2013-11-26

Habitat Selection and Nesting Ecology of Snowy Plover in the Great Basin

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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December 2013

ABSTRACT

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Snowy plovers (*Charadrius nivosus*) are small, ground-nesting shorebirds that are a species of conservation concern throughout North America. Despite increased efforts to understand factors contributing to the decline of snowy plover, little is known about habitat selection and breeding ecology of snowy plover for the large population found in the Great Basin. We tested hypotheses concerning the occupancy and nesting success of snowy plover. First, we identified factors influencing snowy plover nest survival at Great Salt Lake, Utah. We hypothesized that snowy plover would demonstrate differences in nest survival rates across years due to differences in habitat characteristics, predator abundance, human influence, resource availability, and fluctuating water levels. We conducted nest surveys at five sites along the Great Salt Lake to locate new nests or monitor known nests until nest fate was determined. We found 608 nests between 2003, 2005-2010, and 2012. The most common cause of nest failure was predation, followed by weather, abandonment, and trampling. Nest survival estimates ranged from 4.6 – 46.4% with considerable yearly variation. There was no correlation between researcher activity (visits to nests and trapping of adults) and nest survival. Nests in close proximity to roads had lower survival than nests far from roads. Nests located on barren mudflats also had lower survival than nests in vegetated areas or near debris. We found that nests had a higher probability of survival as they increased in incubation stage. Because nesting areas around the Great Salt Lake host some of the largest concentrations of breeding snowy plover in North America, we suggest that managers consider measures to maintain suitable nesting habitat for snowy plover.

Second, we determined factors affecting snowy plover occupancy and detection probabilities in western Utah between 2011 and 2012. We hypothesized that snowy plover would be associated with spring water flows and sparsely vegetated salt flats. We made repeated visits to randomly selected survey plots recording the number of snowy plover adults and habitat characteristics within each plot. We modeled the relationship between snowy plover detection probability and habitat and environmental characteristics. The detection probability was 77% (95% CI = 64 – 86%) and did not vary by year. There was a positive relationship between ambient temperature and detection probability. Next, we modeled the relationship between snowy plover occupancy and individual habitat characteristics including distance to water, distance to roads, land cover types, and vegetative characteristics. Snowy plover occupancy did not vary by year and was estimated at 12% (95% CI = 7 – 21%). Occupancy was best predicted by close proximity to water, playa land cover, and minimal shrub cover. We used habitat characteristics that best predicted snowy plover occupancy to generate a predictive habitat model that can help prioritize future snowy plover surveys and guide conservation efforts.

Keywords: *Charadrius nivosus*, detection probability, Fish Springs National Wildlife Refuge, Great Salt Lake, nest survival, occupancy models, shorebird, snowy plover

ACKNOWLEDGMENTS

First I thank Dr. Randy Larsen and Robbie Knight (U.S. Army Dugway Proving Ground) for giving me the opportunity to do this research. Dugway Proving Ground provided funding for this project and I thank Robbie for that. Randy has advised me in my education and research and without his help I would not have been able to complete this thesis. I thank my graduate committee members, Dr. Brock McMillan and Dr. Steve Petersen for their willingness to assist me with this project. I also thank the Avian Ecology Laboratory at Weber State University for providing sources of funding for this project. I thank Dr. John Cavitt for first introducing me to the snowy plover and whose passion for avian ecology has had lasting effects on me. Finally, I thank my family for providing me with confidence and drive to pursue this degree. My mom has always encouraged me to work hard and I owe everything to her. I especially thank my husband, Clint, for his never-ending supply of patience and encouragement, and my dogs for maintaining my sanity during stressful times.

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CHAPTER 1

FACTORS INFLUENCING SNOWY PLOVER NEST SURVIVAL AT GREAT SALT LAKE, UTAH

ABSTRACT

Reduced nest survival is considered a primary cause for the decline of snowy plover. Previous estimates of nest survival from the Great Salt Lake have suffered from low sample sizes and there is a need to understand spatial and temporal variation in nest survival. Moreover, the influence of climate and habitat variables on nest survival has not been assessed at this important shorebird conservation area. We monitored fates of 589 snowy plover nests from 5 sites at Great Salt Lake in 2003, 2005-2010, and 2012. We used a 5-stage hierarchical modeling procedure and identified 5 competing models ($\Delta AIC_c < 2$) that best described variation in nest survival. These competing models included the influences of study site and year with a quadratic time trend, and covariates quantifying nest age, temperature, precipitation, distance to roads, and nesting substrate (barren mudflat, vegetation patches, or conspicuous objects). Among unsuccessful nests (48%, n = 284), the most common cause of failure was predation (72.9%), followed by weather and abandonment (10.5% and 10.1%, respectively). Daily nest survival rates ranged from 0.74 to 0.99 and varied annually and across sites while generally following a quadratic time trend. We found that nests located on barren flats had a negative relationship with daily survival rate (β = -1.11 ± 0.30, 95% CI = -1.70 – -0.53), whereas daily survival rate was not sensitive to nests located in vegetated patches (β = 0.33 ± 0.31, 95% CI = -0.28 – 0.93) or near conspicuous objects (β = 0.12 ± 0.27, 95% CI = -0.41 – 0.65). Our results further indicated that roads negatively influenced nest survival as nests within 100 m of roads had lower daily survival rates than nests further than 100 m from roads (β = -1.10 ± 0.21, 95% CI = -1.51 – -0.70). The

population of snowy plover at the Great Salt Lake contributes substantially to an overall imperiled North American population. Managers should preserve habitats for snowy plover by considering measures that will maintain high nest survival rates in local populations.

INTRODUCTION

Factors that influence avian nest survival include parental condition (Davis 1975, Croxall et al. 1992, Wiebe and Martin 2000), nest initiation date (Perrins 1996, Johnson and Walters 2008, Barati et al. 2011), and location of the nest in relation to habitat features (Whittingham et al. 2002, Conway et al. 2005b, Smith et al. 2007, Walpole et al. 2008, Catlin et al. 2011). For many birds, earlier initiation of nests within the breeding season results in greater nest survival (Perrins 1996), although this pattern is not always evident (Johnson and Walters 2008, Barati et al. 2011). Habitat features associated with nest survival include amount and type of cover surrounding nests (Page et al. 1985, Norte and Ramos 2004, Conway et al. 2005b, Walpole et al. 2008, Ballantyne and Nol 2011, Colwell et al. 2011), substrate type (Whittingham et al. 2002, Colwell et al. 2005, Greenwald 2009, Colwell et al. 2011), distance to surface water (Conway et al. 2005b, Saalfeld et al. 2011), and distance to roads. Recent evidence, for example, suggests that roads and dikes increased the possible penetration of meso-predators into wetlands and contributed to increased depredation of waterfowl nests (Frey and Conover 2006). Reduced nest survival may have profound implications on population dynamics of avian species.

Reduced nest survival is considered a primary cause of the decline in snowy plover (*Charadrius nivosus*) abundance (U.S. Fish and Wildlife Service 2007). Snowy plovers are broadly, but intermittently distributed across North America and depend on coastal shoreline and brackish, sparsely-vegetated lake habitats for breeding, wintering, and migration stopover areas

(Page et al. 2009). Nest failure for snowy plover is often caused by mammalian and avian predation, weather (e.g., flooding, hail, and wind), trampling, and human disturbance (Page et al. 2009). Recent evidence, for example, suggests that human disturbance reduces snowy plover chick survival as chick mortality was greater where human activity was highest (Ruhlen et al. 2003). Moreover, unlike many shorebirds that are colonial nesters (Siegel-Causey and Hunt 1981, Post and Seals 1993), snowy plover nest in loose conspecific aggregations (Page et al. 1985, Warriner et al. 1986, Paton 1995) where reduced nest survival can be associated with high nest density due to density-dependent predation (Page et al. 1983). The relationship between nest survival and nest density poses conservation challenges for snowy plover as anthropogenic influences reduce availability of suitable nesting habitat (Page et al. 1983).

Nest microhabitat characteristics can potentially affect snowy plover nest survival by altering: nest concealment (Colwell et al. 2011), ability to detect predators (Amat and Masero 2004), thermoregulation (Purdue 1976), and the effects of precipitation (Sexson and Farley 2012). Snowy plover nests are often located near or in clumps of vegetation or conspicuous objects (e.g., debris, gravel, or cow dung; Page et al. 1985, Paton 1995, Saalfeld et al. 2012). Vegetative cover provides concealment and may reduce scent dispersal for eggs and incubating adults (Smith et al. 2007). In contrast, open areas with a substrate allowing for camouflage of eggs (e.g., pebbles, sand, and mud chips) allows adults to maintain an open view of their surroundings to facilitate predator detection (Götmark et al. 1995, Colwell et al. 2011).

The Great Salt Lake hosts approximately 23% of breeding snowy plover in North America (Thomas et al. 2012). The Great Salt Lake and associated shoreline habitat is one of North America’s most important inland shorebird sites and is designated a site of hemispheric importance within the Western Hemisphere Shorebird Reserve Network (Andres et al. 2006).

Despite this designation, changing habitat conditions due to expansion of mineral extraction, encroachment of nonnative common reeds (*Phragmites australis*; Kulmatiski et al. 2010), and reduced fresh water inflow provide conservation challenges that may impact snowy plovers. Previous estimates of snowy plover nest survival from the Great Salt Lake have had considerable annual and area-specific variation (estimates of annual nest survival ranged from 5.4 – 49.2%; Paton 1995). Previous estimates from the Great Salt Lake, however, have suffered from low sample sizes and/or limited temporal and spatial replication. Despite the importance of the Great Salt Lake to snowy plover, there is relatively little known about the breeding biology of snowy plover at this site.

Increased efforts to monitor snowy plover at the Great Salt Lake over the last decade have resulted in a robust data set. Our specific objectives were to use this data set to 1) estimate annual nest survival for snowy plover at the Great Salt Lake 2) test hypotheses about spatial and temporal variation in nest survival in relation to habitat features, and 3) determine probable causes of nest failure. Because human influence can negatively influence shorebird populations (including snowy plovers), there is a need to further understanding of limiting factors affecting these birds (Page et al. 2009). We hypothesized that snowy plover would demonstrate differences in nest survival among sites and across years due to differences in predator abundance, resource quality and availability, fluctuating water levels, and human influence. Specifically, we predicted that nest survival would be higher with earlier nest initiation and that it would be lower near or on roads.

METHODS

Study areas

The Great Salt Lake is a hypersaline lake in north-central Utah. It is a closed-basin system that covers an average of 4,400 km^2 with a maximum depth of approximately 10 m (Arnow and Stephens 1990, Stephens 1990). The Southern Pacific Railroad Causeway divides the lake into two distinct bays with unique ecological characteristics. The northern part of the Great Salt Lake is characterized by high salinity (>25%) due to little freshwater inflow and is rarely used by waterfowl or shorebirds (Stephens 1990, Aldrich and Paul 2002, Loving et al. 2002). The southern part has lower salinity (average 13%) and receives most of the freshwater inflow from several rivers and streams (Stephens 1990, Loving et al. 2002).

The Great Salt Lake is located within the Great Basin, which is classified as a cold desert environment. Average monthly temperatures at Great Salt Lake between 1981 and 2010 ranged from approximately -3° C in January to 25° C in July. Maximum monthly temperatures were highest in July, approximately 33° C. Annual precipitation was approximately 41 cm (Western Regional Climate Center online; www.wrcc.dri.edu; station ID# 427578, accessed 4 Dec 2012).

Vegetation in snowy plover nesting areas comprised of pickleweed (*Salicornia europeae rubra*), iodinebush (*Allenrolfea occidentalis*), and salt grass (*Distichlis spicata*; Flowers 1934). Additionally, the Great Salt Lake is bordered by approximately 1,900 km^2 of freshwater and brackish wetlands, primarily on the east side of the lake (Aldrich and Paul 2002). Our study was conducted at five sites. These sites included the Great Salt Lake Shorelands Preserve, Bear River Migratory Bird Refuge, Ogden Bay Waterfowl Management Area, Farmington Bay Waterfowl Management Area, and Saltair along the eastern and southern edges of the Great Salt Lake (Figure 1).

Nest surveys

We conducted nest surveys ≥ 1 time per week at each site during the breeding season (early April - mid August; Paton 1995) in 2003, 2005-2010, and 2012 to locate new nests or monitor known nests until nest fate was determined. We located nests by observing adult snowy plovers incubating, flushing from, or returning to nests. Once located, we recorded the spatial coordinates of each nest with a handheld GPS unit. We also recorded nest substrate type by noting its location in either vegetation, barren flats, or on or next to conspicuous objects (e.g., debris, cow dung, gravel mound, etc.). We then floated eggs to estimate incubation stage and determine initiation date assuming an egg-laying period of four days and a 27-day incubation period (Paton 1995, Page et al. 2009).

We estimated daily survival rate from the beginning of incubation, which we assumed to begin after the last egg had been laid (Page et al. 2009). Nests were defined as successful if at least one young hatched and a minimum of one chick survived long enough to exit the nest (Mabee and Estelle 2000). Nests were presumed successful when found without eggs near the expected date of hatching and there was indirect evidence of a successful hatching. Indirect evidence included the presence of young, the presence of eggshell tops and bottoms near the nest, egg shell fragments 1-5 mm in size and detached egg membranes within the nest lining (Mabee 1997, Mabee et al. 2006). A nest was presumed depredated when we observed large pieces of eggshell (>8 mm), yolk spots, animal tracks, and similar disturbances in or around the nest. A nest was classified as flooded if there was evidence of a recent rain event, or visible intact eggs near the nest.

Data analysis

To evaluate hypotheses concerning variation in nest survival based on site, climate, location of nest, and timing of nest initiation, we used model selection and the nest survival model within Program MARK v6.2 (Table 1; White and Burnham 1999, Dinsmore et al. 2002). We standardized the earliest date a nest was found, April 26, as day 1 of the nesting season for all sites in each year. Encounter histories for nest survival analysis in Program MARK required input of the day a nest was found, the day it was last observed active, the day it was last checked, and nest fate. We included covariates for the age of the nest when found based on estimated initiation date, the amount of precipitation on each day of the nesting season, the maximum temperature on each day of the nesting season, whether the nest was within 100 m of a road, the average number of times the nest was checked per week, and whether there were any adult capture attempts during incubation. We selected 100 m from roads by plotting apparent survival and distance to roads and noting where the upward trend leveled off (non-linear relationship with distance). Additionally, we included categories for nesting substrate types: vegetation, barren mudflat, or conspicuous objects.

We evaluated relative model support using Akaike's Information Criterion adjusted for small sample sizes (AICc; Akaike 1973, Burnham and Anderson 2002). We used a 5-stage hierarchical modeling procedure, similar to previously-used methods for estimating snowy plover nest survival (Sexson and Farley 2012). To identify the most supported model within each stage, we included every additive combination of covariates of the same type (Table 1). The most supported model or multiple competing models (ΔAICc < 2) from each stage were advanced to the next stage of model building. In stage 1, we built models to assess the relationship between daily survival rate and time, including linear (T) and quadratic relationships

(TT). We also assessed annual and spatial (site) variation in this stage. In stage 2, we added the age of the nest when found to competing models from stage 1. In stage 3, we added temperature and precipitation to the best model from stage 2. Daily maximum and minimum temperatures were correlated ($r = 0.89$, $P < 0.01$) and thus not included in the same models. In stage 4, we added habitat covariates (nest substrate and within 100 m of unpaved roads) to the top two models from stage 3. In stage 5 we added covariates to assess researcher effect including trapping attempt and average number of days each nest was visited per week. In the event of model-selection uncertainty, we generated model-averaged estimates of nest survival (Burnham and Anderson 2002). To evaluate individual covariates, we looked for overlap in confidence intervals around real parameters and whether or not 95% CI around β estimates overlapped zero. We calculated annual estimates of nest success by exponentiating daily survival rate (DSR) to 27, consistent with a 27-day incubation period (Paton 1995, Page et al. 2009).

RESULTS

We found 608 nests during 2003, 2005-2010, and 2012 (Table 2). A 110-day nesting season was estimated from 26 April to 13 August (day first nest discovered to day last nest was active). We estimated the earliest nest to have initiated on 17 April, and the latest on 13 July. We used valid encounter histories, consisting of at least 1 exposure day for 589 nests (Table 2). We could not construct encounter histories for 19 nests (3.1%) because they were found after they had failed or hatched. The most common cause of failure was predation (72.9%), followed by weather and abandonment (10.5% and 10.1%, respectively). Other causes of nest failure included unknown causes such as trampling by cattle, vehicles, and humans; and unviable eggs (6.5%).

Mean daily survival rate was high at Farmington Bay Waterfowl Management Area (0.975; 95% CI = 0.962 – 0.984; *n* = 83), Bear River Migratory Bird Refuge (0.969; 95% CI = 0.943 – 0.983; *n* = 47), Ogden Bay Waterfowl Management Area (0.966; 95% CI = 0.955 – 0.975; *n* = 105), and Great Salt Lake Shorelands Preserve (0.963; 95% CI = 0.965 – 0.969; *n* = 229; Figure 2). Saltair had the lowest daily survival rate (0.917; 95% CI = 0.897 – 0.933; *n* = 125; Figure 2). Overall daily survival rate for all years and sites was 0.959 (95% CI = 0.954 – 0.963). Nest survival over the entire incubation period for snowy plovers at the Great Salt Lake ranged annually from 0.046 – 0.464 ($\bar{x}$ = 0.323; Table 2).

We developed 36 candidate models through a 5-stage hierarchical modeling procedure (see Table 3 for top models resulting from stages 1 through 4 and all models in stage 5). Stage 5 of model building produced 5 models with ΔAICc < 2. Each of these models included the interactive effect of group (study site, year, and quadratic time trend) and nest age. The most parsimonious model included 44 parameters (AICc weight = 0.25), including the interactive effect of study site, year, and quadratic time trend, as well as, nest age (β = 0.03 ± 0.01, 95% CI = 0.01 – 0.06), daily maximum temperatures (β = 0.04 ± 0.02, 95% CI = 0.02 – 0.07), nesting substrate (Figure 3a; objects: β = 0.12 ± 0.27, 95% CI = -0.41 – 0.65; vegetation: β = 0.33 ± 0.31, 95% CI = -0.28 – 0.93; mudflat: β = -1.11 ± 0.30, 95% CI = -1.70 – -0.53), and within 100 m of roads (Figure 3b; β = -1.10 ± 0.21, 95% CI = -1.51 – -0.70) (Table 3). The first competing model (AICc weight = 0.22) included daily precipitation (β = -0.04 ± 0.03, 95% CI = -0.08 – -0.01) replacing daily maximum temperatures. Among the competing models, 95% confidence intervals for β estimates associated with average number of nest checks per week and/or attempted trapping overlapped zero and were considered to be uninformative parameters (Arnold

2010) (Table 4). A quadratic time trend best described daily survival rate for all years suggesting that nest survival was highest mid-season (Figure 2).

DISCUSSION

Estimates of nest survival for snowy plovers were highly variable at the Great Salt Lake and ranged from 0.05 – 0.46 ($\bar{x}$ = 0.32) with considerable site and yearly variation. Our estimates are similar to those from previous studies at the Great Salt Lake (0.05 - 0.49, 0.46 respectively; Paton 1995, Edwards 2009), Southern High Plains of Texas (0.07 - 0.33; Saalfeld et al. 2011), Kansas (0.11 - 0.29; Sexson and Farley 2012), and Oregon (0.13; Wilson-Jacobs and Meslow 1984). However, our estimates have a lower limit than estimates from California (0.36 - 0.77; Powell et al. 2002), Salt Plains National Wildlife Refuge, Oklahoma (0.37 - 0.58; Winton et al. 2000), and were lower than those reported in Puerto Rico (0.61 - 0.73; Lee 1989). Yearly variation in nest survival of shorebirds is common and could be a result of fluctuating water levels, differences in predator abundance, resource quality and availability, and human influence (Colwell 2010).

Different breeding sites in the same local region can contain sub-populations that exhibit differences in reproductive success (Pulliam and Danielson 1991). We observed the lowest average daily survival rate at Saltair, which was the only site in our study that allowed unrestricted public access to all potential nesting habitats. We did not quantify recreational use or the frequency of human presence at any site. However, anecdotal observations suggest Saltair had more human activity in nesting areas than other sites. Human activity has been shown to negatively influence snowy plover (Ruhlen et al. 2003, Webber et al. 2013). Management protocols for predator removal and public access differed considerably among sites. Daily survival rate for snowy plover was high at Bear River Migratory Bird Refuge where there was limited access into nesting areas and predator removal, but the observational nature of our study precluded determination of the effect limited access or predator removal had on nest survival rates. Moreover, it is unclear whether predator removal methods used at Bear River Migratory Bird Refuge are successful in reducing predator populations (Frey and Conover 2007).

Roads are recognized as a threat to avian species through direct mortality, habitat loss, habitat degradation, and reduced connectivity (Forman et al. 2003). However, the majority of road disturbance studies focus on the density of bird species in relation to high-traffic paved roads, even though unpaved roads account for nearly 40% of total road length in the USA (Forman et al. 2003). In our study, proximity to a road was included in our top model and snowy plover nests within 100 m of roads had lower probability of daily survival than nests further than 100 m from roads (Figure 3). Snowy plover nest survival was not highly affected when nests were within 20 m of roads in Kansas (Sexson and Farley 2012). Mammalian meso-predators may be using roads as corridors into nesting areas (Frey and Conover 2006). Similarly, avian predators such as the common raven are strongly associated with the development of roads and linear right-of-ways (Simpson et al. 2011).

The effect of nest microhabitat characteristics on snowy plover nest survival varies among studies and breeding areas. We found that daily survival rate had a negative relationship with nests located on barren flats. In coastal Texas, nests were more successful when located in barren flats than in vegetated areas (Hood and Dinsmore 2007). In some studies, snowy plover nests near debris had lower survival rates than those in open habitats (Page et al. 1985, Winton et al. 2000), however, snowy plover nests near debris had greater survival rates in coastal Texas (Hood and Dinsmore 2007). Although for most nests, the risk of predation decreases with increased cover (Götmark et al. 1995), objects in barren landscapes could be responsible for attracting avian and mammalian predators to nests (Winton et al. 2000). Snowy plover nests in coastal California were more successful on gravel bars with heterogeneous substrates than on beaches with homogeneous substrates (Colwell et al. 2011). We found that nest survival was not sensitive when nests were located in vegetated areas or near debris and objects. Nesting near objects has not been shown to affect nest survival of snowy plover in many studies (Hill 1985, Powell 2001, Norte and Ramos 2004, Saalfeld et al. 2012). In northern California, snowy plover nest survival had a weak relationship with habitat features, possibly because of high predator activity in a small area (Hardy and Colwell 2012). Similarly, nest survival of snowy plovers in Kansas was not highly influenced by nest microhabitat characteristics (Sexson and Farley 2012). Variation in the relationship between habitat features and nest survival across snowy plover populations suggests local differences such as predation, weather, and human disturbance, may overwhelm the effects of nest site selection on survival.

In our study, predation accounted for 73% of snowy plover nest failures while weather and abandonment each accounted for 10%. In many shorebird species, predation is the greatest cause of nest failure (Nguyen et al. 2003, Conway et al. 2005a, Smith et al. 2007). Nest predation is hypothesized to be a limiting factor in plover populations (Johnson and Oring 2002). In Kansas, snowy plover nest failures were primarily attributed to flooding (43%) and predation was much lower than values we observed (15%; Sexson and Farley 2012). In the Southern High Plains of Texas, predation accounted for 40% of nest failures and weather accounted for 36% of nest failures (Saalfeld et al. 2011). Although we did not quantify predator abundances, the main predators observed included coyote (*Canis latrans*), raven (*Corvus corax*), gulls (*Larus spp.*), red fox (*Vulpes vulpes*), and raccoon (*Procyon lotor*).

We found that weather events can have negative impacts on nesting snowy plover at the Great Salt Lake as precipitation ranked high in our top models. Nonetheless, flooding only accounted for 10% of all nest failures. In the Great Plains and Texas, flooding can be a major cause of nest failure (Grover and Knopf 1982, Conway et al. 2005a, Sexson and Farley 2012). Extreme weather events (e.g., hail storms and flooding) do not occur as frequently in northern Utah as in the Great Plains, resulting in fewer nests being destroyed by weather. Management to reduce the negative effects of precipitation has been implemented in other snowy plover populations with varying levels of success. Randomly dispersed mounds or ridges, constructed out of naturally occurring materials that allow water to drain away from nest sites, have shown to successfully mitigate the effects of precipitation on nest survival (Sexson and Farley 2012).

In our study, nest survival was not sensitive to researcher influence (average number of nest visits per week or trapping attempts during incubation) as these effects received very little support as predictors of nest survival. Human activities near nesting areas have been shown to affect reproduction rates of snowy plover (Warriner et al. 1986, Ruhlen et al. 2003, Colwell et al. 2005). Human presence may influence nest survival directly through trampling of nests or disturbance of incubating adults. Indirect effects of human presence may attract nest predators. Ravens, for example, have been shown to depredate snowy plover nests immediately after incubating adults flush from in response to a disturbance (Hardy and Colwell 2012). Our results are consistent with work on mammalian nest predators showing no influence from human scent on success of ground-nesting birds (Skagen et al. 1999).

Our results indicated that nest age was positively associated with survival rates. A positive relationship between nest age and daily survival rate has been previously documented in snowy plovers (Dinsmore et al. 2002, Hood and Dinsmore 2007) and our results support this consensus. Early initiation of nests can be associated with increased nest survival, although this pattern has not been consistent across studies for snowy plover (Page et al. 1983, Powell 2001, Norte and Ramos 2004, Conway et al. 2005a, Saalfeld et al. 2011). This relationship likely exists because the most vulnerable nests fail early (Klett and Johnson 1982). It is also possible that incubating adults change their behavior as nests age, influencing the probability of nest survival (Smith and Wilson 2010). Additionally, some species of biparental shorebirds increase nest defense as their nest ages throughout the breeding season (Smith and Wilson 2010).

The population of snowy plover at the Great Salt Lake is the largest population at any site surveyed during the International Snowy Plover Survey (Thomas et al. 2012). Habitat preservation for snowy plovers at Great Salt Lake should be coupled with measures to maintain high nest survival rates. We found that the predation rate of snowy plover nests at the Great Salt Lake was higher than other North American populations. Predator use of roads as travel corridors has possible implications for the success of nesting snowy plover (Frey and Conover 2006). Because we found that roads can have negative impacts on snowy plover nest survival, management plans should limit roads in nesting areas and install informative signs alerting visitors of the presence of ground-nesting shorebirds during the nesting season. Efforts to manage human activity in snowy plover nesting areas have been successful along the Pacific Coast (Lafferty et al. 2006, Wilson and Colwell 2010). The Great Salt Lake population of snowy plover contributes substantially to an overall imperiled North American population. Therefore, we suggest that managers consider measures to maintain suitable nesting habitat for snowy plover.

ACKNOWLEDGMENTS

We thank members of the Avian Ecology Lab at Weber State University for assistance with field work and data entry, especially C. Edwards, L. Hall, E. Parker, S. Rumsey, and J. Vargas. Support and access to study sites was provided by B. Barrett, S. Vaughn, V. Bachman, C. Brown, R. Hansen, and A. Neville. This study was funded by the Tides Foundation, The Nature Conservancy of Utah, Rio Tinto – BirdLife International Partnership Fund, Weber State University – Office of Undergraduate Research, U.S. Fish and Wildlife Service Region 6, the Utah Division of Water Quality, and the Utah Division of Forestry, Fire and State Lands.

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Table 1-1. Covariates hypothesized to influence snowy plover nest survival at Great Salt Lake, Utah (2003, 2005-2010, 2012). We present mean ± standard error or percentages.

Stage	Abbreviated Covariate	Description	Overall Mean
2	Age	Age of nest when found based on estimated initiation date	10.5 ± 0.30
3	Prcp	Cumulative amount of precipitation on each day of the nesting season (mm)	1.10 ± 0.13
3	Tmax	Maximum temperature on each day of the nesting season (°C)	30.27 ± 0.23
	Substrate:		
4	Obj	Nest located on or next to object	20.37% (120 of 589)
4	Bar	Nest located on barren flat	39.39% (232 of 589)
4	Veg	Nest located in vegetation	40.24% (237 of 589)
4	Road	Nest located within 100 m of road	28.52% (168 of 589)
5	Trap	Attempted trapping at nest any time during incubation	31.41% (185 of 589)
5	AvgC	Average number of times nest was checked per week	2.96 ± 0.13

Table 1-2. Number of snowy plover nests found at Great Salt Lake, Utah (2003, 2005-2010, 2012), during each year, nest fates, number and percent of total nests with a valid encounter history, daily survival rate (DSR) calculated using the means of all covariates in the top model (95% CI), and estimates of annual nest survival (daily survival rate exponentiated to the 27-day incubation period; 95% CI).

	2003	2005	2006	2007	2008	2009	2010	2012	Total
Nests found (*n*)	52	43	45	42	143	102	138	43	608
Nests included (*n*)	52	38	39	39	141	102	135	43	589
Successful (*n*)	34	18	25	14	82	43	80	21	317
Unsuccessful (*n*)	18	18	15	27	60	59	58	22	277
Predation (*n*)	11	15	8	20	45	44	41	18	202 (73%)
Weather (*n*)	0	0	5	2	6	10	6	0	29 (11%)
Trampled (*n*)	0	1	0	0	1	0	3	1	6 (2%)
Abandoned (*n*)	3	2	2	5	2	4	7	3	28 (10%)
Unviable (*n*)	0	0	0	0	2	0	1	0	3 (1%)
Unknown (*n*)	4	0	0	0	4	1	0	0	9 (3%)
Unknown (*n*)	0	7	5	1	1	0	0	0	14
DSR (95% CI)	0.97 (0.96, 0.98)	0.94 (0.91, 0.96)	0.96 (0.94, 0.98)	0.89 (0.84, 0.93)	0.97 (0.96, 0.98)	0.95 (0.93, 0.96)	0.97 (0.96, 0.98)	0.95 (0.93, 0.97)	0.96 (0.95, 0.97)
27-day survival (95% CI)	0.46 (0.30, 0.61)	0.19 (0.08, 0.33)	0.34 (0.18, 0.52)	0.05 (0.01, 0.13)	0.39 (0.30, 0.48)	0.22 (0.14, 0.31)	0.43 (0.33, 0.52)	0.25 (0.12, 0.40)	0.32 (0.28, 0.36)

Table 1-3. Supported models from each stage of analysis for snowy plover nest survival at the Great Salt Lake, Utah (2003, 2005-2010, 2012) showing model stage, model structure, Akaike's Information Criterion adjusted for small sample sizes (AICc), change in AICc from the most supported model (ΔAICc), model weight (w_i), model likelihood, number of parameters (K), and model deviance.

Stage	Model	AICc	ΔAICc	w_i	Model Likelihood	K	Deviance
4	S(year*TT*site+age+Tmax+Substrate+Road)	1586.07	0	0.25	1	44	1497.45
4	S(year*TT*site+age+Prcp+Substrate+Road	1586.28	0.21	0.22	0.90	44	1497.66
5	S(year*TT*site+age+Tmax+Substrate+Road+AvgC)	1586.76	0.69	0.18	0.71	45	1496.12
5	S(year*TT*site+age+Prcp+Substrate+Road+AvgC	1586.88	0.81	0.17	0.67	45	1496.24
5	S(year*TT*site+age+Tmax+Substrate+Road+Trap)	1587.89	1.82	0.10	0.40	45	1497.25
5	S(year*TT*site+age+Prcp+Substrate+Road+Trap	1588.13	2.06	0.09	0.36	45	1497.49
3	S(year*TT*site+age+Tmax)	1628.14	42.07	0	0	41	1545.61
3	S(year*TT*site+age+Prcp)	1629.57	43.50	0	0	41	1547.04
2	S(year*TT*site+age)	1632.41	46.34	0	0	40	1551.90
1	S(year*TT*site)	1641.97	55.69	0	0	39	1563.48

Table 1-4. Model parameters and descriptive statistics of covariates included in the top 5 models of daily survival of snowy plover nests at the Great Salt Lake, Utah (2003, 2005-2010, 2012). Lower and upper 95% CI derived by Program MARK. Covariates with confidence intervals not overlapping 0 flagged with an *. Covariate names match those from table.

Covariate	Weight	β	CI
Age*	100%	0.04	0.02 – 0.07
Road*	100%	-1.13	-1.53 – -0.72
Tmax*	52%	0.04	0.02 – 0.10
Prcp*	48%	-0.04	-0.08 – -0.01
AvgC	34%	0.13	-0.09 – 0.35
Trap	19%	-0.07	-0.37 – 0.23
Substrate:			
Veg	100%	0.33	-0.28 – 0.93
Bar*	100%	-1.11	-1.70 – -0.53
Obj	100%	0.12	-0.41 – 0.65

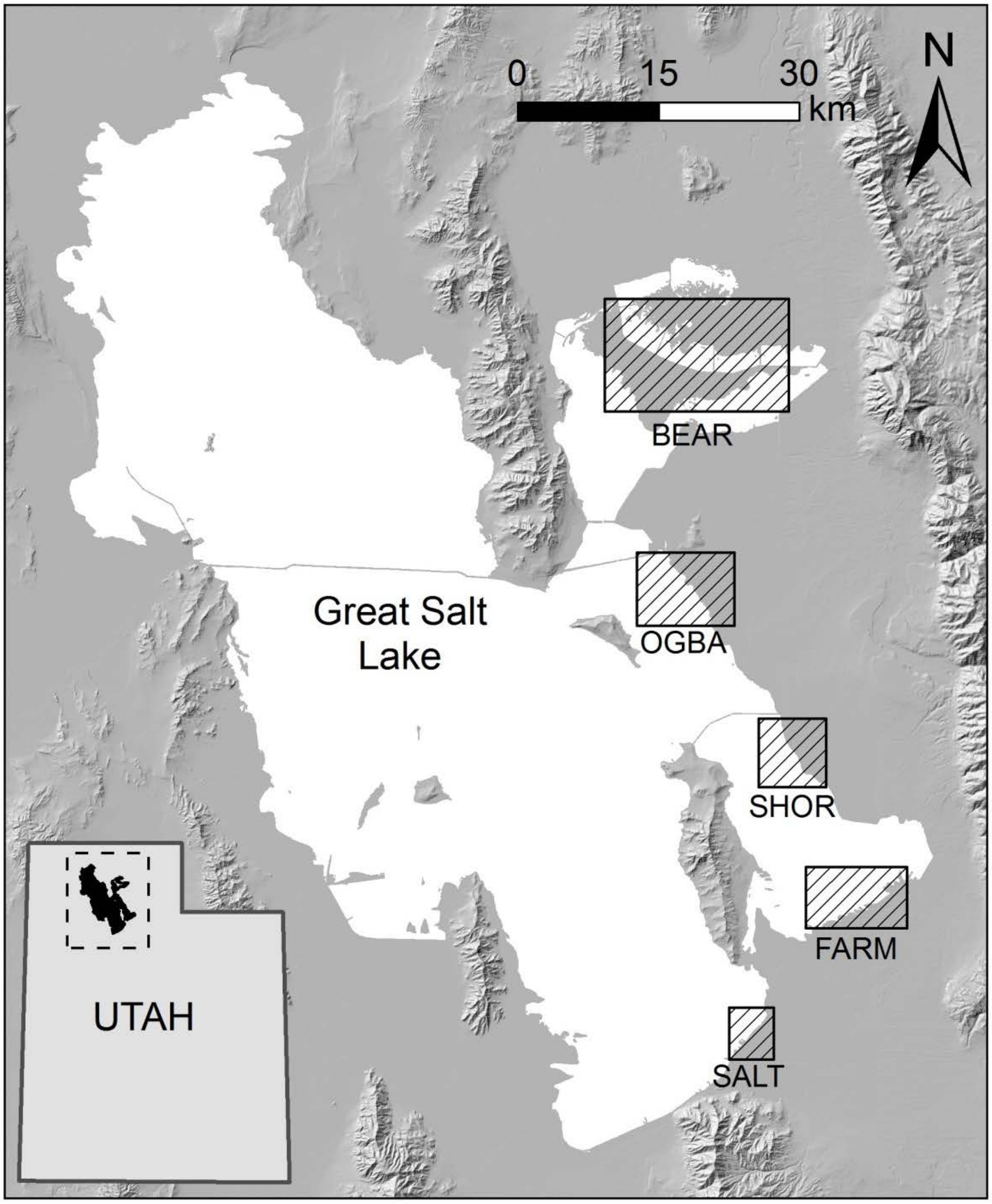

Figure 1-1. Study area at Great Salt Lake, Utah (2003, 2005-2010, 2012) where we investigated factors associated with nest survival of snowy plover. BEAR - Bear River Migratory Bird Refuge, OGBA - Ogden Bay Waterfowl Management Area, SHOR - Great Salt Lake Shorelands Preserve, FARM - Farmington Bay Waterfowl Management Area, SALT – Saltair.

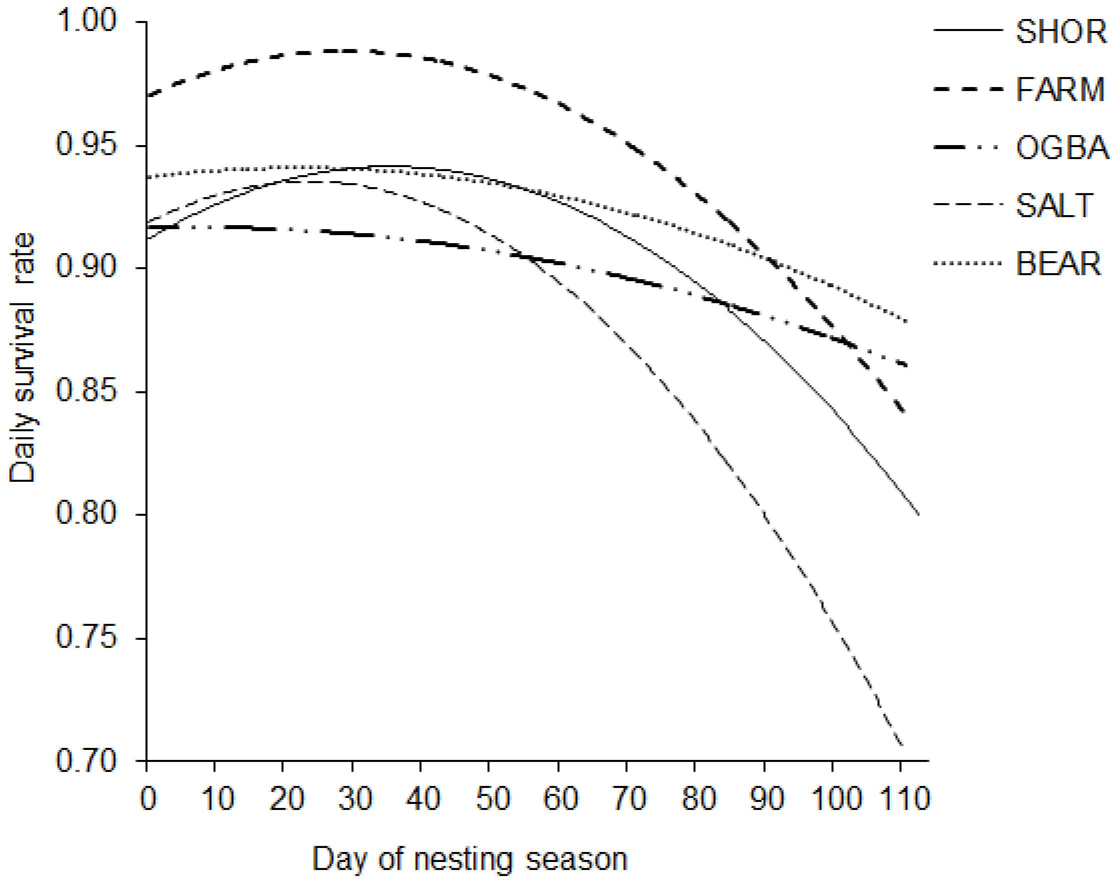

Figure 1-2. Daily survival rate of snowy plover nests at 5 sites over the 110-day nesting season at Great Salt Lake, Utah (2003, 2005-2010, 2012). We calculated daily survival rate using the mean of all covariates in the top model. Day 1 corresponds to 26 April, and day 110 corresponds to 13 August. BEAR - Bear River Migratory Bird Refuge, FARM - Farmington Bay Waterfowl Management Area, OGBA - Ogden Bay Waterfowl Management Area, SHOR - Great Salt Lake Shorelands Preserve, SALT – Saltair.

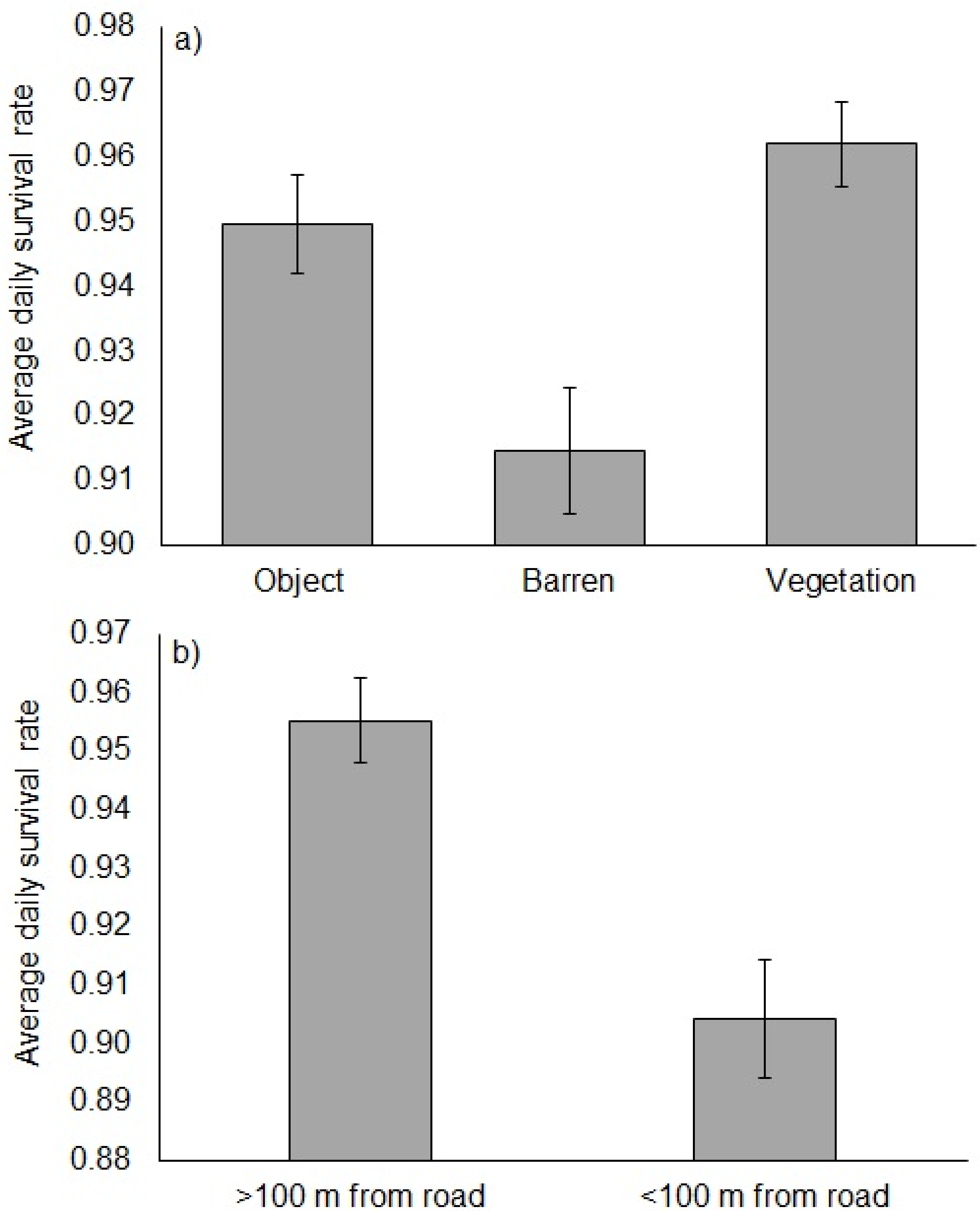

Figure 1-3. Daily survival rates for snowy plover nests found at the Great Salt Lake, Utah (2003, 2005-2010, 2012) in response to changes in habitat covariates with 95% confidence intervals. We calculated daily survival rate using the mean of all other covariates in the top model. We report average daily survival rates and 95% confidence intervals across the 110-day nesting season for nesting substrate at all sites and all years (a), and for nests located > 100 m from road and < 100 m from road at all sites and all years (b).

CHAPTER 2

OCCUPANCY AND HABITAT SELECTION OF SNOWY PLOVER IN WESTERN UTAH

ABSTRACT

A small population of snowy plovers is located in western Utah, however little is known about the distribution and habitat preferences of snowy plover in this area. We conducted a 2-yr study to estimate occupancy of snowy plover in western Utah during 2011 and 2012. We made repeated visits to randomly selected survey plots during the breeding period to estimate detection probability and occupancy rates. We sampled 104 64ha plots in 2011 and 100 64ha plots in 2012, recording the number of adults and habitat characteristics within each plot. We then modeled the relationship between detection of snowy plovers, occupancy of snowy plovers, and covariates that included distance to water, distance to roads, land cover types, and vegetative characteristics. We also included covariates for temperature, cloud cover, and wind speed when modeling detection probability. Detection probability was high (0.769; 95% CI = 0.637 – 0.863) and positively influenced by temperature ($\beta = 0.15 \pm 0.04$, 95% CI = 0.07 – 0.23). Occupancy of 64 ha cells was low (0.123; (95% CI = 0.071 – 0.205) and did not vary by year. Occupancy of snowy plovers was strongly associated with distance to water ($\beta = -5.86 \pm 1.43$, 95% CI = -8.66 – -3.06) and models with this variable received more support than any other variable we evaluated. We used this information to generate a predictive habitat model for western Utah to aid managers with conservation of this imperiled shorebird. Our predictive habitat model suggested that snowy plovers were not evenly distributed within our survey area. The highest concentration of suitable habitat occurred on flat playa near ephemeral water flowing from springs associated with the United States Fish Springs National Wildlife Refuge.

Understanding detection probabilities and occupancy rates in reference to availability of habitat will help further conservation efforts for this species.

INTRODUCTION

Identifying important habitats and predicting species' distributions is fundamental to ecology and conservation. Numerous modeling approaches exist for predicting species distributions (see Elith et al. 2006 for a comparison of several methods). The use of occupancy modeling has become popular over the last decade and is now commonly used to assess and monitor populations (MacKenzie et al. 2006). This modeling approach corrects for imperfect detection of species and models detection probability and occupancy as a function of covariates to provide information about habitat associations (MacKenzie et al. 2006). Occupancy models provide a reasonable method to evaluate populations of rare species when limited detections are expected (Pacifici et al. 2012).

Snowy plovers (*Charadrius nivosus*) are one of the least numerous shorebirds in North America and are believed to be declining throughout much of their geographic range (Brown et al. 2001, Morrison et al. 2006). These plovers are broadly, but intermittently distributed across North America and depend on coastal shoreline and brackish, sparsely-vegetated lake habitats for breeding, wintering, and migration stopover areas (Page et al. 2009). Habitats available to snowy plover and other shorebirds continue to decline as human disturbance and invasive species in these areas increase (Page et al. 2009). North American populations of snowy plover are listed as Highly Imperiled in the United States Shorebird Conservation Plan (Brown et al. 2001) and the Pacific Coast population is listed as Threatened by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 2007).

In western Utah a small population (estimated at < 200 individuals) of snowy plovers is thought to breed on the border of the U.S. Army Dugway Proving Ground and Fish Springs National Wildlife Refuge (hereafter Fish Springs NWR). No snowy plover were detected on survey plots at Dugway Proving Ground during the International Snowy Plover Survey (Thomas et al. 2012). However, snowy plover are regularly observed on Fish Springs NWR and were observed off survey plots during the International Snowy Plover Survey. Interest in developing effective conservation and management planning for snowy plover and their habitats is increasing. However, population distribution and habitat preferences of snowy plover in western Utah remain unknown.

Understanding the influence of habitat features on habitat selection will contribute to improved continental snowy plover conservation (Brown et al. 2001). Snowy plover, and other ground-nesting shorebirds, select for open, sparsely vegetated habitats to facilitate early predator detection (Gochfeld 1984, Martin 1988). Despite numerous studies on snowy plover habitat selection, our understanding is regionally specific and primarily focused on nest-site selection (e.g., Grover and Knopf 1982, Winton et al. 2000, Muir and Colwell 2010, Brindock and Colwell 2011, Saalfeld et al. 2012, Webber et al. 2013). Additionally, few studies involving snowy plover surveys correct counts based on detection probabilities or consider factors affecting detection of snowy plover. More information for habitat selection and detection rates in western Utah will fill a gap for the state, but will also contribute to broader understanding of habitat selection by snowy plover.

Our objectives were to: 1) survey potentially suitable habitat in western Utah and identify occupied habitats; 2) identify factors affecting snowy plover occupancy and detection probability; and 3) generate a predictive habitat model for this species in western Utah. We hypothesized that snowy plover occupancy would be associated with spring water flows and sparsely vegetated salt flats. Also, we hypothesized that detection probability would be high, but not 100%, and influenced by environmental characteristics, such as cloud cover, wind speed, and temperature.

METHODS

Study area

Our study area was located in the alkaline flats and surrounding areas of Tooele county and Juab county, Utah in the southwestern region of Dugway Proving Ground, Tooele County, Utah, and on the adjacent Fish Springs NWR, Juab County, Utah (Fig. 1). Fish Springs National Wildlife Refuge covers 36 km^2 of marsh habitat fed by five major and several minor thermal springs (Stolley et al. 1999). The refuge is managed via impoundments to provide habitat for waterfowl and shorebirds. Spring water flows north onto the alkaline flats of Dugway Proving Ground providing approximately 200 km^2 of breeding and foraging habitat used by snowy plover. As lake bottom from ancient Lake Bonneville, the study area is flat and the soil is saline and alkaline.

With exception to the bordering mountain ranges, the terrain of the study area is characterized by dune systems and alkaline flats that are dominated by pickleweed (*Saliconia europeae*), iodine bush (*Allenrolfea occidentalis*), and salt grass (*Distichlis spicata*) (Stolley et al. 1999*)*. Much of the impoundment area contains emergent marsh vegetation such as native common reed (*Phragmites australis*), cattail (*Typha domingensis*), hardstem bulrush (*Scirpus acutus*), and alkali bulrush (*S. maritimus*) (Stolley et al. 1999). Annual precipitation for the period 1960-2012 averaged 20 cm and mean daily summer temperature extremes greater than

35° C were typical (Western Regional Climate Center online; www.wrcc.dri.edu; station ID #422851, accessed 20 December 2012).

Study design

To select occupancy sampling points, we stratified the study area into high, medium, and low likelihood of occupancy based on land cover types (Southwest Regional Gap Analysis data layer; Lowry et al. 2005) and distance to water using geographic information systems (GIS; ArcMap®, version 10, Environmental Systems Research Institute, Redlands, California). Suitable snowy plover habitat included sparsely vegetated flats and the shorelines of ponds and streams. We used high resolution imagery (obtained in 2011 from the National Agricultural Imagery Program) of the study area to generate random sample points in each area of likelihood with 70% of sample points in high, 20% in medium and 10% in low likelihood areas. We spaced all sample points a minimum of 2 km apart to avoid double counting non-incubating snowy plover (Paton 1995).

At each sample point, we surveyed 800 m^2 plots centered at the random location using accepted snowy plover survey protocol (Hood and Dinsmore 2007, Thomas et al. 2012). From 5 May - 2 August 2011 and 7 May - 15 June 2012 we surveyed each plot on two separate occasions by a different observer who was naïve to the survey location. We conducted each plot revisit within 7 days of the first survey. Repeated sampling provided data for estimation of detection probabilities. In Utah, snowy plover arrive in late March and begin laying eggs during mid-April (Paton 1995). The breeding season continues through the end of July (Paton 1995). Our survey dates ensured occupancy surveys were conducted during the core breeding period and after spring migrants had moved through the area. Nonetheless, some movement in or out of the population may have occurred during this period, however, relaxation of the closure assumption for occupancy models is acceptable if movements occur at random (MacKenzie et al. 2006).

To eliminate extraneous sources of variation in detection probability, we surveyed each plot in a standardized pattern by foot and attempted to maintain equal survey time (about 1 hour) across all visits. We conducted surveys only when there was no precipitation and wind speeds were < 50 km/h. During each survey, we recorded the number of adults observed within the plot boundaries. Because we walked through the plot in a standardized pattern from one end to the other we believe risk of double-counting individuals was minimized. To understand factors affecting detection probability of snowy plover, we also measured cloud cover (1 = clear sky, 2 = partly cloudy, 3 = overcast), wind speed, and temperature during the survey. For cloud cover, wind speed, and temperature covariates, we averaged the values between the two surveys and used them as plot-specific covariates when modeling detection probability.

For factors influencing occupancy of snowy plover, we measured habitat characteristics at a random location within each sample plot during the first visit. Along 25 m transects in each cardinal direction from the random location, we measured vegetative cover (percent shrub, percent grass, and percent litter) using the line-intercept method (Canfield 1941). In addition, we used ArcGIS (version 10, Environmental Systems Research Institute, Redlands California, USA) to assign each survey point a land cover type from the Southwest Regional Gap Analysis data layer (Lowry et al. 2005), a distance to water value generated from water data layers (Utah National Wetland Inventory layer and Utah springs layer from the National Hydrography Dataset; http://gis.utah.gov/data), and a distance to roads. Because snowy plover were exclusively observed in either playa or marsh land cover types, we reclassified each point as playa, marsh, or other for simplicity. Playa was classified as sparsely vegetated or barren mudflat with high salinity, and marsh was classified as a wetland with herbaceous emergent vegetation (Lowry et al. 2005). We used these habitat characteristics as plot-specific covariates when modeling occupancy (Table 1).

Following completion of an occupancy model, we developed a predictive habitat model in ArcMap using β estimates associated with covariates from supported occupancy models. Using imagery of the study area (NAIP 2011), water data layers (Utah National Wetland Inventory layer and Utah springs layer from the National Hydrography Dataset), and land cover data (Southwest Regional Gap Analysis; http://earth.gis.usu.edu/swgap/), we created a new raster layer representing predicted snowy plover occupancy.

Data analysis

We used model selection (Burnham and Anderson 2002) within Program MARK (White and Burnham 1999) to evaluate 17 *a priori* hypotheses concerning detection probability and site occupancy based on environmental characteristics. We used a two-step modeling process suggested by MacKenzie et al. (2006). First, we modeled sampling covariates that we thought would influence detection probabilities (average temperature, cloud cover, wind speed, year, session), while holding occupancy constant. Second, we evaluated occupancy of snowy plover simultaneously with the best model(s) for detection probability incorporated (> 2 ΔAIC; MacKenzie et al. 2006). Prior to model selection, we evaluated covariates for multicollinearity, but found no covariates with $r > 0.5$ and thus did not limit combinations of covariates (Graham 2003). All continuous covariates were standardized to avoid problems with parameter estimation.

We evaluated relative model support using Akaike's Information Criterion adjusted for small sample sizes (AICc; Akaike 1973, Burnham and Anderson 2002). In the event of model-selection uncertainty, we generated model-averaged estimates of both detection probability and occupancy rates (Burnham and Anderson 2002). To evaluate effect sizes, we looked for overlap in confidence intervals associated with estimates and assessed the influence of individual covariates by determining whether confidence intervals around β estimates overlapped zero.

RESULTS

We detected snowy plover at 22 of 104 plots surveyed in 2011 and 18 of 100 plots surveyed in 2012 (Table 1). The average number of days (± SE) between the first and second survey was 4.10 ± 0.14. Land cover and habitat characteristics varied across the study area (Table 1). Sites were classified as playa (109; 53.4%), marsh (5; 2.5%), and other (90; 44.1%). Percent shrub, grass, and litter ranged from 0 – 92%, 0 – 54%, and 0 – 10% across sites, respectively.

The first competing model for predicting detectability (AICc weight = 0.62) included a constant detection across years and survey sessions and the temperature covariate (Table 2). There was a positive relationship between temperature and detection probability (β = 0.15 ± 0.04, 95% CI = 0.07 – 0.23). The second competing model (AICc weight = 0.22) also included constant detection across years and survey sessions with an additive effect of percent shrub (β = -3.71 ± 1.45, 95% CI = -6.57 – -0.85). We used the temperature model for detection probability when assessing site occupancy given the support for this model (Table 2). Our model-averaged estimate of detectability for snowy plover was 0.769 (95% CI = 0.637 – 0.863).

The most parsimonious model for predicting occupancy of snowy plover (weight = 0.68) included constant occupancy across years, distance to water (β = -5.86 ± 1.43, 95% CI = -8.66 – -3.06) and the land cover types: playa (β = 2.37 ± 0.74, 95% CI = 0.92 – 3.82), marsh (β = 0.97 ±

0.69, 95% CI = -0.38 – 2.32), or other (β = -19.77 ± 9.91, 95% CI = -39.19 – -0.35; Table 3). The second competing model (AICc weight = 0.13) also included a constant occupancy rate, distance to water, and percent shrub (β = -0.28 ± 0.02, 95% CI = -0.58 – -0.01). We found a negative relationship between snowy plover occupancy and distance to water, percent shrub, and all land cover types other than playa or marsh (Table 4; Fig. 2). Playa had a positive relationship with snowy plover occupancy (Table 4). The apparent occupancy rate in our study area was 0.196, and the model-averaged estimate of occupancy was 0.123 (95% CI = 0.071 – 0.205). Using the coefficient estimates concerning occupancy rates with distance to water and land cover types, we generated a predictive habitat model for the basin north of Fish Springs NWR, south of Interstate 80, east of the Deep Creek Mountain Range, and west of Granite Mountain in western Utah showing high probability of occurrence around springs and standing water (Fig. 3).

DISCUSSION

Estimating occupancy, while accounting for detectability, has recently gained popularity for assessing the status of a wide variety of taxa. In this study, we demonstrated an application of the MacKenzie et al. (2006) occupancy framework as a practical approach to management. Further, we used the occupancy and detection modeling approach to identify high priority areas for snowy plover in western Utah. Although we demonstrate our results in a regional application, the approach can be applied to other regions and taxa.

Distance to water was strongly associated with occupancy of snowy plover in western Utah and received more support than any other covariates we evaluated. The average distance to water from occupied survey plots was 309.2 ± 81.8 m, whereas the average distance to water from unoccupied survey plots was 2975.6 ± 211.8 m (Table 1). Our results concerning snowy plover occupancy and distance to water support previous work for this species in other areas. At the Salt Plains National Wildlife Refuge in Oklahoma, for example, snowy plover were found on salt flats near water (mean distance 129.2 ± 173.2 m; Grover and Knopf 1982). Snowy plover were also found along seasonally ephemeral streams in Oklahoma (Winton et al. 2000). At Owens Lake, California, snowy plover averaged 379 ± 38 m from water (Ruhlen et al. 2006). Understanding the relationship between snowy plover and water is especially important at sites where water is scarce or ephemeral and this information can be used to identify areas needed for conservation. Climate change or management actions that result in reductions in water availability are likely to negatively influence snowy plover.

Our study also demonstrated the importance of playa habitat for snowy plover in western Utah. Playas in western Utah are flat and the soil is saline and alkaline (Stolley et al. 1999). We found that dune areas had no snowy plover usage. Snowy plover in coastal Florida preferred tall dunes when playa habitats were not available (Webber et al. 2013). Populations of snowy plover in southwestern Mexico were absent from dunes and preferred playa (Mellink et al. 2009). Variation in snowy plover occupancy suggests that snowy plover demonstrate regional differences in habitat preferences.

Snowy plover, and other ground-nesting shorebirds, occupy sparsely vegetated habitats to facilitate early detection of predators (Gochfeld 1984, Martin 1988). Our study found that an increase in percent shrub cover was negatively associated with snowy plover occupancy. In coastal northern California, snowy plover were found on sparsely vegetated shorelines and riverine gravel bars (Colwell et al. 2010). In this area, they avoided areas where dense beachgrass (*Ammophila arenaria*) had spread (Muir and Colwell 2010). Similarly, wintering snowy plovers selected habitats with limited vegetation cover and more invertebrates (Brindock and Colwell 2011). Inland wetland systems in North America are experiencing rapid expansion of nonnative common reeds (*Phragmites australis*) which will limit suitable habitats for snowy plover and other ground-nesting shorebirds if allowed to invade open shoreline (Chambers et al. 1999, Kulmatiski et al. 2010).

The amount of litter present was not significant in predicting snowy plover occupancy. Other studies have found that a higher percentage of litter and debris is positively associated with habitat use (Grover and Knopf 1982, Colwell et al. 2005, Saalfeld et al. 2012, Webber et al. 2013). This discrepancy may be because we only counted adult snowy plover during the breeding season. Habitat selection most likely occurs on several spatial scales and may differ for mixed flocks (adults and juveniles) or during other periods of the year.

Snowy plover occupancy was not sensitive to roads as the β estimate around distance to road overlapped zero. In areas with high human activity, snowy plover occupancy has been negatively influenced by human disturbances (Webber et al. 2013). The relationship between snowy plover and disturbance is likely influenced by the type, frequency, and intensity of disturbance. Western Utah is remote with low visitation by humans. Additionally, the majority of our sample sites were on military land with restrictive access.

The effect of varied detection probability on bird surveys has received considerable attention (Thompson 2002). Snowy plover are cryptic birds that can be difficult to detect. Using 64-ha plots for surveys, our detection probability was high (0.769), but not 100%. Previous snowy plover surveys have assumed 100% detection in 9-ha plots (Thomas et al. 2012). Alternatively, snowy plover surveys using 100-ha plots estimated detection at 0.58 (95% CI = 0.50 – 0.65; Hood and Dinsmore 2007). We also found a positive relationship between temperature and snowy plover detectability. One hypothesis for this pattern is that breeding adults take more frequent breaks from incubating during high daytime temperatures making them easier to detect by surveyors. Snowy plover are biparental incubators and spend relatively more time shading their eggs during the hottest part of the day (Purdue 1976). To cope with the heat stress that comes with protecting embryos during extreme heat, the closely-related Kentish plover (*Charadrius alexandrinus*) will limit the duration of incubation bouts between pairs to relieve each other more frequently from incubation (Amat and Masero 2004, AlRashidi et al. 2010). Given the imperfect detection we observed and variation attributed to temperature, we suggest future surveys attempt to estimate detection probability whenever possible.

Our results demonstrate the utility of occupancy surveys to describe habitat use in a poorly sampled population of snowy plover in western Utah. Using easily obtained GIS layers, we successfully developed a habitat model capable of identifying areas likely to support snowy plover. This modeling effort highlighted habitat associated with naturally occurring sources of water in western Utah and will help prioritize future snowy plover surveys and guide conservation efforts.

Even though we focused our modeling and sampling efforts on a single species, this approach is broadly applicable to any species that has specific habitat requirements. Many species, especially those of conservation concern, have low or variable detection rates and thus require multiple periods to confirm presence/absence (Thompson 2002). The concept of repeatedly visiting sites to increase the likelihood of encountering a target species is generally understood. However, the estimate of detectability can be used to design monitoring projects or survey protocol based on likelihood of detecting the target species. Estimates generated from occupancy models can be compared to future studies making it possible to detect changes in occupancy.

ACKNOWLEDGMENTS

We thank K. Fitzgerald, T. Schmuki, M. Smith, and S. Philips for assistance in the field. Special thanks to Fish Springs National Wildlife Refuge for lodging and use of facilities while we conducted this study. Funding for this project was provided by the US Army Dugway Proving Ground.

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Table 2-1. Environmental covariates hypothesized to influence occupancy at plots sampled for snowy plover in western Utah, 2011 – 2012. We present mean and standard error values for distance to water (m), distance to roads (m), shrub (%), grass (%), litter (%), and counts for three land cover types.

Covariate	Occurrence	
	Detected	Not detected
Distance to water	309.2 (81.8)	2975.6 (211.8)
Distance to roads	2520.0 (283.6)	3574.2 (218.1)
Shrub	8.5 (1.8)	18.3 (1.6)
Grass	1.5 (1.4)	10.4 (0.7)
Litter	0.1 (0.02)	1.2 (0.07)
Land cover type:		
Playa	36	73
Marsh	4	1
Other	0	90

Table 2-2. Model selection results of snowy plover detection probability in western Utah, 2011 – 2012 showing model stage, model structure, Akaike's Information Criterion adjusted for small sample sizes (AICc), change in AICc from the most supported model (ΔAICc), model weight (w_i), model likelihood, number of parameters (K), and model deviance.

Model	AICc	ΔAICc	w_i	Model Likelihood	K	Deviance
p(. + Temp), Ψ(.)	273.64	0.00	0.62	1	3	267.52
p(. + Temp + % Shrub), Ψ(.)	275.69	2.05	0.22	0.36	4	267.49
p(. + Wind), Ψ(.)	278.02	4.37	0.07	0.11	3	271.90
p(.), Ψ(.)	279.71	6.06	0.03	0.05	2	275.65
p(. + Cloud), Ψ (.)	280.39	6.75	0.02	0.03	3	274.27
p(year), Ψ (.)	281.64	7.99	0.01	0.02	3	275.52
p(session), Ψ (.)	281.70	8.06	0.01	0.02	3	275.58
p(session*year), Ψ(.)	285.70	12.06	<0.01	0.002	5	275.40

Table 2-3. Model selection results of snowy plover occupancy in western Utah, 2011 – 2012 showing model stage, model structure, Akaike's Information Criterion adjusted for small sample sizes (AICc), change in AICc from the most supported model (ΔAICc), model weight (w_i), model likelihood, number of parameters (K), and model deviance.

Model	AICc	ΔAICc	w_i	Model Likelihood	K	Deviance
p(. + Temp), Ψ(. + DWater + Landcover type)	228.27	0.00	0.68	1	6	168.34
p(. + Temp), Ψ(. + DWater + PerShrub)	231.65	3.37	0.13	0.19	5	221.34
p(. + Temp), Ψ(. + DWater + PerShrub + PerGrass + PerLitter)	231.87	3.60	0.11	0.17	7	217.30
p(. + Temp), Ψ(. + DWater)	233.39	5.12	0.05	0.08	4	225.19
p(. + Temp), Ψ(. + DWater + DRoad)	235.49	7.22	0.02	0.03	5	225.18
p(. + Temp), Ψ(. + DWater + PerLitter)	236.56	8.28	0.01	0.02	4	228.35
p(. + Temp), Ψ(. + DWater + PerGrass)	241.60	13.32	<0.01	<0.01	4	233.40
p(. + Temp), Ψ(.)	255.38	27.11	0	0	3	249.26
p(. + Temp), Ψ(year)	257.08	28.81	0	0	4	248.88

Table 2-4. β estimates, SE, and 95% confidence intervals for parameters in the top models of detection probability and occupancy for snowy plover in western Utah, 2011 – 2012. Covariates with confidence intervals not overlapping 0 are flagged with an *.

Parameter	β	SE	Lower 95% CI	Upper 95% CI
Detection				
Cloud cover	0.78	0.69	-0.57	2.14
Wind speed	0.38	0.20	-0.03	0.77
Temperature*	0.15	0.04	0.07	0.23
% Shrub*	-3.71	1.45	-6.57	-0.85
Occupancy				
Distance to water*	-5.86	1.43	-8.66	-3.06
Distance to road	-0.37	0.99	-0.19	0.19
% Shrub*	-0.28	0.02	-0.58	-0.01
% Grass	-0.003	0.03	-0.06	0.05
% Litter	-1.48	0.93	-3.30	0.35
Land cover type:				
Playa*	2.37	0.74	0.92	3.82
Marsh	0.97	0.69	-0.38	2.32
Other*	-19.77	9.91	-39.19	-0.35

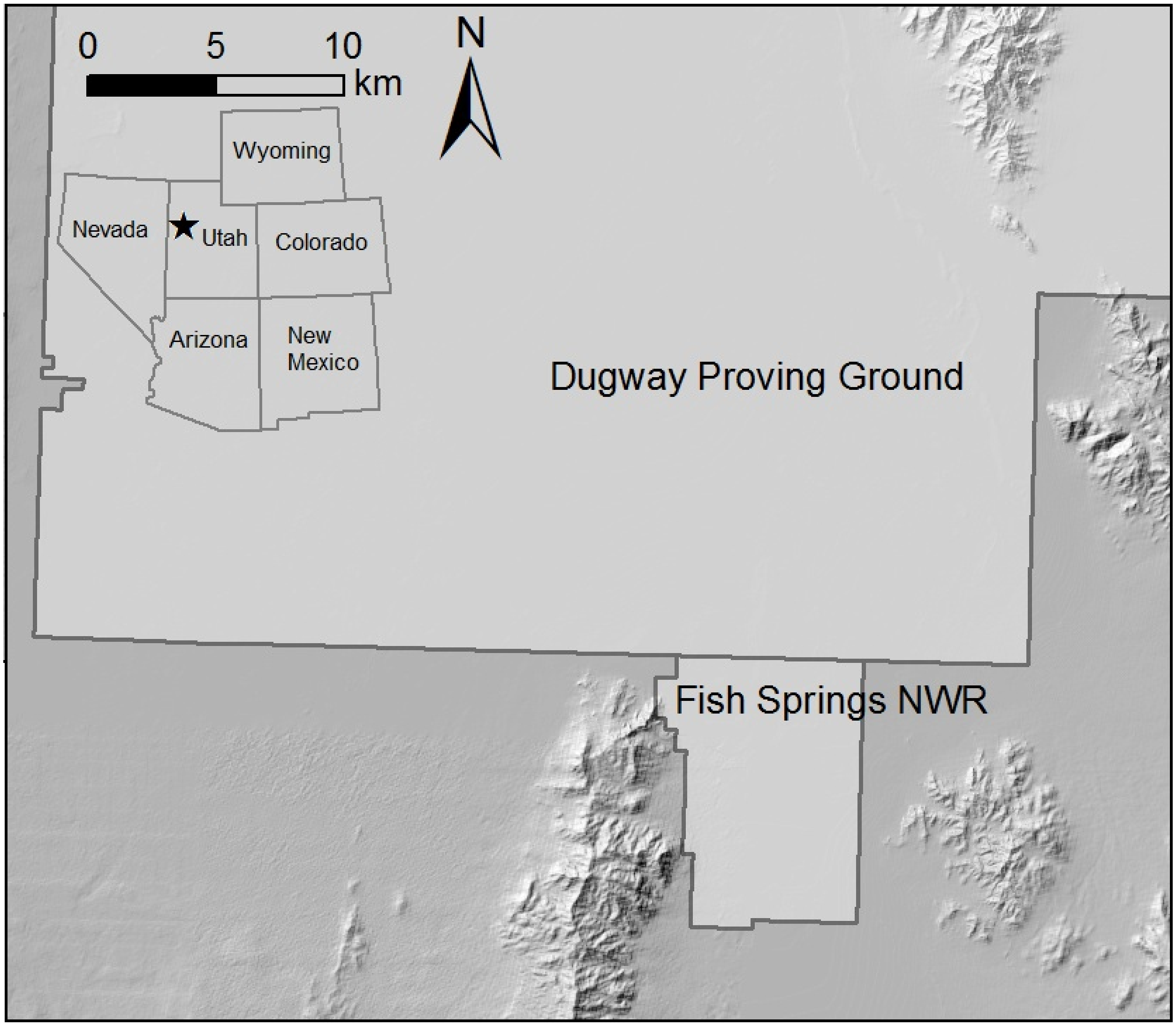

Figure 2-1. Location of study area at Dugway Proving Ground and Fish Springs National Wildlife Refuge (NWR) in western Utah where we sampled snowy plover occupancy in 2011 and 2012. The star in the regional map indicates the study area.

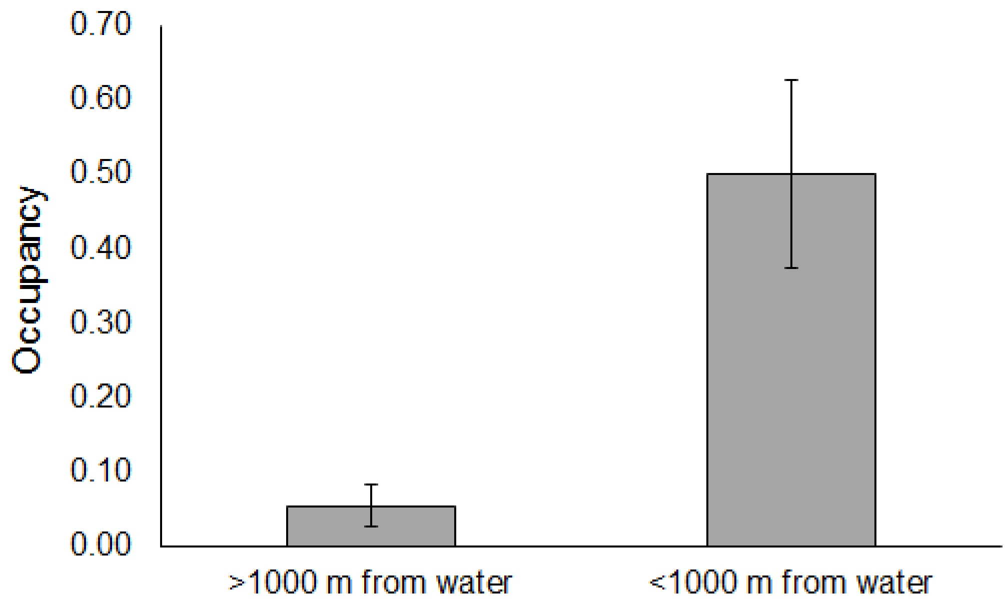

Figure 2-2. Mean occupancy rates (95% confidence intervals) of snowy plover in western Utah (2011 and 2012) in response to changes in distance to water. We calculated occupancy by holding all other covariates in the top model at their mean value

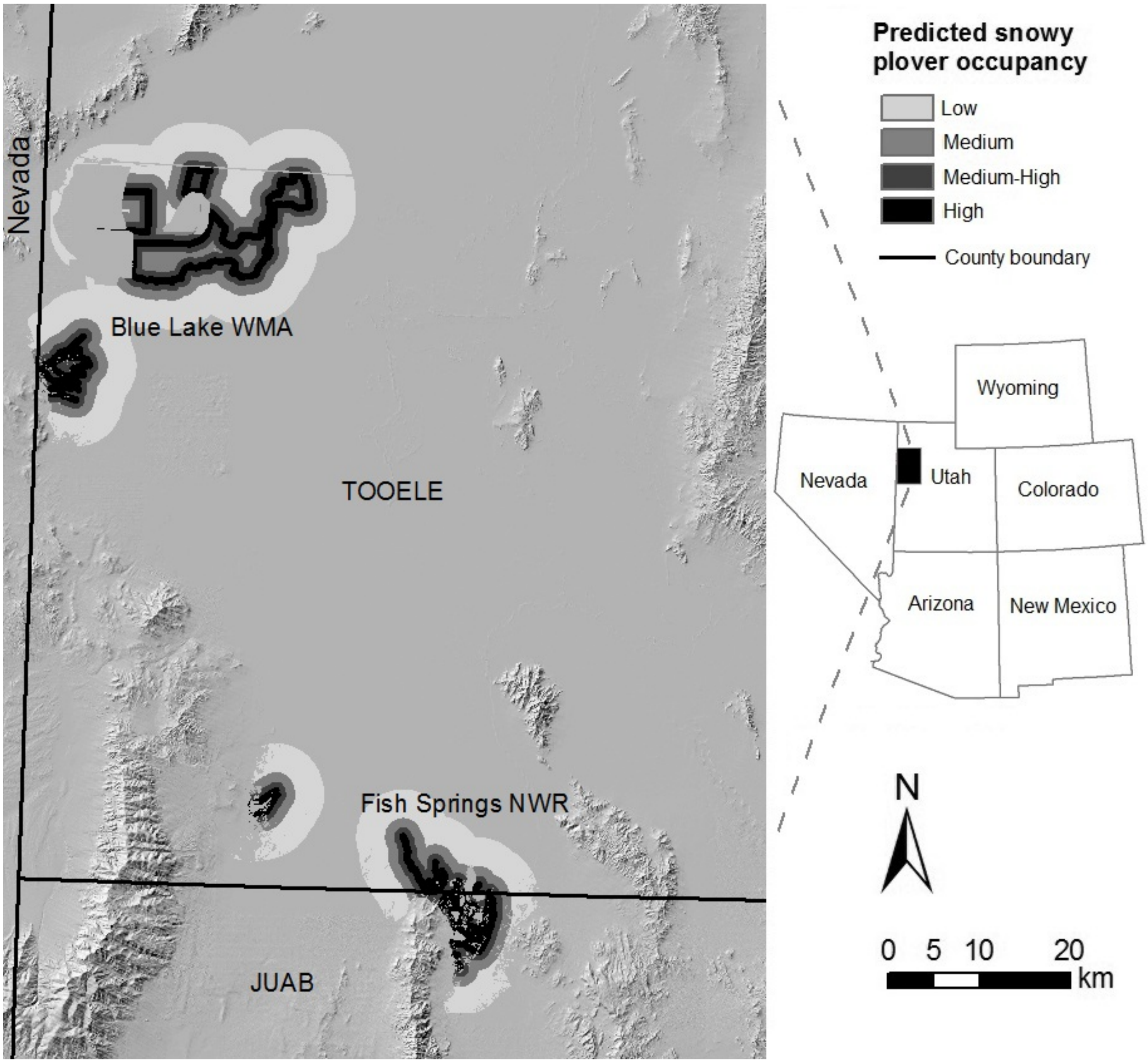

Figure 2-3. Predicted habitat for snowy plover in western Utah based on occupancy surveys conducted in 2011 and 2012.