REPRODUCTIVE ECOLOGY OF LONG-BILLED CURLEWS BREEDING IN GRAZED LANDSCAPES OF WESTERN SOUTH DAKOTA

BY

JESSICA N. CLARKE

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Wildlife and Fisheries Sciences

South Dakota State University

2006

REPRODUCTIVE ECOLOGY OF LONG-BILLED CURLEWS BREEDING IN GRAZED LANDSCAPES OF WESTERN SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

12-06-06

Dr. Kent C. Jensen
Major Advisor
Date

12-06-06

Dr. Charles G. Scalet
Head, Department of Wildlife
and Fisheries Sciences
Date

ACKNOWLEDGEMENTS

I would first like to thank my advisor, Dr. Kent Jensen, for giving me the opportunity to work on such a challenging and rewarding project. He not only took the time to make sure I had all the resources I needed for my research, but also took the extra time to make me feel welcome and at home in South Dakota. I will always be grateful for his guidance and support throughout my two and a half years at SDSU.

I would also like to thank the following members of my committee for all of their insight and suggestions for improving my thesis. Thanks to Dr. Kristel Bakker who has shown a great deal of interest in this project from the very beginning, Dr. Gary Larson who introduced me to a vast world of grasses that I never knew existed, and Dr. Marilyn Redlin who took the time to serve as my graduate faculty representative.

I had an endless amount of support on this project and I would like to thank the following individuals for their assistance, both in the field and on the SDSU campus. Doug Backlund and Eileen Dowd from the South Dakota Department of Game, Fish and Parks played a vital role in getting this project started. Thanks to Ryan Williamson and Eric Rasmussen for all of their hard work and enthusiasm as technicians on this project. Thanks to Nicki McGee, who traveled all the way to South Dakota from the University of Manchester, England to work on this project, without whom I never would have made it through my first field season. Breifne Buckley, who also traveled from the University of Manchester, was a tremendous help in the field and a great friend. Dan Ackerman, Madeline Schickel, and Becky McAtee volunteered to help nest drag, conduct censuses, and capture curlews. Mark Norton introduced me to several field techniques and helped

me analyze data back at the office. Thanks to Terri Symens, Di Drake, and Carol Jacobson for all of their hard work and patience. And thank you to all of Dr. Jensen's graduate students for advice and support throughout this process.

I would like to give a special thanks to all of the folks on the Triple U Buffalo Ranch including the owners of the ranch, Kaye Ingle and Shari Amiotte, who generously allowed me to live on the ranch, play with their dogs, and roam freely over their land chasing after birds. Kyle Tibbs, and Jen and B.J. Humble provided entertainment and friendship during my time on the ranch. Galen, Vicki, and Tomisue Humble welcomed me into their home and involved me in all of their family activities. Thanks to David Hansen, for all of his interest and insight into the wildlife on the ranch, especially the curlews. And thank you to Vee and Milo at the Chantier Creek Resort for providing a wonderful place to stay during my first few months on this project.

I would also like to thank my parents, Wes and Hattie Clarke, for giving me the opportunity to pursue a higher education and for all of their guidance and financial support during my six and a half years at the College of Wooster and SDSU. Thank you to my grandparents, Bob and Argyle, and sister Eva, for all of their love and support over the years. And I would especially like to thank Nick Radabaugh for being my source of strength throughout this process and for always being there to keep me calm and help me work through my problems. I already consider you a very important part of my family.

Funding for this study was provided by State Wildlife Grants administered through the South Dakota Department of Game, Fish and Parks and through matching

funds from South Dakota State University. Additional support was provided by the South Dakota State University graduate school.

ABSTRACT

REPRODUCTIVE ECOLOGY OF LONG-BILLED CURLEWS BREEDING IN GRAZED LANDSCAPES OF WESTERN SOUTH DAKOTA

Jessica N. Clarke

December 2006

Long-billed curlews (*Numenius americanus*) are currently undergoing significant population declines mainly attributed to the destruction of important breeding habitat for agriculture and development. Uncultivated native rangelands and pastures support a majority of long-billed curlew breeding populations and reproductive success in these areas plays a major role in population dynamics. The western portion of South Dakota provides important mixed-grass prairie breeding habitats for long-billed curlews and most of these habitats are used as pastureland for grazing domestic livestock. The main objectives of this study were to estimate nesting success and brood survival and to characterize nesting and brood-rearing habitats of a population of long-billed curlews breeding in western South Dakota. This study was conducted during the spring and summer of 2005 and 2006 on the Triple U Buffalo Ranch in Stanley County, South Dakota. Nest sites were located by dragging a rope through pastures to flush incubating adults. Broods were monitored by tracking radio-marked adults that successfully hatched young. Habitat preferences were characterized by comparing habitat at nest sites and brood location points to habitat at points randomly distributed throughout the study site. A total of 48 nests were located and 43 adult curlews (21 males, 22 females) were radio-

marked over the 2 years of this study. Habitat measurements were taken at 48 nest sites, 80 brood location points, and 154 random points. In 2005, curlews used nest sites similar to random points with an average of 55% grass cover, 47% forb cover and an average visual obstruction reading (VOR) of 27 cm. In the fall of 2005, a natural range fire burned a large area of the study site. The following year, forb cover and VOR's at nest sites, brood points, and random points decreased significantly ($p<0.05$). This reduction in vegetative cover also corresponded to a severe drought and a non-peak year for the biennial forb yellow sweetclover (*Melilotus officinalis*). Nest success decreased from 0.39 in 2005 to 0.15 in 2006 due to a large increase in the rate of nest predation which accounted for 64% of nest failure in 2006. Daily nest survival rates for 2005 and 2006 combined were positively related to average VOR's taken at nest sites ($\beta=6.45$) and negatively related to the density of bison grazed in pastures containing nests ($\beta=-1.29$). Despite the negative impact of reduced vegetative cover on reproductive success, curlews selected nest sites in shorter vegetation with lower VOR's than random points in 2006. Curlews selected nest sites composed of a greater proportion of junegrass (*Koeleria macrantha*) and buffalograss (*Buchloe dactyloides*) than random points in 2005 and 2006 and daily survival rate at nest sites dominated by these species was 100% during both years. In 2006, nest sites also had a greater amount of forb cover than random points and daily survival rate for 2005 and 2006 combined was higher at nest sites dominated by forb cover (98%) than at nest sites dominated by grass cover (91%). Of the 15 broods produced by radio-marked curlews in 2005 and 2006, only 33% were known to produce fledglings. Possible causes of chick mortality included avian predation and heat

prostration. Broods used habitats composed of a greater proportion of sixweeks fescue (*Vulpia octoflora*), indianwheat (*Plantago patagonica*), junegrass, and American vetch (*Vicia americana*) than random points in 2005 and a greater proportion of creeping spikerush (*Eleocharis palustris*) and water than random points in 2006. In 2006, broods also used areas with less grass cover and more bareground than random points. Nest success and brood survival was low for the population of long-billed curlews breeding on the Triple U Buffalo Ranch during both years of this study. Uncontrollable climatic factors that affect the vegetative structure of habitat appear to have a large impact on the reproductive success of long-billed curlews breeding in South Dakota. Controllable factors such as grazing pressure should be manipulated to help maximize nesting success and brood survival. This may require reducing livestock densities in pastures used by breeding curlews during the nesting period in order to reduce the risk of nest trampling.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS iii

ABSTRACT vi

LIST OF TABLES xi

LIST OF FIGURES xiii

LIST OF APPENDICES xvii

CHAPTER 1-INTRODUCTION 1

CHAPTER 2-BACKGROUND INFORMATION 5

Breeding Chronology 5

Survival 5

Habitat use 7

CHAPTER 3-STUDY AREA AND METHODS 11

Study Area 11

Density Censuses 12

Nest Survival 14

Capture and Marking 16

Adult and Brood Survival 17

Nesting and Brood-rearing Habitat 18

Movements 20

CHAPTER 4-RESULTS 22

Density Censuses 22

Breeding Chronology and Renesting 22

Nest Survival 23

Adult and Brood Survival 25

Habitat use 26

Movements 29

CHAPTER 5-DISCUSSION 32

Nest Survival and Nesting Habitat 32

Brood Survival and Brood-rearing Habitat 41

Management and Research Recommendations 44

LITERATURE CITED 49

LIST OF TABLES

Table 1. Mean clutch sizes and nesting chronology of long-billed curlew nests located in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. 58

Table 2. Bison densities in pastures containing long-billed curlew nests located in 2005 on the Triple U Buffalo Ranch, Stanley County, South Dakota. "N" indicates that nests were not trampled in the corresponding pasture; "Y" indicates that nests were trampled in the corresponding pasture. 59

Table 3. Bison and cattle densities in pastures containing long-billed curlew nests located in 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. "N" indicates that nests were not trampled in the corresponding pasture by the type of livestock specified; "Y" indicates that nests were trampled in the corresponding pasture by the type of livestock specified. 60

Table 4. Evaluation of daily survival rate (DSR) models using Akaike's Information Criterion corrected for a small sample size (AICc) for long-billed curlew nests located in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. 61

Table 5. Variable weights and daily survival rates (DSR) with associated 95% confidence intervals for categorical variables from the set of "best models" used to explain variation in daily survival rates of long-billed curlew nests located in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. 63

Table 6. Variable weights and β-values with associated 95% confidence intervals for continuous variables from the set of "best models" used to explain variation in daily survival rates of long-billed curlew nests located in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. 64

Table 7. Average heights of forb species representing at least 1% composition of the vegetation at nest sites, brood points, or random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. "+" indicates the species was used in a proportion greater than availability; "-" indicates the species was used in a proportion lower than availability; "0" indicates no difference between use and availability. 65

Table 8. Average heights of graminoid species representing at least 1% composition of the vegetation at nest sites, brood points, or random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. "+" indicates the species was used in a proportion greater than availability; "-" indicates the species was used in a proportion lower than availability; "0" indicates no difference between use and availabilty. 66

Table 9. Abiotic factors representing at least 1% composition at nest sites, brood points, or random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. "+" indicates the factor was used in a proportion greater than availability; "-" indicates the factor was used in a proportion lower than availability; "0" indicates no difference between use and availability.....67

Table 10. Mean habitat measurements taken at long-billed curlew nest sites and brood location points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota.....68

Table 11. Estimates of Mayfield (1975) nest success from long-billed curlew studies conducted in Wyoming, Idaho, and Oregon compared to nest success estimates in 2005 and 2006 for curlews breeding on the Triple U Buffalo Ranch, Stanley County, South Dakota.....69

LIST OF FIGURES

Figure 1. Current breeding and wintering distributions of the long-billed curlew in North America. Source: Dugger and Dugger 2002. 70

Figure 2. South Dakota Gap Analysis draft for the breeding distribution of long-billed curlews in South Dakota. The map was constructed using known distributions (shown in red) and predicted distribution models (shown in yellow) based on wildlife-habitat relationships. Source: Smith et al. 2002.....71

Figure 3. A. Location of the Triple U Buffalo Ranch in Stanley County, South Dakota. B. Perimeters of the Triple U Buffalo Ranch (shown in yellow), the core area of the study site (shown in blue), and the area of the study site burned in fall 2005 (shown in red).....72

Figure 4. Average total precipitation in April-July from 1948-2005 compared to total precipitation in April-July for 2005 and 2006 in Pierre, South Dakota. Data sources: HPRCC 2006 and NCDC 2006.....73

Figure 5. Average maximum temperatures in April-July from 1948-2005 compared to maximum temperatures in April-July for 2005 and 2006 in Pierre, SD. Data sources: HPRCC 2006 and NCDC 2006. 74

Figure 6. Ten-meter subsection of 50-m transects used for sampling habitats at nest sites, brood points, and random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Measurements taken along transects included Robel (1970) visual obstruction readings (R), Daubenmire (1959) plots (D), and species composition of the vegetation (S).....75

Figure 7. Number of viable long-billed curlew broods (broods with at least 1 viable chick) with radio-marked adults 0-4 weeks after hatching in 2005 on the Triple U Buffalo Ranch, Stanley County, South Dakota.....76

Figure 8. Number of viable long-billed curlew broods (broods with at least 1 viable chick) with radio-marked adults 0-4 weeks after hatching in 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota.....77

Figure 9. Mean visual obstruction readings (VOR) with 95% confidence intervals taken at nest sites, brood points, and random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. VOR measurements were taken using a decimeter scale and converted to a centimeter scale. Asterisks (*) indicate that nest sites or brood points were significantly different from random points at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.....78

Figure 10. Mean percentages of grass, bareground, forb, and shrub cover with 95% confidence intervals at nest sites, brood points, and random points in 2005 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate that nest sites or brood points were significantly different from random points at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.....79

Figure 11. Mean distance to the nearest source of water with 95% confidence intervals from nest sites, brood points, and random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Nest sites and brood points were not significantly different from random points in either year.....80

Figure 12. Mean slope measurements with 95% confidence intervals for the ground at nest sites, brood points, and random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate that nest sites or brood points were significantly different from random points at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001. 81

Figure 13. Mean distance to the nearest conspicuous object (manure piles) with 95% confidence intervals at nest sites and random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate that nest sites were significantly different from random points at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001. 82

Figure 14. Mean percentage of grass, bareground, forb, and shrub cover with 95% confidence intervals at long-billed curlew nest sites in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate a significant difference between years at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.....83

Figure 15. Mean percentage of grass, bareground, forb, and shrub cover with 95% confidence intervals at long-billed curlew brood location points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate a significant difference between years at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001. 84

Figure 16. Mean percentage of grass, bareground, forb, and shrub cover with 95% confidence intervals at random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate a significant difference between years at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001. 85

Figure 17. Mean percentage of total composition of the vegetation at random points represented by the forb species desert biscuitroot (lom), field pennycress (fpc), scarlet globemallow (sglo), scarlet gaura (gaura), common yarrow (cyar), goatsbeard (gb), silverleaf scurfpea (scurf), yellow sweetclover (clov), and indianwheat (iw) with 95% confidence intervals in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate a significant difference between years at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001. 86

Figure 18. Mean percentage of total composition of the vegetation at random points represented by the graminoid species western wheatgrass (wht), green needlegrass (gng), Japanese brome (jbr), buffalograss (buff), junegrass (june), needleandthread (nat), sun sedge (sedge), creeping spikerush (creep), Kentucky bluegrass (kybg), and sixweeks fescue (swf) with 95% confidence intervals in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate a significant difference between years at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001. 87

Figure 19. Mean height of the tallest piece of vegetation with 95% confidence intervals at nest sites, brood points, and random points in 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate that nest sites or brood points were significantly different from random points at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001. 88

Figure 20. Mean percentage of grass, bareground, forb, and shrub cover with 95% confidence intervals at nest sites, brood points, and random points in 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate that nest sites or brood points were significantly different from random points at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.....89

LIST OF APPENDICES

Appendix 1. Individual egg masses from long-billed curlew clutches weighed in 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. 90

Appendix 2. List of vascular plant species identified at nest sites, brood location points, and random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. 91

Appendix 3. Body measurements for long-billed curlews captured in 2005 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Individuals are identified by radio-transmitter frequencies and band numbers.....93

Appendix 4. Body measurements for long-billed curlews captured in 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Individuals are identified by radio-transmitter frequencies and by darvic color bands and metal bands on the right and left legs. R=red, G=green, Y=yellow, O=orange, B=Blue, Bk=black, W=white, M=metal. Numbers in parentheses indicate numbered color bands. Two frequencies are shown for individuals captured in 2005 and recaptured in 2006. 94

CHAPTER 1-INTRODUCTION

Of the 72 shorebird taxa (species and subspecies) investigated by the National Shorebird Conservation Assessment, 19% are undergoing an apparent decline in population and 26% are endangered or undergoing significant population declines (Brown et al. 2001). Among the shorebird species experiencing a significant decline is the largest North American shorebird, the long-billed curlew. This decline has been attributed mainly to the loss of important breeding habitat over the last 150 years, especially throughout the eastern portion of the long-billed curlew's historic range (Sugden 1933; Yocum 1956; Dugger and Dugger 2002). On the national level, long-billed curlews are now considered vulnerable throughout their range (Dugger and Dugger 2002) and "highly imperiled" by the United States Shorebird Conservation Plan (Brown et al. 2001). In South Dakota, long-billed curlews are listed as a bird of conservation concern in all four of the U.S. Fish and Wildlife Service bird conservation regions that encompass South Dakota (Prairie Potholes, Badlands and Prairies, Shortgrass Prairie, and Central Mixed-grass Prairie) (USFWS 2002) and are given a state natural heritage ranking of S3B indicating that they are rare and local throughout their breeding range (SDGFP 2006).

The long-billed curlew's former breeding distribution included central British Columbia east to southern Manitoba and south to northeastern California and northern Texas (AOU 1983). However, curlews have been removed from most of the eastern part of their range, including Manitoba, Michigan, Minnesota, Wisconsin, Illinois, Iowa, eastern Nebraska, and eastern Kansas (De Smet 1992), due to the destruction of native

prairie for agriculture and development. Today the long-billed curlew's breeding range is restricted to short-grass and mixed-grass habitats in the Great Plains, the Great Basin, and intermontane valleys of the western U.S. and southwestern Canada (Figure 1). In South Dakota, curlews are mainly restricted to the portion of the state west of the Missouri River (Figure 2). However, breeding may still occur in several counties just east of the Missouri River (Campbell, Walworth, Potter, Sully, Hughes, Buffalo, Brule, Charles Mix, and Douglas) where there is still some remaining native mixed-grass prairie habitat (Tallman et al. 2002). On breeding grounds, long-billed curlews are opportunistic foragers, feeding on a variety of terrestrial invertebrates. Upon arriving in wintering areas, which include coastal and inland habitats in California, Texas, Louisiana, Florida, the Carolinas, and Mexico (Figure 1), curlews shift to a more specialized diet of marine crustaceans and benthic invertebrates. Long-billed curlews are considered short distance migrants, however, there is currently no existing data linking populations from a specific breeding area to a specific wintering ground (Dugger and Dugger 2002).

There are currently two recognized long-billed curlew subspecies. *N.a. americanus* (the focus of this study) is present throughout most of the short-grass and mixed-grass prairies of South Dakota. *N.a. americanus* has suffered a greater decline in breeding distribution nationwide and is currently declining at a faster rate than *N. a. parvus*, which has a more western distribution and is restricted to the northwestern corner of South Dakota (Dugger and Dugger 2002). Current population trends suggest that only the Great Basin, where *N.a. parvus* is more common, supports stable long-billed curlew

breeding populations (Sauer et al. 1995). Conversely, the greatest population declines appear to be occurring within the Great Plains (Sauer et al. 1995).

After synthesizing a majority of research conducted on long-billed curlews, Dugger and Dugger (2002) identified several priorities for research to help establish appropriate conservation practices and aid in the recovery of long-billed curlew populations. These priorities included investigating the effects of human disturbance and land-use practices on curlew populations, as well as determining the annual and seasonal survival of chicks, subadults, and adults throughout the curlew's breeding range. Despite the fact that western South Dakota provides important breeding habitat for long-billed curlews, no major research on these parameters has been conducted in the state. Because most of the habitat used by curlews in South Dakota is also used as pastureland for grazing livestock, South Dakota provides an excellent area to study the effects of grazing practices on the reproductive ecology of long-billed curlews.

The main objective of this study was to provide baseline information on the reproductive ecology of a population of long-billed curlews breeding in grazed landscapes of western South Dakota. This objective was achieved by:

- estimating breeding densities
- estimating nesting success
- tracking brood survival over time
- characterizing nesting and brood-rearing habitats
- investigating the relationship between nesting habitats and nest survival
- estimating breeding season home range sizes and,

- determining the effects of grazing practices on reproductive success.

The information obtained during this study will help clarify the status of curlew populations in South Dakota as well as provide management guidelines for habitat in grazed areas throughout the long-billed curlew's breeding range.

CHAPTER 2-BACKGROUND INFORMATION

Breeding Chronology

Long-billed curlews form monogamous pairs soon after arriving on breeding grounds between mid-March and late-April and often build nests within one week of pairing. A nest consists of a shallow scrape on the ground lined with various materials such as pebbles, bark, livestock droppings, grass, small stems, twigs, seeds, and leaves (Jenni et al. 1981). Clutches, generally consisting of four eggs, are laid beginning in mid- to late-April. Curlews are territorial and defend nest sites throughout incubation. Incubation lasts for a period of 27 to 29 days (Forsythe 1972; Pampush and Anthony 1993), during which males and females share incubation responsibilities. Eggs hatch synchronously, with the last egg usually hatching within four to six hours of the first (Allen 1980; Jenni et al. 1981). Curlew chicks are precocial and leave the nest only a few hours after hatching (Jenni et al. 1981). Generally one to three weeks after the chicks hatch, the female turns over complete care of the brood to the male, although sometimes the female will stay with the brood until fledging (Allen 1980). Fledging occurs 38 to 45 days after hatching (King 1978; Allen 1980; Jenni et al. 1981). Curlews generally depart breeding grounds from early to mid-July but in some areas remain until mid-August (Dugger and Dugger 2002).

Survival

Uncultivated rangelands and pastures support a majority of long-billed curlew breeding populations (Cochran and Anderson 1987) and reproductive success in these

areas plays an important role in population dynamics. Curlew nesting success and brood survival depend on many factors, including predation, land-use practices, and quality of available habitat. Several studies have identified mammals, such as badgers (*Taxidea taxus*), coyotes (*Canis latrans*), and other canids, as the most significant predators of long-billed curlew nests (Redmond and Jenni 1986; Pampush and Anthony 1993; Paton and Dalton 1994). Livestock trampling, investigator disturbance, and avian predation have been identified as less common causes of nest failure (Redmond and Jenni 1986). Research conducted in Washington, Idaho, and Utah has indicated that curlews will not renest once a nest is destroyed (Allen 1980; Redmond and Jenni 1986; Paton and Dalton 1994). Cannings (1999) suggested that long nesting and fledging periods along with an early migration prevent curlews from renesting within a single breeding season. However, Sugden (1933) found some indirect evidence that curlews nesting near the Great Salt Lake in Utah may lay another set of eggs if the first set is destroyed.

Previous studies on long-billed curlews and other closely related curlew species have identified avian predation as the most common cause of chick mortality (Redmond and Jenni 1986; Grant et al. 1999). In Northern Ireland, hatching date, chick body condition, and hatching weight had no effect on Eurasian curlew (*Numenius arquata*) chick survival to 31 days of age (Grant et al. 1999). Instead, 74% of observed chick mortality was due to predation, and predation rates decreased with chick age. In western Idaho, the survival of radio-marked curlew chicks 0-5 days after hatching depended more on their ability to feed than on avoiding predation (Redmond and Jenni 1986). After five

days, the main cause of radio-marked chick mortality shifted to predation by raptors, which was responsible for 73% of all pre-fledgling mortality.

Long-billed curlews are long-lived with an average lifespan of 8-10 years (Dugger and Dugger 2002). There are no confirmed predators for adult long-billed curlews and most adult mortality is associated with human activities. Annual survival of adult long-billed curlews during a study conducted in Idaho was approximately 85%, and all adult mortality was attributed to some type of human disturbance including illegal shooting (Redmond and Jenni 1986). Long-billed curlews are legally protected from hunting and collection in the U.S. and Canada under the Federal Migratory Birds Convention Act of 1994 (Cannings 1999).

Habitat use

Habitats used by long-billed curlews during the breeding season must provide the basic requirements for courtship, nesting, and brood-rearing activities. Habitats that curlews select for nesting and brood-rearing affect their ability to obtain invertebrates needed to meet the energetic demands of reproduction, and habitat characteristics determine how secure nests, chicks, and adults are against predation. Previous studies have attempted to identify breeding habitat requirements by determining what biotic and abiotic features make habitat appropriate for curlew use (King 1978; Allen 1980; Bicak et al. 1982; Redmond and Jenni 1986; Cochran and Anderson 1987; Pampush and Anthony 1993). In general, long-billed curlews use short- and mixed- grassland habitat with flat to rolling topography and avoid areas with tall, dense vegetation and a high density of shrubs during the breeding season (Dugger and Dugger 2002). Several studies have

shown that curlews select nest sites in vegetation with a low density and height structure (King 1978; Allen 1980; Jenni et al. 1981). Long-billed curlew use of areas with short, sparse vegetative cover differs from many bird species that use dense vegetation for predator avoidance and the enhancement of cryptic coloration. Several hypotheses have been proposed to explain how the use of open habitat increases curlew fitness. One hypothesis suggests that using open habitat increases the ability to detect predators and therefore increases predator avoidance (Pampush and Anthony 1993). Redmond and Jenni (1986) hypothesized that nesting in open habitat may also reduce predation pressure. They found that during a year with abnormally heavy rainfall, an increase in lush vegetative cover provided more protection for small mammals from predation. This resulted in long-billed curlew chicks becoming more important in the diets of avian predators.

Another hypothesis suggests that use of open habitat increases the rate of invertebrate prey-capture. Long-billed curlew morphology is adapted to wading in shallow water and feeding on coastal mudflats, and thus tall vegetation can hinder mobility and reduce foraging efficiency. Bicak et al. (1982) found that prey-capture was higher for long-billed curlews in short-grass habitat compared to tall-grass habitat, even though prey-density was lower. Additionally, short vegetation might enhance intraspecific communication (Bicak et al. 1982), which is important during the breeding season when finding mates, defending territories, and detecting predators is essential.

The species composition of vegetation may also play a role in habitat-selection during the breeding season. Long-billed curlews have been found to tolerate and even

prefer some invasive plant species. Pampush and Anthony (1993) found that curlew nest density in the Columbia Basin was highest in invasive cheatgrass (*Bromus tectorum*) habitat and that curlews selected cheatgrass habitat in greater proportion than availability while avoiding bitterbrush (*Purshia tridentata*) and dense forb habitat. Native bunchgrass habitat was used in proportion to availability or avoided. However, curlews have been found to respond negatively to exotics that provide tall, thick growth such as knapweeds (genus *Centaurea*) and crested wheatgrass (*Agropyron cristatum*) (Cannings 1999).

Several different abiotic factors may also be involved in breeding habitat-selection. Previous studies have indicated that curlews often build their nests close to conspicuous objects, such as sagebrush limbs, rocks, dirt mounds, dead furrows, manure piles, rusty cans, and tumbleweeds (King 1978; Allen 1980; Cochran and Anderson 1987). The importance of free standing water to breeding curlews is unclear. However, 39% of curlew observations were made within 0.4 km of standing water during a study in Colorado (King 1978). Cochran and Anderson (1987) indicated that bareground components, shade, and abundant prey are also essential requirements for curlew nesting habitat.

Grazing and fire play major roles in shaping the landscapes within which curlews select nesting and brood-rearing habitats. Bison (*Bison bison*) were the dominant grazers in the Great Plains prior to European settlement, numbering close to 30 million (McHugh 1972). Free-roaming bison herds may have historically provided the short vegetative structure used by curlews during the breeding season. Although few free-ranging bison

herds now exist, curlews are breeding on pastureland grazed by herds of domesticated bison raised for commercial purposes. Today, domestic cattle (*Bos taurus*) have replaced bison as the predominant ungulate grazer in the Great Plains (Hartnett et al. 1997) and play a major role in shaping the vegetative landscape throughout much of the long-billed curlew's breeding range. The type of livestock grazed in an area can have varying impacts on vegetative structure due to differences in diet, grazing patterns, and foraging behavior (Matlack et al. 2001). In the Great Basin, areas grazed by sheep had proportionately more hectares of short vegetation than cattle-grazed areas and the number of curlews per kilometer surveyed was positively correlated to number of hectares of short vegetation (Bicak et al. 1982). However, in South Dakota sheep have been shown to pose a greater trampling threat to curlew nests than cattle, resulting in the absence of nesting curlews from some sheep-grazed pastureland (Timken 1969).

Wildfires and controlled burns before or after the nesting period can have a positive effect on the abundance of curlews in an area by providing vegetation with a low vertical profile and density. Redmond and Jenni (1986) found that the breeding density of long-billed curlews in western Idaho increased the year after a fire and attributed this increase to the fire's reduction of vegetative cover. In some areas, fire suppression can lead to forest encroachment and growth of dense thatch which may hinder the movement and foraging of adults and chicks. Removal of patches of encroaching forest led to an increase in curlew abundance in East Kootenay, Canada (Ohanajanian 1992).

CHAPTER 3-STUDY AREA AND METHODS

Study Area

This study was conducted during the spring and summer of 2005 and 2006 within a 100 km^2 core area of the Triple U Buffalo Ranch (44˚30'N to 44˚N - 100˚41'W to 100˚57'W) (Figure 3B). The Triple U is located in Stanley County, South Dakota just northwest of Pierre (Figure 3A). Stanley County is located in the Pierre Hills region of the Missouri Plateau and is characterized by gently undulating to rolling topography with 6-40% slopes and well-drained clayey soils (Borchers 1980). Elevations on the ranch range from approximately 580-700 m. The Triple U contains approximately 242 km^2 of unbroken native mixed-grass prairie and is located in the transitional zone between the Northern Wheatgrass-Needlegrass Plains and Northern Mixed Grass Prairie vegetation types of the Great Plains (Johnson and Larson 1999). In general these vegetation types are dominated by upland graminoids such as western wheatgrass (*Elymus smithii*), needleandthread (*Hesperostipa comata*), and green needlegrass (*Nassella viridula*). Dominant forbs and shrub species include western snowberry (*Symphoricarpos occidentalis*), scarlet globemallow (*Sphaeralcea coccinea*), American vetch (*Vicia americana*), and various scurfpea species (genus *Psoralea*). Hundreds of stock ponds and natural wetlands are scattered throughout the ranch and a limited number of plains cottonwoods (*Populus deltoides*) grow near wet areas. Creeping spikerush (*Eleocharis palustris*), foxtail barley (*Hordeum jubatum*), and inland saltgrass (*Distichlis spicata*) are more common components in wet areas.

The Triple U is primarily used as pastureland for domestic bison and cattle. In 2005, the ranch supported approximately 2,000 head of bison and 450 head of cattle. In 2006, the bison herd remained at approximately 2,000 head while the cattle herd increased to approximately 500 head. The bison and cattle herds are broken into smaller herds and rotated among 30 pastures fenced off within the ranch, leaving some pastures void of livestock at all times. Livestock densities over the two years of this study ranged from 0-223 bison/km^2 and 0-42 cattle/km^2 within various pastures.

Average maximum temperatures for the Pierre area (1948-2005) range from -2 °C in January to 31.8 °C in July and total precipitation averages 14.1 cm and 6.2 cm for these months respectively (HPRCC 2006). Eighty percent of annual precipitation falls in the six months from April to September (Borchers 1980). During the 2005 field season, total precipitation in April-June was close to average or wetter than average followed by an extremely dry July (Figure 4) while maximum temperatures were average or slightly higher than average (Figure 5). There was a severe drought during the spring and summer of 2006 and all 4 months of the field season (April-July) had well below average precipitation levels (Figure 4) while maximum temperatures were several degrees above average (Figure 5). In the fall of 2005, a natural range fire burned approximately 30 km^2 of pastureland on the ranch within the core study area (Figure 3).

Density Censuses

In 2006, density censuses were conducted for a 2-week period from 14 April-28 April. Censuses were conducted in 12 pastures frequented by breeding long-billed curlews, covering 40 km^2 of the core area of the study site. Each pasture was censused

individually, using modified strip transects with the assumption that all curlews within the strips were detected (Buckland et al. 1993). Transects paralleled established fencelines and were run in the direction of the longest fenceline. Each strip had a width of 500 m with 250 m on each side of the transect line. The number of transects in each pasture was determined by the width of the pasture being censused. The length of each transect varied depending on the shape of the pasture and was measured using a Garmin 76CS GPS unit.

Two observers traveled each transect on ATV's, stopping every 400 m to thoroughly scan the area around the transect with binoculars. Searching was focused within 250 m of the transect line. However, unlike traditional strip transect sampling, curlews spotted outside of the strip were also recorded. The radial distance (estimated using a rangefinder) and approximate angle in relation to the transect line was recorded for each curlew located in order to avoid counting birds located outside of the strip transect multiple times. Curlews observed in flight were included in the censuses but care was taken to note the destination of these individuals, so that they were not counted more than once. Curlews observed outside of the pasture being surveyed were not counted. The sex of each curlew observed was determined using the length and shape of the bill, which is longer and less symmetrical in females than in males.

A density estimate was calculated for each pasture censused by dividing the number of curlews observed by the area of the pasture in which they were observed. Some pastures were only partially covered during censuses. In these cases, the total area of the strip transects rather than whole pasture areas were used for density calculations.

Relationships between curlew densities and livestock grazing densities were analyzed using linear regression analyses. Densities were also compared between bison-grazed, cattle-grazed, and ungrazed pastures using a Kruskal-Wallis test and between burned and unburned pastures using a Mann-Whitney test. A significance level of 0.05 was used for all analyses.

Nest Survival

Nest dragging was conducted during May of 2005 (16 May-27 May) and 2006 (2 May-25 May) in pastures frequented by breeding curlews. Nests were located by dragging a hemp rope with either a 2-cm (2005) or 1.25-cm (2006) diameter between two ATV's to flush incubating adults. The smaller diameter rope was used in 2006 in order to prevent damage to eggs that occurred when the heavier rope was used in sparsely-vegetated areas during 2005. In 2006, nests were also located by tracking adults with operational radio-transmitters attached in 2005 (see *Capture and Marking* methods). Upon location of a nest, clutch size was recorded and the location of each nest was marked with a Garmin 76CS GPS unit and a wire flag or wooden stake placed approximately 10 m to the north of the nest. In 2005, incubation initiation dates were estimated by backdating successful nests using an approximate 28-day incubation period. In 2006, eggs were floated to determine approximate incubation initiation dates using a floating schedule designed specifically for shorebirds (Liebezeit et al. In press). Eggs in five clutches were also weighed individually in 2006 to estimate the energetic requirements of egg production.

Nest fate was monitored by checking nests several times per week until hatching or failure. Nests were observed from a distance and only approached if there was no adult incubating the nest. If an adult was on the nest, the nest was assumed to be viable. Any time a nest was approached throughout the breeding season, the investigator's trail was covered with paradichlorobenzene (PDB) crystals to prevent attracting mammalian predators. Because PDB crystals are relatively small and volatile, they evaporate quickly and should not have had a long-lasting effect (Redmond and Jenni 1986). Cause-specific nest failure was determined using eggshell evidence (Sargeant et al. 1998) and nest success was estimated using the Mayfield (1975) method. Egg hatchability was estimated as the percentage of eggs present at hatching time that produced chicks.

Using the nest survival analysis in program MARK (White and Burnham 1999), nest survival probabilities were estimated as a function of both continuous and categorical variables related to habitat and land-use factors at nest sites and within nesting pastures. Continuous variables used in the analysis included bison density in nesting pastures (bison), visual obstruction readings taken at nest sites (VOR), and total vegetative cover at nest sites (totcover). Categorical variables used in the analysis included the presence or absence of bison in nesting pastures (grazed), dominant species of vegetation at nest sites (species), dominant cover type at nest sites (forbs, grasses, or bareground) (cover type), renesting status (renest), and year of nest location (year). The year variable was used to determine whether data could be pooled between years for this analysis. Support for a model containing the year variable would suggest that nest survival should be analyzed separately for each year. Methods for measuring all of the

vegetative variables used in this analysis are described in the *Habitat use* section of this chapter.

All possible single-variable models along with a constant daily survival rate (DSR) model were compared using Akaike's Information Criterion corrected for small sample size (AICc) (Akaike 1973; Burnham and Anderson 2002). Variables used in single-variable models with greater support than the constant DSR model were then selected for further evaluation. Models using all 1-, 2-, 3-, and 4-way additive combinations of these variables were compared and all models within 2 units of the minimum AICc model were considered to be among the best approximating models in explaining variation in nest survival (Burnham and Anderson 1998). Variable weights were calculated by summing the AICc weights of all models that included the variable of interest in order to assess each variable's relative importance (Burnham and Anderson 2002). Beta estimates for continuous variables contained in the set of best models were used to indicate the direction of the effect for each variable. Daily survival rate estimates were used to indicate how categorical variables affected nest survival.

Capture and Marking

Adult curlews were captured during the day on the nest with a 12-m long, 100-mm mesh mist net using a technique developed by Redmond and Jenni (1986). This technique involved placing the mist net on poles and holding the net parallel to the ground and fully stretched between two people. Starting from between 30-50 m to the north of the nest, mist netters simply walked to the nest and placed the mist net directly on top of the incubating adult. It was often possible to catch both members of a breeding

pair during the day by returning to the nest at different times until the targeted individual was incubating the nest. However, in 2006 one male curlew was captured at night using a new glowstick method. This method involved flushing the targeted bird at dusk and placing a glowstick adjacent to the nest. Netters then returned to the nest in complete darkness and conducted the same mist netting method used during the day using the glowstick as a guide for placement of the net. When the net was in place, a third member of the capture team would shine a one million candle power spotlight in the direction of the glowstick for visual location of the bird.

Each curlew captured was sexed, weighed, banded on the metatarsus with a size six metal band, and equipped with a 10.7 g VHF transmitter (150-151 MHZ range, ATS Model A3950 with mortality sensor) using a necklace-type mount. In 2006, adults were also banded with two red darvic bands on the right leg and a unique 3-band color combination on the left leg. Lengths of the exposed culmen, head, and out-stretched wing (from the wrist to the tip of the longest primary feather) were also measured. Radio-marked curlews were tracked throughout the breeding season using a receiver and either a hand-held or vehicle-mounted antenna. Vehicle-mounted antennas used a null-peak telemetry system.

Adult and Brood Survival

Adult curlews with broods were visually located at least three times per week using signals from radio-transmitters. Brood viability was determined by visually locating chicks using a spotting scope or by identifying aggressive behavior often displayed by brood-rearing adults. A brood was considered viable if at least one chick

was still alive. Adult survival over the breeding season was estimated by approaching transmitters emitting mortality signals and recording the cause of mortality. Minimum adult survival between years was estimated as the percentage of curlews radio-marked in 2005 that were known to return to the study site in 2006 with functional transmitters.

Nesting and Brood-rearing Habitat

Habitat measurements were taken at nest sites, brood location points, and points randomly selected throughout the core area of the study site using Arc View (ESRI, Redlands, CA). Random points were used to estimate the availability of habitat characteristics throughout the study area. All points characterized were at least 100 m apart. In 2005, habitat data at nest sites was collected after all nests had hatched while in 2006, habitat data was taken at each nest within a few days of hatching or failure. Habitat measurements at brood location points were taken within one week of locating chicks at a specific point while data at random points was taken as nests hatched and throughout the brood-rearing period.

Habitat data was collected along two perpendicular 50-m transects running in the north-south and east-west directions centered over the nest, brood, or random point (Figure 6). A line-transect method was used to characterize the species composition of the vegetation at each point sampled. At every one-meter mark along the transects, species of vegetation touching the transects were recorded (Figure 6). If there was no vegetation at a 1-m sampling-point then bareground was recorded as the composition type at that point. Similarly, if a transect intersected a body of water, then water was recorded as the composition type for each meter of the transect covered by water. The

percentage of 1-m sampling points represented by each species of vegetation or abiotic factor (bareground and water) was calculated for each sample. Only species or abiotic factors that represented at least 1% of composition at nest sites, brood points, or random points were used in species composition analyses.

At each ten-meter mark along the transects, visual obstruction readings (VOR's) were taken from 4 m away and 1 m above the ground in each of the four cardinal directions using a standard Robel pole (Robel et al. 1970) with a 1-dm scale (Figure 6). Vertical cover of grasses, bareground, forbs, and shrubs was estimated every 10 m using a 25-cm by 50-cm rectangular Daubenmire plot (Daubenmire 1959) placed 1 m away from the transects in each of the four cardinal directions (Figure 6). Vertical cover was estimated using six cover scales as follows: 0=0%, 1=1-5%, 2=6-25%, 3=26-50%, 4=51-75%, 5=76-95%, 6=96-100%. The midpoint value for each cover class was used for analyses.

A single measurement of the slope of the ground was taken at nest sites, brood points, and random points using a clinometer. The locations of water sources (man-made stock ponds and natural wetlands) in the core area of the study site were marked using a Garmin 76CS GPS unit and distances to the nearest water source from nest sites, brood points, and random points were calculated using program MapSource (Garmin Ltd. Version 6.0). Distance to the nearest conspicuous object was measured only from nest sites and random points. In 2006, an additional measurement of height of the tallest piece of vegetation touching the nest bowl was taken in the 4 cardinal directions immediately

after finding a nest. A single measurement of height of the tallest piece of vegetation was also taken at brood points and random points.

All measurements were analyzed using the means for each point sampled. Measurements taken at brood location points were further averaged for each individual brood to avoid biasing the results toward broods with a greater number of sampling points. Vegetative characteristics (species composition, vertical cover composition, VOR, and height) as well as slope, and distance to water were compared between nest sites, brood points, and random points using ANOVA or Kruskal-Wallis tests depending on normality of the data and homogeneity of variances. Tukey tests or Kruskal-Wallis pair-wise comparisons tests were used to identify specific differences between groups. Only differences between nest sites and random points, and brood points and random points are reported. Vegetative characteristics were also compared between years using a t-test or Mann-Whitney test depending on normality of the data and homogeneity of variances. A significance level of 0.05 was used for all analyses.

Movements

Home range sizes over the entire breeding season were estimated using the home range analysis extension (Rodgers and Carr 1998) in Arc View (ESRI, Redlands, CA) for radio-marked individuals and pairs with at least 20 location points. Home ranges were also estimated for the nesting and brood-rearing periods for pairs with at least 20 locations for each period. The nesting period was defined as the period from clutch initiation to hatching or failure of the nest. The brood-rearing period was defined as the period from hatching of the chicks to fledging or mortality. Ninety-five percent and 50%

home range sizes were estimated using the fixed-kernel method with a smoothing parameter determined by least-squares cross-validation (Seaman et al. 1999).

Distances from original nests to renesting attempts were estimated using GPS locations in program MapSource. For individuals radio-marked in 2005 that returned to nest with functional transmitters in 2006, distances between nest locations in different years were also calculated using program MapSource. If returning birds had multiple nesting attempts in 2006, the nest closest to their 2005 nest was used to estimate distance from previous nest-site.

CHAPTER 4-RESULTS

Density Censuses

A total of 129 adult long-billed curlews (72 males, 39 females, 18 unknown) were observed during censuses in 2006 resulting in a density estimate of 3.2 adults/km^2 over the area censused. Curlew densities in each pasture were not linearly related to bison densities (F=0.13; df=1,9; r^2=0.01; P=0.7279) or cattle densities (F=0.23, df=1,9; r^2=0.03; P=0.6396). There was also no difference in curlew densities between pastures grazed by bison, pastures grazed by cattle, and pastures without grazing pressure (H=0.25; df=2; P=0.8805). Curlew densities did not differ between burned and unburned pastures (t=0.22; df=9; P= 0.5282).

Breeding Chronology and Renesting

Some curlews had already arrived on the ranch in early April when both the 2005 and 2006 field seasons were initiated. Mean clutch size of nests known to be complete in 2005 (n=15) was 3.6 eggs (range 2-4 eggs). Mean date of long-billed curlew nest incubation initiation for successful nests (n=11) was 1 May (range 23 April–12 May). Mean hatch date of successful nests was 27 May (range 20 May–8 June). In 2005, only 25% of radio-marked pairs with failed first nesting attempts renested (1 renest/4pairs). The single known renesting attempt had a clutch size of 3 eggs, an incubation initiation date of 6 June, and did not produce any chicks. Mean fledging date of broods known to fledge at least one young (n=3) was 2 July (range 25 June-15 July). Approximately 93% of radio-marked curlews departed the study area by 1 July in 2005 (range 5 June-21 July).

Mean departure date was 15 June for females (range 5 June-25 June) and 22 June for males (range 5 June-21 July).

In 2006, 46% of radio-marked pairs with failed first nesting attempts renested (6 renests/13 pairs) and 33% of renesters had two renesting attempts. Mean clutch size of all nests known to be complete (n=26) was 4.08 eggs (range 4-5 eggs). Mean clutch size of second attempt nests known to be complete (n=4) was 4.25 eggs (range 4-5 eggs) and of third attempt nests known to be complete (n=2) was 4 eggs (both 4-egg clutches). Mean individual egg mass of clutches weighed in 2006 (n=5) was 64.8 g/egg (range 62.0-66.5 g/egg; Appendix 1). Mean approximate incubation initiation date for all nests that were floated (n=29) was 11 May (range 13 April-3 June). Mean incubation initiation date for second-attempt nests (n=6) was 21 May (range 7 May-28 May) and for third-attempt nests (n=2) was 30 May (range 25 May-3 June). Mean hatch date for successful nests (n=5), none of which were known to be renesting attempts, was 3 June (range 17 May-23 June). Mean fledging date of broods known to fledge at least one young (n=2) was 7 July (range 19 June-25 July). In 2006, 83% of radio-marked curlews had departed the study area by 1 July. Mean departure dates were 21 June for females (range 3 June-1 Aug) and 27 June for males (range 16 June-28 July). A summary of nesting chronology and clutch sizes for nesting attempts in 2005 and 2006 is provided in Table 1.

Nest Survival

Eighteen nests were located in 2005, 15 of which had known fates and were used in nest survival analyses. Overall, 73% of nests with known fates located in 2005 produced chicks (n=11), 20% were trampled by bison (n=3, 75% of failure), and 7% were

abandoned after being disturbed (n=1, 25% of failure). Nests were trampled starting at a density of approximately 218 bison/km^2 (Table 2). Egg hatchability was 76% indicating that 24% of eggs present at hatch time were inviable. Mayfield (1975) nest success was estimated as 0.39 indicating a 39% chance that a nest would survive through the 28-day incubation period.

A total of 30 nests were located in 2006, 27 of which had known fates and were used in nest survival analyses. Overall, 19% of nests with known fates produced chicks (n=5), 19% were trampled by bison (n=5, 23% failure), 11% were trampled by cattle (n=3, 14% failure), and 52% were predated (n=14, 64% failure). Mayfield (1975) nest success was estimated as 0.15. Eggshell evidence at predated nest sites suggested that canid predators, inlcuding coyotes and red fox (*Vulpes vulpes*), were the primary predators responsible for curlew nest predation. Nests were trampled starting at a density of approximately 77 bison/km^2 and 33 cattle/km^2 (Table 3). Egg hatchability in 2006 was 95%.

Nest survival analyses in program MARK (White and Burnham 1999) estimated the constant daily survival rate (DSR) for nests as 0.94 (95% CI=0.91-0.96) for 2005 and 2006 combined. However, the constant DSR model had a ΔAICc value of 17.47 (Table 4), suggesting that models using habitat and land-use variables were necessary to explain variation in daily survival rates. Models with ΔAICc values ≤2.0 (with rounding)(Table 4) used the categorical variables plant species (0.99 variable weight; Table 5) and cover type (0.39 variable weight; Table 5) and the continuous variables bison (0.39 variable weight; Table 6) and VOR (0.30 variable weight; Table 6) to explain variation in nest

survival. There was a 100% daily nest survival rate at nest sites dominated by yellow sweetclover (*Melilotus officinalis*), junegrass (*Koeleria macrantha*), green needlegrass (*Nassella viridula*), and buffalograss (*Buchloe dactyloides*), while daily nest survival rates were considerably lower at nest sites dominated by Japanese brome (*Bromus japonicus*) and western wheatgrass (*Elymus smithii*) (Table 5). Daily nest survival was highest at nest sites dominated by forb cover, followed by nest sites dominated by bareground, and lowest at nest sites dominated by grass cover (Table 5). Daily nest survival was negatively related to the density of bison grazed in a pasture and positively related to VOR measurements taken at nest sites (Table 6). Because the single-variable year model did not have more support than the constant DSR model (Table 4), separate nest survival analyses were not conducted for 2005 and 2006.

Adult and Brood Survival

Out of 10 broods produced from successful nests of radio-marked adults in 2005, only 50% were still viable one week after hatching (Figure 7). Sixty-percent of broods that survived to one week are known to have produced fledglings. Out of five broods produced from successful nests of radio-marked adults in 2006, only 40% were still viable one week post-hatch (Figure 8), but 100% of these broods produced fledglings. Most chick mortalities were not recovered. However, four chicks from two different broods perished in or close to the nest in 2006, apparently due to heat prostration.

One-hundred percent radio-marked adult survival over the breeding season was observed in both 2005 and 2006. A minimum of 58% (n=15) of adult curlews radio-marked in 2005 (n=26) survived the winter and returned to the ranch to breed in 2006.

However, this number underestimates adult survival between years because the minimum operational life of the deployed transmitters was only 259 days, and several radio-marked curlews with non-operational transmitters were observed in 2006.

Habitat use

Habitat was characterized at 18 nest sites, 43 brood location points (corresponding to 6 different broods with radio-marked adults), and 70 random points in 2005. Measurements of VOR (H=2.47; df=2; P=0.2915; Figure 9), grass cover (F=0.30; df=2,91; P=0.7403; Figure 10), percentage of bareground (H=4.76; df=2; P=0.0925; Fig. 10), forb cover (F=2.72; df=2,91; p=0.0713; Figure 10), and distance to water (F=0.21; df=2,90; P=0.8146; Fig.11) did not differ between nest sites, brood points, and random points. There was less shrub cover at nest sites than at random points (H=17.30; df=2; P=0.0002; Figure 10). Slope of the ground was steeper at random points than at nest sites (H=8.71; df=2; P=0.0129; Figure 12) and distance to the nearest conspicuous object (all piles of manure) was shorter from nest sites than from random points (H=22.37; df=1; P<0.0001; Figure 13).

Seventy-three different species of vascular plants were identified at nest sites, brood location points, and random points in 2005 and 2006 (Appendix 2). In 2005, American vetch (H=12.24; df=2; P=0.0022; Table 7), junegrass (H=14.21; df=2; P=0.0008; Table 8), and buffalograss (H=21.25; df=2; P<0.0001; Table 8) represented a higher proportion of species composition at nest sites than at random points. Sixweeks fescue (*Vulpia octoflora*) (F=5.98; df=2,90, P=0.0159; Table 8), indianwheat (*Plantago patagonica*) (H=14.78; df=2; P=0.0006; Table 7), junegrass (H=14.21; df=2; P=0.0008;

Table 8) and American vetch (H=12.24; df=2; P=0.0022; Table 7) represented a higher proportion of species composition at brood points than at random points.

In 2006, habitat was characterized at 30 nest sites, 37 brood location points (corresponding to 3 broods with radio-marked adults and 11 broods with non-marked adults), and 84 random points. Nest sites had lower VOR measurements (H=34.11; df=1; P<0.0001; Figure 9), a higher percentage of bareground (H=25.91; df=1; P<0.0001; Figure 14), and less forb cover (H=28.57; df=1; P<0.0001; Figure 14) in 2006 than in 2005. Brood points had lower VOR measurements (H=12.57; df=1, P=0.0004; Figure 9), less grass cover (t=3.49; df=18; P=0.0026; Figure 15), a higher percentage of bareground (H=10.88; df=1; P=0.001; Figure 15), and less forb cover (H=12.00; df=1; P=0.0005; Figure 15) than in 2005. Brood points were also located almost 200 m closer to water on average than in 2005 (Figure 11), however this difference was not statistically significant (t=1.80; df=18; 0.0854). Random points had lower VOR measurements (H=88.32; df=1; P<0.0001; Figure 9), less grass cover (H=5.93; df=1; P=0.0149; Figure 16), a higher percentage of bareground (H=31.82; df=1; P<0.0001; Figure 16), and less forb cover (H=99.57; df=1; P<0.0001; Figure 16) than in 2005. Overall, the grass to forb ratio of cover composition on the study site (according to changes at random points) increased from approximately 2:1 in 2005 to 7:1 in 2006.

Species composition of vegetation available on the study site changed considerably between 2005 and 2006 according to changes in composition that occurred at random points. At random points in 2006, biscuitroot (*Lomatium foeniculaceum*) (H=11.45; df=1; P=0.0007; Figure 17), field pennycress (*Thlaspi arvense*) (H=23.05;

df=1; P<0.0001; Figure 17), western wheatgrass (H=61.52; df=1; p<0.0001; Figure 18), buffalograss (H=17.32; df=1; P<0.0001; Figure 18), sun sedge (*Carex inops*) (H=19.72; df=1; P<0.0001; Figure 18), and bareground (H=61.82; df=1; P<0.0001) represented a higher proportion of species composition than in 2005 and Japanese brome (H=21.00; df=1; P<0.0001; Figure 18), junegrass (H=36.13; df=1; P<0.0001; Figure 18), common yarrow (*Achillea millefolium*) (H=5.90; df=1; P=0.0152; Figure 17), American vetch (H=14.77; df=1; P=0.0001; Figure 17), Kentucky bluegrass (*Poa pratensis*) (H=21.67; df=1; P<0.0001; Figure 18), sixweeks fescue (H=12.97; df=1; P=0.0003; Figure 18), goatsbeard (*Tragopogon dubius*) (H=17.51; df=1; P<0.0001; Figure 17), silverleaf scurfpea (*Psoralea argophylla*) (H=9.51; df=1; P=0.002; Figure 17), and yellow sweetclover (H=110.11; df=1; P<0.0001; Figure 17) represented a smaller proportion of species composition than in 2005. Overall, the grass to forb ratio of species composition on the study site (according to changes that occurred at random points) increased from approximately 2:1 in 2005 to 10:1 in 2006.

In 2006, both nest sites and brood points had lower VOR measurements (H=29.76; df=2; P<0.0001; Figure 9) and shorter vegetation (H=27.83; df=2; P<0.0001; Figure 19) than random points. Nest sites had more forb cover (F=7.14; df=2,125; P=0.0012; Figure 20), less shrub cover (H=12.54; df=2; P=0.0019; Figure 20), and were significantly closer to piles of manure (H=37.66; df=1; P<0.0001; Figure 13) than random points. Brood points had less grass cover (F=5.22; df=2,125; P=0.0066) and a higher percentage of bareground (F=10.02; df=2,125; P<0.0001) than random points (Figure 20). Random points were on steeper slopes than nest sites and brood points

(H=17.20; df=2; P=0.0002; Figure 12). Distance to water did not differ between groups (H=3.74; df=2; P=0.1540; Figure 11).

In 2006, scarlet globemallow (H=22.59; df=2; P<0.0001; Table 7), American vetch (H=12.14; df=2; P=0.0023; Table 7), buffalograss (H=14.36; df=2; P=0.0008; Table 8), and junegrass (H=10.81; df=2; P=0.0045; Table 8) represented a larger proportion of species composition at nest sites than at random points while needleandthread (H=9.20; df=2; P=0.01; Table 8) represented a smaller proportion of species composition at nest sites than at random points. At brood points, bareground (H=14.87; df=2; P=0.0006; Table 9), water (H=24.82; df=2; P=<0.0001; Table 9), and creeping spikerush (H=8.14; df=2; P=0.0171; Table 8) represented a larger proportion of species composition than at random points. A summary of all habitat characteristics (except for species composition) at nest sites and brood points in 2005 and 2006 is provided in Table 10.

Movements

In 2005, 14 adult male and 12 adult female long-billed curlews were captured and radio-marked. In 2006, a total of 17 adult females and 15 adult males were tracked throughout the breeding season, including 6 individuals that were recaptured to replace transmitters, 9 individuals that retained working transmitters from 2005, and 17 individuals that were captured and radio-marked for the first time in 2006. Body measurements for individuals captured in 2005 and 2006 are located in Appendices 3-4. Over 800 locations were taken for radio-marked individuals and curlew pairs in 2005 and 2006. Breeding season home ranges were calculated using a minimum of 20 locations

and a mean of 26.8 locations (n=5, range 20-35) in 2005 and 32.5 locations (n=13, range 20-43) in 2006. Mean sizes of 95% and 50% home ranges for the entire breeding season (n=5) were 1.87 km^2 (range 0.70-4.89) and 0.32 km^2 (range 0.15-0.82 km^2) respectively in 2005. Mean 95% and 50% home range sizes for the brood-rearing period (n=3) were 0.75 km^2 (range 0.52-1.00) and 0.12 km^2 (range 0.08-0.15 km^2) respectively. No pairs had a large enough sample of locations to estimate home range sizes during the nesting period in 2005. In 2006, mean size of 95% and 50% breeding season home ranges (n=13) were 7.71 km^2 (range 1.15-29.11 km^2) and 1.35 km^2 (range 0.18-4.21 km^2) respectively. Only one pair had enough locations for estimating a nesting season home range in 2006 with a 95% home range estimate of 0.882 km^2 and 50% home range estimate of 0.086 km^2. There was also only one pair with enough locations to estimate home range size for the brood-rearing period in 2006, with a 95% home range estimate of 4.8 km^2 and a 50% home range estimate of 0.40 km^2. Breeding season home range sizes were significantly larger in 2006 than in 2005 (H=6.92; df=1; P=0.0085). However, comparing home range sizes between years may not be appropriate because in 2005 most birds were captured and radio-marked at the end of the incubation period while in 2006, birds that returned with functional transmitters from 2005 were tracked from arrival throughout the entire nesting and brood-rearing periods.

The single known renesting attempt in 2005 was placed 331.5 m away from the original nest. The mean distance renesting attempts were placed from original nests in 2006 was 1.03 km (range 0.85 km-5.85 km, n=8). Curlews that were radiomarked in

2005 and returned to the ranch with working transmitters to nest in 2006 (n=10) placed their nests a mean distance of 608.6 m from previous nest sites (range 0.089 km-1.1 km).

CHAPTER 5-DISCUSSION

Nest Survival and Nesting Habitat

The two years over which this study was conducted provided a landscape with two extremely different vegetative structures for breeding curlews. During the nesting period of 2005 (April-June), precipitation was average to slightly higher than average in the Pierre area. This provided a substantial supply of moisture during the growing season and promoted the growth of tall, dense vegetation. In addition, 2005 was a peak year for the biennial forb yellow sweetclover, which represented close to 25% of species composition available at random points and created tall, dense stands of forb cover throughout the study site. Within this landscape, curlews nested in areas with similar vegetative characteristics to those available at random points. Nest sites were located in habitats with an average of 55% grass cover, 47% forb cover, and an average VOR close to 30 cm. Following the 2005 field season, a natural fall range fire burned 30 km^2 of prairie within the core area of the study site leaving large areas nearly void of vegetation residue. The fire was followed by a severe drought during the spring and summer of 2006 which corresponded to a non-peak year for the forb yellow sweetclover. When curlews returned to the ranch to breed in 2006, the landscape had greatly reduced vegetative cover and curlews nested in areas with an average of 46% grass cover, 11% forb cover, and an average VOR of only 10 cm.

The decrease in vegetative cover at nest sites in 2006 corresponded to a major increase in the frequency of nest predation, reducing nest survival to a rate much lower than observed in previous studies (Table 11). In 2005, no nests with known fates failed

as a result of predation. In contrast, 52% of nests with known fates located in 2006 were predated which accounted for approximately 64% of nest failure. Nest survival analyses showed a positive relationship between nest survival and average VOR measurements at nest sites, providing evidence for a direct relationship between vegetative structure and nest survival. Because curlews arrive early in the spring to breed, nesting cover for many first nesting attempts is provided entirely by residual vegetation. The removal of large areas of residual vegetation by the fall 2005 fire may have had a large impact on nest survival rates. Similar increases in nest predation rates of grassland bird nests were observed after a fire and grazing reduced vegetative cover in tallgrass prairie habitat in Oklahoma (Rohrbaugh et al. 1999).

Despite that a reduced vegetative structure appeared to negatively affect their reproductive success, curlews selected nest sites in habitats with even shorter and less dense vegetation than what was available at random points in 2006. These results suggest that curlews breeding on the ranch had a strong preference for nesting habitats with short, non-dense vegetation. This preference may not have been evident in 2005 because of the homogeneous nature of the tall, dense vegetation available on the ranch resulting in a low availability of open habitats during the nesting period. Hypotheses proposed to explain curlews' preference for open habitats during the breeding season include increased predator detection, mobility, and foraging efficiency (Bicak et al. 1982; Pampush and Anthony 1993). Reduced vegetative cover at nest sites in 2006 did not affect adult survival (100% during both years) but had a negative effect on nest survival,

suggesting that if predator detection did increase, it did not result in increased reproductive fitness.

Increased foraging efficiency may provide a better explanation for curlews' preference for open nesting habitats in 2006. Curlews lay large eggs and the energetic requirements of producing those eggs is also large. The amount of energy transferred from a female bird to its eggs can vary widely among bird species, from around 4.2 kJ/g in passerines to 8.4 kJ/g in waterfowl (Gill 1995). Similarly to waterfowl eggs, curlew eggs produce large precocial young, and thus energy transferred to curlew eggs is likely close to that of waterfowl species. Mean egg mass in 2006 was approximately 65 g (Appendix 1). Therefore, female curlews may transfer close to 520 kJ of energy to a single egg. However, because the efficiency of energy transfer to eggs is only around 20% (Gill 1995), a female may need to consume close to 2,600 kJ to produce a single egg and thus over 10,000 kJ to produce an entire 4-egg clutch. Leeman (2000) estimated that the daily energy requirement for a female long-billed curlew during the winter is approximately 825 kJ/day. This indicates that energetic demands during the breeding season are much higher than at other times of the year and may present a strong selective force for the use of habitat that increases foraging efficiency.

In 2006, renesting effort was considerably higher (46%) than in 2005 (25%) and two females actually renested twice. This was some what surprising since research in other states has indicated that curlews will not renest even a single time during the breeding season (Allen 1980; Redmond and Jenni 1986; Paton and Dalton 1994; Dugger and Dugger 2002). The difference in renesting effort between years may be partially due

to the fact that nest dragging was conducted later during the nesting period in 2005 and some of the nests located may have been renesting attempts without our knowledge. However, the energetic demands of foraging in the tall, dense vegetation available in 2005 may also have reduced the ability of females to gain enough energy to produce additional clutches. On average, the mass of one egg was equal to approximately 1/10 of a female curlew's body mass (629 g; Appendix 4) in 2006. The two females that laid three 4-egg clutches in 2006, both laid their third clutches within 1 month of laying their first clutches. This means that these females had to acquire enough energy (approximately 120,000 kJ) over a relatively short period of time to produce 12 eggs equal to approximately 120% of their own body mass. This suggests that these females were able to acquire a large amount of energy when nesting in open habitats in 2006. Grasshoppers (order *Orthoptera*) have been identified as one of the most common prey items of long-billed curlews during the breeding season (Redmond and Jenni 1985; King 1978) and research suggests that grasshopper abundance is directly related to quality and quantity of vegetation in an area (Fielding and Brusven 1995; Capinera and Sechrist 1982). This further supports the foraging efficiency hypothesis for habitat selection since the amount of energy acquired appeared to be higher in 2006 despite the fact that prey density was most likely lower than in 2005.

In addition to the low renesting effort in 2005, the mean clutch size (3.6 eggs) was lower than the mean clutch size in 2006 (4.08 eggs). Redmond (1986) observed reduced clutch size among long-billed curlews during one year of their study in Idaho and concluded that this was most likely an adaptation to the dense vegetative cover that

dominated their study site that year. Because curlews prefer to forage in less dense vegetation, adults had to fly longer distances from their nest sites to forage. Long flights to foraging areas most likely limited protein reserves of female curlews because of extra strain on flight muscles resulting in reduced clutch size. Although there is no evidence that curlews flew further away from nest sites to forage in 2005, a decrease in prey acquisition or increase in energy expended for foraging in dense vegetation may have limited protein reserves in a similar way.

Despite the many differences between habitats at nest sites in 2005 and 2006, several nest-site characteristics remained consistent between years. As found in previous studies (King 1978; Allen 1980; Redmond and Jenni 1986; Cochran and Anderson 1987) curlews selected nest sites close to piles of manure on flat to gently sloping hills with a low density of shrubs. Vertical movement requires approximately 10 times more energy than movement in a horizontal plane (Clapperton 1964; Brockway and Gessaman 1977; Parker et al. 1984). A gently sloping topography, along with a low density of shrubs most likely decreases the amount of energy curlews use for mobility. In addition, these features may increase visibility around the nest site and increase predator detection. Nesting close to manure piles may help camouflage incubating adults and make their nests less detectable by predators. Additionally, placing nests close to manure piles may make relocating nests easier for curlews after spending time away from the nest.

In 2006, curlews selected nest sites that had greater forb cover than available at random points suggesting that forb cover may be an important nest site characteristic. Due to the drought conditions on the study site in 2006, the small amount of forb cover

available generally maintained a low vertical profile. For this reason curlews may have been able to nest in forb cover with a potentially larger abundance of invertebrate prey without sacrificing foraging efficiency. Forb cover may also help conceal curlew nests from predators. Nest survival analyses showed that nest survival was highest at forb-dominated nest sites and lowest at grass-dominated nest sites. The increased grass to forb ratio of cover composition observed in 2006 may have left curlew nests more prone to predation.

In 2005, curlews selected nest sites with an average of 55% grass cover, 47% forb cover, and an average height of 27 cm (based on VOR's). Studies in Washington and Idaho have indicated that curlews generally select nest-sites with less than 50% vegetative cover and a height of less than 10 cm (Allen 1980, Jenni et al. 1981), similar to the nest sites selected during this study in 2006. According to radio-tracking data, a minimum of 58% of the curlews radio-marked in 2005 returned to the ranch to breed in 2006. Returning curlews nested an average of only 600 m away from where they nested in 2005. This would remain not only within the breeding season home range sizes estimated during this study (0.70 km^2-29.11 km^2) but also within the nesting home range size estimated in 2006 (0.88 km^2). This implies that curlews not only use traditional breeding areas, but many also use traditional nesting territories within those breeding areas from year to year. Curlews may have nested in areas with dense vegetation in 2005 simply because it was the only vegetation available in traditional nesting territories despite an apparently strong preference for shorter, less dense vegetative cover. Curlews that renested after failed nesting attempts also placed their nests close to original nesting

attempts (1 km on average), lending further support for a high fidelity to nesting territories.

Not only did the general height, density, and cover of the vegetation on the study area change between years, but the species composition of vegetation changed drastically as well. There was a large increase in the grass to forb ratio of the species available on the study site in 2006, which is a common occurrence following a fire (Hartnett and Fay 1998). The largest changes in species composition of the vegetation were decreases in the representation of yellow sweetclover (24% decrease in relative cover; Figure 17) and Japanese brome (13% decrease in relative cover; Figure 18), and an increase in the representation of western wheatgrass (26% increase in relative cover; Figure 18). Changes in representation of Japanese brome and western wheatgrass may be explained by the post-fire and drought conditions in 2006. Japanese brome is neither drought-resistant nor fire tolerant and may have been assisted in its invasion of northern mixed-grass prairies historically because of reductions in fire frequency (Whisenant 1985). Subsequently, fires and drought tend to benefit western wheatgrass by removing competition from Japanese brome (Haferkamp et al. 1997; Haferkamp et al. 1998). Whisenant (1985) found that spring burning significantly increased western wheatgrass tiller density during the first growing season after a fire while it significantly reduced the standing crop, tiller density, and seed production of Japanese brome. Gartner et al. (1978) also found that fall, winter, or spring burning successfully reduced Japanese brome densities for at least 2 years post-burn. The absence of the biennial forb yellow

sweetclover, a tall species that can easily outcompete species of smaller stature, may also have allowed western wheatgrass to become more dominant on the landscape in 2006.

Despite the differences in species composition that occurred on the study site between years, species of vegetation selected in greater proportion to their availability by nesting curlews remained similar. During both years, curlews selected nest sites in areas where American vetch, buffalograss, and junegrass represented a higher proportion of species composition than available at random points. The species selected represent a variety of native grass and forb species of short to moderate heights, ranging from an average height of 10 cm (buffalograss) to an average height of 45 cm (junegrass). Survival at nest sites dominated by junegrass and buffalograss was 100% during both 2005 and 2006. Conversely, nest survival was lowest at nest sites dominated by western wheatgrass. A species composition biased toward western wheatgrass in 2006 may have played a role in the reduced nest survival rate. However, the actual pathway by which these diverse species may affect nest survival, whether structural or otherwise, is unknown. The three species preferentially selected at nest sites consisted of a forb species and two native bunchgrass species. This preference differs from the Columbia basin, where curlews used nesting areas with a greater proportion of invasive cheatgrass than available (in which nest success was the highest and predation rate was the lowest) and generally avoided habitats dominated by dense forbs and native bunchgrasses (Pampush and Anthony 1993).

Trampling by livestock posed a significant threat to nests during both years of this study, accounting for 75% of nest failure in 2005 and 37% of nest failure in 2006. In

both 2005 and 2006, the risk of nest trampling appeared to be dependent on the density of livestock grazed in a pasture. This was supported by nest survival analyses that showed nest survival rates decreased with increasing bison densities. In 2005, nest-trampling began to occur at a density of 218 bison/km^2. In 2006, nest trampling occurred at a much lower density of around 77 bison/km^2. The reduction in vegetative cover observed on the ranch in 2006 may have increased the area needed by bison to meet their foraging requirements, and thus increased the risk of trampling at lower livestock densities. Historically, free-roaming bison herds most likely would have migrated out of a drought-affected area and thus naturally decreased the density of animals grazing that area (Heitschmidt et al. 1999). Because bison are confined by fences on the ranch, this prevented natural shifts away from drought-affected areas and may have held densities at an unnatural level for the amount of vegetation available.

Additionally, in 2006 nests were trampled by cattle at even lower densities than bison, at around 33 cattle/km^2. Differences in foraging ecology between bison and cattle may have resulted in cattle posing larger threats to nests at lower densities than bison. Cattle tend to be more selective foragers than bison and may spend more time searching for high-quality patches of forb cover (Peden et al. 1974; Plumb and Dodd 1993). In 2006 when the grass to forb ratio of vegetative cover and species composition was particularly high, cattle may have covered larger areas than bison to meet their foraging requirements and thus posed a greater threat to nests at lower densities. Personal observations on the study site also indicate that cattle may graze in more tightly packed herds, while bison distribute themselves more evenly across pastures. Tightly packed

herds of cattle that intersect nest sites may leave little chance of nest survival, while more loosely packed herds of bison may have a greater chance of avoiding nests.

Brood Survival and Brood-rearing Habitat

Maximizing nest success will neither increase nor sustain curlew populations if chicks produced from successful nests do not survive to reproduce. Very few chicks survived to fledge during both years of this study. In western Idaho, a majority of long-billed curlew chick mortality was due to predation by raptors (Redmond and Jenni 1986). Most chick mortality in this study was not directly observed because chicks were not radio-marked. However, many chicks may have fallen prey to avian predators such as short-eared owls (*Asio flammeus*) and northern harriers (*Circus cyaneus*), which were observed in large numbers on the study site, especially in 2005. Research in Idaho has also shown that lush vegetative cover may shift the diets of avian predators from small mammals to curlew chicks by providing more protection for small mammals (Redmond and Jenni 1986). Predation pressure may have been high due to dense vegetative cover on the ranch in 2005. Alternatively, the absence of open habitat may have hindered the movement of freshly hatched chicks and reduced their ability to feed.

In 2006, several chicks were found dead in or near the nest most likely due to heat prostration. This may have resulted from the lack of shade in combination with record high temperatures in 2006. Newly hatched bird chicks in general have poorly developed thermoregulatory systems (Myhre et al. 1975; Aulie 1976; Allen et al. 1977) and tend to be more vulnerable to extreme weather conditions (Flanders-Wanner et al. 2004). Extremely high temperatures in particular may negatively affect chick survival because it

takes a lower amount of heat energy to increase a chick's body temperature to lethal levels than an adult's (Calder 1974). An appropriate amount of vegetative cover may decrease the threat of high temperatures by decreasing the intensity of solar radiation as it passes through the plant canopy (Guthery 2002). High temperatures may also reduce the amount of time chicks can spend foraging by increasing the amount of time required for seeking shade (Ahlborn 1980).

During both years of this study, there was a large amount of chick mortality the first week after hatching followed by a relatively high percentage of remaining broods surviving to fledge. This suggests that there may be a threshold age past which chicks become less susceptible to mortality as they become more mobile and adept at escaping from predators and eventually become capable of flight. Previous studies on grassland-nesting bird species have shown that survival increases with brood age (Bergerud and Gratson 1988; Grant et al. 1999) most likely due to increases in thermoregulatory and flight capabilities (Aulie 1976).

When little open habitat was available in 2005, brood-rearing areas were located in habitats with vegetation similar to random points (59% grass cover, 33% forb cover, and an average VOR of 20 cm). In 2006, adults with broods used areas on gentle slopes with less grass cover, more bareground, and shorter, less dense vegetation than random points. Brood use of flat, open areas may increase mobility and prey acquisition. In the Columbia Basin, curlews with broods avoided dense forb habitat where mobility decreased due to the high mean vertical density (Pampush 1981). Curlew chicks are precocial and leave the nest only a few hours after hatching (Jenni e al. 1981) at which

point they are entirely responsible for obtaining food. Survival may depend greatly on curlew chicks acquiring enough prey to sustain energetic demands and any hinderance to movement may prevent them from acquiring the nutrients that they need to survive.

In 2005, adults selected brood-rearing areas in which sixweeks fescue, indianwheat, junegrass, and American vetch represented a greater proportion of species composition than at random points. Species selected represent a variety of native grass and forb species with varying height structures. The availability of both tall and short species of vegetation may be particularly important in habitats used by broods because chicks have a variety of requirements including shade, escape cover, and appropriate foraging areas. As discussed earlier, the availability of short species of vegetation (sixweeks fescue, indianwheat) may be particularly important to allow enough mobility so that chicks can acquire enough nutrients to meet their daily energetic requirements. However, on a number of occasions when investigators approached chicks during this study, chicks responded by crouching under patches of tall grass or forbs. Thus, patches of relatively taller vegetation (junegrass, vetch species) may provide important escape cover that helps chicks avoid predation. Patches of tall vegetation may also be an important source of shade during the hot summer months.

In 2006, the only species of vegetation brood-rearing adults selected more than available at random points were sun sedge and creeping spikerush. Additionally, they selected areas in which bareground and water made up a significantly higher percentage of composition than random points. Most of these characteristics are associated with wetlands or man-made stock ponds. In 2006, brood locations on average were

approximately 200 m closer to water than in 2005. Although this difference was not statistically significant between years, broods were often located close to stock ponds and their dams in 2006. Broods may have needed to stay closer to water in 2006 for thermoregulation and to meet daily water requirements due to the heat and drought.

Management and Research Recommendations

Density estimates from censuses conducted on the study site in 2006, suggest that the Triple U Buffalo Ranch supports a fairly large breeding population of long-billed curlews and is an important breeding area in South Dakota. However, curlew productivity was most likely low on the ranch during both years of this study due to low nest survival and brood survival rates. Management efforts should be focused on improving these survival probabilities in order to stabilize or increase long-billed curlew populations in South Dakota.

Because uncontrollable factors such as drought and wildfires appear to have a significant impact on curlew nest survival rates, it is important to maximize nesting success by manipulating other factors that *can* be controlled, such as grazing pressure. Livestock pose a significant trampling threat to nests during the nesting period. However, completely removing grazing pressure from nesting areas may have a negative impact on curlew abundance in an area and most likely is not feasible for private landowners. The density of curlews observed in April censuses on the ranch did not relate to the density of livestock being grazed in a pasture. Grazing history may affect the attractiveness of habitats more than current grazing regimes and unfortunately data on grazing history in pastures on the ranch were not available for analyses. However,

grazing livestock creates the short vegetative structure that data from this study suggests may attract curlews and increase foraging efficiency. Using grazing to create habitats with short vegetative structures may attract new breeders to traditional breeding areas as well as to new areas that may not have supported a breeding curlew population in the past

Instead of removing grazing pressure from an area, timing, density, and spatial distribution of grazing may be manipulated to maximize the attractiveness of habitats to curlews and minimize the threat of trampling. Based on earliest incubation dates and latest hatching dates of nests over both years of this study, reducing grazing pressure from 10 April to 25 June in pastures used by breeding curlews should considerably reduce the threat of nest trampling. This may require reducing livestock densities more for cattle (below 33 cattle/km^2) than for bison (below 220 bison/km^2) and reducing livestock densities more during years of drought or following a fire (below 77 bison/km^2) when the risk of nest trampling may be higher at lower livestock densities. Decreasing livestock densities during years of drought or following a fire will also prevent further reducing vegetative cover and increasing the already high risk of nest predation. Alternatively, bison may be shifted to pastures with steeper topography during the nesting period since curlews generally nest in flatter areas with a lower slope gradient. However, this may not be feasible for cattle because their movement has been found to be constrained by slope and vertical distance to water (Van Vuren 2001). More research investigating nest trampling should be conducted in order to identify specific density thresholds for different types of livestock.

Prescribed burning before the nesting period may also be used to create habitat with a short vegetative structure without the associated risk of nest trampling. However, possibly due to high nest site fidelity, curlew densities did not differ between burned and unburned pastures in 2006. Burning may also be less desirable than grazing treatments because it can create large homogeneous tracts with little vegetation and a considerable amount of bareground when followed by drought. This type of habitat may not provide the diverse cover requirements of curlew broods. Grazing livestock should create a patchier habitat structure than burning, and result in more appropriate habitat for the brood-rearing period.

The low egg hatchability observed during this study in 2005 when approximately 24% of eggs present at hatching time were inviable, may also pose a threat to the reproductive fitness of curlews breeding on the ranch. A similar phenomenon was observed in curlews nesting in alfalfa fields in Nevada. Inviable eggs collected in Nevada showed that eggshells were thinner than known to be historically (A. Hartman, University of Nevada-Reno, personal communication). It has been hypothesized that this thinning may be caused by chemicals ingested on wintering grounds in Mexico, where chemicals such as DDT (dichloro-diphenyl-trichloroethane) may still be in use. Egg samples from Nevada are currently undergoing ecotoxicological analyses to confirm whether or not chemicals are the cause of egg inviability. Ecotoxicological analyses of inviable eggs from South Dakota would provide valuable information that may provide support for or against this theory. Additionally, the use of platform terminal transmitters to track the migration of curlews breeding in South Dakota to a specific wintering area

would be critical in order to determine whether South Dakota breeders winter in Mexico or other areas where exposure to DDT may occur.

The wide variations in habitat conditions observed between the two years of this study are common occurrences in prairie ecosystems. Organisms, such as long-billed curlews, that use prairie habitats have evolved adaptations that allow them to persist in these unpredictable environments. The ability to produce a large number of energetically costly eggs during a single breeding season, as observed in 2006, may be one such adaptation. During years with extremely low nest survival probabilities, a female curlew's ability to produce multiple clutches may be important in increasing the chance of recruiting chicks into the population. Birds use both endogenous and exogenous sources of fat and protein during egg production (Blem 1980) and the importance of these different sources varies among bird species. Research on the energetics of egg production in long-billed curlews should be conducted in order to determine the relative importance of both endogenous and exogenous resources in supporting egg production. This research would help identify the geographic areas and habitat types that are most important for providing these resources. These may include habitats on wintering and breeding areas as well as important stopover sites along migration routes. Research on energetics may also provide insight into the early departure of female curlews observed both in previous studies (Dugger and Dugger 2002) and during this study. Female curlews that have exhausted most of their energetic reserves may abandon broods early to dedicate more time to foraging activities and to migrate to wintering areas where prey species have higher energetic rewards.

Brood survival was low during both years of this study, and management should focus on creating habitat that provides all of the essential components required for a chick to survive to fledging. This may require focusing on chick requirements within the first week after hatching when a majority of mortality occurs. Brood-rearing home ranges were fairly small during this study (0.52 km^2-4.8 km^2), suggesting that these requirements may need to be provided within close proximity to one another. In general, habitat with a diverse community of native graminoid and forb species should provide high quality brood-rearing areas. However, native habitats that are not grazed by livestock may allow vegetation to become too dense to allow proper mobility and foraging. Conversely, areas that are grazed too extensively may not provide important escape cover and shade. Moderate stocking densities should create habitats with patchy vertical distributions that provide all of these essential requirements and help increase the probability of chick survival.

LITERATURE CITED

Ahlborn, G.G. 1980. Brood-rearing habitat and fall-winter movements of lesser prairie chickens in eastern New Mexico. M.S. Thesis, New Mexico State University, Las Cruces, NM.

Akaike, H. 1973. Information theory as an extension of the maximum likelihood principle. Pages 267-281 in B.N. Petrov and F. Csaki, editors. Second International Symposium on Information Theory. Akademiai Kiado, Budapest, Hungary.

Allen, H.H., C. Boggs, E. Norris, and M. Doering. 1977. Parental behavior of captive willow grouse *Lagopus l. lagopus*. Ornis Scandinavica 8:175-183.

Allen, J.N. 1980. The ecology and behavior of the long-billed curlew in southeastern Washington. Wildlife Monographs 73:1-67.

American Ornithologist's Union (AOU). 1983. Check-list of North American birds, 6th edition. Washington DC.

Aulie, A. 1976. The pectoral muscles and the development of thermoregulation in chicks of willow ptarmigran (*Lagopus lagopus*). Comparative Biochemistry and Physiology 53A:343-346.

Bergerud, A.T., and M.W. Gratson. 1988. Adaptive strategies and population ecology of northern grouse. Volume 2. University of Minnesota, Minneapolis, MN.

Bicak, T.K., R.L. Redmond, and D.A. Jenni. 1982. Effects of grazing on long-billed curlew (*Numenius americanus*) breeding behavior and ecology in southwestern Idaho. Proceedings of the Wildlife-stock Relationships Symposium. University of Idaho Forest, Wildlife and Range Experiment Station.

Blem, C.R. 1990. Avian energy storage. Current Ornithology 7:59-114.

Borchers, G.A. 1980. Soil Survey of Stanley County, South Dakota. U.S. Department of Agriculture, Soil Conservation Service, Forest Service and U.S. Department of the Interior, Bureau of Indian Affairs and South Dakota Agricultural Experiment Station. Washington D.C.

Brockway, J.M., and J.A. Gessaman. 1977. The energy costs of locomotion on the level and on the gradients for the red deer (*Cervus elaphus*). Quarterly Journal of Experimental Physiology 62:333-339.

Brown, S., C. Hickey, and B. Harrington. 2001. United States Shorebird Conservation Plan. Manomet Center for Conservation Sciences, Manomet, MA.

Buckland, S.T., Anderson, D.R., Burnham, K.P. and Laake, J.L. 1993. Distance Sampling: Estimating Abundance of Biological Populations. Chapman and Hall, London, reprinted 1999 by RUWPA, University of St. Andrews, Scotland.

Burnham, K.P., and D.R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York, NY.

Burnham, K.P., and D.R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, NY.

Calder, W.A. 1974. Consequences of body size for avian energetics. Publications of the Nuttall Ornithilogical Club 15:86-151.

Cannings, R.J. 1999. Status of the long-billed curlew in British Columbia. Wildlife Working Report No. WR-96.

Capinera, J.L., and T.S. Sechrist. 1982. Grasshoppers (Acrididae) of Colorado; Identification, Biology and Management. Colorado State University Agriculture Experimental Station Bulletin 584S.

Clapperton, J.L. 1964. The energy metabolism of sheep walking on the level and on gradients. British Journal of Nutrition 18:47-54.

Cochran, J.F., and S.H. Anderson. 1987. Comparison of habitat attributes at sites of stable and declining long-billed curlew populations. Great Basin Naturalist 47:459-466.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-64.

De Smet, K.D. 1992. Status report on the long-billed curlew *Numenius americanus* in Canada. Communications on the Status of Endangered Wildlife in Canada.

Dugger, B.D., and K.M. Dugger. 2002. Long-billed curlew (*Numenius americanus*). *In* The Birds of North America, No. 628 (A. Poole and F. Gill, editors). The Birds of North America, Inc., Philadelphia, PA.

Fielding, D.J., and M.A. Brusven. 1995. Grasshopper densities on grazed and ungrazed rangeland under drought conditions in southern Idaho. Great Basin Naturalist 55:352-358.

Flanders-Wanner, B.L., G.C. White, and L.L. McDaniel. 2004. Weather and prairie grouse: dealing with effects beyond our control. Wildlife Society Bulletin 32:22-34.

Forsythe, D.M. 1972. Observations on the nesting biology of the long-billed curlew. Great Basin Naturalist 32:88-90.

Gartner, R.G., R.I. Butterfield, W.W. Thompson and L.R. Roath. 1978. Prescribed burning of range ecosystems in South Dakota. International Rangeland Congress 1:687-690.

Gill, F.B. 1995. Ornithology. 2nd edition. W.H. Freeman and Co., New York, NY.

Grant, M.C., C. Orsman, J. Easton, C. Lodge, M. Smith, G. Thompson, S. Rodwell, and N. Moore. 1999. Breeding success and causes of breeding failure of curlew (*Numenius arquata*) in northern Ireland. Applied Ecology 36:59-74.

Guthery, F.S. 2002. The technology of bobwhite management: theory behind the practice. Iowa State University, Ames, IA.

Haferkamp, M.R., R.K. Heitschmidt, and M.G. Karl. 1997. Influence of Japanese brome on western wheatgrass yield. Journal of Range Management 50:44-50.

Haferkamp, M.R., R.K. Heitschmidt, and M.G. Karl. 1998. Clipping and Japanese brome reduce western wheatgrass standing crop. Journal of Range Management 51:692-698.

Hartnett, D.C., A.A. Steuter, and K.R. Hickman. 1997. Comparative ecology of native and introduced ungulates. Pages 72-101 in F. Knopf and F. Sampson, editors. Ecology and conservation of Great Plains vertebrates. Springer, New York, NY.

Hartnett, D.C. and P.A. Fay. 1998. Plant populations: patterns and processes. Pages 81-100 in A.K. Knapp, J.M. Briggs, D.C. Hartnett and S.L. Collins, editors. Grassland Dynamics: long-term ecological research in tallgrass prairie. Oxford University Press, New York.

Heitschmidt R.K., M.R. Haferkamp, M.G. Karl, and A.L. Hild. 1999. Drought and grazing: I. Effects on quantity of forage produced. Journal of Range Management. 52:440-446.

High Plains Regional Climate Center (HPRCC). 2006. Historical Climate Summaries. http://www.hprcc.unl.edu/ (VERSION 23OCT2006).

Jenni, D.A., R.L. Redmond, and T.K. Bicak. 1981. Behavioral ecology and habitat relationships of long-billed curlew in western Idaho. Department of the Interior, Bureau of Land Management, Boise District, Idaho.

Johnson, J.R. and G.E. Larson. 1999. Grassland Plants of South Dakota and the Northern Great Plains. South Dakota State University College of Agriculture and Biological Sciences, South Dakota Agricultural Experiment Station, Brookings, SD.

King, R. 1978. Habitat use and related behaviors of breeding long-billed curlews. M.S. thesis, Colorado State University, Fort Collins, CO.

Leeman, T.S. 2000. Importance of coastal pastures to long-billed curlews (*Numenius americanus*). M.S. thesis, Humboldt State University, Arcata, CA.

Liebezeit, J.R., P.A. Smith, R.B. Lanctot, H. Schekkerman, I. Tulp, S.J. Kendall, D.M. Tracy, R.J. Rodrigues, H. Meltofte, J.A. Robinson, C. Gratto-Trevor, B.J. McCaffery, J. Morse, and S.W. Zack. In press. Assessing the development of shorebird eggs using the flotation method: species-specific and generalized regression models. Condor 109.

Matlack, R.S., D.W. Kaufman, and G.A. Kaufman. 2001. Influence of grazing by bison and cattle on deer mice in burned tallgrass prairie. American Midland Naturalist 146:361-368.

Mayfield, H.F. 1975. Suggestions for calculating nest success. The Wilson Bulletin 87:456-466.

McHugh, T. 1972. The time of the buffalo. University of Nebraska Press, Lincoln.

Myhre, K., M. Cabanac, and G. Myhre. 1975. Thermoregulatory behavior and body temperature in chicks of willow grouse (*Lagopus Lagopus Lagopus*). Poultry Science 54:1174-1179.

National Climate Data Center (NCDC). 2006. NCDC climate data online. http://www.ncdc.noaa.gov. (VERSION 25SEPT2006).

Ohanjanian, I.A. 1992. Numbers, distribution and habitat dynamics of long-billed curlews in the East Kootenay. Wildlife Branch, BC Environ., Cranbrook, BC.

Pampush, G.J. 1981. Breeding Chronology, habitat utilization, and nest-site selection of the long-billed curlew in north-central Oregon. M.S. Thesis, Oregon State University, Corvallis, OR.

Pampush, G.J., and R.G. Anthony. 1993. Nest success, habitat utilization, and nest-site selection of long-billed curlews in the Columbia Basin, Oregon. Condor 95:957-967.

Parker, K.L., C.T. Robbins, and T.A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management 48:474-488.

Paton, P.W., and J. Dalton. 1994. Breeding ecology of long-billed curlews at Great Salt Lake, Utah. Great Basin Naturalist 54:79-85.

Peden, D.G., G.M. Van Dyne, R.W. Rice, and R.M. Hansen. 1974. The trophic ecology of *Bison bison* L. on shortgrass plains. The Journal of Applied Ecology 11:489-497.

Plumb, G.E., and J.L. Dodd. 1993. Foraging ecology of bison and cattle on a mixed-grass prairie: implications for natural area management. Ecological Applications 3:631-643.

Redmond, R.L. 1984. The behavioral ecology of long-billed curlews (*Numenius americanus*) breeding in Western Idaho. Ph.D. dissertation, University of Montana, Missoula, MT.

Redmond, R.L. and D.A. Jenni. 1985. Note on the diet of long-billed curlew chicks in western Idaho. Great Basin Naturalist 45:85-86.

Redmond, R.L., and D.A. Jenni 1986. Population ecology of the long-billed curlew (*N. americanus*) in W. Idaho. The Auk 103: 755-767.

Robel, R., J. Briggs, A. Dayton, and L. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management 23:295-297.

Rodgers, A.R., and A.P. Carr. 1998. HRE: The home range extension for Arc View. Users manual. Beta Test Version 0.9, July 1998. Centre for Northern Ecosystem Research, Ontario Ministry of Natural Resources, Thunder Bay, Ontario, Canada.

Rohrbaugh Jr., R.W., D.L. Reinking, D.H. Wolfe, S.K. Sherrod, and M.A. Jenkins. 1999. Effects of prescribed burning and grazing on nesting and reproductive success of three grassland passerine species in tallgrass prairie. Studies in Avian Biology 19:165-170.

Sargeant, A.B., M.A. Sovada, and R.J. Greenwood. 1998. Interpreting evidence of depredation of duck nests in the prairie pothole region. U.S. Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, ND and Ducks Unlimited, Inc., Memphis, TN.

Sauer, J.R., B.G. Peterjohn, S. Schwartz, and J.E. Hines. 1995. The Grassland Bird Home Page. Version 95.0. Patuxent Wildlife Research Center, Laurel, MD.

Seaman, D.E., J.J. Millspaugh, B.J. Kernohan, G.C. Brundige, K.J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimate. Journal of Wildlife Management 63:739-747.

Smith, V.J., J.A. Jenks, C.R. Berry, Jr., C.J. Kopplin, and D.M. Fecske. 2002. The South Dakota Gap Analysis Project. Final Report. Research Work Order No. 65. Department of Wildlife and Fisheries Sciences, South Dakota State University, Brookings, South Dakota.

South Dakota Game, Fish and Parks (SDGFP). 2006. Rare, threatened, or endangered animals. South Dakota Natural Heritage Program. http://www.sdgfp.info/wildlife/Diversity/RareAnimal.htm. (Version 17JAN2006).

Sugden, J.W. 1933. Range restriction of the long-billed curlew. The Condor 35:3-9.

Tallman, D.A., D.L. Swanson, and J.S. Palmer. 2002. Birds of South Dakota. 3rd ed. The South Dakota Ornithologist's Union, Aberdeen, SD.

Timken, R.L. 1969. Notes on the long-billed curlew. Auk 86:750-751.

U.S. Fish and Wildlife Service (USFWS). 2002. Birds of conservation concern 2002. Division of Migratory Bird Management, Arlington, VA.

Van Vuren, D.H. 2001. Spatial relations of American bison (*Bison bison*) and domestic cattle in a montane environment. Animal Biodiversity and Conservation 24:117-124.

Whisenant, S.G. 1985. Effects of fire and/or atrazine on Japanese brome and western wheatgrass. Western Society of Weed Science Proceedings 38:169-176.

White, G.C., and K.P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study Supplement 46:120-139.

Yocom, C.F. 1956. Re-establishment of breeding populations of long-billed curlews in southeastern Washington. Wilson Bulletin 68:228-231.

Table 1. Mean clutch sizes and nesting chronology of long-billed curlew nests located in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota.

Year	**Nest Attempt**	**Clutch Size (range)**	**Incubation Date (range)**	**Hatch Date (range)**
2005	All	3.60 (2-4) n=15	1 May (23 April-12 May) n=11	27 May (20 May-8 June) n=11
	2	3.00 n=1	6 June n=1	NA
	3	None	NA	NA
2006	All	4.08 (4-5) n=26	11 May (13 April-3 June) n=29	3 June (17 May-23 June) n=5
	2	4.25 (4-5) n=4	21 May (7 May-28 June) n=6	NA
	3	4 (4-4) n=2	30 May (25 May-3 June) n=2	NA

Table 2. Bison densities in pastures containing long-billed curlew nests located in 2005 on the Triple U Buffalo Ranch, Stanley County, South Dakota. "N" indicates that nests were not trampled in the corresponding pasture; "Y" indicates that nests were trampled in the corresponding pasture.

Pasture (Area km^2)	**Nests Trampled**	**Bison/km^2**
Butte (10.6)	N	0
NOB (3.1)	N	0
Big L (3.6)	N	0
Cooley (18.6)	N	82.45
Triangle (4.0)	Y	217.50
Geyor (3.9)	Y	223.08

Table 3. Bison and cattle densities in pastures containing long-billed curlew nests located in 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. "N" indicates that nests were not trampled in the corresponding pasture by the type of livestock specified; "Y" indicates that nests were trampled in the corresponding pasture by the type of livestock specified.

Pasture (Area km^2)	**Nests Trampled by bison**	**Bison/km^2**	**Nests trampled by cattle**	**Cattle/km^2**
Triangle (4.0)	N	0	N	0
E. Road (1.8)	N	0	N	0
S. Creek (4.0)	N	0	N	0
Six Section (7.7)	N	0	Y	32.64
Big L (3.6)	N	0	Y	42.25
Dairy Cattle (0.5)	N	0	N	9.8
W. Road (0.6)	N	0	N	0
Cooley (18.6)	N	10.74	N	0
NOB (3.1)	N	42.35	N	0
Geyor (3.9)	Y	76.92	N	0
House (6.2)	Y	81.04	N	0
Butte (10.6)	Y	94.07	N	0

Table 4. Evaluation of daily survival rate (DSR) models using Akaike's Information Criterion corrected for a small sample size (AICc) for long-billed curlew nests located in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. [a]

Models	**No. of parameters**	**AICc**	**ΔAICc**	**AICc weight**
S(species)	3	159.48	0.00	0.27191
S(species+cover type)	5	160.35	0.86	0.17663
S(species+bison)	4	160.39	0.90	0.17300
S(species+VOR)	4	161.52	2.04	0.09827
S(species+bison+VOR+ cover type)	6	162.01	2.53	0.07682
S(species+bison+cover type)	6	162.05	2.57	0.07528
S(species+VOR+cover type)	6	162.35	2.87	0.06479
S(species+bison+VOR)	5	162.44	2.95	0.06217
S(bison+VOR)	3	173.40	13.92	0.00026
S(bison+VOR+cover type)	5	174.47	14.99	0.00015
S(bison)	2	174.64	15.16	0.00014
S(VOR+cover type)	4	174.79	15.30	0.00013
S(bison+cover type)	4	174.96	15.47	0.00012
S(VOR)	2	175.12	15.63	0.00011
S(cover type)	3	176.21	16.73	0.00006
Constant DSR	1	176.95	17.47	0.00004

Table 4. Continued.

Models	**No. of parameters**	**AICc**	**ΔAICc**	**AICc weight**
S(year)	2	177.84	18.36	0.00003
S(renest)	2	178.59	19.10	0.00002
S(totcover)	2	178.68	19.20	0.00002

[a] Abbreviations: dependent variable S=daily survival probabilities; DSR=daily survival rate; species=dominant species of vegetation at nest site; cover type=dominant type of cover at nest site; VOR=average visual obstruction reading at nest site; totcover=total vegetative cover at nest site; grazed=presence or absence of bison in nesting pasture; bison=bison density in nesting pasture; year=year of nest location; renest=renesting status.

Table 5. Variable weights and daily survival rates (DSR) with associated 95% confidence intervals for categorical variables from the set of "best models" used to explain variation in daily survival rates of long-billed curlew nests located in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota.[a]

Variable	**Variable weight**	**Category**	**DSR**	**Lower 95% CI**	**Upper 95% CI**
Species	0.99	clov	1.00	1.00	1.00
		june	1.00	1.00	1.00
		gng	1.00	1.00	1.00
		buff	1.00	1.00	1.00
		jbr	0.92	0.82	0.97
		whtgrs	0.90	0.86	0.94
Cover type	0.39	forb	0.98	0.87	0.99
		bg	0.95	0.91	0.97
		grass	0.91	0.86	0.94

[a] Abbreviations: Nest sites dominated by clov=yellow sweetclover; june=junegrass; gng=green needlegrass; buff=buffalograss; jbr=Japanese brome; whtgrs=western wheatgrass; forb=forb cover; grass=grass cover; bg=bareground.

Table 6. Variable weights and β-values with associated 95% confidence intervals for continuous variables from the set of "best models" used to explain variation in daily survival rates of long-billed curlew nests located in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota.[a]

Variable	**Variable weight**	**β**	**Lower 95% CI**	**Upper 95% CI**
Bison	0.39	-1.29	-2.42	-0.15
VOR	0.30	6.45	-1.99	14.89

[a] Abbreviations: bison=density of bison in nesting pasture; VOR=average visual obstruction reading at nest site

Table 7. Average heights of forb species representing at least 1% composition of the vegetation at nest sites, brood points, or random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. "+" indicates the species was used in a proportion greater than availability; "-" indicates the species was used in a proportion lower than availability; "0" indicates no difference between use and availability.

Species	**Average height (cm)**	**Duration**	**Nest sites**	**Brood locations**
Scarlet globemallow (*Sphaeralcea coccinea*)	20	Perennial	0 (2005) + (2006)	0 (2005) 0 (2006)
Indianwheat (*Plantago patagonica*)	< 25	Annual	0 (2005) 0 (2006)	+ (2005) 0 (2006)
Desert biscuitroot (*Lomatium foeniculaceum*)	<28	Perennial	0 (2005) 0 (2006)	0 (2005) 0 (2006)
Scarlet gaura (*Gaura coccinea*)	30	Perennial	0 (2005) 0 (2006)	0 (2005) 0 (2006)
Field pennycress (*Thlaspi arvense*)	31	Annual	0 (2005) 0 (2006)	0 (2005) 0 (2006)
American vetch (*Vicia americana*)	38	Perennial	+ (2005) + (2006)	+ (2005) 0 (2006)
Silverleaf scurfpea (*Psoralea argophylla*)	46	Perennial	0 (2005) 0 (2006)	0 (2005) 0 (2006)
Common yarrow (*Achillea millefolium*)	51	Perennial	0 (2005) 0 (2006)	0 (2005) 0 (2006)
Goatsbeard (*Tragopogon dubius*)	53	Biennial	0 (2005) 0 (2006)	0 (2005) 0 (2006)
Yellow sweetclover (*Melilotus officinalis*)	107	Biennial	0 (2005) 0 (2006)	0 (2005) 0 (2006)

Table 8. Average heights of graminoid species representing at least 1% composition of the vegetation at nest sites, brood points, or random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. "+" indicates the species was used in a proportion greater than availability; "-" indicates the species was used in a proportion lower than availability; "0" indicates no difference between use and availabilty.

Species	**Average height (cm)**	**Duration**	**Nest**	**Brood**
Buffalograss (*Buchloe dactyloides*)	10	Perennial	+ (2005) + (2006)	0 (2005) 0 (2006)
Sixweeks fescue (*Vulpia octoflora*)	10	Annual	0 (2005) 0 (2006)	+ (2005) 0 (2006)
Sun sedge (*Carex inops*)	18	Perennial	0 (2005) 0 (2005)	0 (2005) + (2006)
Western wheatgrass (*Elymus smithii*)	45	Perennial	0 (2005) 0 (2006)	0 (2005) 0 (2006)
Junegrass (*Koeleria macrantha*)	45	Perennial	+ (2005) + (2006)	+ (2005) 0 (2006)
Creeping spikerush (*Eleocharis palustris*)	51	Perennial	0 (2005) 0 (2006)	0 (2005) + (2006)
Japanese brome (*Bromus japonicus*)	55	Annual	0 (2005) 0 (2006)	0 (2005) 0 (2006)
Needleandthread (*Hesperostipa comata*)	61	Perennial	0 (2005) - (2006)	0 (2005) 0 (2006)
Kentucky bluegrass (*Poa pratensis*)	65	Perennial	0 (2005) 0 (2006)	0 (2005) 0 (2006)
Green needlegrass (*Nassella viridula*)	80	Perennial	0 (2005) 0 (2006)	0 (2005) 0 (2006)

Table 9. Abiotic factors representing at least 1% composition at nest sites, brood points, or random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. "+" indicates the factor was used in a proportion greater than availability; "-" indicates the factor was used in a proportion lower than availability; "0" indicates no difference between use and availability.

Abiotic factor	**Nest**	**Brood**
Water	0 (2005) 0 (2006)	0 (2005) + (2006)
Bareground	0 (2005) 0 (2006)	0 (2005) + (2006)

Table 10. Mean habitat measurements taken at long-billed curlew nest sites and brood location points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota.[a]

	Type	VOR (cm)	%G	%B	%F	%S	Distance to Water(m)	Slope (deg.)	Distance to Manure(m)
2005	Nest	27.01	55.05	8.50	46.86	0	452.99	3.83	0.08
	Brood	20.29	59.36	16.06	32.62	1.09	502.32	4.22	NA
2006	Nest	10.19	45.59	36.22	10.75	0.03	377.55	4.77	0.38
	Brood	10.36	34.59	53.17	5.32	0.11	309.71	4.01	NA

[a] Abbreviations: VOR=visual obstruction reading, G=grass cover; B=baregound; F=forb cover; S=shrub cover.

Table 11. Estimates of Mayfield (1975) nest success from long-billed curlew studies conducted in Wyoming, Idaho, and Oregon compared to nest success estimates in 2005 and 2006 for curlews breeding on the Triple U Buffalo Ranch, Stanley County, South Dakota.

State	Nest Success	Paper
South Dakota	0.39 (2005) 0.15 (2006)	Current study
Wyoming	0.37	Cochran & Anderson 1987
Idaho	0.39-0.41	Redmond 1984
Oregon	0.65-0.69	Pampush & Anthony 1993

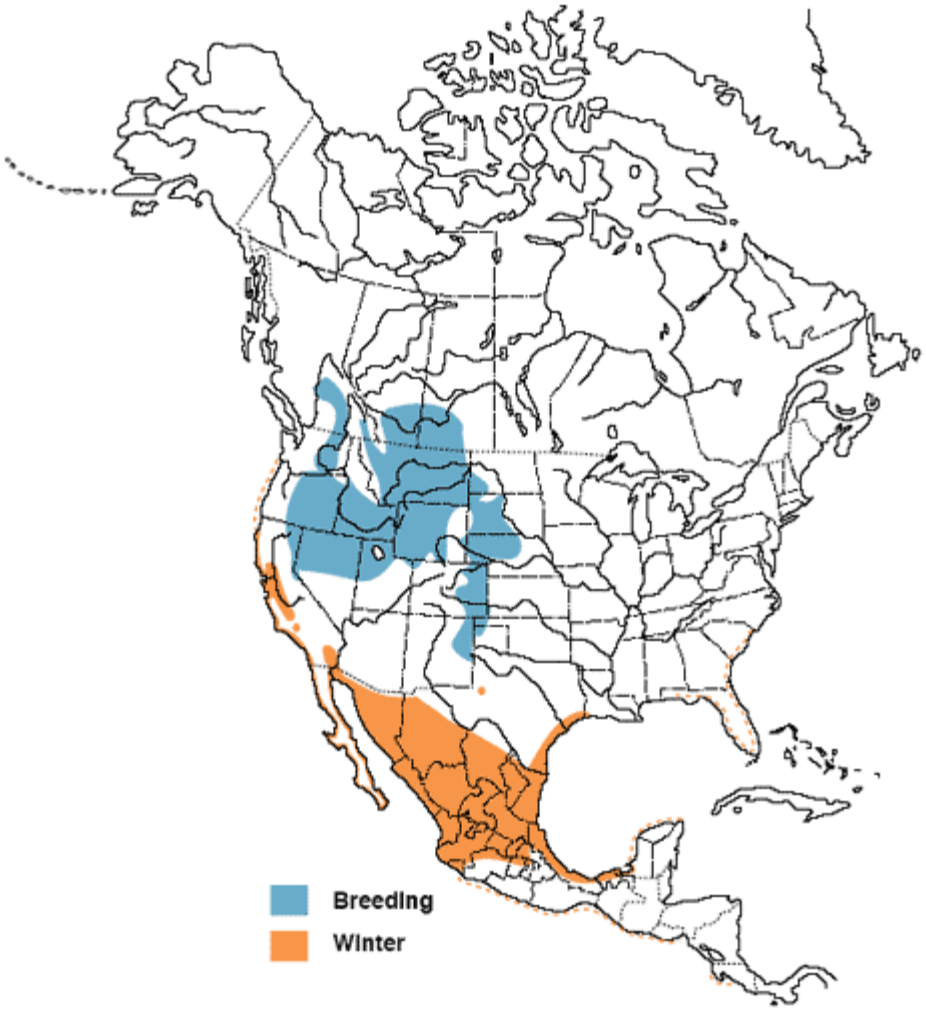

Figure 1. Current breeding and wintering distributions of the long-billed curlew in North America. Source: Dugger and Dugger 2002.

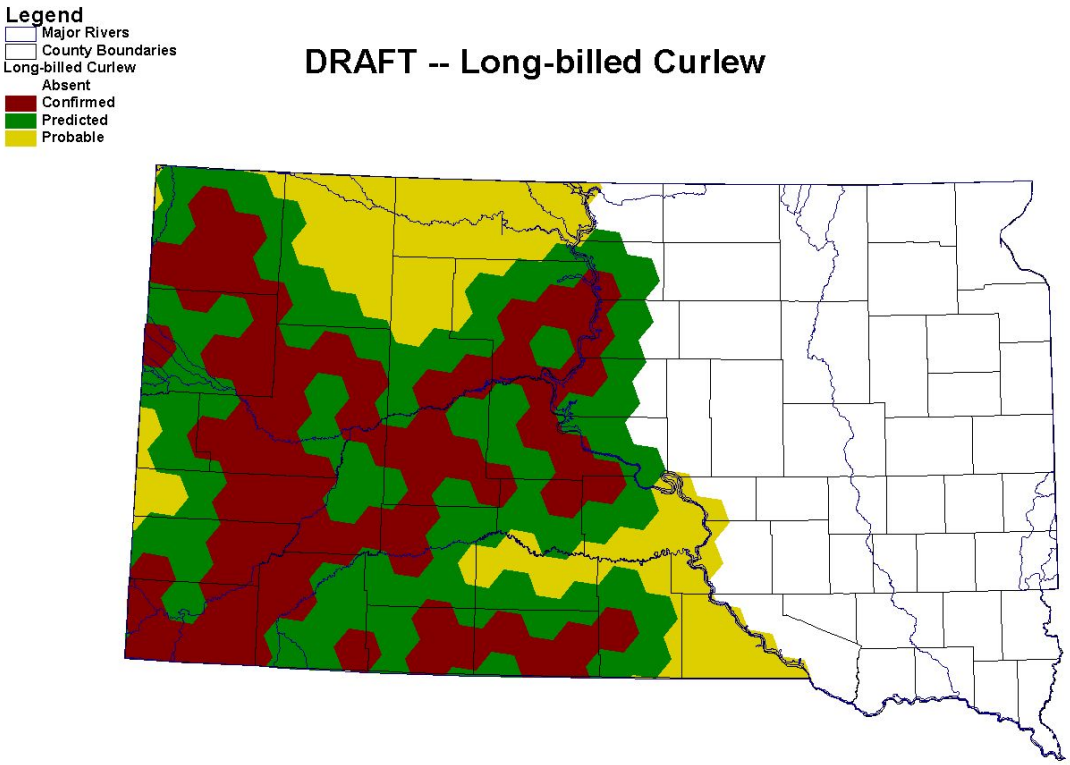

Figure 2. South Dakota Gap Analysis draft for the breeding distribution of long-billed curlews in South Dakota. The map was constructed using known distributions (shown in red) and predicted distribution models (shown in yellow) based on wildlife-habitat relationships. Source: Smith et al. 2002.

A.

B.

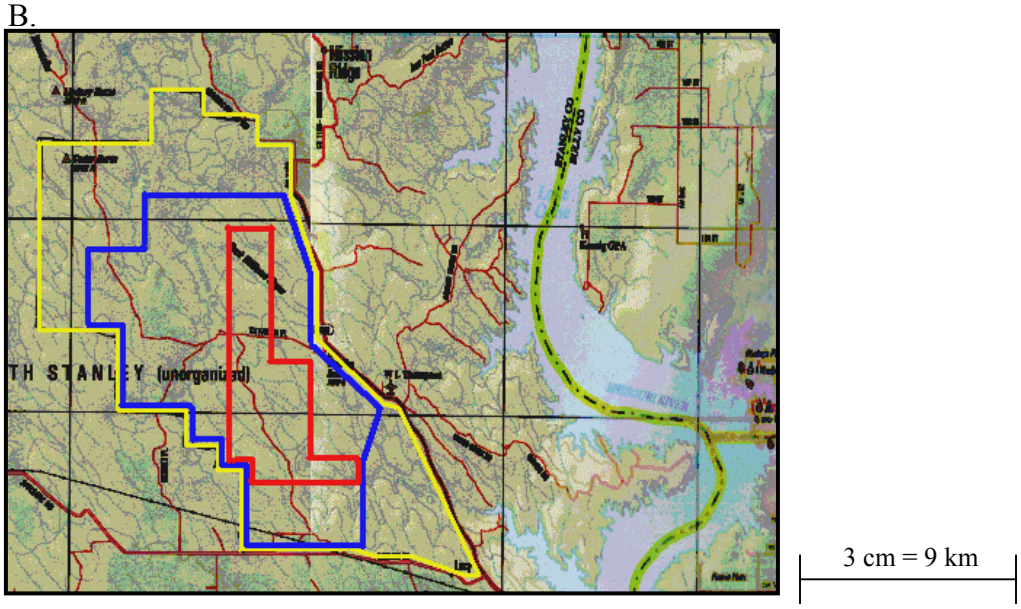

Figure 3. A. Location of the Triple U Buffalo Ranch in Stanley County, South Dakota. B. Perimeters of the Triple U Buffalo Ranch (shown in yellow), the core area of the study site (shown in blue), and the area of the study site burned in fall 2005 (shown in red).

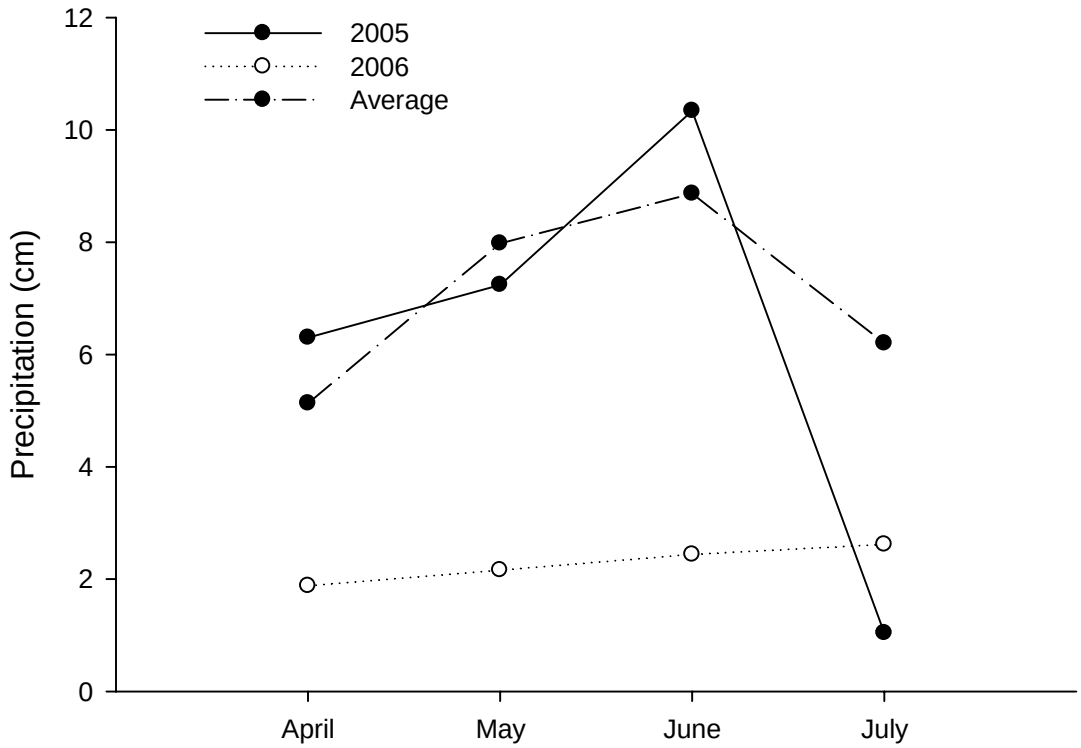

Figure 4. Average total precipitation in April-July from 1948-2005 compared to total precipitation in April-July for 2005 and 2006 in Pierre, South Dakota.
Data sources: HPRCC 2006 and NCDC 2006.

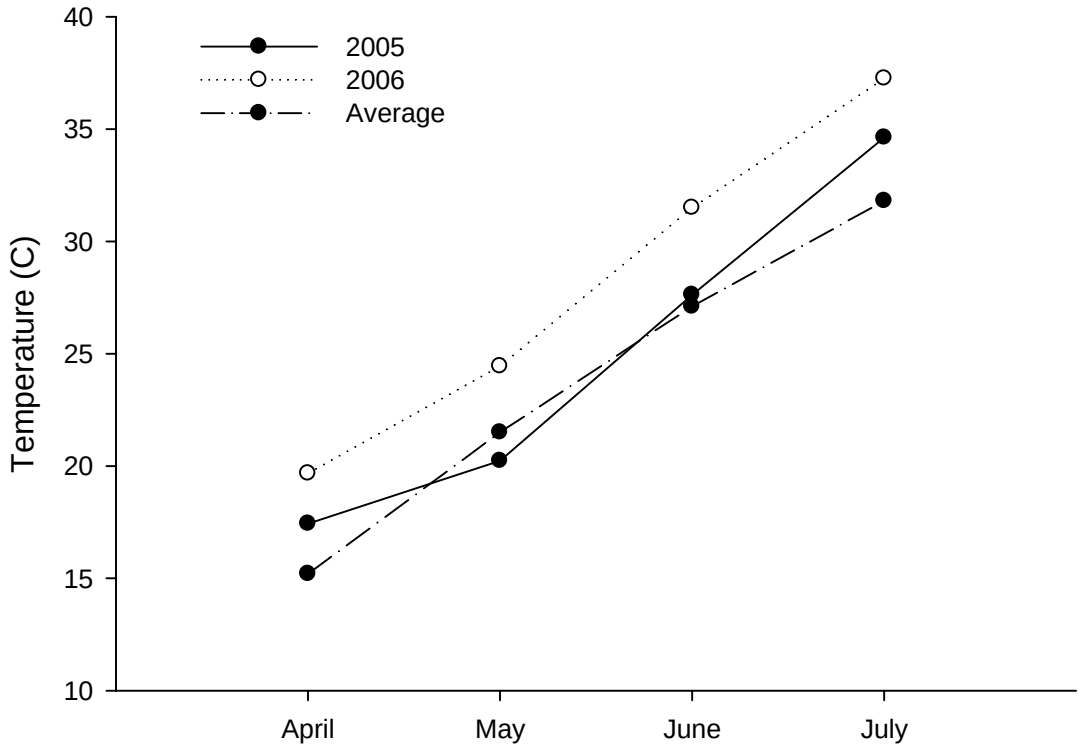

Figure 5. Average maximum temperatures in April-July from 1948-2005 compared to maximum temperatures in April-July for 2005 and 2006 in Pierre, SD.
Data sources: HPRCC 2006 and NCDC 2006.

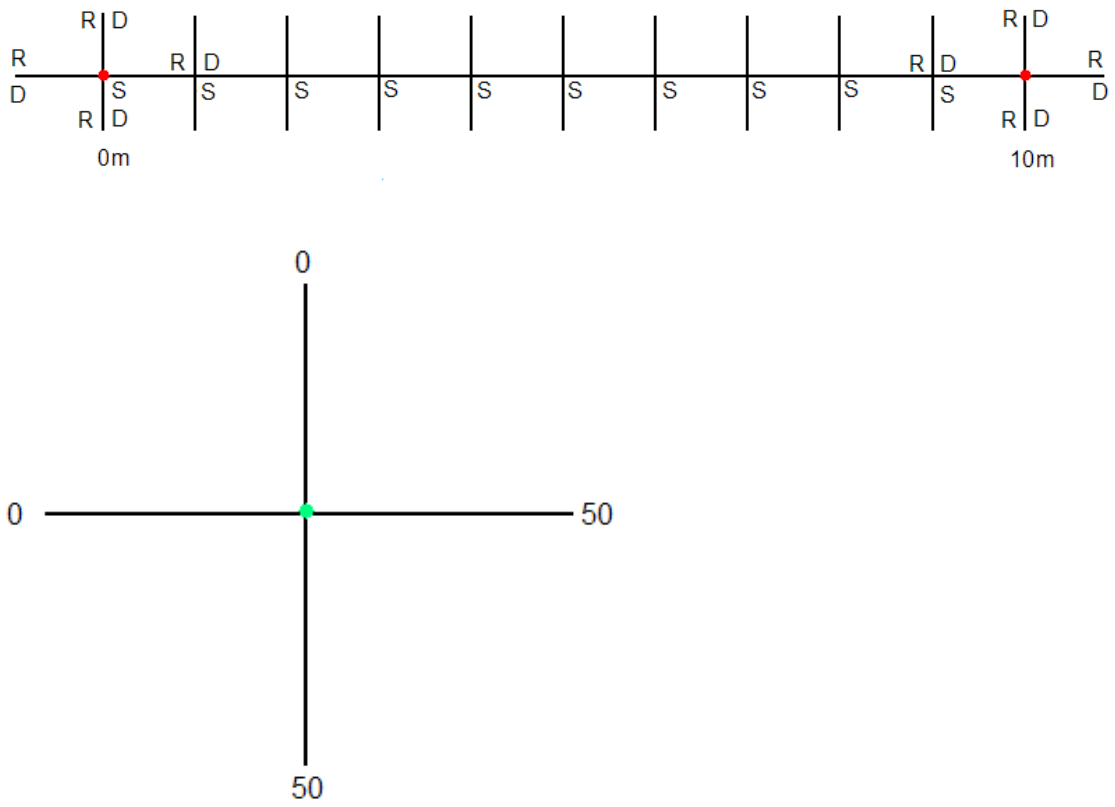

Figure 6. Ten-meter subsection of 50-m transects used for sampling habitats at nest sites, brood points, and random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Measurements taken along transects included Robel (1970) visual obstruction readings (R), Daubenmire (1959) plots (D), and species composition of the vegetation (S).

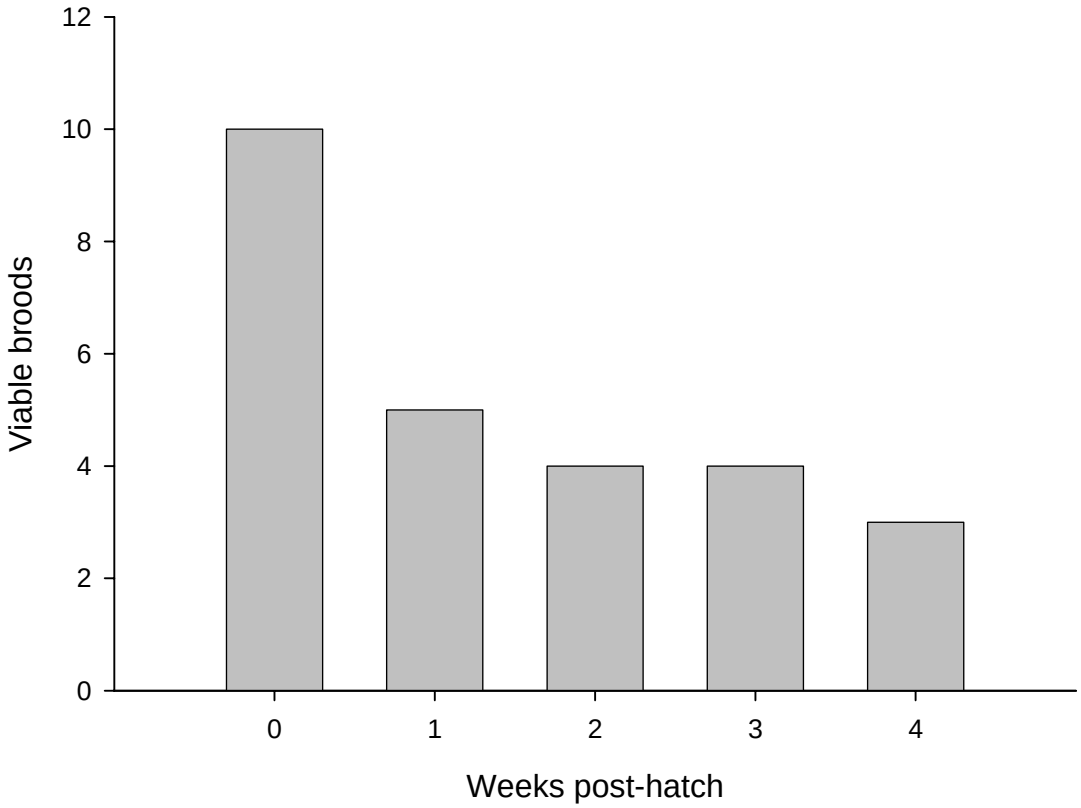

Figure 7. Number of viable long-billed curlew broods (broods with at least 1 viable chick) with radio-marked adults 0-4 weeks after hatching in 2005 on the Triple U Buffalo Ranch, Stanley County, South Dakota.

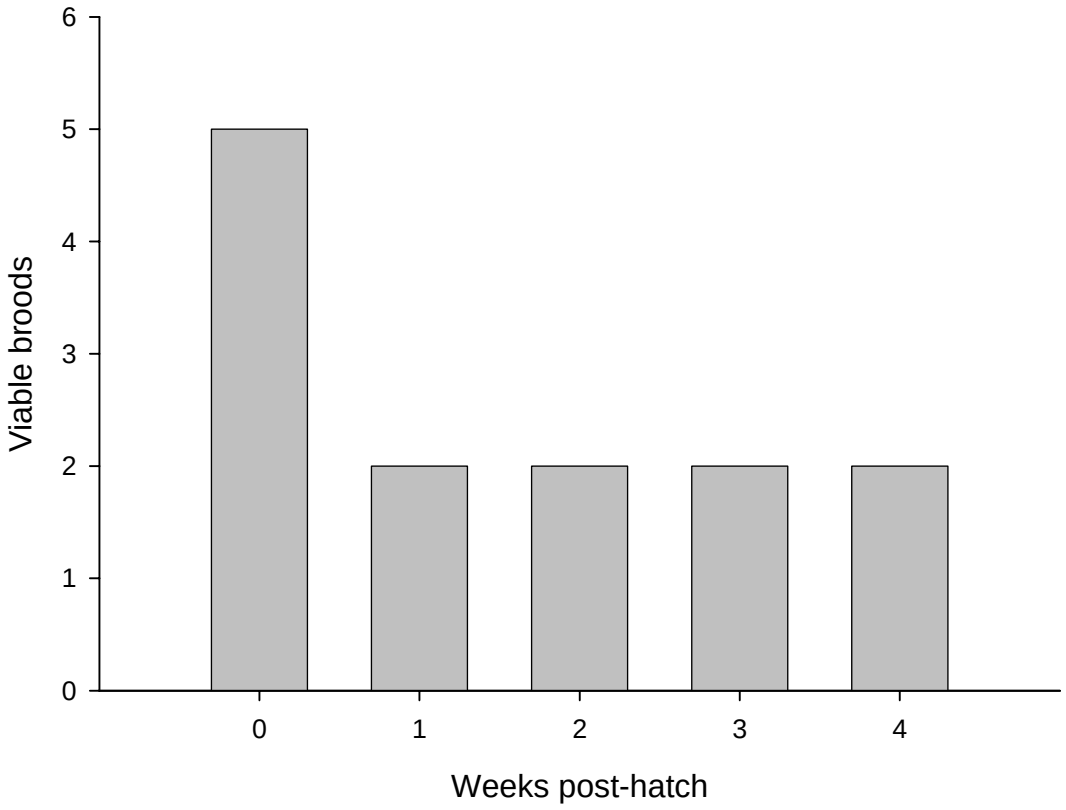

Figure 8. Number of viable long-billed curlew broods (broods with at least 1 viable chick) with radio-marked adults 0-4 weeks after hatching in 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota.

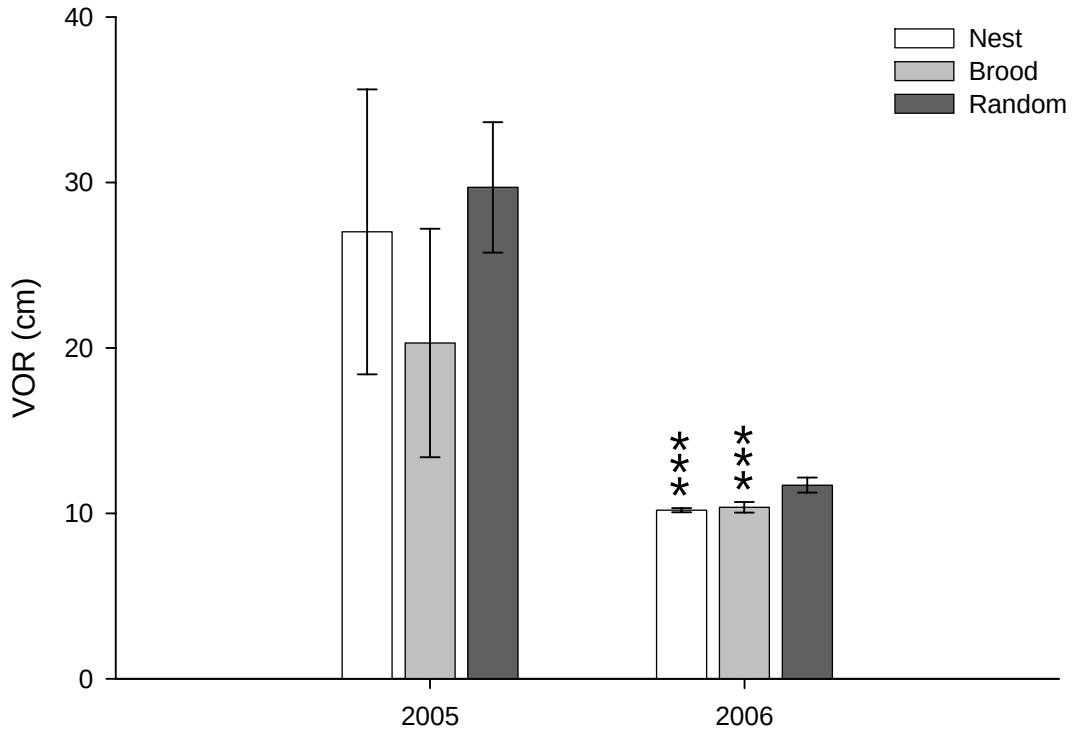

Figure 9. Mean visual obstruction readings (VOR) with 95% confidence intervals taken at nest sites, brood points, and random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. VOR measurements were taken using a decimeter scale and converted to a centimeter scale. Asterisks (*) indicate that nest sites or brood points were significantly different from random points at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.

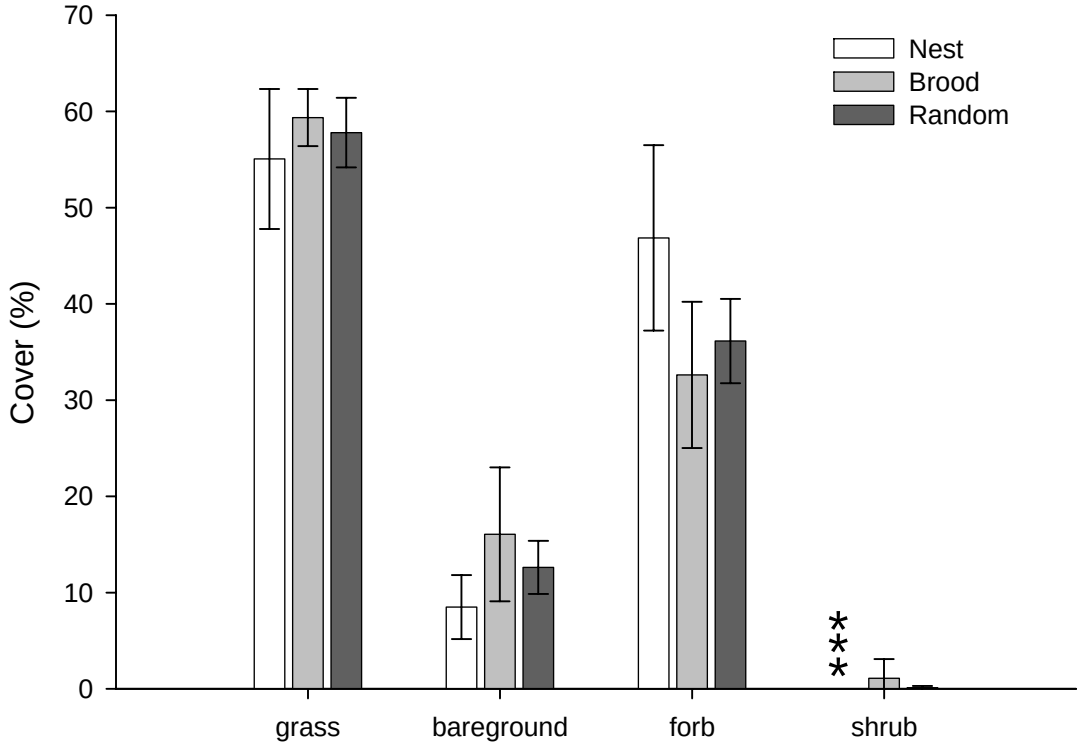

Figure 10. Mean percentages of grass, bareground, forb, and shrub cover with 95% confidence intervals at nest sites, brood points, and random points in 2005 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate that nest sites or brood points were significantly different from random points at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.

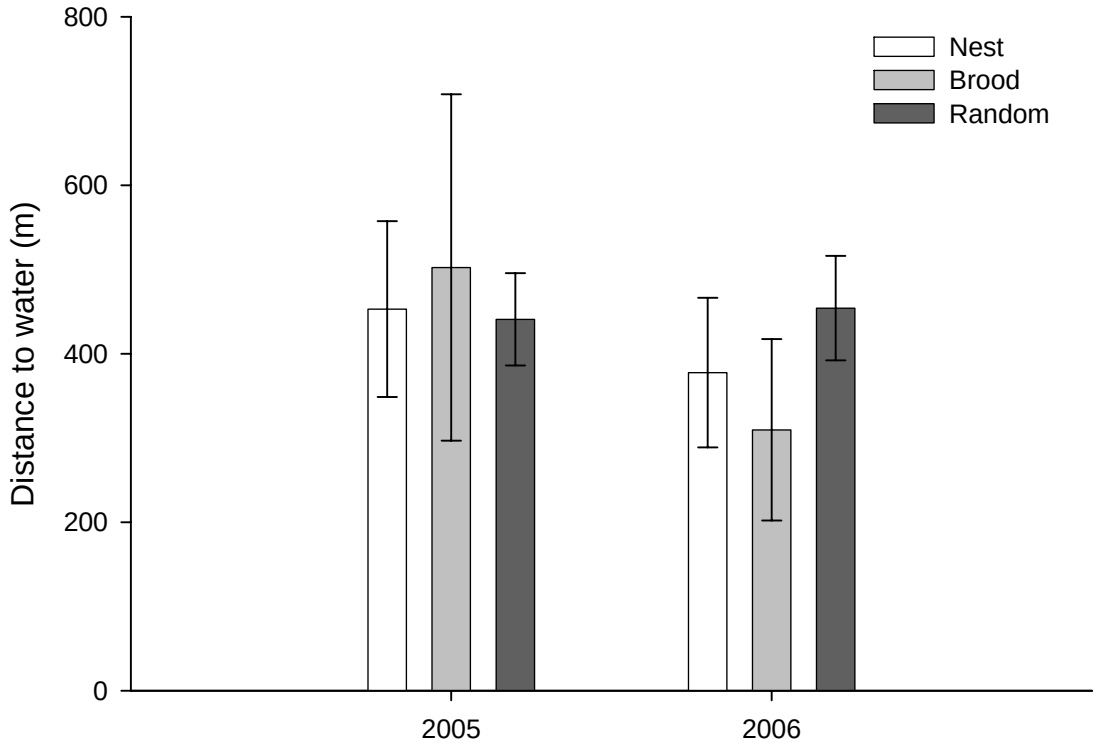

Figure 11. Mean distance to the nearest source of water with 95% confidence intervals from nest sites, brood points, and random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Nest sites and brood points were not significantly different from random points in either year.

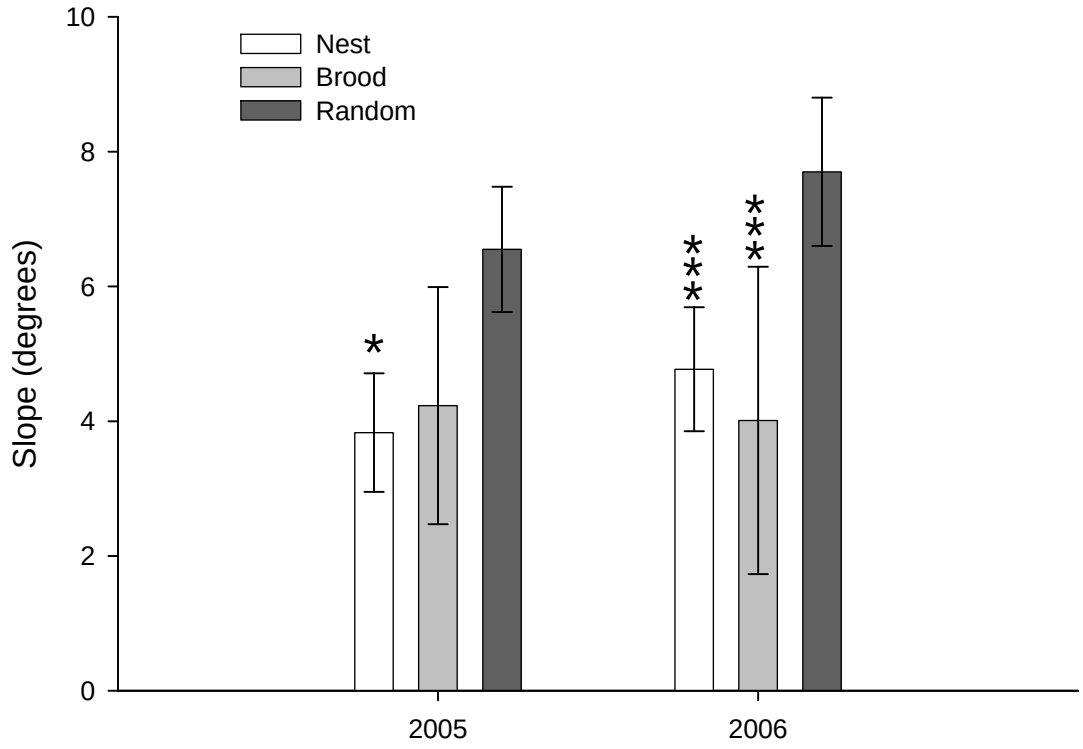

Figure 12. Mean slope measurements with 95% confidence intervals for the ground at nest sites, brood points, and random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate that nest sites or brood points were significantly different from random points at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.

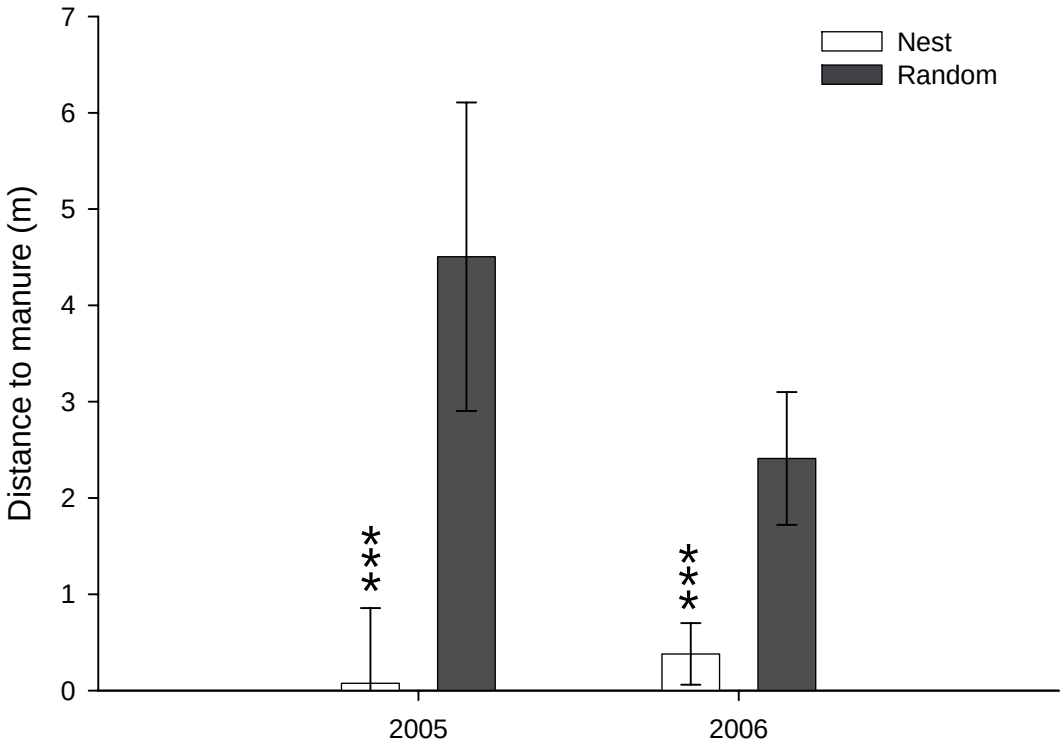

Figure 13. Mean distance to the nearest conspicuous object (manure piles) with 95% confidence intervals at nest sites and random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate that nest sites were significantly different from random points at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.

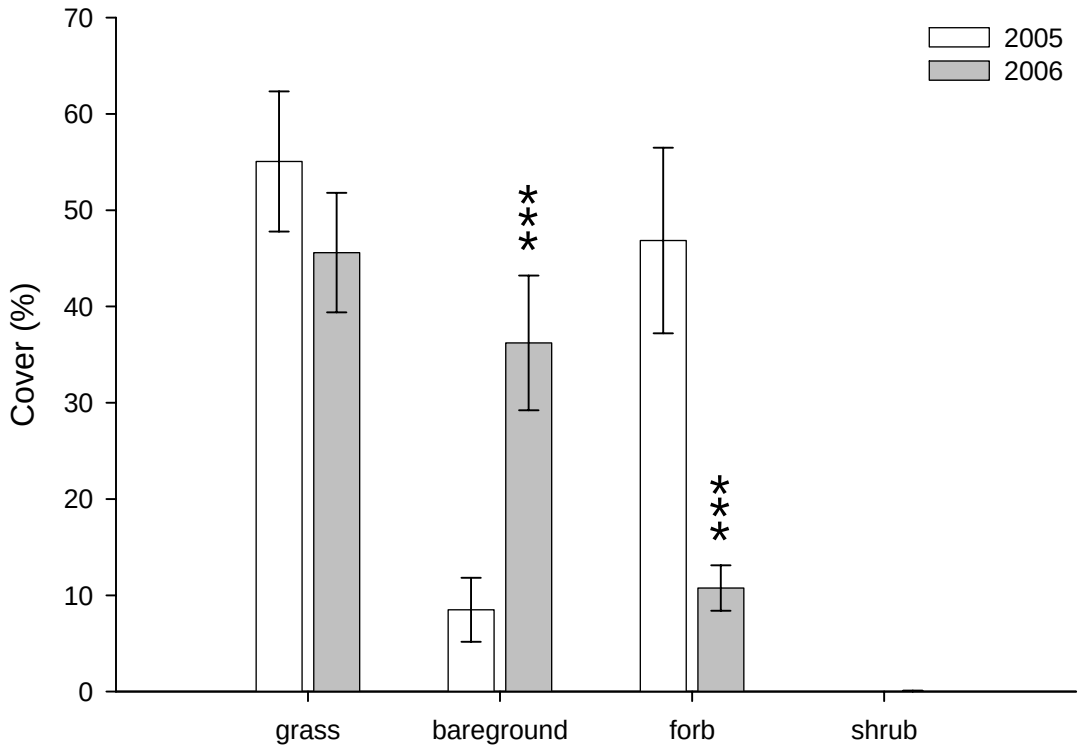

Figure 14. Mean percentage of grass, bareground, forb, and shrub cover with 95% confidence intervals at long-billed curlew nest sites in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate a significant difference between years at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.

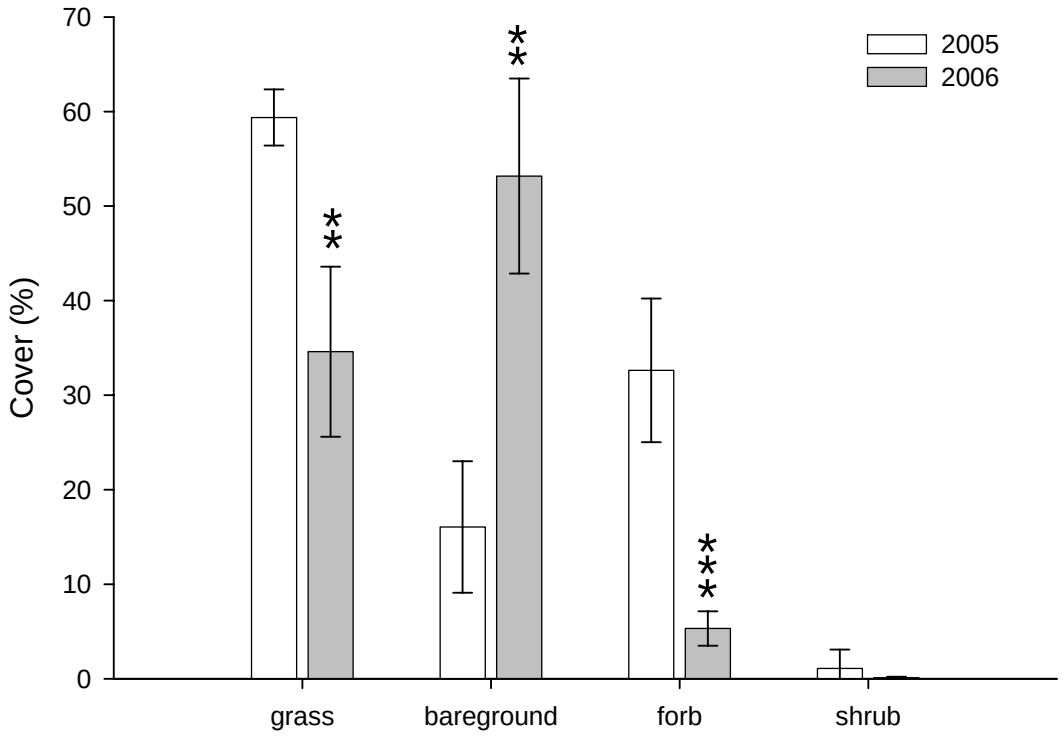

Figure 15. Mean percentage of grass, bareground, forb, and shrub cover with 95% confidence intervals at long-billed curlew brood location points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate a significant difference between years at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.

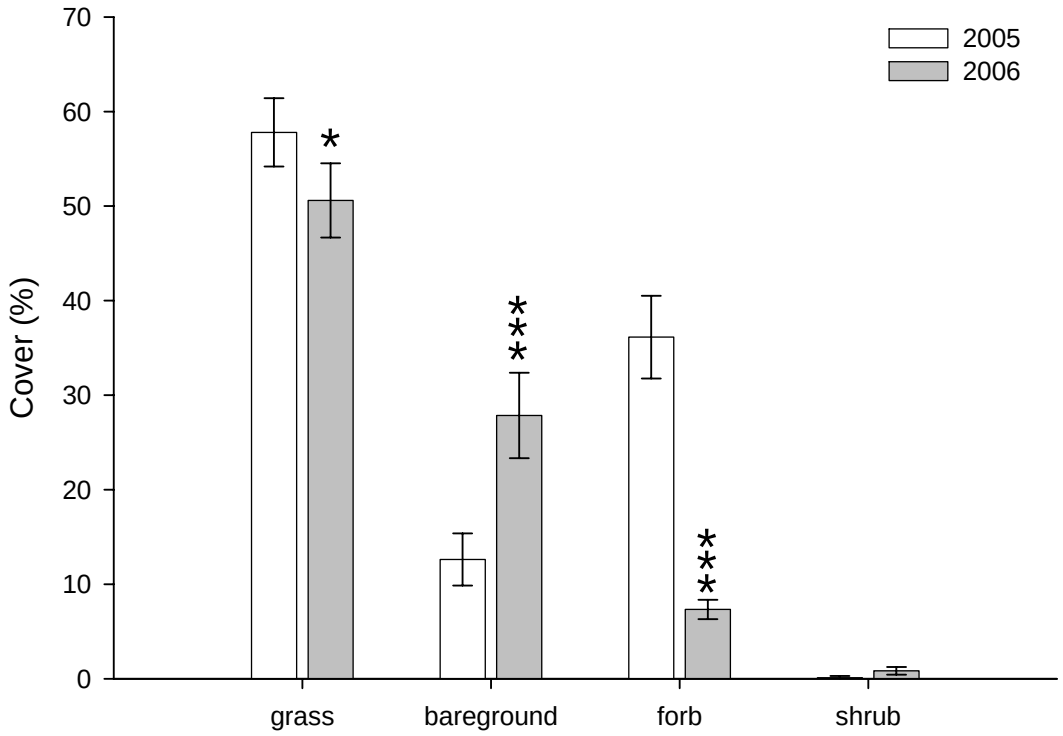

Figure 16. Mean percentage of grass, bareground, forb, and shrub cover with 95% confidence intervals at random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate a significant difference between years at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.

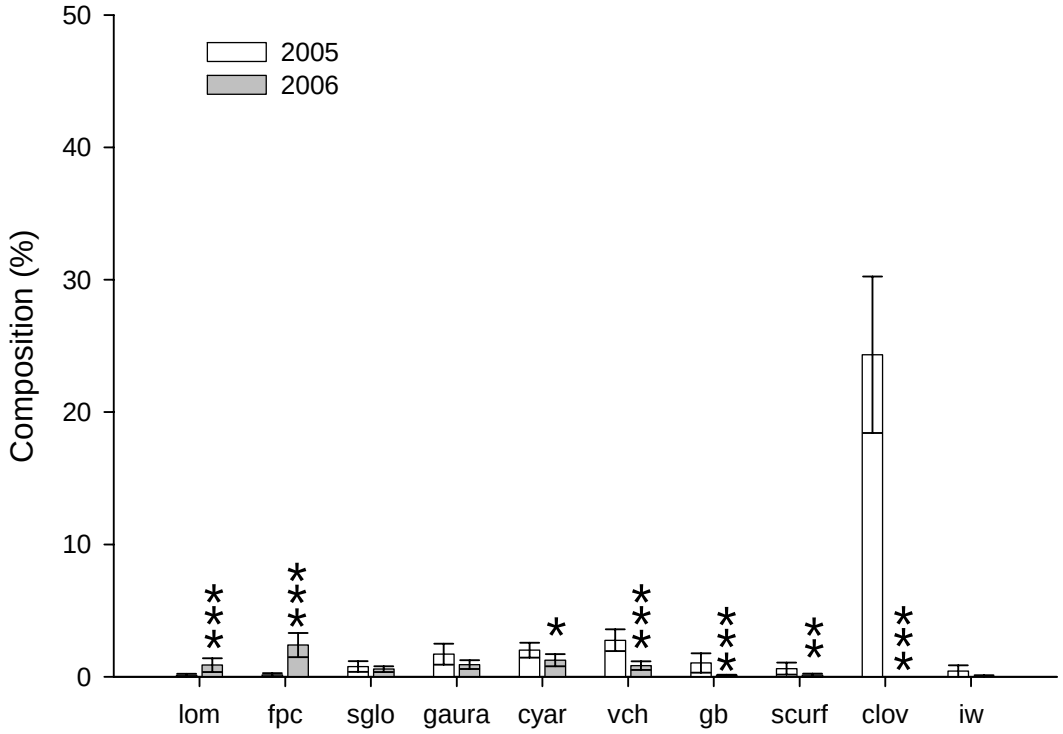

Figure 17. Mean percentage of total composition of the vegetation at random points represented by the forb species desert biscuitroot (lom), field pennycress (fpc), scarlet globemallow (sglo), scarlet gaura (gaura), common yarrow (cyar), goatsbeard (gb), silverleaf scurfpea (scurf), yellow sweetclover (clov), and indianwheat (iw) with 95% confidence intervals in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate a significant difference between years at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.

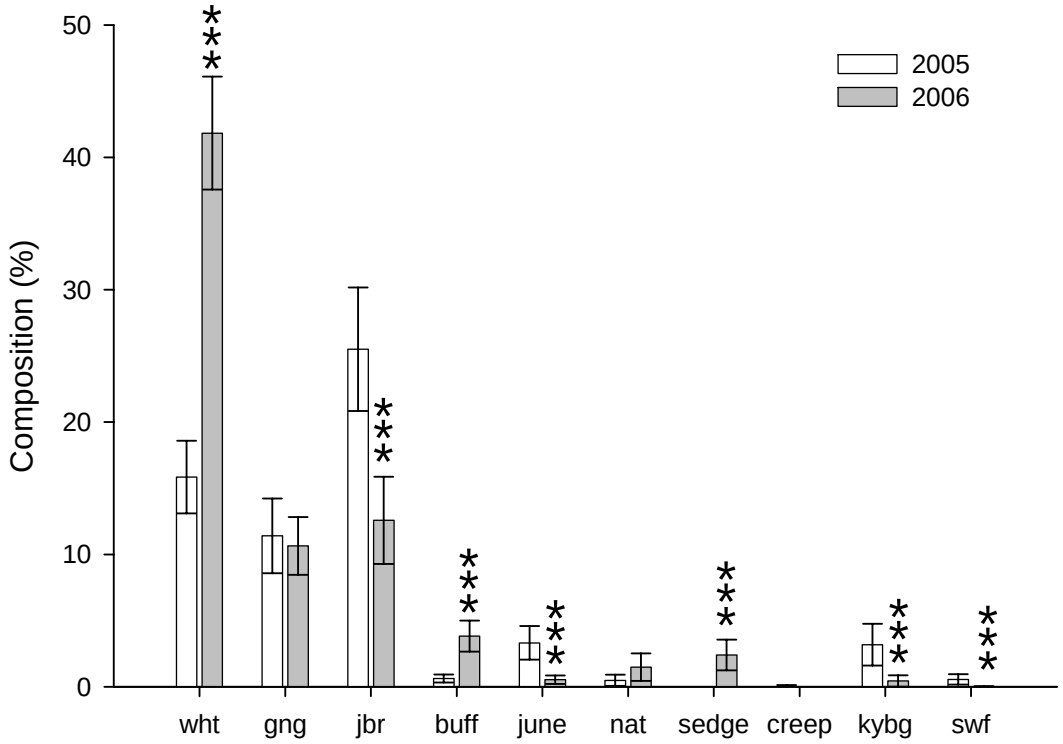

Figure 18. Mean percentage of total composition of the vegetation at random points represented by the graminoid species western wheatgrass (wht), green needlegrass (gng), Japanese brome (jbr), buffalograss (buff), junegrass (june), needleandthread (nat), sun sedge (sedge), creeping spikerush (creep), Kentucky bluegrass (kybg), and sixweeks fescue (swf) with 95% confidence intervals in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate a significant difference between years at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.

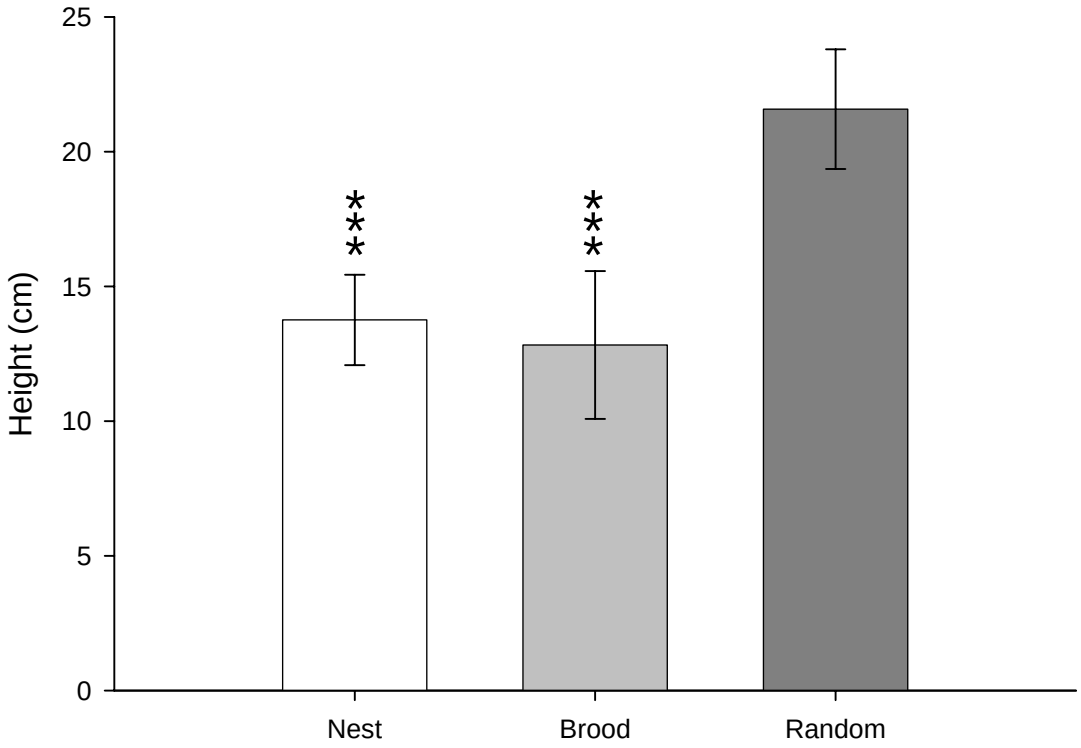

Figure 19. Mean height of the tallest piece of vegetation with 95% confidence intervals at nest sites, brood points, and random points in 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate that nest sites or brood points were significantly different from random points at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.

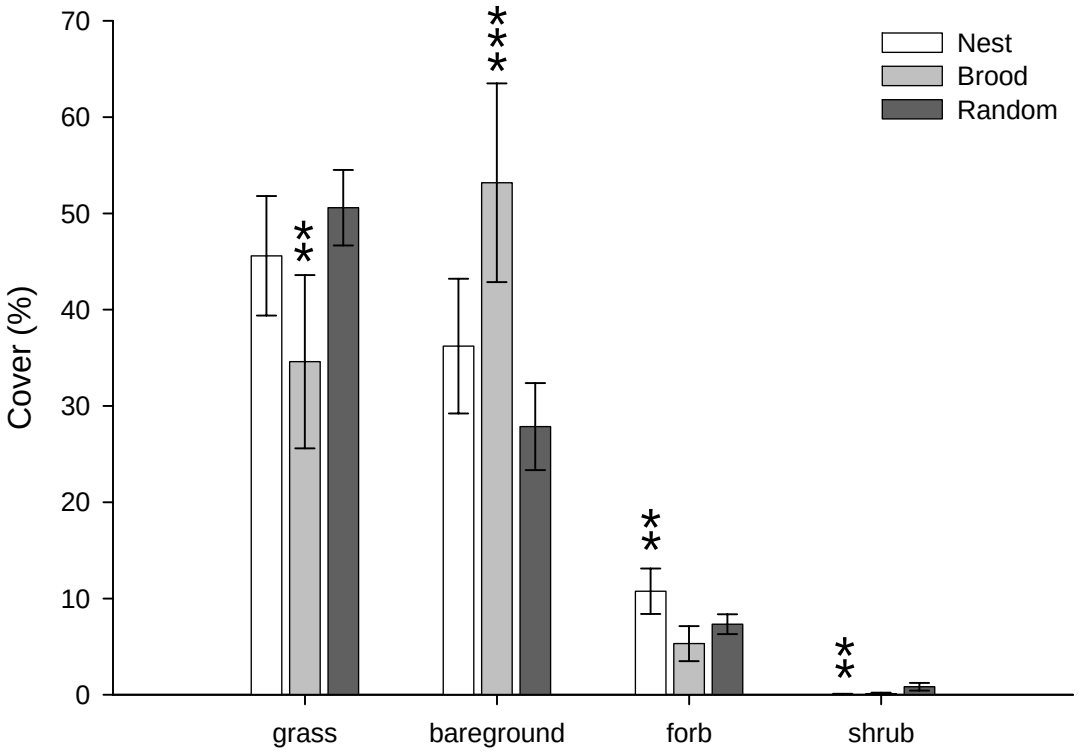

Figure 20. Mean percentage of grass, bareground, forb, and shrub cover with 95% confidence intervals at nest sites, brood points, and random points in 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Asterisks (*) indicate that nest sites or brood points were significantly different from random points at the following significance levels: 1 asterisk = P<0.05; 2 asterisks = P<0.01; 3 asterisks = P<0.001.

Appendix 1. Individual egg masses from long-billed curlew clutches weighed in 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota.

Female Band #	**Egg 1 (g)**	**Egg 2 (g)**	**Egg 3 (g)**	**Egg 4 (g)**	**Mean (g)**
706-66573	63	68	67	66	66.0
706-66593	64	62	59	63	62.0
706-66592 (male)	63	68	64	66	65.3
706-66579	66	66	62	63	64.3
706-66588	68	66	68	64	66.5
					64.8

Appendix 2. List of vascular plant species identified at nest sites, brood location points, and random points in 2005 and 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota.

American vetch (*Vicia americana*)
Barnyardgrass (*Echinochloa muricata*)
Blue grama (*Bouteloua gracilis*)
Bracted spiderwort (*Tradescantia bracteata*)
Broom snakeweed (*Gutierrezia sarothrae*)
Buffalograss (*Buchloe dactyloides*)
Canada bluegrass (*Poa compressa*)
Canada wildrye (*Elymus canadensis*)
Charlock mustard (*Sinapis arvensis*)
Cocklebur (*Xanthium strumarium*)
Common dandelion (*Taraxacum officinale*)
Common yarrow (*Achillea millefolium*)
Creeping spikerush (*Eleocharis palustris*)
Crested wheatgrass (*Agropyron cristatum*)
Cudweed sagewort (*Artimesia ludoviciana*)
Curlycup gumweed (*Grindelia squarrosa*)
Daisy fleabane (*Erigeron strigosus*)
Desert biscuitroot (*Lomatium foeniculaceum*)
Dotted gayfeather (*Liatris puncata*)
Downy brome (*Bromus tectorum*)
False boneset (*Brickellia eupatorioides*)
Fescue sedge (*Carex brevior*)
Field bindweed (*Convolvulus arvensis*)
Field pennycress (*Thlaspi arvense*)
Flatspine stickweed (*Lappula occidentalis*)
Foxtail barley (*Hordeum jubatum*)
Goatsbeard (*Tragopogon dubius*)
Green needlegrass (*Nassella viridula*)
Hairy rockcress (*Arabis hirsuta*)
Hardstem bulrush (*Schoenoplectus acutus*)
Heath aster (*Aster ericoides*)
Indianwheat (*Plantago patagonica*)
Inland saltgrass (*Distichlis spicata*)
Japanese brome (*Bromus japonicus*)
Junegrass (*Koeleria macrantha*)
Kentucky bluegrass (*Poa pratensis*)
Little barley (*Hordeum pusillum*)
Littlepod false flax (*Camelina microcarpa*)
Maximilian sunflower (*Helianthus maximiliani*)
Missouri goldenrod (*Solidago missouriensis*)

Appendix 2. Continued

Muttongrass (*Poa fendleriana*)
Narrowleaf dock (*Rumex stenophyllus*)
Needleandthread (*Hesperostipa comata*)
Needleleaf sedge (*Carex duriuscula*)
Plains prickly pear (*Opuntia polyacantha*)
Plains sunflower (*Helianthus annuus*)
Povertyweed (*Iva axillaris*)
Prairie coneflower (*Ratibida columnifera*)
Prairie cordgrass (*Spartina pectinata*)
Prairie plantain (*Plantago elongata*)
Prickly rose (*Rosa acicularis*)
Prince's plume (*Stanleya pinnata*)
Purple coneflower (*Echinacea angustifolia*)
Purple-flowered alfalfa (*Medicago sativa*)
Saline saltbush (*Atriplex subspicata*)
Sandberg's bluegrass (*Poa secunda*)
Sandreed (*Calamovilfa longifolia*)
Scarlet gaura (*Gaura coccinea*)
Scarlet globemallow (*Sphaeralcea coccinea*)
Sideoats grama (*Bouteloua curtipendula*)
Silver sagebrush (*Artemisia cana*)
Silverleaf scurfpea (*Psoralea argophylla*)
Sixweeks fescue (*Vulpia octoflora*)
Slenderleaf collomia (*Collomia linearis*)
Stiff goldenrod (*Oligoneuron rigidum*)
Sun sedge (*Carex inops*)
Textile onion (*Allium textile*)
Western snowberry (*Symphoricarpos occidentalis*)
Western tansymustard (*Descurainia pinnata*)
Western wallflower (*Erysimum asperum*)
Western wheatgrass (*Elymus smithii*)
Wild parsley (*Musineon divaricatum*)
Yellow sweetclover (*Melilotus officinalis*)

Appendix 3. Body measurements for long-billed curlews captured in 2005 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Individuals are identified by radio-transmitter frequencies and band numbers.

Frequency	Band #	Sex	Mass (g)	Wing (mm)	Head (mm)	Culmen (mm)
151.194	706-66552	F	608	273	45.5	164.5
150.823	706-66553	F	604	285	41.1	168.0
151.015	706-66554	F	658	285	46.4	148.5
150.883	706-66557	F	592	286	45.5	159.5
150.723	706-66559	F	628	288	41.9	170.5
151.274	706-66560	F	659	285	41.2	166.1
151.054	706-66561	F	609	286	45.9	168.5
151.152	706-66566	F	604	292	40.9	179.5
150.964	706-66567	F	633	280	42.2	173.5
150.903	706-66573	F	639	290	42.2	148.3
151.214	706-66574	F	623	295	39.4	153.0
151.115	706-66575	F	584	271	39.4	153.9
Mean	**-**	**F**	**620**	**285**	**42.6**	**162.8**
150.943	706-66550	M	NA	NA	45.54	115.5
150.744	706-66551	M	511	254	48.19	135.1
151.214	706-66555	M	493	272	40.80	115.7
150.924	706-66556	M	453	262	43.05	123.0
151.254	706-66558	M	504	274	42.12	126.2
151.233	706-66562	M	506	258	35.37	129.5
150.763	706-66563	M	503	268	42.53	117.1
150.704	706-66564	M	508	271	38.99	129.4
151.074	706-66565	M	493	270	42.36	133.9
151.095	706-66568	M	526	266	36.79	121.8
150.864	706-66569	M	536	282	41.99	135.0
151.134	706-66570	M	524	270	37.79	130.1
150.844	706-66571	M	526	269	36.71	122.3
151.036	706-66572	M	525	270	40.31	122.8
Mean	**-**	**M**	**508**	**268**	**40.90**	**125.5**

Appendix 4. Body measurements for long-billed curlews captured in 2006 on the Triple U Buffalo Ranch, Stanley County, South Dakota. Individuals are identified by radio-transmitter frequencies and by darvic color bands and metal bands on the right and left legs. R=red, G=green, Y=yellow, O=orange, B=Blue, Bk=black, W=white, M=metal. Numbers in parentheses indicate numbered color bands. Two frequencies are shown for individuals captured in 2005 and recaptured in 2006.

Frequency 2006 (MHZ)	**Frequency 2005 (MHZ)**	**Band #**	**Right leg**	**Left leg**	**Sex**	**Mass (g)**	**Wing (mm)**	**Head (mm)**	**Culmen (mm)**
150.245	-	706-66591	R,R,M	G,W,R	F	551	265	40	169
150.103	-	706-66587	R,R,M	Y,Bk,R	F	586	275	47	166
150.582	-	706-66586	R,R,M	Y,R,G	F	594	285	43	170
150.263	-	706-66583	R,R,M	Y,R,O	F	674	291	44	168
150.603	-	706-66576	R(225),R(226),M	-	F	615	285	39	148
150.483	-	706-66579	R,R,M	Y,B,O	F	634	285	41	170
151.344	-	706-66578	R,R,M	Y,B,G	F	606	284	43	169
150.642	-	706-66584	R,R,M	Y,R,Bk	F	592	285	38	176
150.085	-	706-66588	R,R,M	Y,Bk,O	F	682	280	41	179
150.323	-	706-66593	R,R,M	G,W,Y	F	683	282	38	175
150.663	151.274	706-66560	R,R	Y,G,B,M	F	702	-	-	-
Mean	**-**	**-**	**-**	**-**	**F**	**629**	**282**	**41**	**169**
150.463	-	706-66589	R,R,M	Y,Bk,G	M	531	272	40	132
150.145	-	706-66585	R,R,M	Y,R,B	M	485	259	37	126
150.063	-	706-66582	R,R,M	Y,G,R	M	482	275	35	119
150.502	-	706-66577	R(222),R(223),M	R (224)	M	483	265	45	139
150.045	-	706-66581	R,R,M	Y,R,W	M	482	260	39	119
150.344	-	706-66580	R,R,M	Y,G,O	M	535	273	36	138
150.804	-	706-66592	R.R.M	G,W,B	M	468	265	39	117
150.383	150.763	706-66563	R,R	Y,Bk,W,M	M	504	-	-	-
150.362	150.864	706-66569	R,R,M	Y,B,R	M	546	-	-	-
151.362	150.744	706-66551	R,R	Y,B,W,M	M	495	-	-	-
151.301	150.704	706-66564	R,R	Y,G,W,M	M	496	-	-	-
150.563	151.254	706-66558	R,R	Y,G,Bk,M	M	513	-	-	-
Mean	**-**	**-**	**-**	**-**	**M**	**502**	**267**	**39**	**127**