Short-Horned Lizard (*Phrynosoma hernandesi*) Survey in South Dakota 2008 – 2009

Final Report Submitted to the
South Dakota Department of Game, Fish and Parks

31 December 2009

Hugh Quinn, Brian Smith, Holly Quinn and Gwen H. Writer

Department of Biology
Black Hills State University
1200 University Street Unit 9044
Spearfish, SD 57709-9044

Table of Contents

Executive Summary……... 3

Introduction …….. 5

Materials and Methods
- *Identifying Sites* ……... 6
- *Searching for Animals* ……...……... 7

Results and Discussion
- *Historical and New Site Surveys* ……..... 7
- *Climatic, Temporal, and Habitat Parameters under which Short-horned Lizards were Found* …….. 7
- *Detection Probabilities and Declaring a Site Unoccupied* ……..... 9
- *Estimated Distribution in the State* ……..... 11
- *Conservation Concerns and Management Recommendations* ……..... 12
- *Further Research* …….. 14

Acknowledgements ……...15

Literature Cited …… 15

Tables
- Table 1. Climatic conditions, times of day and elevations at which short-horned lizards were found during this study…… 20
- Table 2. Search effort in hours per short-horned lizard and detection rate in lizards per hour for 2008 and 2009 …….....21
- Table 3. Size of short-horned lizards encountered from June through September 2008 – 2009……..22
- Table 4. Habitat description of sites where short-horned lizards were found…….. 23
- Table 5. Detection probabilities (*p*) and the minimum number of surveys required of a given site to demonstrate the absence of short-horned lizards (N_{min}) as calculated from sites where lizards were found……..24
- Table 6. Factors potentially influencing detectability of short-horned lizards during site searches ……... 25

Figures
- Figure 1. Distribution of short-horned lizards in South Dakota……... 26

Appendices
- Appendix I. Short-horned lizard "wanted poster" …….. 27
- Appendix II. Systematic sampling survey form utilized in this study…….28

Executive Summary

The wide-ranging short-horned lizard (*Phrynosoma hernandesi*) is found from central Mexico north through much of the Rocky Mountain west, including portions of Arizona, New Mexico, Texas, Nevada, Utah, Colorado, Nebraska, Idaho, Wyoming, South Dakota, Montana, North Dakota, and into southernmost British Columbia and Alberta, Canada. In South Dakota, possibly the easternmost extent of its range, this lizard is known only from 19 localities (South Dakota Department of Game, Fish and Parks Natural Heritage Database), all west of the Missouri River. It is considered secure range-wide but imperiled within South Dakota due to its rarity (G5/S2). To better understand the status and distribution of this lizard in the state, we: 1) visited each of the 19 historical collecting localities in an effort to determine if populations still persist; 2) located new locales where short-horned lizards exist; and 3) examined effective methods to detect the presence of this elusive species.

Historical localities were provided through the South Dakota Department of Game, Fish and Parks Natural Heritage Database. Additional sites were obtained from the Badlands National Park, Black Hills National Forest, and Buffalo Gap National Grassland records. Further records were obtained through discussions and correspondence with individuals who had observed short-horned lizards in the field. Interviews with landowners in the field also provided insight into lizard distribution. One site was identified by investigating the origin of a short-horned lizard photograph that appeared in the *Rapid City Journal*. Additionally, a "wanted poster" requesting information about short-horned lizard sightings was prepared and distributed to various individuals and organizations.

A total of 167.5 person-hours were spent searching for short-horned lizards in the field, with 45 lizard sightings. This represents a search effort of 3.7 hours per lizard, or an average rate of 0.29 lizards per person-hour. Of the 19 short-horned lizard historical sites listed in the South Dakota Department of Game, Fish and Parks Natural Heritage Database: 1) lizards were observed at three; 2) no lizards were found at eight; and 3) eight sites were not surveyed, as access was denied by landowners, landowners were unavailable to grant access, or habitat appeared inappropriate for lizard habitation. One of these non-surveyed sites was on the Pine Ridge Indian Reservation where we did not request permission to search. In addition to finding lizards at three historical sites, we also observed them at four new sites. An additional six sites containing lizards were reported to us by reliable sources. Thus, a total of 13 sites contained lizards, seven of which we verified.

The environmental and habitat parameters under which we and others found short-horned lizards can serve as a guide for those wishing to find them for future investigations. In general, these lizards seemed to first appear in the morning on summer days as temperatures began rising. They were active until warming temperatures in late morning or early afternoon forced them to seek shelter, at which time they became less detectable. Lizards were active under a variety of sky conditions, ranging from clear to mostly cloudy (greater than 75% cloud cover), but most were found under clear skies. They were observed on calm as well as windy days. We found lizards in both prairie and forest environments. While populations can be found in areas of dense and sparse ground cover, they appear to be more abundant in the latter, although data were inadequate to quantitatively analyze habitat preference. In the forest they were found in areas of scattered trees and open canopy, which provide ample basking opportunities. Soil compaction has also been shown to be an important determinant of short-horned lizard presence, as lizards often dig beneath the surface to escape the heat of midday and must be able to burrow to survive the cold temperatures of winter. While lizards can be found on ground that is stony or firm, there are usually some areas of fine, loose soil present. We found lizards at elevations from 756 - 1525 m (2479 – 4984 ft.). In terms of finding lizards, our most productive month was August,

followed by September. Most babies are born in early August, so populations are at their peak during this time, making detectability at its highest. We found the best search method is to walk slowly through habitat. When approached within about 1 m (ca. 3 ft.) by an observer, the lizards run a short distance, making them detectable.

We calculated detection probabilities (the probability of finding at least one short-horned lizard when searching a site where the species is known to reside) for all occupied sites visited more than once. These values ranged from 0.33 – 1.00, and if all occupied sites are combined, the overall detection probability was 0.73. From this probability we calculated the minimum number of visits necessary before concluding a site unoccupied, which was 2.3. Constructing a 95% confidence interval for this figure yielded 1.2 – 4.0 visits. Therefore, using the upper limit, if any site is searched four times and no lizards are found, we can say with relative confidence the site is unoccupied. Using this value, no historical sites can be declared unoccupied as none were searched that many times. However, three sites were searched 2 – 3 times (within our 95% confidence interval), and five sites were searched one time (slightly outside our confidence interval). We feel reasonably confident (although not 95% so) that lizards do not exist at the three sites we searched multiple times.

Based on our limited number of visits to each historical site and findings at new sites, our work suggests that today this species may range only in Harding, Perkins, extreme western Lawrence, Fall River, Shannon, and perhaps Butte and extreme southwestern Custer Counties, and may no longer persist in Meade, Pennington, Stanley, and western Jackson Counties. The constriction of short-horned lizard range in South Dakota is probably a result of conversion of native prairie to cropland or densely planted pasture, our major conservation concern for this species. Other conservation concerns include widespread insecticide use (killing lizard food sources), heavy use of sand or dirt roads through short-horned lizard habitat, and the potential for commercial collection.

While we saw no lizards in Harding County, we feel they occur there, as suitable habitat exists, and 37% of historical records are within its boundaries. Additionally, we were unable to survey many Harding County sites due to access issues and the imprecise nature of some locality data, which in some cases are very old. Of interest, at one of the historical sites in Harding County, it appeared to us that the habitat had been converted to cropland and then abandoned to grow back to an altered mixed-grass prairie. This was evident by the natural grasses now growing in furrows. We believe activity such as this would have eliminated short-horned lizards at the site. There may be additional cases where lizards no longer exist at historically occupied sites due to past habitat alteration, even though today the habitat appears suitable.

Further research needs for the short-horned lizard in South Dakota include continuing surveys to better understand the distribution of this species in the state. The use of predictive ecological niche modeling should further help define appropriate areas to search for lizards and provide insight into their potential distribution. Such modeling also can be coupled with molecular genetic population data to link the geographic configuration of population distributions with analyses of genetic differentiation. Predictive models of future distributions can direct conservation efforts by highlighting populations at risk of losing genetic diversity, and managing those populations to mitigate a loss in diversity at the species level. Additionally, population changes over time can be monitored to see how they covary with environmental, biological or anthropogenic factors.

To further understand the habitat needs of short-horned lizards, research regarding microhabitat use would be beneficial. This information then can be applied to investigations about the impact of various land management practices on short-horned lizard populations. Little is known about the population dynamics of these lizards. It appears to us that populations are scattered in patches across a landscape of seemingly appropriate habitat, and that they rise and fall in various locations over the course of time. Gaining a better understanding of this

potential process and the gene flow associated with it should provide insight into the landscape needs of conserving this species.

Population viability analyses are important in designing conservation plans for species. Demographic data such as age specific fertility and survival are important components of predicting population trends. Such data are not available for South Dakota short-horned lizard populations.

The population of short-horned lizards found near 1525 m (5000 ft.) elevation in the mixed ponderosa pine and burr oak forest is intriguing. Not only is the habitat of this population in sharp contrast to that of the prairie populations, but the timing of reproduction seems to be earlier and in sync with more northerly populations (Canada). The genetic distinctiveness of this population should be investigated, and a comparison made with various natural history and behavioral traits to nearby prairie populations.

Introduction

The following report details short-horned lizard (*Phrynosoma hernandesi*) surveys conducted range-wide in South Dakota by the authors under the Wildlife Diversity Small Grants Program of the South Dakota Department of Game, Fish and Parks from June 2008 through September 2009.

Horned lizards (genus *Phrynosoma*) are endemic to the western United States, Mexico, and Canada. They are cryptic animals, spending considerable time partially buried in sand and under cover (Sherbrooke 2003). They are dietary specialists: the 13 species have diets that are predominantly comprised of ants (Hotton 1955, Pianka and Parker 1975, Montanucci 1981, Powell and Russell 1984, Sherbrooke 2003). Three species, *P. mcallii*, *P. coronatum*, and *P. cornutum*, are of conservation concern due to habitat fragmentation, urbanization, insecticide use, introduced fire ants, and introduced predators (Price 1990, Donaldson et al. 1994, Brattstrom 1997, Beauchamp et al. 1998, Fisher et al. 2002, Audsley et al. 2006, Barrows et al. 2006).

Phrynosoma hernandesi is found within South Dakota. Its range is broad, extending from central Mexico north through the Rocky Mountain west, including portions of Arizona, New Mexico, Texas, Nevada, Utah, Colorado, Nebraska, Idaho, Wyoming, South Dakota, Montana, North Dakota, and into the southernmost tip of British Columbia and Alberta, Canada (Sherbrooke 2003, Leaché and McGuire 2006). Only the farthest western reaches of South Dakota are included within the range of *P. hernandesi*. Some records of the South Dakota Department of Game, Fish and Parks Natural Heritage Database may represent eastern range extensions.

The status of *P. hernandesi* within the state is poorly known, having been reported from only 19 sites since 1912 (South Dakota Department of Game, Fish and Parks Natural Heritage Database). It is considered secure range-wide but imperiled within South Dakota due to its rarity in the state (G5/S2, South Dakota Department of Game, Fish and Parks Natural Heritage Database). There have been no systematic surveys of the species in the state. In 2007, we searched for these lizards without success at nine historical localities. Clearly an assessment of their status within the state was needed.

Phrynosoma can be difficult to locate. Grant and Doherty (2007) used detection probability methods to ascertain that *P. mcallii* are more common than typically assumed, presumably due to their cryptic nature. Nonetheless, visual searches seem to be the best method to survey horned lizards, as numerous researchers have collected *Phrynosoma* using this method (Grant and Doherty 2007, Mathies and Martin 2008, Mathies pers. comm.). However, factors that may affect detectability during visual searches, such as searcher experience and weather conditions, can impact survey results (Kery 2002, Bailey et al. 2004). Defining such factors can help focus future surveys for this species.

The objectives of this study were threefold: 1) visit each of the 19 historical collecting localities at least once to determine if populations of short-horned lizards still persist; 2) locate new locales where short-horned lizards exist; and 3) examine effective methods to detect the presence of short-horned lizards.

Materials and Methods

Identifying Sites: Historical localities were provided through the South Dakota Department of Game, Fish and Parks Natural Heritage Database. Additional sites were obtained from Badlands National Park (National Park Service), Black Hills National Forest (U.S. Forest Service), and Buffalo Gap National Grassland (U.S. Forest Service) records. Further records were obtained through discussions and correspondence with individuals who had observed short-horned lizards in the field. Interviews with landowners in the field also provided insight into lizard distribution. One site was identified by investigating the origin of a short-horned lizard photograph that appeared in the *Rapid City Journal*. Sites from all the above sources are displayed in Figure 1.

Sites or populations were considered separate if they occurred 1 km (0.6 mi.) or 5 km (3.1 mi.) apart in unsuitable or suitable habitat, respectively (NatureServe 2009). Using this definition, Sites 18, 20, 21, and 28 (Figure I) were each rather widespread, so we divided them into subsites (Site 18 A – D, Site 20 A – E, Site 21 A – B, and Site 28 A – C). Subsites were thus defined as locales from 1 to <5 km (0.6 to <3.1 mi.) apart in suitable habitat. Habitat use by short-horned lizards in South Dakota is poorly described, but may be similar to that in other regions. A range of habitats can thus be considered suitable, from shortgrass or sage prairies with rocky or sandy areas, sparse vegetation and sun-baked soil, to open piñon-juniper, pine-spruce, and spruce-fir forests, as well as rocky rims of coulees and shale outcrops (Mosimann and Rabb 1952, Dood 1980, Hudson 1985, Russell and Bauer 1993, Degenhardt et al. 1996, Hammerson 1999, Werner et al. 2004, Kiesow 2006). Sparse vegetation at ground level seems to be common to most areas inhabited by this species (NatureServe 2009), but not all (our observations). Inhabited areas in forest have spaces in the canopy to allow direct penetration of sunlight (Sherbrooke 2003). Although this species burrows where loose sand is available, it is also found commonly with firm soil (Baxter and Stone 1980), but usually some fine, loose soil is present (Wheeler and Wheeler 1966). While these lizards occur as high as 3172 m (10,400 ft.) elevation in the San Francisco Mountains of northern Arizona (Sherbrooke 2003) and 2440 m (8,000 ft.) in Colorado (Hammerson 1999), they are only found below about 1983 m (6500 ft.) in Wyoming and Montana (Baxter and Stone 1980, Werner et al. 2004). Therefore, most elevations in South Dakota would be considered suitable for short-horned lizard habitation except the highest peaks of the Black Hills.

Examples of unsuitable habitat include densely-planted pasture and monoculture cropland (Reynolds 1979), as well as areas of dense canopy or dense vegetation at ground level (Sherbrooke 2003). Reynolds (1979) found that replacing sagebrush with grass communities caused local population declines in *Phrynosoma douglasii*, the closely-related pygmy horned lizard. Areas containing compact soils without patches of loose soils for burrowing may also be unsuitable for horned lizards, as they often dig beneath the surface to escape the heat of midday (Sherbrooke 2003), and must burrow to survive the cold temperatures of winter (Mathies and Martin 2008). Based on elevations where lizards were found in Wyoming and Montana, peaks of the Black Hills above 1983 m (6500 ft.) elevation may also be unsuitable for lizard habitation.

Sites or populations were also considered separate if barriers existed between them. Barriers may include busy highways; highways with obstructions such that lizards rarely if ever cross successfully; a major river, lake, pond, or deep marsh; and an urbanized area dominated by buildings and pavement (NatureServe 2009).

A "wanted poster" featuring the short-horned lizard (Appendix I) requesting information about lizard sightings was distributed to various agencies, organizations, and individuals. A request for such information was also posted on the Dakota Amphibian and Reptile Network (DARN) listserv. Appeals were made during presentations about reptiles or as announcements to the Norbeck Society, Northern Hills Bird Club, Oglala Lakota College Field Ecology Class, the DARN annual meeting, and a museum class at the South Dakota School of Mines and Technology.

Searching for Animals: Initially it was thought that the use of cover boards may be an effective way of finding short-horned lizards, as this method has been used successfully to locate other herpetofauna (Kjoss and Litvaitis 2001, Hampton 2007), but walking slowly though habitat and watching carefully for lizard movement was found to be the most effective method (Mathies pers. comm., our observations). Short-horned lizards are very cryptic and extremely difficult to see when motionless, but when approached within about 1 m (ca. 3 ft.) by an observer, they run a short distance, making them detectable. Therefore, we conducted timed visual searches (Crump and Scott 1994) of sites, recording date, search time, names of searchers, site location, habitat description, weather conditions, and animals observed (see Appendix II for the Systematic Sampling Survey data form utilized). Habitat was described in general terms (i.e., prairie, scattered ponderosa pine forest), often with brief descriptions of some of the known plants in the area, and percent ground cover was estimated within a 0.5 m (1.6 ft.) radius of lizards at five sites. Average wind speed (over a two minute period), temperature and relative humidity were measured with a handheld weather station. Cloud cover was estimated as: 0 = clear or few clouds (<10% cover); 1 = partly cloudy (10 – 25% cover); 2 = 25 – 50% cover; 3 = 50 – 75% cover; and 4 = mostly cloudy, fog, or mist (>75% cover). Snout-to-vent length (SVL) was measured on a representative sample of animals, and sex was determined by the presence of enlarged post-anal scales and hemipenal bulges in males (Sherbrooke 2003, Mathies pers. comm.). Voucher photos were taken at all sites where lizards were found.

Results and Discussion

Historical and New Site Surveys: A total of 167.5 person-hours were spent searching for short-horned lizards in the field, with 45 lizard sightings. This represents a search effort of 3.7 hours per lizard, or an average rate of 0.29 lizards per person-hour. Of the 19 short-horned lizard historical sites listed in the South Dakota Department of Game, Fish and Parks Natural Heritage Database: 1) lizards were observed at three; 2) no lizards were found at eight; and 3) eight sites were not surveyed, as access was denied by landowners, landowners were unavailable to grant access, or habitat appeared inappropriate for lizard habitation. One of these non-surveyed sites was on the Pine Ridge Indian Reservation where we did not request permission to search. In addition to finding lizards at three historical sites, we also observed them at four new sites. An additional six sites containing lizards were reported to us by reliable sources. Thus, a total of 13 sites contained lizards, seven of which we verified. The map in Figure 1 illustrates this graphically.

Climatic, Temporal, and Habitat Parameters under which Short-horned Lizards were Found: Lizards were found at temperatures ranging from 20.5 – 33.9 ^{o}C, $\bar{x}$ = 26.0 +/- 3.6 ^{o}C (68.8 – 93.0 ^{o}F, $\bar{x}$ = 78.9 +/- 6.3 ^{o}F), under sky conditions 0 – 4 ($\bar{x}$ = 0.4 +/- 0.9) (see Methods section and Table 1 for definitions of sky conditions), with average wind speeds 1.0 – 18.2 km/h, $\bar{x}$ = 4.6 +/- 4.5 km/h (0.6 – 11.3 mph, $\bar{x}$ = 2.8 +/- 2.7 mph), at elevations 756 – 1520 m, $\bar{x}$ = 1186 +/- 188 m (2479 – 4984 ft., $\bar{x}$ = 3889 +/- 616 ft.), at relative humidities of 25 – 39% ($\bar{x}$ = 32.7

+/- 5.9 %), and between 0835 – 1250 h ($\bar{x}$ = 1039 +/- 1.2 h) (Table 1). The above parameters do not demonstrate the range of conditions under which lizards can be observed, but illustrate the range under which we found them. These figures simply represent observations, and were not tested against lizard activity or detectability. They can, however, serve as a guide for those wishing to find these lizards for future investigations.

In general, short-horned lizards first appeared in the morning on summer days as temperatures began rising. They were active until warming temperatures in late morning or early afternoon forced them to seek shelter, at which time they became less detectable. In the laboratory this species has a mean preferred body temperature of 35° C, range 33 – 36° C (95° F, range 91.4 – 96.8^{o} F) (Prieto and Whitford 1971). Therefore, when temperatures in the field rise above this range, the lizards probably retreat to cooler underground or shady conditions. Most of our lizards were found mid-to-late morning when temperatures averaged around 27° C (80° F) (Table 1), well below Prieto and Whitford's (1971) findings for preferred body temperatures in the laboratory. Our readings, however, did not reflect body temperatures of basking lizards, but ambient temperature 1 m (ca. 3 ft.) above the substrate. Body temperatures may have been higher due to basking behavior and warmer substrate temperatures. It is quite possible that lizards are active in late afternoon or early evening when temperatures begin to cool, but we did not search during these times. Additionally, they also may be active during the entire day when afternoon temperatures are not excessively warm. Others have observed this general activity pattern of avoiding extreme heat during the day as well (Russell and Bauer 1993, Sherbrooke 2003, Mathies pers. comm.).

The lizards were active under a variety of sky conditions, ranging from clear to mostly cloudy (greater than 75% cloud cover), but most were found under clear skies (Table 1). Wind speed, at least up to 18.1 km/h (11.3 mph) (the highest average speed at which lizards were observed), did not seem to impact activity. Lizards were observed on calm as well as windy days (Table 1). Relative humidity was taken on only a few searches, so the figures presented in Table 1 may not provide a representative sample.

Lizards were found at elevations from 756 to nearly 1525 m (2479 - 5000 ft.). They may exist at higher elevations in the Black Hills if appropriate habitat and dispersal corridors exist, as this species has been found up to 1983 m (6500 ft.) in South Dakota's adjacent states of Wyoming and Montana (Baxter and Stone 1980, Werner et al. 2004). Records from even higher elevations occur in more southerly Colorado (3355 m, 11,000 ft.) (Hammerson 1999) and Arizona (3172 m, 10,400 ft.) (Sherbrooke 2003).

We found short-horned lizards from late June to mid-September in South Dakota, however we only searched from May through September, and our search effort varied among months (Table 2). For nearby states/provinces, lizards have been found from mid-May to early September in Alberta (Russell and Bauer 1993), late April to October in Montana (Werner et al. 2004), May through September or rarely October in Wyoming (Baxter and Stone 1980), and April to October in Colorado (Hammerson 1999). While short-horned lizard activity in South Dakota is probably similar to that in adjacent Wyoming and Montana, our most productive month regarding search effort per lizard and detection rate was August, followed by September (Table 2). When *Phrynosoma hernandesi* are born, they are 2.0 – 2.6 cm (0.79 – 1.02 in.) snout-to-vent length (SVL) (Gelbach 1965, Russell and Bauer 1993, Mathies pers. comm.). It appears that in South Dakota prairie populations, females give birth in early August, as it was during this month that we first observed newborn animals (ca. 2.5 cm or 0.98 in. SVL), and most of the animals we found were in this size class (Table 3). It seems reasonable that the lizards are more readily seen when population sizes are high, and since females give birth to 6 – 48 young (Smith 1941; Tanner 1942, 1953, 1954; Dammann 1949; Woodin 1953; Hudson 1985; Russell and Bauer 1993; Hammerson 1999), population sizes are probably at their peak shortly after the females give birth. For this reason, and since we found that neonates are easily detectable,

August appears to be the best month to locate short-horned lizard populations in South Dakota. It should be noted that neonates were found in June in the highest elevation population surveyed (1520 m, 4984 ft.). Climatic conditions at this elevation may impact the lizard's life history traits, and such traits deserve further investigation. Range-wide, parturition in this species has variously been reported from the end of June into September, depending on latitude and elevation (Bragg and Dundee 1949 [1950], Woodin 1953, Gehlbach 1956, Harris 1963, Douglass 1966, Goldberg 1971, Pianka and Parker 1975, Guyer and Linder 1985).

Scant habitat data were taken during this study (Table 4), but from our notes, some preliminary statements can be made about habitats associated with short-horned lizard populations in South Dakota. This information also can be useful in helping locate additional populations of these lizards in the state. All populations except one were found on the prairie. The single exception was also the highest-elevation population, and was found in a mixed ponderosa pine and burr oak forest (Site 2). The forest was fairly open, with scattered trees, and the soil was primarily loose sand. The prairie sites contained scattered plants such as sage, winterfat, cactus, and grasses, depending on the site. The percent ground cover was estimated within a 0.5 m (1.6 ft.) radius of animals observed for eight lizards representing five sites, and ranged from 10 – 80% (Table 4). The density of ground cover appears to be an important factor in horned lizard survival. Reynolds (1979) compared Idaho pygmy horned lizard (*Phrynosoma douglasii*) populations in grazed and ungrazed (by sheep) habitat dominated by sagebrush (*Artemisia tridentata*), as well as in grazed and ungrazed habitat that had been converted from sagebrush to densely-planted crested wheatgrass (*Agropyron cristatum*). Crested wheatgrass was introduced to the U.S. from Siberia in the late 1800s, and is commonly used as forage for livestock and as a soil binder along roadsides to prevent erosion (Larson and Johnson 1999). Reynolds found the lizards preferred sagebrush habitats to areas dominated by crested wheatgrass, and that they were most plentiful in the grazed areas dominated by big sagebrush. He hypothesized that the fewer forbs and grasses in the grazed sage study area resulted in more or improved basking sites for horned lizards. He concluded that converting sagebrush range to crested wheatgrass resulted in the reduction of the population levels of the lizards. Additionally, once the native vegetation was replaced by crested wheatgrass, grazing did not appear to further affect the lizard populations. While replacing sagebrush with grass communities causes local horned lizard population declines, populations can still persist, as noted at our Site 3 (Table 4).

Soil compaction has also been shown to be an important determinant of horned lizard presence, as lizards often dig beneath the surface to escape the heat of midday (Sherbrooke 2003), and must be able to burrow to survive the cold temperatures of winter (Mathies and Martin 2008). Stebbins (1985) indicates the ground may be stony, sandy or firm, but usually some fine, loose soil is present. Most of our sites either had burrowing-suitable soft soils (or patches of such soils), or a thin (ca. 0.5 cm or 0.2 in.) hard, cracked crust with soft soil underneath. However, at Site 3, soil was mostly hard, but loose substrate was found on nearby bluffs and draws (Table 4).

Of interest, at one of the historical sites in Harding County, it appeared to us that the habitat had been converted to cropland and then abandoned to grow back to an altered mixed-grass prairie. This was evident by the natural grasses now growing in furrows. We believe activity such as this would have eliminated short-horned lizards at the site. There may be additional cases where lizards no longer exist at historically occupied sites due to past habitat alteration, even though today the habitat appears suitable.

Detection Probabilities and Declaring a Site Unoccupied: What are the chances of seeing short-horned lizards at a given site if they are there? If short-horned lizards are not observed at a given site, how many searches of the site are necessary before it is declared unoccupied? These are important questions to answer when conducting surveys to estimate the distribution of these

lizards and to identify changes in population status over time. For example, when visiting a historical site (where short-horned lizards have been reported to exist in the past), what are our chances of finding a lizard there if populations still persist, and if they are now extinct from the site, how many visits would be necessary to make such a determination?

Detection probabilities (p) can be used to estimate the chance of encountering an animal (short-horned lizard) during any one visit to a site where that species is known to occur (Kery, 2002). Such estimates for short-horned lizards can be derived by visiting sites known to contain lizards multiple times, and simply dividing the number of visits when lizards were observed (n_o) by the number of times the site was searched (n_s), or:

$$p = n_o/n_s \qquad (1)$$

There are many factors that may impact detectability (and thus detection probabilities) of short-horned lizards during a search. Examples are: 1) temperature during search; 2) size of area searched; 3) population size; 4) month searched; 5) duration of search; and 6) experience of searchers in finding lizards. To determine an accurate detection probability for a given site, all the above factors (and probably more) would need to be held constant across all searches, which typically is not likely. For example, if searches are made when temperatures are not conducive to lizard activity, animals may be hidden and less likely seen. Larger search areas may make encounters more likely than smaller ones. If the population size fluctuates, animals may be more likely encountered when more lizards are present. Neonates are usually born in early August in our area (Table 3), adding substantially to the population size and thus detectability. The population then begins diminishing as predation and other forms of lizard mortality occur. Therefore, encounters are probably most likely to occur in August, and diminish gradually during each month of the active season until the following August. It seems reasonable that longer search durations may make encounters with lizards more likely than shorter ones. We feel experienced searchers, those who have found lizards previously and developed a search image, have a better chance of detecting lizards than those without such experience.

We calculated detection probabilities for all sites visited more than once where we found short-horned lizards (Table 5). Since there was variation among all the above listed factors that may impact detectability (Table 6), the detection probabilities should be viewed with caution. Also, the number of visits to any given site was small, ranging from 2 – 5, adding further concern to the reliability of these estimates. Detection probabilities for individual sites ranged from 0.33 – 1.00, and if all sites are combined, the overall detection probability is 0.73.

Kery (2002) developed a method utilizing detection probabilities to estimate the number of surveys required of a given site to demonstrate within a given confidence level the absence of a species, represented by the following model:

$$N_{min} = \log(\alpha) / \log(1 - p), \qquad (2)$$

where N_{min} is the minimum number of visits necessary before concluding a site is unoccupied, α is the probability of not seeing an animal after N visits, and p is the detection probability. If we set a confidence level of 95% (and thus $\alpha = 0.05$), we get:

$$N_{min} = \log(0.05) / \log(1 - p). \qquad (3)$$

From this we can calculate N_{min} for all populations with known detection probabilities (Table 5). N_{min} for individual sites ranged from 1.0 – 7.4, and if all sites are combined, the overall N_{min} is 2.3. Confidence intervals of N_{min} were estimated as suggested by McArdie (1990) by plugging the upper and lower confidence limits for p into formula 2. Confidence limits for p were

calculated as described for proportions (Steele and Torrie 1960) according to the following equation:

$$p +/- z_{.05}(\text{normal}) \sqrt{[p(1-p)/n]} \qquad (4)$$

where *p* is the observed proportion of times lizards were sighted at all sites combined in Table 5 (combined detection probability, 0.73), and n is the number of combined visits (22) to all sites. With the tabular value of $z_{.05} = 2.07$ (for n = 22), upper and lower 95% confidence limits were thus calculated for *p* as 0.9239 and 0.5308, respectively. Plugging these values into equation 3, the estimated 95% confidence interval of N_{min} is 1.2 - 4.0. Therefore, using the upper limit, if any site is searched four times and no lizards are found, we can say with relative confidence the site is unoccupied. Using this value, no historical site can be declared unoccupied. However, Sheep Mountain Table in Badlands National Park, Pennington Co., represents a historical site that was surveyed three times, with no lizards found (Site 11). Thus, it is doubtful that a population exists there. If we use a less conservative N_{min} of 2, two additional sites can be declared unoccupied (Sites 8 and 9 in Harding Co.), and using a N_{min} of 1 (slightly outside our 95% confidence interval), five more sites are declared unoccupied (Sites 4 – 7 and 10).

Estimated Distribution in the State: The distribution of *Phrynosoma hernandesi* in South Dakota is presented in Figure 1. It is a species of the Great Plains Steppe Ecosystem, ranging west of the Missouri River. In the historical past, it may have ranged throughout much of this ecosystem, except perhaps the southeastern portion, which contains Gregory, Tripp, Todd, Melette, Lyman and Jones Counties. No records of *Phrynosoma* exist from this region in South Dakota or in adjacent areas of neighboring Nebraska (Lynch 1985). Records from Stanley and Perkins Counties may indicate a distribution that once spanned the two sites through Dewey, Zebach and Carson Counties, thus embracing the northwestern corner of the Great Plains Steppe Ecosystem.

Short-horned lizards also intrude into South Dakota's Black Hills ecosystem in areas of relatively open canopy and sandy or soft soils. While such an intrusion may have been more prevalent in the past, our observations suggest it may only be occurring today in a somewhat isolated area of extreme western Lawrence County, adjacent to the Wyoming border. For descriptions of the above two ecosystems, see South Dakota Department of Game, Fish and Parks (2006).

Our work suggests that today this species may only range in Harding, Perkins, extreme western Lawrence, Fall River, Shannon, and perhaps Butte and extreme southwestern Custer Counties. Historically reported from Meade, Pennington, Stanley, and western Jackson Counties, this species may no longer persist there. The constriction of the range is probably a result of conversion of native prairie to cropland or densely planted pasture. In the Black Hills, populations of short-horned lizards may have been suppressed through policies that promoted dense canopy cover. For a discussion on these factors, see the following section on *Conservation Concerns and Management Recommendations*.

The populations of short-horned lizards in the southwestern corner of South Dakota (Fall River and Shannon Counties) appear strong (See Sites 1, 18, 20, 22 - 25, 27, and 30). In this region, short-horned lizards also have been reported in the adjacent Nebraska counties of Sioux, Dewes, and Sheridan (Lynch 1985). The lizards probably range broadly in Fall River County across much of the remaining natural prairie within and south of the Cheyenne River basin. Site 24 indicates they also may range into the extreme southwestern corner of Custer County in the Dewey area. However, they have not been observed in the Angostura Reservoir (of the Cheyenne River) area in central Fall River County (William Collignon, pers. comm.) (Angostura Recreation Area), so they may range slightly south of this region (Sites 1 and 27), and eastward

into and through much of Shannon County (Platt 2004, Platt et al. 2004, Snethen et al. 2009) (Sites 18, 25, 29, and 30).

The Pennington County population (Site 11) appears to have vanished. There may be no populations further north in that county (Randy Griebel, pers. comm.) (Wall Ranger District, Buffalo Gap National Grassland), and no records indicate short-horned lizards from other areas. Our searches of the Jackson County site within Badlands National Park (Site 28 A - C), today's most easterly record in the state, and perhaps within the entire range of the species, revealed no lizards.

The Lawrence County record (Site 2) probably represents an extension of a population in Crook County, Wyoming (Site 26), and may be the sole representative population remaining in Lawrence County and in the Black Hills. As discussed in the *Conservation Concerns and Management Recommendations* and *Further Research* sections below, this population needs further investigation and should be carefully monitored and protected.

We found no short-horned lizards at one historical Butte County site (Site 4), and were unable to gain access to the other (Site 13). Additionally, no lizards have been sighted at a large ranch a few miles west of Belle Fourche (Jodi Massie, pers. comm.) or at Bear Butte State Park (Jim Jandreau, pers. comm.). From this information, persistence of short-horned lizard populations in Butte County is questionable. However, there are numerous historical records of short-horned lizards to the north from adjacent Harding County, and they also have been reported in neighboring Crook County, Wyoming, to the west (Site 26), but have not been reported from adjacent Carter County, Montana (Werner et al. 2004). Given this information, coupled with our observations that portions of northern and western Butte County appear suitable to support short-horned lizard populations, the lizards may still persist in these areas.

We did not find lizards in Harding County, but it is very difficult to evaluate populations there, as most sites are on private land, and access was either denied or landowners could not be located to gain access permission (see Sites 4, 8 – 10, and 12 - 16). It is possible that there are lizard populations in this county, as suitable habitat exists, and 37% of the historical records in the South Dakota Department of Game, Fish and Parks Natural Heritage Database are from there. This is tempered, however, by the fact that ownership of these lands is primarily in private hands, and it is difficult to evaluate land usage patterns in the county. In at least one historical locality in Harding County, it is possible that habitat alteration in the past caused the elimination of a short-horned lizard population (see pages 9 – 10). Short-horned lizards have been reported from adjacent Bowman County, North Dakota (Jeff LeClere, pers. comm.), but not from neighboring counties in Montana (Werner et al. 2004).

The lizards appear to range from Harding through northern Perkins Counties (Site 3) and, since Site 3 is in close proximity to Corson County, they may range into the northwestern corner there as well.

Once reported from Meade, Stanley, and Pennington Counties, the lizards now appear extinct from those areas, perhaps due to conversion of native prairie to cropland and densely-planted pasture (see discussion on *Conservation Concerns and Management Recommendations,* below). It should be noted, however, that populations in these counties may persist, but have gone undetected or unreported.

Conservation Concerns and Management Recommendations: As mentioned above, our major concern regarding threats to this species in South Dakota is the conversion of native prairie into cropland or densely-planted pasture. Because of such action, the range of short-horned lizards in the state may be shrinking. This impact appears most prevalent in the northeast and central portions of the range within the state, as noted from our observations in Stanley and Meade Counties (Sites 17 and 19), but is also apparent elsewhere (Site 5). Reynolds (1979) concluded that converting sagebrush range to crested wheatgrass resulted in the reduction of population

densities of pygmy horned lizards (*Phrynosoma douglasii*), a closely-related species. He felt that increased plant density may be a negative factor for lizard survival. It should be noted that we observed apparently healthy short-horned lizard populations in cattle-grazed areas of natural prairie (areas without supplemental planting) (Sites 1, 20, and 21), and one site with dense ground cover (Site 3). It is of concern that more acreage of natural prairie habitat may be converted to densely planted pasture or to monocultures of various crops, resulting in further decline of short-horned lizard populations. Habitat alteration is also a concern at higher elevation sites in the Black Hills National Forest, managed by the U.S. Forest Service. For example, the western Lawrence County locality is scheduled for logging in the near term, although the U.S. Forest Service has worked with us to decrease the likelihood that this population will be adversely affected by such activity.

The main dietary component of short-horned lizards is ants, with smaller amounts of grasshoppers, beetles and crickets (Hotton 1955, Pianka and Parker 1975, Montanucci 1981, Powell and Russell 1984). If the food sources are eliminated from an area, short-horned lizards residing there will not survive. Therefore, the widespread use of insecticides is of conservation concern for lizard populations. Such use is not only for pest control to protect crops, but also to combat diseases such as West Nile virus and plague. An example of such disease control measures may have been demonstrated at one of the historical short-horned lizard sites (Site 11). Lizards had been reported from this site, which was within a large prairie dog town. Plague struck the prairie dogs, and the town was dusted with insecticide in 2008 to kill the plague-carrying fleas (Eddie Childers, pers. comm.) (Badlands National Park). While surveying this site in 2009 it was noticed that few ants were evident (only one mound could be located), and no lizards were found. While no direct cause and effect can be demonstrated between these events, insecticide use may have been a factor in ant, and thus short-horned lizard, declines. Diseases must be fought, and crops must be protected from insect invasions, but we encourage use of insecticides in as discriminating a manner as possible, especially if short-horned lizard populations are known to exist in these areas. Studies regarding the effect of insecticides used in prairie dog towns on non-target organisms, such as insects other than plague-carrying fleas, are underway (Dan Licht, National Park Service, pers. comm.).

Short-horned lizards sometimes can be found on or very near sand or dirt roads (Tom Mathies pers. comm., our observations). They may be attracted to such roads due to their lack of ground cover (providing basking opportunities) and soft, disturbed soil (enhancing burrowing). We have received reports of lizards being killed on these roads (Lynn Hetlet and Grace Kostel, pers. comm.) (Buffalo Gap National Grassland and Black Hills State University, respectively), creating concern regarding vehicle use within areas known to contain short-horned lizard populations.

Commercial collection of short-horned lizards for the pet trade was once an issue of conservation concern, but due to legal constraints of this activity, such collection is no longer occurring to our knowledge. However, monitoring of the situation should continue, and information about specific lizard collection sites should be released only for legitimate use, thus preventing potential unlawful collection for the pet trade. Noncommercial collection of a limited number of animals for educational displays in institutions or for research is probably not of conservation concern at this time, as few animals are removed from wild populations for these purposes. However, individuals legally conducting such activities should note that maintaining these animals in captivity is difficult and requires special equipment and specific food resources (Montanucci 1983). Another concern is the non-commercial collection of the species by individuals who simply want them as pets. We have been told by a variety of people that they have found one or more lizards in the wild and decided to keep them in captivity. Unfortunately, the lizards usually die quickly. When feasible, such collection activity should be discouraged.

Further Research: Further surveys for short-horned lizards in South Dakota need to be conducted to better understand their distribution in the state. The climatic, temporal, and habitat parameters, as well as the search techniques defined above, can help researchers in their efforts to find additional lizard populations. The use of predictive ecological niche modeling should help further define appropriate areas to search for lizards and provide insight into the potential distribution of these lizards in the state (Peterson 2001, Peterson et al. 2002, Illoldi-Rangel et al. 2004). Such modeling also can be coupled with molecular genetic population data to link the geographic configuration of population distributions with analyses of genetic differentiation (Hodges *in prep.*). Predictive models of future distributions can direct conservation efforts by highlighting populations at risk of losing genetic diversity, and managing these populations to mitigate a loss in diversity at the species level.

Little is known about the population dynamics of short-horned lizards. During our searches for these lizards, we surveyed large areas where none were found, but also encountered patches containing several animals, all in seemingly appropriate habitat to support populations. From this, we feel that lizard populations are localized, creating clumped distributions throughout the landscape, and that they rise and fall in various locations over time. Gaining a better understanding of this potential process and the gene flow associated with it should provide insight into the landscape requirements to conserve this species.

The proportion of sites where a species has been observed can serve as a crude estimate of the proportion of area occupied (Hecnar and M'Closkey 1997, Pilliod and Peterson 2001). Ideally, surveys conducted to make such an estimate should be made over a short time interval from a large number of sites. This information, along with individual counts (the total number of specimens observed) (Petranka et al. 1993, Hecnar and M'Closkey 1997, Aubry 2000) can be compared over time or space to make inferences about temporal changes in community status or the effects of environmental or anthroprogenic factors (Petranka et al. 1993, Skelly et al. 1999, Pilliod and Peterson 2001).

To further understand the habitat requirements of short-horned lizards, research regarding microhabitat use is needed. This information can then be applied to investigations about the impact of various land management practices on lizard populations. As noted by Reynolds (1979) and discussed above, certain practices can be detrimental to lizard populations. In particular, we noticed lizards apparently absent in some historical sites that have been converted to cropland and densely-planted pasture, and in one site in which it appeared that the site had been converted to pasture and then allowed to lie fallow and revegetate with wild grasses (see pages 9 – 10). *In situ* uranium mining is planned for areas inhabited by short-horned lizards in the Burdock/Dewey area (northwestern Fall River and southwestern Custer Counties), creating an ideal setting for investigating the impact of such activities. We found apparently healthy populations of lizards in cattle-grazed areas of natural prairie in Buffalo Gap National Grassland (Sites 17, 20, and 21). With the cooperation of National Grassland personnel, plots could be established to examine the impact of cattle grazing on lizard populations. We suspect light cattle grazing in natural prairie may positively affect short-horned lizard populations, as cattle, like their bison predecessors, may help prevent dense vegetative growth. As discussed above, such growth is detrimental to horned lizard populations (Reynolds 1979).

Population viability analyses are important in designing conservation plans for species. Demographic data such as age specific fertility and survival are important components of predicting population trends. Such data are not available for South Dakota short-horned lizard populations.

The population of short-horned lizards found near 1525 m (5000 ft.) elevation in the mixed ponderosa pine and burr oak forest is intriguing (Site 2). Not only is the habitat of this population in sharp contrast to that of the prairie populations, but the timing of reproduction seems to be earlier and in sync with more northerly populations (Canada). The genetic

distinctiveness of this population should be investigated, and a comparison made with various natural history and behavioral traits to nearby prairie populations.

As a final note regarding future research for this species, we found that its extremely localized distribution, coupled with the imprecise locality data, made it difficult to find historical populations. For example, several such populations are each listed as occurring in a given section of land (precision of 1 square mile), and other sites are even less precisely located (for example, "White Butte, South Dakota"). A small population of lizards could exist anywhere in these relatively large search areas. We have been much more successful in locating populations using recent data that were recorded using Global Positioning Systems (GPS). While we realize this is not always feasible at the time lizards are encountered, coordinates should be obtained as soon as possible by revisiting the populated sites with GPS devices to obtain the data. With such precise data, locating sites on subsequent visits to monitor lizard populations is often successful. We want to emphasize that obtaining precise locality data is critical in conserving short-horned lizard populations.

Acknowledgements

This project was funded by the South Dakota Department of Game, Fish and Parks. Doug Backlund and Eddie Childers issued scientific permits for the State and Badlands National Park, respectively. Doug Backlund is also thanked for providing short-horned lizard historical site locales from the South Dakota Department of Game, Fish and Parks Natural Heritage Database. For assistance in the field we are indebted to Amanda Bowe, John Duvall-Jisha, Lynn Hetlet, Jim Holmes, Tamara Lawson, Mark Mazza, Kristen Spiel, and Scott Weins, and for taking the time and effort to lead us to sites where they had observed short-horned lizards, we thank Lynn Hetlet and Scott Weins. We also thank Nate Arnold, Doug Backlund, Valerie Carlson, Eddie Childers, William Collignon, Lynn Hetlet, Steve Hirtzel, Mark Hollenbeck, Grace Kostel, Daryl E. Mergen, Richard and Juanita Peterson, Steve Platt, Daniel G. Snethen, David Swanson, Nuvi Uzunlar, Scott Weins, Arlin Whirlwind Horse, and Elijah Whirlwind Horse for providing locality data of short-horned lizard sightings. For general information about short-horned lizard sightings (or lack thereof), we thank Bob Hodorff and Randy Griebel. A special thanks goes to Tom Mathies, who shared his wealth of experience about how to search for short-horned lizards and how to sex them. For guidance regarding detection probability analysis, we thank Gary Casper.

Literature Cited

Aubry, K.B. 2000. Amphibians in managed, second-growth Douglas-fir forests. Journal of Wildlife Management 64:1041-1052.

Audsley, B.W., C.E. Bock, Z.F. Jones, J.H. Bock, and H.M. Smith. 2006. Lizard abundance in an ex-urban southwestern savanna, and the possible importance of roadrunner predation. American Midland Naturalist 155:395-401.

Bailey, L.L., T.R. Simons, and K.H. Pollock. 2004. Estimating site occupancy and species detection probability parameters for terrestrial salamanders. Ecological Applications 14(3):692-702.

Barrows, C.W., M.F. Allen, and J.T. Rotenberry. 2006. Boundary processes between a desert sand dune community and an encroaching suburban landscape. Biological Conservation 131:486-494.

Baxter, G.T. and M.D. Stone. 1980. Amphibians and reptiles of Wyoming. Bulletin 16. Wyoming Game and Fish Department, Cheyenne, Wyoming. 137 pp.

Beauchamp, B., B. Wone, S. Bros, and M. Kutilek. 1998. Habitat use of the flat-tailed horned lizard (*Phrynosoma mcallii*) in a disturbed environment. Journal of Herpetology 32:210-216.

Bragg, A.N., and H.A. Dundee. 1949 [1950]. Reptiles in the vicinity of Las Vegas, New Mexico. Great Basin Naturalist 9(3-4):55-57.

Brattstrom, B.H. 1997. Status of the subspecies of the coast horned lizard, *Phrynosoma coronatum*. Journal of Herpetology 31:434-436.

Crump, M.L., and N.J. Scott, Jr. 1994. Visual encounter surveys. Pp. 84-92 in Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Heyer, W.R., M.A. Donnelly, R.W. McDiarmid, L.C. Hayek, and M.S. Foster, eds. Smithsonian Institution Press, Washington, D.C.

Dammann, J. 1949. Birth of 18 young *Phrynosoma douglasii hernandesi* (Girad). Herpetologica 5:144.

Degenhardt, W.G., C.W. Painter, and A.H. Price. 1996. Amphibians and reptiles of New Mexico. University of New Mexico Press, Albuquerque, New Mexico. 431 pp.

Donaldson, W., A.H. Price, and J. Morse. 1994. The current status and future prospects of the Texas horned lizard (*Phrynosoma cornutum*) in Texas. The Texas Journal of Science 46:97-113.

Dood, A.R. 1980. Terry Badlands nongame survey and inventory: final report (BLM contract # YA-512-CT8-217), Montana Department of Fish, Wildlife, and Parks. 70 pp.

Douglass, C.L. 1966. Amphibians and reptiles of Mesa Verde National Park, Colorado. University of Kansas Publications of the Museum of Natural History 15(15):711-744.

Fisher, R.N., A.V. Suarez, and T.J. Case. 2002. Spatial patterns in the abundance of the coastal horned lizard. Conservation Biology 16:205-215.

Gehlbach, F.R. 1956. Annotated records of southwestern amphibians and reptiles. Transactions of the Kansas Academy of Science 59(3):364-372.

Gelbach, F.R. 1965. Herpetology of the Zuni Mountains region, northwestern New Mexico. Proceedings of the US National Museum 116:243-322.

Goldberg, S.R. 1971. Reproduction in the short-horned lizard *Phrynosoma douglassi* in Arizona. Herpetologica 27(3):311-314.

Grant, T.J., and P.F. Doherty, Jr. 2007. Monitoring of the flat-tailed horned lizard with methods incorporating detection probability. Journal of Wildlife Management 71:1050-1056.

Guyer, C. and A.D. Linder. 1985. Thermal ecology and activity patterns of the short-horned lizard (*Phrynosoma douglassi*) and the sagebrush lizard (*Sceloporus graciosus*) in southeastern Idaho. Great Basin Naturalist 45(4):607-614.

Hammerson, G.A. 1999. Amphibians and reptiles in Colorado. University Press of Colorado, Niowt, Colorado. 484 pp.

Harris, A.H. (ed.). 1963. Ecological distribution of some vertebrates in the San Juan Basin, New Mexico. Museum of New Mexico Papers in Anthropology (8):1 – 64.

Hampton, P. 2007. A comparison of the success of artificial cover types for capturing amphibians and reptiles. Amphibia-Reptilia 28:433-437.

Hecnar, S.J., and R.T. M'Closkey. 1997. Spatial scale and determination of species status of the green frog. Conservation Biology 11:670-682.

Hodges, K. *in prep*. Coupling genetic data and ecological niche modeling for turtle conservation. Wildlife Genetics Laboratory, Institute for Applied Ecology, University of Canberra ATC, Australia.

Hotton, N., III. 1955. A survey of adaptive relationships of dentition to diet in North American Iguaidae. American Midland Naturalist 53(1):88-114.

Hudson, G.E. 1985. The amphibians and reptiles of Nebraska. Nebraska Conservation Bulletin 24. University of Nebraska Conservation and Survey Division, Lincoln, Nebraska. 146 pp.

Illoldi-Rangel, P., V. Sánchez-Cordero, and A.T. Peterson. Predicting distributions of Mexican mammals using ecological niche modeling. Journal of Mammalogy 85(4):658-662.

Kery, M. 2002. Inferring the absence of a species – A case study of snakes. Journal of Wildlife Management 66(2):330-338.

Kiesow, A.M. 2006. Field guide to amphibians and reptiles of South Dakota. South Dakota Department of Game, Fish and Parks, Pierre, South Dakota. 178pp.

Kjoss, V.A., and J.A. Litvaitis. 2001. Comparison of two methods to sample snake communities in early successional habitats. Wildlife Society Bulletin 29:153-157.

Larson, T.E., and J.R. Johnson. 1999. Plants of the Black Hills and Bear Lodge Mountains. South Dakota State University, Brookings, South Dakota. 608pp.

Leaché, A.D., and J.A. McGuire. 2006. Phylogenetic relationships of horned lizards (*Phrynosoma*) based on nuclear and mitochondrial data: Evidence for a misleading mitochondrial gene tree. Molecular Phylogenetics and Evolution 39(2006):628-644.

Lynch, J.D. 1985. Annotated checklist of the amphibians and reptiles of Nebraska. Transactions of the Nebraska Academy of Sciences XIII:33–57.

Mathies, T., and D.J. Martin. 2008. Overwintering site selection by short-horned lizards (*Phrynosoma hernandesi*) in northeastern Colorado. Journal of Herpetology 42(1):163-171.

McArdle, B.H. 1990. When are rare species not there? Oikos. 57:276-277.

Montanucci, R.R. 1981. Habitat separation between *Phrynosoma douglassi* and *P. orbiculare* (Lacertilia: Iguanidae) in Mexico. Copeia 1981(1):147-153.

Montanucci, R.R. 1983. Breeding, captive care and longevity of short-horned lizard *Phrynosoma douglassi*. International Zoo Yearbook 23:148-156.

Mosimann, J.E., and G.B. Rabb. 1952. The herpetology of Tiber Reservoir Area, Montana. Copeia 1952:23-27.

NatureServe. 2009. NatureServe Explorer: An online encyclopedia of life (web application). Version 7.1. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. (Accessed: October 13, 2009).

Peterson, A.T. 2001. Predicting species' geographic distributions based on ecological niche modeling. Condor 103:599-605.

Peterson, A.T., L.G. Ball, and K.C. Cahoon. 2002. Predicting distributions of tropical birds. Ibis 144:e27-e32.

Petranka, J.W., M.E. Eldridge, and K.E. Haley. 1993. Effects of timber harvesting on southern Appalachian salamanders. Conservation Biology 7:363-370.

Pianka, E.R., and W.S. Parker. 1975. Ecology of horned lizards: a review with special reference to *Phrynosoma platyrhinos*. Copeia 1975(1):141-142.

Pilliod, D.S., and C.R. Peterson. 2001. Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. Ecosystems 4:322-333.

Platt, S. G. 2004. Herpetological surveys of southwestern South Dakota April – October 2004. Final project report to the South Dakota Department of Game, Fish and Parks, 523 East Capitol Avenue, Pierre, South Dakota 57501.

Platt, S. G., Z. Fast Horse, S. Mannel, C. Comes Killing, and T. R. Rainwater. 2004. A herpetofaunal survey of southwestern South Dakota with emphasis on species of conservation concern. Report to the South Dakota Department of Game, Fish and Parks, 523 East Capitol Avenue, Pierre, South Dakota 57501.

Powell, G.L., and A.P. Russell. 1984. The diet of the eastern short-horned lizard (*Phrynosoma douglassi brevirostre*) in Alberta and its relationship to sexual size dimorphism. Canadian Journal of Zoology 62(3):428-440.

Price, A.H. 1990. *Phrynosoma cornutum*. Catalogue of American Amphibians and Reptiles 469:1-7.

Prieto, A.A., Jr., and W.G. Whitford. 1971. Physiological responses to temperature in the horned lizards, *Phrynosoma cornutum* and *Phrynosoma douglasii*. Copeia 1971:498-504.

Reynolds, T.D. 1979. Response of reptile populations to different land management practices on the Idaho National Engineering Laboratory site. Great Basin Naturalist 39(3):255-262.

Russell, A.P., and A.M. Bauer. 1993. The amphibians and reptiles of Alberta. University of Calgary Press, Calgary, Alberta, Canada. 264 pp.

Sherbrooke, W.C. 2003. Introduction to Horned Lizards of North America. University of California Press, Berkeley, California. 178 pp.

Skelly, D.K., E.E. Werner, and S.A. Cortwright. 1999. Long-term distributional dynamics of a Michigan amphibian assemblage. Ecology 80:2326-2337.

Smith, C. 1941. Birth of horned toads. Copeia 1941:114.

Snethen, D. G., E. Whirlwind Horse, and A. Whirlwind Horse. 2009. Extension of the known range of the short-horned lizard *Phrynosoma hernandesi* from eastern Shannon County, South Dakota. Dakota Amphibian and Reptile News: 2(2): 11-12.

South Dakota Game, Fish and Parks. 2006. South Dakota comprehensive wildlife conservation plan. South Dakota Department of Game, Fish and Parks, Pierre, South Dakota. Wildlife Division Report 2006 – 2008. 213 pp.

Stebbins, R.C. 1985. A field guide to western reptiles and amphibians. Houghton Mifflin Company, Boston. 336 pp.

Steele, R.G.D., and J.H. Torrie. 1960. Principles and procedures of statistics with special reference to the biological sciences. McGraw-Hill Book Company, Inc. New York. 481 pp.

Tanner, V.M. 1942. Notes on the birth and growth of horned lizards. Great Basin Naturalist 3:60.

Tanner, W.W. 1953. Herpetological notes. Herpetologica 9:139-140.

Tanner, W.W. 1954. Herpetological notes concerning some reptiles of Utah and Arizona. Herpetologica 10:92-96.

Werner, J.K., B.A. Maxell, P. Hendricks, and D.L. Flath. 2004. Amphibians and reptiles of Montana. Mountain Press Publishing Co., Missoula, Montana. 262 pp.

Wheeler, G.C., and J. Wheeler. 1966. The amphibians and reptiles of North Dakota. The University of North Dakota Press, Grand Forks, North Dakota.

Woodin, W.H. 1953. Notes on some reptiles from the Huachuca area of southeastern Arizona. Bulletin of the Chicago Academy of Science 9:285-296.

Table 1. Climatic conditions, times of day and elevations at which short-horned lizards were found during this study. Sky conditions are 0 = clear or few clouds (< 10% cover); 1 = partly cloudy (10 – 25% cover); 2 = 25 – 50% cover; 3 = 50 -75% cover; 4 = mostly cloudy, fog or mist (> 75% cover).

	Time h	Temperature ^{o}C (^{o}F)	Sky Conditions	Average wind speed km/hour (miles/hour)	Elevation m (feet)	Relative humidity
Mean	1051 +/- 1.2	26 +/- 3.6 (78.9 +/- 6.3)	0.4 +/- 0.9	4.6 +/- 4.5 (2.8 +/- 2.7)	1186 +/- 188 (3889 +/- 616)	32.7 +/- 5.9
Range	0835 – 1250	20.5 – 33.9 (68.8 – 93.0)	0 – 4	1.0 – 18.2 (0.6 – 11.3)	756 - 1520 (2479 – 4984)	25 – 39
Sample size	30	30	33	25	33	7

Table 2. Search effort in hours per short-horned lizard and detection rate in lizards per hour for 2008 and 2009.

	May	June	July	August	September	Total
Number of lizards found	0	5	0	30	10	45
Total hours searched	17	31	26	69.5	24	167.5
Hours/lizard	-----	6.2	-----	2.3	2.4	3.7
Lizards/hour	0	0.16	0	0.43	0.42	0.29

Table 3. Size (snout-to-vent length, or SVL) of short-horned lizards encountered from June through September 2008 – 2009. Not all lizards found were measured.

2009 Julian Date	Calendar Date	SVL (cm)
181	30 Jun 2009	4.1
218	05 Aug 2008	2.5, 2.5, 2.5, 7.0, 7.0, 7.5
222	09 Aug 2008	2.2, 2.5, 7.8, 7.8
226	13 Aug 2008	2.6
233	20 Aug 2008	2.6, 5.0, 5.2
242	30 Aug 2009	2.5, 2.9
243	31 Aug 2009	2.6, 2.7
245	02 Sep 2009	2.4, 2.6, 2.9, 3.0
247	03 Sep 2008	3.0
253	09 Sep 2009	2.7, 2.9
259	15 Sep 2009	3.0
261	17 Sep 2009	2.9, 3.0

Table 4. Habitat description of sites where short-horned lizards were found. Multiple ground cover estimates per site indicate measures for multiple lizards. Such measures were not made for all lizards encountered.

Site number (County)	**General habitat description**	**Description of vegetation within general area of lizard**	**Estimated % ground cover within 0.5 m (1.6 ft.) radius of lizard**	**Soil description within 0.5 m (1.6 ft.) radius of lizard**
1 (Fall River)	Prairie	Scattered grasses, sunflowers and sage	----------	Ca. 0.5 cm (0.2 in.) hard, cracked crust with soft, loose soil underneath
2 (Lawrence)	Mixed, open ponderosa pine and burr oak forest	----------	----------	Loose sand
3 (Perkins)	Prairie	Dense grass	----------	Mostly hard soil. Loose soil on nearby bluffs and in draws.
20 (Fall River)	Prairie	Scattered big sage and grasses	50 – 75 50	Ca. 0.5 cm (0.2 in.) hard, cracked crust with soft, loose soil underneath
21 (Fall River)	Prairie	Scattered winterfat (*Drashkinninikovia lantana*), grasses and cactus (*Opuntia*)	75 – 80 50 – 60 10 50	Ca. 0.5 cm (0.2 in.) hard, cracked crust with soft, loose soil underneath
22 (Fall River)	Prairie	Scattered big sage, grasses and cactus (*Opuntia*)	50	Soft soil, perhaps shale
23 (Fall River)	Prairie	Scattered sage, grasses and cactus (*Opuntia*)	30	Ca. 0.5 cm (0.2 in.) hard, cracked crust with soft, loose soil underneath

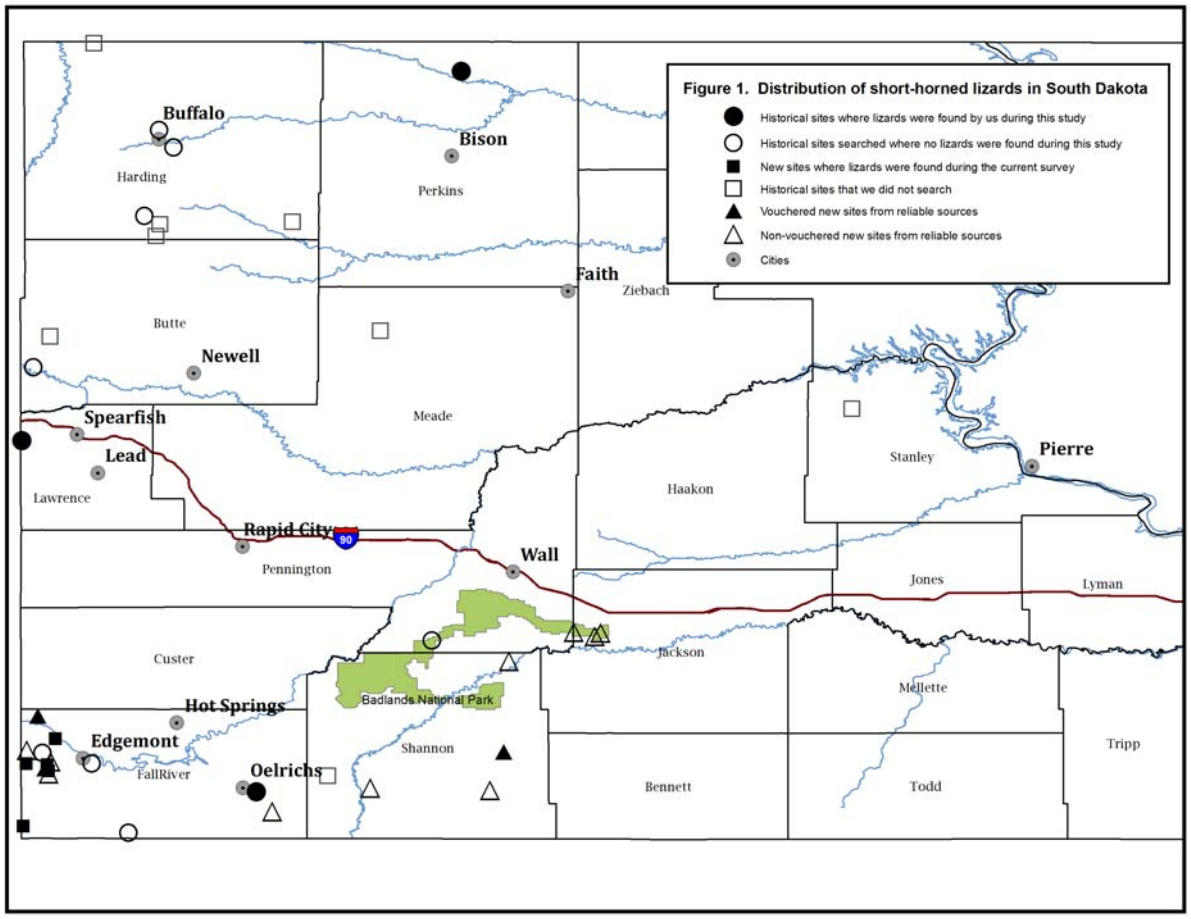
Table 5. Detection probabilities (*p*) and the minimum number of surveys required of a given site to demonstrate the absence of short-horned lizards (N_{min}) as calculated from sites where lizards were found. The 95% confidence interval for the combined results N_{min} is 1.2 – 4.0. For descriptions of sites (corresponding to site number), and for models used in calculations, see the text.

Site number	Number of times site searched (n_s)	Number of times lizards were found (n_o)	Detection probability ($p = n_o/n_s$)	N_{min}
1 (Fall River)	3	1	0.33	7.4
2 (Lawrence)	3	2	0.67	2.7
3 (Perkins)	2	1	0.50	4.3
20 – A (Fall River)	5	4	0.80	1.9
21 (Fall River)	4	4	1.00	1.0
22 (Fall River)	3	2	0.67	2.7
23 (Fall River)	2	2	1.00	1.0
Combined results	22	16	0.73	2.3

Table 6. Factors potentially influencing detectability of short-horned lizards during site searches (see text for complete list). Size of area searched was not included, as such measures were not made. Indicators of searcher experience were also not included, as such attributes are difficult to quantify. Relative population size is represented by the maximum number of lizards seen during any one visit. Sites listed are those where lizards were found.

Site number (County)	Temperature range during searches °C (°F)	Relative population size	Months surveyed	Range of search duration (person-hours)
1 (Fall River)	25 - 31 (76 – 88)	1	Jun, Aug, Sep	3 – 7
2 (Lawrence)	20 - 30 (68 – 85)	3	Jun	5 - 12
3 (Perkins)	20 (68)	3	Aug	3
20 – A (Fall River)	21 - 23 (70 – 87)	14	Jun, Aug, Sep	2 – 6
21 (Fall River)	24 - 31 (75 – 87)	4	Aug, Sep	4 – 5
22 (Fall River)	23 - 32 (74 – 90)	4	Jul, Aug	4 – 7
23 (Fall River)	26 - 34 (78 – 93)	1	Sep	3

Figure 1. Distribution of short-horned lizards in South Dakota.



Appendix I. Short-horned lizard "wanted poster."

HAVE YOU SEEN ME?

Photo by Doug Backlund

Short-Horned Lizard

(also called a Horned Lizard, a Horned Toad, or a Horny Toad)

We're working with the South Dakota Department of Game, Fish and Parks to conduct a statewide survey for short-horned lizards during the summers of 2008 and 2009. Basically, we want to know where they're found. If you've seen one, please let us know where and when, by e-mail or phone.

Contact Information:

Dr. Brian Smith
Department of Biology
Black Hills State University
Brian.Smith@BHSU.edu
605-642-6879

Dr. Hugh Quinn & Holly Quinn
Department of Biology
Black Hills State University
DoubleHQ@aol.com
605-342-0583

Appendix II. Systematic sampling survey form utilized in this study.

Systematic Sampling Survey

Survey type: ☐VES ☐Calling Date: Search time (start/end/total):

Number of searchers: Searcher Name(s):

Location (descriptive, state, county, place):

UTM zone/datum: Elevation:

Easting/Northing +/- accuracy:

Lat/Long: TRS Location:

Habitat description:

Wind*: Clouds*: Precip*: Moon*: Temp (^{o}F, ^{o}C):

Species observed (include UTM coordinates, Lat/Long and elevation for each if possible and/or reasonable, life state if known, vouchers or photographs taken, other data)

Survey number (office use): Entered by (office use):

o----------o

*Wind: 0 = smoke rises vertically; 1 = wind direction shown by smoke drift; 2 = wind felt on face, leaves rustle; 3 = leaves and small twigs in constant motion, light flag extended; 4 = raises dust and loose paper, small branches are moved; 5+ for higher winds.

*Clouds: 0 = clear or few clouds (<10% cover); 1 = partly cloudy (10 – 25% cover); 2 = 25 – 50% cover; 3 = 50 – 75% cover; 4 = mostly cloudy, fog, or mist (>75% cover).

*Precip: 0 = none; 1 = drizzle; 2 = light rain; 3 = showers

*Moon: N/A = daylight; 0 = none, new moon or covered by clouds; 1 = crescent to half moon; 2 = half to full moon.

Form revised 24 May 2008