Fish and Wildlife Service (USFWS) determined that listing greater sage-grouse under the Endangered Species Act (ESA) was not warranted (Stiver 2011). However, a complaint filed in July 2006 by Western Watersheds alleged the 2005 finding was incorrect, arbitrary, and unwarranted (Ashe 2010). The U.S. District Court for Idaho subsequently ruled the USFWS determination was arbitrary and capricious and remanded the finding to the USFWS. In March 2010, the USFWS concluded that the sage-grouse was warranted for protection under ESA, but listing was precluded because of higher priorities (Ashe 2010); this agency agreed to issue a final determination by September 2015. The listing decision identified habitat loss/fragmentation, including habitat treatments, and lack of adequate regulatory mechanisms as the major factors contributing to declines in sage-grouse populations (Connelly 2014).

In addition to the work by Schroeder et al. (2004), other publications have assessed sage-grouse population change. Connelly and Braun (1997) concluded that by 1994 breeding populations had declined by 17-47% from long-term averages. Connelly et al. (2004) reported that sage-grouse populations declined at an overall rate 2.0% per year from 1965-2003. Similarly, an analysis by the Western Association of Fish and Wildlife Agencies (WAFWA 2008) indicated range wide declining trends for sage-grouse from 1965-2007. The most recent analysis (Garton et al. (2011) assessed long-term changes in sage-grouse populations by sage-grouse management zone (Stiver et al. 2006), reconstructed population abundance, and evaluated the likelihood of long-term persistence of populations. These authors' findings generally agreed with previous studies documenting declining populations of sage-grouse. Moreover, Garton et al. (2011) generated models that suggested at least 3 of 23 populations but no Sage-Grouse Management Zones (SMZs) may decline below effective population size of 50 within the next 30 years and at least 18 of 23 populations and 2 of 7 SMZs are likely to decline below effective population size of 500 within 100 years if current conditions and trends persist.

Recently, state and federal agencies have implemented a variety of conservation plans and programs to improve sage-grouse populations and habitats (NTT 2011, Baruch-Mordo et al. 2013, Copeland et al. 2013, Connelly 2014). Although federal conservation actions have been criticized (Connelly 2014) and some positive impacts of CRP on sage-grouse populations in Washington had been documented through 2010 (Schroeder and Vander Haegen 2011), no current evaluations of the status of sage-grouse at the population, SMZ, or range-wide scales exist that provide insight into current status of sage-grouse or that may allow an evaluation of effectiveness of conservation actions to date. If implementation of current conservation programs were effective and sufficient, we would expect that trends for many sage-grouse over the last 6 years would have begun to stabilize or in some cases may have begun to increase. With availability of 6 additional years of data since the Garton et al. (2011) publication, our objectives were to update the analyses of Garton et al. (2011) and evaluate our predictions. Thus, we 1) assess recent changes (2007-2013) in sage-grouse populations by SMZ; 2) reconstruct population abundance back to 1965 for each population, SMZ and range-wide; 3) evaluate the probability of persistence of sage-grouse populations; and 4) validate forecasts of future sage-grouse population abundance critical to estimating probability of persistence. We then examine these findings for evidence of stabilizing or increasing populations that could be attributed to recent conservation programs.

Methods

We obtained lek counts from 2007 to 2013 from each state fish and game agency except Colorado to reconstruct the sage-grouse populations for 6 additional years and use these estimates of the minimum number of males attending leks to model population changes and project probabilities of persistence for each population, SMZ population and the entire metapopulation using an analogous approach to that presented in Garton et al. (2011) and in a similar analysis for Lesser Prairie Chickens (Garton et al. in press). All states except Colorado contributed data on lek surveys that were combined with earlier data (Garton, et al. 2011:293) yielding a total of 89,749 surveys conducted from 1965 to 2013 at 10,060 individual leks. Detailed descriptions of each population and SMZ are provided in Garton et al. 2011.

Population Reconstruction

Leks surveyed in previous years (1965-2007) as well as leks added to the counts or discovered since 2007 were used to reconstruct an index of population abundance for each population (Fig. 1) and SMZ population ($N(t)$) based on the maximum count of males out of 3 or more surveys at each lek. The population index was estimated from the total number of males counted and the associated standard error from mean counts in 2007 to 2013, finite rates of change ($\lambda(t)$) and relative sizes of the previous years' populations ($\theta(t)$) in each pair of years using ratio estimators (Garton et al. 2011:301) to extend earlier estimates from 1965 to 2013. Only repeated counts of leks from consecutive years were included in the estimates to insure that they produce unbiased estimates of population size and rates of change. New leks added to the surveys or missed leks were included in estimation once they had been counted in successive years. New leks substantially increased the precision of the most recent estimates of minimum male abundance because of a 50% increase in the number of leks counted in most areas over the last 10 years of surveys. Confidence intervals for the reconstructed populations were calculated from the variance of mean lek counts in 2013 combined with the variances of successive ratios of previous year to current year abundance ($\theta(t)$) back to the year in question as in Garton et al. (2011:302). Thus we began at 2013 and reconstructed population sizes for each population and SMZ back to the earliest lek counts available to us, typically 1965. Finite rates of change ($\lambda(t)$) were transformed to instantaneous rates of change ($r(t)=\ln\lambda(t)$) to model population growth. These estimates provided an index of population abundance from 1965-2013 for modeling changes in population, population projections, and identifying the probability of the species persistence.

Modeling Population Growth

We fit the same suite of 26 stochastic population growth models as described by Garton et al. (2011:302) to the time series of reconstructed minimum male population indices for each SMZ and population. The first 2 models are a more efficient and realistic version of the classic trend models (WAFWA 2008) assuming no density dependence in the rates of population change but either a single trend through time portraying exponential growth with process error (EGPE; Dennis et al. 1991) or exponential growth with differing mean rates of change between two time periods (period 1 = 1967–1987, period 0 = 1987–2013). We also fit density-dependent models of annual rates of change based on either Ricker-type density dependence in population growth (Dennis and Taper 1994) in which rates of change decline in proportion to abundance, or Gompertz-type density dependence in population growth (Dennis et al. 2006) in which rates of change decline logarithmically in proportion to abundance. Because of the apparent cyclic pattern of population growth observed in come populations and management zones (Rich 1985, Garton et al. 2011) we incorporated either 0,1 or 2 year time lags (Δ)into the density dependent Ricker and Gompertz models. To portray the apparent difference in growth patterns through time as either a difference between the 2 time periods identified above or as a continuously changing carrying capacity, each density dependent model was combined with a period effect (period, as described above), and a time trend in population carrying capacity (year) or both (Garton et al. 2011:302). Letting $N(t)$ be the observed population index at time t ,$Y(t)$ = log[$N(t)$], and the annual growth rate $r(t) = Y(t+1) - Y(t)$. The global stochastic model incorporating Ricker-type density dependence was

$$r(t) = a + b \times N(t-\Delta) + c \times Year + d \times Period + E(t) , \qquad (1)$$

and the analogous model for Gompertz-type density dependence was

$$r(t) = a + b \times \ln\left(N(t-\Delta)\right) + c \times Year + d \times Period + E(t) \qquad (2)$$

where $Y(t) = \log[N(t)]$, the annual growth rate $r(t) = Y(t+1) - Y(t)$.

The global statistical model incorporated a difference in time periods by setting Period = 1 if Year = 1965 – 1996 and Period = 0 if Year = 1997 – 2013. *E*(t) represented environmental (i.e., process) variation in realized growth rates and was a normally distributed random deviate with mean = 0 and variance = σ^2. These models yielded five parameters (i.e., *a, b, c, d,* and σ^2) that were estimated via maximum likelihood using the indices to past abundance data estimated from the population reconstruction.

The only difference between the Ricker and Gompertz models is that the Ricker assumes growth rates are a linear function of population size and the Gompertz assumes growth rates are a linear function of the natural log of population size. Density dependent models such as Gompertz and Ricker provide an objective approach to estimate a carrying capacity or quasi-equilibrium (hereafter carrying capacity), which is defined as the population size at which the growth rate is 0. This carrying capacity represents a turning point in abundance below which population size tends to increase and above which population size tends to decrease. Adding period or year effects to these density dependent models evaluate the possibility that carrying capacity varied between the early time period and more recently or that it has changed through the years or both. This set of 24 density dependent models produce an efficient approach to evaluate and estimate 2 types of density dependence (arithmetic vs logarithmic for Ricker vs Gompertz) with 3 lags (0, 1 or 2 years) with potential differences in periods of time (2 periods) with constant or continuously changing carrying capacities (changing or constant, i.e. year or no year effect) yielding 2 by 3 by 2 by 2 combinations or 24 total density dependent models that we would hypothesize might best describe the observed reconstructed population abundance indices through time. Note that the 2 density independent models appear superficially similar to classic trend models obtained by simply converting reconstructed annual abundance indices to logarithms and regressing log abundance on year to “fit a trend line” through the data or as done by WAFWA (2008) fitting separate trend lines to the 2 time periods but at the conceptual level they differ fundamentally. Fitting a single or 2 trend lines is far less efficient (Humbert et al. 2009) and falsely treats error around the regression line as errors in observation, while our approach to estimating trend estimates logarithmic rates of change *r(t)* in each year and then estimates the average or an average for each time period as an efficient estimator of trend, treating errors in the estimates as estimates of process error rather than observation error. Estimating process error in this way provides a straight-forward approach to forecast future abundance incorporating process error (see below) whereas observation error estimated by regression is not useful for forecasting future patterns of abundance.

Parameter Estimation

To each set of observed abundance data, we fit these 26 models using general linear mixed models in the statistical computing program R (R Development Core Team 2014) and mixed procedure of Program SAS (SAS Institute 2003) in the same manner as applied earlier to sage-grouse (Garton et al. 2011:303 eq. 15.10) and applied to Lesser Prairie Chicken (*Tympanuchus pallidicinctus*, Garton et al. in press). These stochastic growth models treat annual rates of