Reproductive ecology of the Long-billed Curlew (*Numenius americanus*) in Western Nebraska

by

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CHAPTER I. GENERAL INTRODUCTION

Many species that were once common in Nebraska have declined, and some are now considered threatened and are targeted for conservation measures. The Nebraska Natural Legacy Project (NNLP) aims to reverse those declines and to provide a comprehensive, systematic, and proactive approach to conserving the full array of Nebraska's biological diversity (Schneider 2005). This systematic approach of identifying and prioritizing the conservation of at-risk species is a fundamental step towards conserving multiple populations and communities of Nebraska's wildlife. For example, a primary goal of the NNLP is to reverse the declines of at-risk species (Schneider 2005). One such species is the Long-billed Curlew (*Numenius americanus*). This grassland shorebird is a "Tier 1 at-risk" species that is imperiled or vulnerable throughout its breeding range. Many grassland species like the curlew have faced similar declines due to the conversion of grasslands to agriculture and many remain threatened and limited in range. One of the remaining strongholds for these species is the Nebraska Sandhills, a unique ecoregion specifically mentioned as an important breeding site for the Long-billed Curlew. It is the goal of the NNLP to learn more about the curlew and to reverse the decline of this species.

The Long-billed Curlew is a large and distinctive shorebird of dry short- and mixed-grass prairies of western North America. From April to July, it breeds throughout much of the Great Plains and from August to March it winters along the West Coast, throughout interior Mexico, and sparingly along the Gulf and East coasts (Small 1994, Stevenson and Anderson 1994, Howell and Webb 1995). Historical records show that curlews bred in grasslands throughout the Great Plains east to Indiana, Michigan, and probably even Ohio

(Bent 1929) although their relative abundance in these areas was not well documented. However, the breeding range has been reduced by approximately 30% (Fellows and Jones 2009) and curlews are now found in the Great Plains east only to western Nebraska and western South Dakota. It is listed as a bird of conservation concern in five U.S. Fish and Wildlife regions (Fellows and Jones 2009) and as "highly imperiled" by the United States Shorebird Conservation Plan (USSCP; Brown et al. 2000, Fellows et al. 2001). This dramatic reduction during the last 150 years is attributed to grassland conversion to row-crop agriculture (Bent 1927, Yocum 1956) and unregulated hunting in migration areas (Dugger and Dugger 2002).

Estimates of the continental population size of the Long-billed Curlew have been debated and Brown et al. (2000) estimated 20,000 birds but thought it only accurate to ±50%. Morrison et al. (2006) later estimated the continental population of Long-billed Curlews at between 55,000 and 123,500 individuals. Stanley and Skagen (2007) surveyed the entire curlew breeding range and estimated 164,515 (SE = 42,047) breeding birds in 2004 and 109,533 (SE = 31,060) in 2005. A statewide population estimate of breeding Long-billed Curlews has never been published for Nebraska and reported numbers from surrounding states collectively suggest that the Long-billed Curlew is an uncommon breeding bird of the central Great Plains.

Past studies of Long-billed Curlew breeding biology have been conducted in many western states including Idaho, Nevada, Oregon, South Dakota, Utah, Washington, and Wyoming but research is scarce for Nebraska; only one published study with this species has been conducted in the state (Bicak 1977). Nest survival of curlews in Nevada and South Dakota ranged from 15% to 39% (Clarke 2006, Hartman and Oring 2009) but nest and chick

survival has not been studied in Nebraska. A study in Idaho (Redmond and Jenni 1986) found chick survival ranged from 15% to 75% and Hartman and Oring (2009) estimated chick survival at 47%. Clarke (2006) found that vegetation variables such as visual obstruction and forb cover affected nest and chick survival.

Understanding the population trends, nest survival, and chick survival of the Long-billed Curlew in Nebraska is of great importance. Each of these findings has important conservation implications, especially at the eastern edge of the curlew's range where grassland habitats continue to vanish. Further degradation and disappearance of this habitat will result in the continuation of population decline and reduction that the curlews have suffered for the last 150 years.

I studied several aspects of Long-billed Curlew breeding ecology in Nebraska to build on the current knowledge of this uncommon species. Nebraska was chosen for this study because a) determining their status in Nebraska was a stated priority of Fellows and Jones (2009), b) estimating nest/chick survival were priorities listed by Dugger and Dugger (2002), and c) neither abundance or nest/chick survival had ever been studied in Nebraska. Nebraska historically had breeding curlews throughout the state but due to the vanishing grasslands in the eastern portions, curlews now only occupy western grasslands in the state. This gave me the unique opportunity to study the abundance and nest/chick survival in an area that had witnessed dramatic reductions in the last 150 years. My objectives (Chapter II) were to 1) modify curlew survey techniques used by Stanley and Skagen (2006), 2) estimate curlew density and extrapolate to estimate total curlew abundance, and 3) to examine what factors affected detection. I studied curlew nest ecology (Chapter III) to 1) estimate nest success, 2) examine vegetative and temporal factors affecting nest survival, and 3) study the scale at

which vegetative factors affected nest survival. I also studied curlew chick ecology (Chapter IV) to 1) estimate chick survival, 2) examine what vegetative and temporal factors affected survival, and 3) quantify post-hatch movements of precocial young. The purposes of this study were to highlight habitat needs throughout the life-cycle of the curlew and to further our baseline knowledge of this declining grassland species. I hope these findings will enable land managers and ranchers to better manage for the habitat needs of the curlew and ultimately aid in the recovery of this emblematic shorebird in Nebraska.

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CHAPTER II. ESTIMATING THE ABUNDANCE OF LONG-BILLED CURLEWS (*NUMENIUS AMERICANUS*) IN NEBRASKA

A paper to be submitted to *The Condor*

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Abstract

The Long-billed Curlew (*Numenius americanus*) is an imperiled shorebird of western North America. Populations have declined dramatically in the last 150 years from the conversion of prairie to agriculture and the curlew is now listed as a "Tier I at-risk" species in Nebraska. I undertook a 2-year study to estimate the density and statewide abundance of breeding Long-billed Curlews in Nebraska during 2008 and 2009. Unlike the Breeding Bird Survey, my surveys occurred in April during the pre-nesting period when curlews are most easily detected. I used a simple random sample of roadside survey routes (n = 39), each consisting of 40 5-min point counts at 800 m intervals. I used Program Distance to model detection probability and found that wind speed negatively affected detectability; I found no evidence of year effects or observer bias. I estimated there were 0.0038 curlews/hectare (0.38 curlews/km^2) along survey routes and by extrapolation we estimated that there were 23,909 (SE = 1,685; 95% CL: 20,810-27,471) Long-billed Curlews in Nebraska. This population estimate far exceeds estimates from surrounding states and points to the need for a thorough and quantitative survey approach for estimating curlew abundance. My population estimate confirms that Nebraska holds a sizeable portion of the continental Long-billed Curlew

population; this population should continue to be monitored to ensure that this imperiled grassland species remains viable.

Introduction

The desire to monitor population trends, determine threats to species, and improve management techniques creates the need to understand population sizes of birds. In addition to the population estimates, it is important to better understand the factors that affect population change. Habitat associations have been studied in relation to population estimates (Saalfeld et al. 2010) and have provided valuable aids to management (Johns 2005). Learning about avian responses to environmental change is also an important result of studying bird population estimates (Rosenstock et al. 2002). Together, these ideas solidify our need to further understand bird population estimates, especially those of declining or at-risk species. This information can a) aid an understanding of population trends, potentially giving merit for updating the conservation status of declining or recovering species (Kuczynski et al. 2010), and b) help conserve habitats for species that are declining and in need of additional protection (Johns 2005).

Populations of many grassland birds have sharply declined due to the loss of native prairies and grasslands (Knopf 1994). The Long-billed Curlew (*Numenius americanus*) is a large and distinctive shorebird of western North America whose historic breeding range has been reduced by approximately 30% (Fellows and Jones 2009). It is one of only nine grassland birds considered endemic to the Great Plains (Dugger and Dugger 2002) and is listed as a bird of conservation concern in five U.S. Fish and Wildlife regions (Fellows and Jones 2009). The Long-billed Curlew is classified as “highly imperiled” by the United States Shorebird Conservation Plan (USSCP; Brown et al. 2001, Fellows et al. 2001) and is listed as

"vulnerable" in Canada. The Long-billed Curlew is listed as a "Tier I at-risk" species by the Nebraska Natural Legacy Project (Schneider et al. 2005). These concerns were initiated by the decline of suitable breeding habitat and the overharvest by humans through the 1800s and early 1900s (Dugger and Dugger 2002). Because habitat loss remains a threat today (Fellows and Jones 2009), further understanding of their habitat needs is important. Similarly, because many population estimates are poorly understood, estimation of breeding numbers is imperative (Dugger and Dugger 2002). Together, further research could support broad-scale conservation efforts and this species' recovery (Dugger and Dugger 2002).

Unlike many shorebird species, the Long-billed Curlew is terrestrial and breeds in dry short- and mixed-grass prairies. From April to July, it breeds throughout much of the Great Plains and from August to March it winters along the West Coast, throughout interior Mexico, and sparingly along the Gulf and East coasts. Historical records show that curlews bred in grasslands throughout the Great Plains east to Indiana, Michigan, and probably even Ohio (Bent 1929). However, curlews are now found in the Great Plains east only to western Nebraska and western South Dakota. This decline during the last 150 years is believed to be caused by conversion of grasslands used by breeding curlews to row-crop agriculture (Bent 1927, Yocum 1956) and unregulated hunting in migration areas (Dugger and Dugger 2002). Historical records confirming its breeding range within Nebraska are lacking and most sources indicate curlews were once a statewide breeder, although they were probably more common in the western half of the state (Ducey 2000). Curlews were once found in Nebraska east to the Missouri River and south to the Platte and Little Blue rivers, but it was extirpated from these areas by the late 1800s (Ducey 2000). Since 1900, its range has stabilized and is centered primarily in the Sandhills and shortgrass prairies of north-central

and northwest Nebraska respectively. Breeding Bird Survey data suggest highest densities occur in Cherry County south to McPherson County and west to Garden County, although the BBS has limitations in detecting early-breeding species (Sauer et al. 2008). The current eastern limit of the curlew's range in Nebraska is poorly understood and some sources indicate breeding east to Rock and Loup counties (Mollhoff 2001, Sauer et al. 2008). Currently, Nebraska lies along the eastern edge of the curlew's breeding range and, because of the species' decline during the last 150 years, understanding their population and threats, both potential and existing, is of great importance.

Estimates of the continental population size of Long-billed Curlews have been debated. Brown et al. (2001) estimated 20,000 birds but thought it only accurate to ±50%. Morrison et al. (2006) later estimated the continental population of Long-billed Curlews at between 55,000 and 123,500 individuals, the former being based on expert opinion and the latter based on statistical results by Stanley and Skagen (2007). Stanley and Skagen (2007) surveyed the entire curlew breeding range using a stratified random sample of survey routes in 16 western states and estimated 164,515 (SE = 42,047) breeding birds in 2004 and 109,533 (SE = 31,060) in 2005. The large differences and low precision of these estimates hint at some of the difficulties associated with surveying a low density, terrestrial shorebird across a broad geographic area. A statewide population estimate of breeding Long-billed Curlews has never been published for Nebraska. Nebraska potentially hosts a sizeable portion of the continental population and determining their status in Nebraska is a priority (Fellows and Jones 2009). Breeding population estimates from bordering states are also poorly understood. A breeding population survey in Kansas reported 100-500 individuals (L. W. Oring, personal communication), a similar survey in Wyoming reported 200-1,000

individuals (S. L. Jones, personal communication), an estimate in South Dakota reported 1,000-3,000 individuals (Tallman 2002), and in Colorado 943-3,233 individuals were estimated (Kingery 1998). Collectively, these estimates suggest that the Long-billed Curlew is an uncommon breeding bird of the central Great Plains.

I used distance sampling (Buckland et al. 2004) to estimate the density of curlews breeding in Nebraska, and then extrapolated this density to provide an estimate of the statewide breeding population. Together, these baseline data will be valuable in aiding long-term conservation of curlews in Nebraska by assessing current breeding status and enabling resource managers to make informed choices regarding habitat management to benefit the curlew.

Methods

Study Area

I surveyed for Long-billed Curlews throughout their suspected breeding range in Nebraska during April 2008 and 2009. I used a distribution estimate from Breeding Bird Survey data (Sauer et al. 2005) to narrow my sampling area to parts of 22 counties, mostly in the panhandle and north-central Nebraska (Figure 1). The dominant ecoregion of the eastern survey area was the Sandhills, a mix of grass-stabilized sand dunes and shallow wetlands that stretches from Box Butte County east to Rock and Loup counties (Schneider et al. 2005). Comprised of roughly 50,000 km^2, the Sandhills are considered the largest wetland ecosystem in the country (U.S. Fish and Wildlife Service 2007), the largest dune system in the western hemisphere, and one of the largest grass-stabilized dune systems in the world (Schneider et al. 2005). The dominant ecoregion in the western portions of the survey area

was mixed and shortgrass prairie that stretches from Sioux and Dawes counties south to Banner and Morrill counties.

Survey Methods

To survey for breeding curlews I established a series of roadside survey routes (Stanley and Skagen 2007), each consisting of 40 stops spaced 800 m apart. I chose this methodology because roadside surveys are an efficient method to survey large areas in which public land is limited and field crews are small (Jones et al. 2008). For all surveys, I randomly selected a) the sample unit (township) within the suspected curlew range in Nebraska, b) the starting point of each route, and c) the direction of the route and turns at every intersection. I searched for curlews by sight and sound for 5 min at each of the 40 stops. All point counts were conducted from outside the vehicle and on the roadside. Binoculars were used to search for curlews when needed. I recorded the number of curlews, the sex of the curlew (when possible, based on bill length and shape), the exact distance in m. (<1 km) to any curlews measured with a Bushnell Sport Pro laser rangefinder (Bushnell Corporation, Overland Park, USA), and the time of all curlew sightings in 1 min intervals. If my approach flushed a curlew from a roadside, I noted this and treated it as a detection in the first minute along with the distance from the point where it flushed. I also recorded general habitat at each stop with respect to type (grazed, ungrazed, crop) and vegetation height (short, medium, tall). Vegetation was considered short if it stood ≤10 cm, medium if it stood between 10 and 50 cm, and tall if it stood ≥50 cm. I recorded wind speed (km/hr) which is thought to influence bird detectability (Robbins 1981) at the start, middle, and finish of each survey. Surveys were conducted only during daylight hours and in all weather conditions except heavy rain or snow, lightning, or wind speeds > 50 km/hr. In cases of partial route completion before

inclement weather impeded the count (n = 6 routes), I kept the completed points and used them in my analyses. I surveyed one route per day most days but occasionally two routes per day were possible.

Surveys were conducted only on passable, public roads and streets; interstates, private roads, and urban areas were not considered part of a route and were skipped. I sampled townships without replacement within year but sampled with replacement between years. Stratification of routes was considered in my survey design but ultimately dismissed due to a) the lack of an existing defensible estimate of curlew density throughout the state, and b) the relatively homogeneous habitat present throughout the sampling area which removes the need for habitat stratification. In addition, Stanley and Skagen (2007) and Jones et al. (2008) suggested the use of simple random sampling because stratification had no effect on the precision of population estimates in their surveys for Long-billed Curlews.

Surveys were conducted during the pre-incubation period (April) to ensure that displaying curlews were easily detected (Redmond et al 1981, Jones et al. 2003). I avoided surveying in May and June, as the Breeding Bird Survey requires (Sauer et al. 2008), due to the secretive nature of incubating adults at that time of year (Stanley and Skagen 2007). I chose to use roadside surveys instead of off-road or foot surveys due to the vast areas to be surveyed, the small number of surveyors, the limited survey period, and the limited access to private land that comprises most of western Nebraska. Although resulting roadside bias is a concern, I believe the effects are minimal in this study because a) as stated by Stanley and Skagen (2007), roadside habitats used by summering curlews are generally representative of their non-roadside habitat, b) Jones et al. (2008) noted that there is no evidence curlews are affected behaviorally by presence of roads, c) the roads were often very rural and lacked

ditches, fencing, and other defining edges, and d) vehicular traffic and disturbance was relatively rare. Roads were present in all townships sampled and there was no evidence of roads occurring systematically in wet areas which would bias the estimate positively. Although I was logistically unable to explicitly test roadside bias by conducting off-road surveys, I believe that roadside bias had little impact on the resulting estimates of density and overall abundance.

One of the assumptions that must be met for the removal method of distance sampling to be viable is the closure assumption of no movement during survey period (Jones et al. 2008). If the closure assumption is violated and there is immigration or emigration of birds relative to the survey point, the resulting estimate can be biased. To meet the closure assumption, I did not include curlews that were seen only in flight, curlews that flew in and landed during the 5-min counts, or curlews that were only heard. I took note and was careful not to double-count curlews if any flew from previous points to future points.

Statistical Analyses

I pooled 2008 and 2009 survey results for analyses in Program Distance (Version 6.0, release 2). I pooled these data because a preliminary analysis found no evidence of year effects in detectability. Pooling was an acceptable method because I surveyed breeding birds instead of migrants and because territorial curlews generally use the same area repeatedly between years (Clarke 2006). I divided the raw distance data into bins to minimize variation in distance estimates (Stanley and Skagen 2007). I explored the use of different distance bins and ultimately chose four bins because it resulted in adequate detections within each bin for my analyses. The bins were 0 to 300 m, 301 to 500 m, 501 to 700 m, and 701 to 1000 m. I imported the binned data into Program Distance and built four models to estimate overall

density. Model adjustments suggested by Buckland et al. (2004) were uniform/simple polynomial, uniform/cosine, half-normal/cosine, half-normal/hermite polynomial, hazard-rate/cosine, and hazard-rate/simple polynomial (Table 1). In all analyses, hazard-rate adjustments failed to converge and were thereafter removed.

I created four models to test for potential differences in curlew detection rates. These effects were observer, years, wind speed, and a model that did not consider any covariates. Both year and observer effects were analyzed by post-stratifying the data and using the Conventional Distance Sampling (CDS) analysis engine in Program Distance. To test for wind effects, wind speed (km/hr) was used as a continuous covariate using the Multiple Covariate Distance Sampling (MCDS) analysis engine. In the open environments occupied by grassland birds, wind speed is thought to be an important factor affecting their activity patterns and thus their detectability (Robbins 1981). Wind speeds were measured three times throughout each survey but the intermediate wind speeds were later interpolated by smoothing values between known measurements. For routes with missing wind speed data (n = 5), the missing values were replaced by the overall mean wind speed. The result was an estimate of wind speed for each survey point. I used Akaike's Information Criterion (AIC) to select the best model(s) for inference. The model with the lowest AIC value was considered best and all models within 2.0 AIC units of that model were considered competitive. I measured model fit using the χ^2 goodness-of-fit test in Program Distance and results with non-significant P-values were considered best fitting.

I used the estimate of density from the single best model to extrapolate to the sampling area defined as the shaded area in the Sauer et al. (2005) curlew range map. I used ArcGIS 9.2 (Environmental Systems Research Institute, Inc., Redlands, California) to

calculate the sample area in hectares (ha). I excluded urban areas from the sampling area by summing the digitized urban polygons around each town/city and subtracting this area total from the entire sampling area. Lastly, I multiplied my overall density estimate from my best model to the total sampling area to obtain my final statewide population prediction (±SE) along with a 95% confidence interval. We used the point count data in ArcMap to generate a curlew density estimate for the state of Nebraska. Using the mean number of birds per route and trimming the area to the Sandhills ecoregion, we used kriging interpolation (Geostatistical Analyst extension) to generate an estimate map of curlew density (Figure 2.2). Slight differences occur between the survey area map (Figure 2.1) and the density map (Figure 2.2) because the density estimate is clipped to general ecoregions whereas my survey area is clipped to a previous estimate of curlew density.

Results

During April of 2008 and 2009, two observers surveyed 39 routes in western Nebraska (Figure 1) for a total of 1398 point counts (Table 2). All routes were surveyed once between 8 and 29 April (8-28 April in 2008 and 15-29 April in 2009). Each route took an average of 6.04 hours to complete in 2008 and 6.44 hours in 2009. Curlews were detected on 78% of survey routes (n = 29) and 8% of survey points (n = 112). A total of 188 curlew detections was tallied (Table 2). The primary observer (CG) accounted for 68% of survey effort (951 points) while the secondary observer (TB) accounted for the remaining 32% (447 points).

The best model, which I used for all inferences, was the half-normal with a cosine adjustment plus wind speed (WIND) as a covariate, which yielded a 7.0% coefficient of variation (CV) on the estimate of density. The density estimate was 0.0038 curlews per ha (0.38 curlews per km^2; Table 3, Figure 3). I found no support for observer effects

(OBSERVER) or year effects (YEAR) in my analyses (all ΔAIC values > 2.0; Table 3). I addressed the goodness-of-fit of the null model using the χ^2 test and the data showed good fit (P = 0.96). A total of 11,849 ha of town/city areas were removed from the total survey area of 6,298,351 ha for a resulting total survey area of 6,286,502 ha. On the basis of my surveys, I estimated that 23,909 (SE = 1,685; 95% CL: 20,810-27,471 curlews) Long-billed Curlews were present in Nebraska.

Discussion

Conservation measures often rely on an estimate of the number of birds in a population. Those estimates, from a variety of survey methodologies or capture-recapture techniques, provide an important metric upon which to gauge the present status of the population and allow future inferences about population change. My study provides an estimate of the Long-billed Curlew density and overall abundance in Nebraska. This information can then be used in state, regional, and range-wide conservation planning. Below, I discuss some aspects of a distance sampling approach to estimate curlew density and how Nebraska's curlew numbers compare regionally and nationally.

Environmental variables are known to affect the behavior of birds and reduced detection rates have been noted in owl surveys (Kissling et al. 2010) and seabird surveys (Ronconi and Burger 2009). Wind can negatively affect detection rates of birds (Mack et al. 2002). I suspected wind speed would play a role during this study because of the consistently open habitat and the near-constant winds in western Nebraska. I addressed the effect of wind on detection rates by building a model in Program Distance that accounted for wind speed. I found that wind speed did have an effect on the detection probability, which is consistent with the findings of other studies (Rosenstock et al. 2002, Bas et al. 2008). The

best model incorporated wind speed and I suggest that future studies also attempt to account for wind speed.

Observer skill is another important aspect that may affect detection probability and density estimates. Observer effects have been studied since the 1980s and are commonly recognized as a potential source of error (Ralph and Scott 1981, Kendall et al. 1996). Nichols et al. (2000) stated that observer identity and experience are recognized as covariates that are likely to be relevant to variation in detection probability. Differences in observer skill have been noted in studies with seabirds (Barbraud and Thiebot 2009) and terrestrial grassland birds (Diefenbach et al. 2003). To accommodate this possible effect, I tested for observer differences by incorporating observer into models used for determining the density of curlews. I did not expect observer differences to have a significant effect in the detection probability because both observers (CG and TB) were experienced and skilled in bird detections. The OBSERVER model in Program Distance verified this by yielding non-significant differences between observers. Specifically, the model was more than 4.0 ΔAIC units lower than the best model and was therefore not well supported.

My population estimate for Long-billed Curlews in Nebraska corresponds well with the range-wide estimates reached by Stanley and Skagen (2007). By taking my estimate and dividing by their prediction of 164,515 (SE = 42,047) breeding birds in 2004 and 109,533 (SE = 31,060) in 2005, approximately 15-22% of the continental breeding population of Long-billed Curlews occurs in Nebraska. There were no previous estimates of the Long-billed Curlew population for Nebraska, even though Kansas, Colorado, Wyoming, and South Dakota all have crude estimates. Most of these estimates are based on personal communications and expert opinions rather than rigorous sampling. My estimate of 23,909

Long-billed Curlews in Nebraska is more than seven times the population size estimated in any bordering state. This discrepancy points to a) the need for rigorous sampling for states with no survey-based estimates of their curlew population and b) the possibility that the Sandhills of western Nebraska are home to far more curlews than areas in bordering states.

My study emphasizes the importance of Nebraska to the continental population of the Long-billed Curlew. Nebraska was thought to hold a sizeable portion of the range of the Long-billed Curlew (Fellows and Jones 2009) but little was known about the population size. It is now apparent that Nebraska, although on the eastern edge of the species' range, hosts up to 22% of the species' breeding population. This could be the result of several different factors that make Nebraska unique. The Sandhills are a large region of contiguous dry grassland and are 95% maintained as native grasslands for livestock production (Schneider et al. 2005). This, along with the rough terrain, poorly developed sandy soil, and semiarid conditions collectively prevent the land from being converted to agriculture. The flora and fauna of the Sandhills, including several federally endangered species, make it a unique landscape and stronghold for breeding curlews not found in surrounding states. However, the Sandhills are not secure as a long-term refuge for curlews. Potential threats to species and habitats include lack of fire regimes, annual mid-summer haying of meadows, wind power development, exotic plant species invasion, and livestock grazing practices that reduce native plant diversity are all of concern (Schneider et al. 2005, Fellows and Jones 2009). These threats to the Sandhills could further jeopardize the Long-billed Curlew in Nebraska, and if at all possible, should be addressed by land managers and ultimately avoided.

Recent studies of shorebird populations using distance sampling have found that this survey approach offers a precise, defensible, and scientifically-based method for deriving a

population estimate if the assumptions of this approach can be met. Along with the estimate from Stanley and Skagen (2007), my study shows that the original range-wide estimate of 20,000 curlews made by Brown et al. (2001) was most likely biased low. My study also confirms that the contiguous grasslands of the Sandhills of Nebraska hold a sizeable portion of the continental Long-billed Curlew population and that these numbers should continue to be monitored to maintain this imperiled grassland species.

Acknowledgements

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Table 2.1. Model adjustments of binned Long-billed Curlew (*Numenius americanus*) density data in Nebraska, 2008-2009. Models are ordered by Akaike's Information Criterion (AIC). K is the number of parameters and ΔAIC is the AIC difference from the top model. C = cosine, SP = simple polynomial, and HP = hermite polynomial.

Model[a]	K	ΔAIC[b]	Density birds/ha	D LCL[c]	D UCL[d]	CV[e]
Half-normal + C	2	0.00	0.005	0.004	0.006	0.088
Half-normal + HP	1	25.93	0.003	0.003	0.003	0.083
Uniform + C	2	32.90	0.002	0.002	0.003	0.080
Uniform + SP	3	48.60	0.003	0.002	0.003	0.146

[a] Models recommended by Buckland et al. (2004). Two hazard-rate models were removed due to poor convergence.
[b] The AIC value of the best model was 410.80.
[c] Lower 95% confidence limit.
[d] Upper 95% confidence limit.
[e] Coefficient of variation.

Table 2.2. The number of survey routes, the number of Long-billed Curlews (*Numenius americanus*) detected, and the number of curlews detected in each distance bin from roadside surveys in north and northwest Nebraska, 2008-2009.

Year	Total no. of routes	No. of routes with curlews	Distance bin (m)				Total curlews
			0-300	>300-500	>501-700	>700-1000	
2008	14	14	42	15	6	7	70
2009	25	19	69	28	13	8	118
Total	39	33	111	43	19	15	188

Table 2.3. Models showing the effects of wind speed (WIND), observer (OBSERVER), and year (YEAR) on the detection probability of Long-billed Curlew (*Numenius americanus*) in Nebraska, 2008-2009. Models are ordered by Akaike's Information Criterion (AIC). K is the number of parameters and ΔAIC is the AIC difference from the top model. All models were run with a half-normal/cosine adjustment.

Model	K	ΔAIC[a]	Density birds/ha	D LCL[b]	D UCL[c]	CV[d]
WIND	3	0.00	0.0038033	0.0033	0.0044	0.070
EMPTY (NULL)	2	2.17	0.0037966	0.0032	0.0045	0.088
OBSERVER	4	4.37	0.0036661	0.0031	0.0044	0.088
YEAR	4	5.36	0.0040562	0.0034	0.0049	0.092

[a] The AIC value of the top model in this analyses was 408.62.
[b] Lower 95% confidence limit.
[c] Upper 95% confidence limit.
[d] Coefficient of variation.

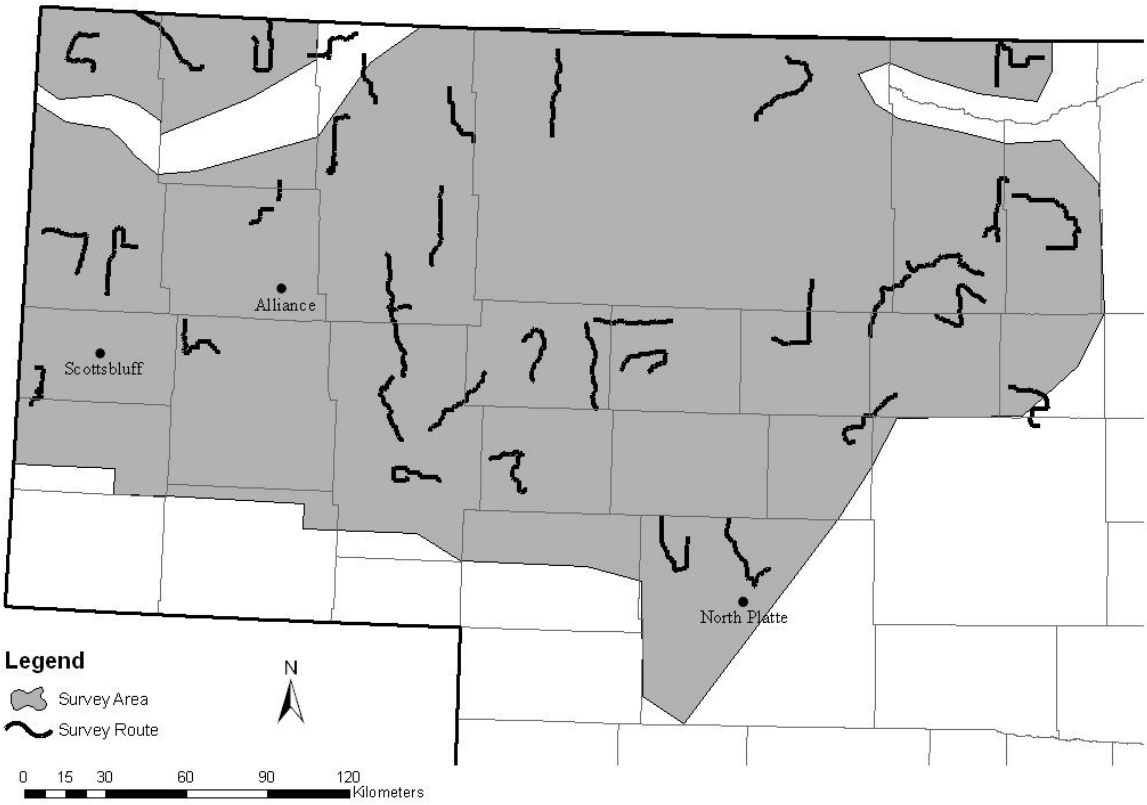

Figure 2.1. Long-billed Curlew (*Numenius americanus*) survey routes in Nebraska, 2008-2009. Some routes overlapped between years, which explains why only 37 routes are visible on the map. Some routes (n = 3) extended beyond the targeted survey area (gray region) because survey protocol called for random start points and direction.

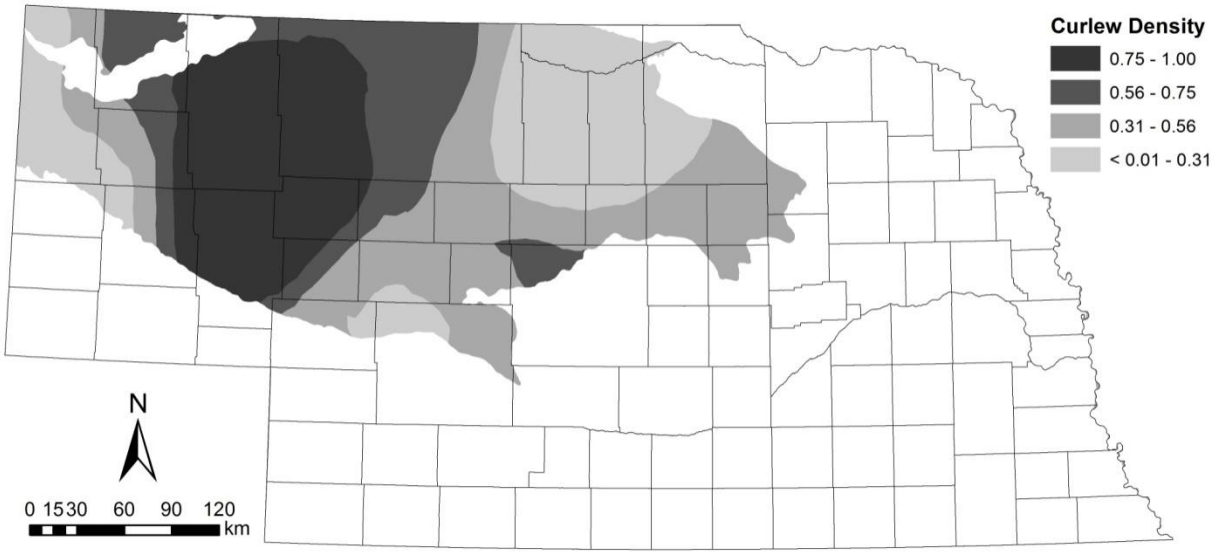

Figure 2.2. Long-billed Curlew (*Numenius americanus*) density in Nebraska using interpolated (kriging) survey data from our study (Courtesy of J. Jorgensen. ArcMap, ESRI; Geostatistical Analyst extension). The legend is without units because the original density was rescaled from 0 (no birds) to 1 (maximum density).

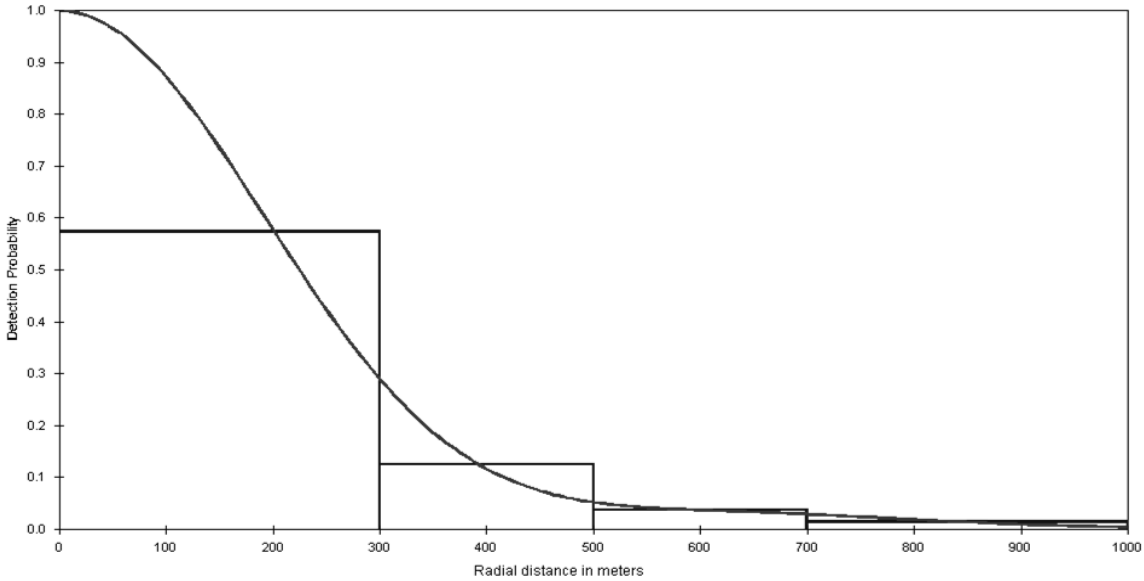

Figure 2.3. The detection probability for binned distances of Long-billed Curlews (*Numenius americanus*; 2008-2009) using the WIND model (half-normal/cosine adjustment).

Appendix

Date surveyed and start/stop GPS coordinates for survey routes of Long-billed Curlews (*Numenius americanus*) in Western Nebraska, 2008-2009.

Date Surveyed	Route Starting Point (N)	Route Starting Point (W)	Route Stopping Point (N)	Route Stopping Point (W)
4/8/2008	41º 29.094'	102º 10.156'	41º 29.716'	102º 18.535'
4/14/2008	41º 54.299'	101º 21.238'	41º 48.867'	101º 14.882'
4/16/2008	42º 21.745'	99º 19.367'	42º 28.684'	99º 37.826'
4/17/2008	41º 59.320'	100º 40.809'	42º 11.052'	100º 31.637'
4/18/2008	41º 39.080'	100º 20.726'	41º 48.635'	100º 09.017'
4/20/2008	41º 22.257'	100º 52.948'	41º 13.342'	100º 42.359'
4/22/2008	41º 50.404'	102º 20.595'	42º 03.799'	102º 20.633'
4/23/2008	42º 06.517'	103º 40.747'	42º 01.660'	101º 32.825'
4/24/2008	42º 50.666'	103º 15.976'	42º 57.804'	103º 30.885'
4/25/2008	43º 00.037'	103º 01.243'	42º 56.515'	103º 05.463'
4/27/2008	41º 52.625'	103º 10.294'	41º 59.216'	103º 19.454'
4/27/2008	41º 22.523'	101º 10.467'	41º 17.733'	101º 03.592'
4/28/2008	42º 13.315'	102º 14.240'	42º 32.453'	102º 12.047'
4/15/2009	42º 00.022'	102º 23.153'	42º 15.080'	102º 25.715'
4/15/2009	41º 50.215'	102º 22.031'	41º 37.444'	102º 20.810'
4/16/2009	42º 24.952'	102º 55.887'	42º 26.715'	102º 55.805'
4/16/2009	42º 18.422'	103º 03.222'	42º 22.016'	102º 56.635'
4/19/2009	42º 43.845'	102º 31.080'	41º 58.344'	102º 34.581'
4/19/2009	42º 40.492'	102º 38.158'	41º 30.733'	102º 43.443'
4/20/2009	42º 53.118'	102º 50.947'	42º 52.232'	102º 44.054'
4/20/2009	42º 47.685'	103º 47.883'	42º 54.925'	103º 46.798'
4/21/2009	42º 10.356'	103º 48.186'	42º 13.974'	104º 00.494'
4/21/2009	41º 40.596'	103º 59.184'	41º 47.963'	103º 57.821'
4/22/2009	41º 39.120'	102º 12.803'	41º 51.936'	101º 58.001'
4/22/2009	41º 28.047'	101º 45.697'	41º 34.350'	101º 54.168'
4/23/2009	41º 57.310'	100º 16.569'	42º 12.065'	100º 06.799'
4/23/2009	42º 02.656'	99º 52.111'	42º 08.694'	99º 47.898'
4/24/2009	42º 13.216'	99º 47.490'	42º 15.258'	100º 05.904'
4/24/2009	41º 50.549'	99º 38.202'	41º 43.122'	99º 30.036'
4/25/2009	42º 31.505'	99º 39.397'	42º 19.668'	99º 41.962'
4/25/2009	42º 20.826'	99º 30.047'	42º 26.384'	99º 24.092'
4/26/2009	42º 55.656'	100º 38.965'	42º 45.595'	100º 46.363'
4/26/2009	42º 56.427'	099º 29.624'	42º 51.953'	099º 42.564'
4/27/2009	42º 32.747'	101º 58.849'	42º 45.768'	102º 11.087'
4/27/2009	42º 37.755'	101º 42.820'	42º 56.516'	101º 41.907'
4/28/2009	42º 21.376'	102º 12.052'	42º 14.371'	102º 14.198'
4/29/2009	42º 01.854'	101º 32.219'	41º 41.805'	101º 27.197'
4/29/2009	41º 58.975'	101º 46.701'	41º 44.902'	101º 43.737'

CHAPTER III. NEST SURVIVAL OF THE LONG-BILLED CURLEW (*NUMENIUS AMERICANUS*) IN NEBRASKA

A paper to be submitted to the *Wader Study Group Bulletin*

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Abstract

The Long-billed Curlew (*Numenius americanus*) is an imperiled shorebird of western North America. Populations have declined dramatically in the last 150 years from the conversion of prairie to agriculture and the curlew is now listed as a "Tier I at-risk" species in Nebraska. I undertook a 3-year study (2008-2010) to study the nest survival of Long-billed Curlews in Nebraska. I measured vegetation characteristics at each nest site (n = 14 nests) on two different spatial scales and used program MARK to model nest survival as a function of multiple covariates. Apparent nest survival was 29% (n = 4 successful nests) and my model-based estimate of nest survival was 33% (95% CL: 24%, 93%). This estimate is similar to other estimates of curlew nest survival in Nevada (31%) and South Dakota (15% to 39%). Visual obstruction reading height ($\beta_{o.vor}$ = -4.17, 95% CL: -7.58, -0.77) and forb cover at the nest (β_{forb} = -12.49, 95% CL: -26.14, 1.17) negatively affected survival. Bare ground cover positively affected nest survival (β_{bare} = 3.28, 95% CL: -1.03, 7.59) but I found no evidence that nest age, grass cover, or litter depth affected nest survival. These findings suggest that Long-billed Curlews in Nebraska have a relatively low nest survival rate, but it is within the

expected range for this species. Furthermore, nest survival is affected negatively by tall vegetation and forb cover at and near the nest.

Introduction

Nest survival is a crucial component of the annual cycle of most bird species (Easton and Martin 2002). Likewise, nest habitat measures are of interest because nest-site characteristics often affect nest survival (Martin 1993, Gloutney and Clark 1997). The type of habitat utilized by nesting birds may directly influence predation pressures and thus the evolution of life history traits (Lima 2009, Martin and Briskie 2009). This link between nest-site habitat and nest survival is especially important when studying ground-nesting species. The surroundings of a nest placed on the ground potentially have a direct effect on nest and bird concealment and ultimately nest success (Singh et al. 2010). Without an understanding of these habitat and nest-site characteristics, management actions may not be suitable for conservation of the target species.

Many grassland bird populations have sharply declined due to the loss of native prairies and grasslands (Knopf 1994, Samson and Knopf 1994, Wilson et al. 2005). The Long-billed Curlew (*Numenius americanus*) is a large and distinctive shorebird of western North America and one of only nine grassland birds considered endemic to the North American Great Plains (Dugger and Dugger 2002). It is listed as a bird of conservation concern in five U.S. Fish and Wildlife regions (Fellows and Jones 2009). The Long-billed Curlew is classified as a “Tier I at-risk” species by the Nebraska Natural Legacy Project (Schneider et al. 2005) and as “highly imperiled” by the United States Shorebird Conservation Plan (USSCP; Brown et al. 2000, Fellows et al. 2001). The decline of this species is attributed to the destruction of suitable breeding habitat and overharvest by humans

(Dugger and Dugger 2002). Because habitat loss remains a main threat today (Fellows and Jones 2009), further understanding of curlew nest survival and habitat needs is important. Together, further research could support broad-scale conservation efforts and this species' recovery (Dugger and Dugger 2002).

The Long-billed Curlew is terrestrial and nests in dry short- and mixed-grass prairies throughout much of the Great Plains. It breeds from April to July and winters along the West Coast, Gulf Coast, and throughout Mexico from August to March (Small 1994, Stevenson and Anderson 1994, Howell and Webb 1995, Dugger and Dugger 2002). Historically, the Long-billed Curlew bred in prairies throughout the Great Plains east to Indiana, Michigan, and probably even Ohio (Bent 1929). However, the Long-billed Curlew now nests east in the Great Plains only to western Nebraska and western South Dakota. This range reduction during the last 150 years is thought to be associated with overharvest by hunters (Dugger and Dugger 2002) and farming practices that eliminated the grasslands used by breeding curlews (Bent 1927, Yocum 1956). More recently, its range has stabilized in Nebraska and is centered primarily in the Sandhills and shortgrass prairies of the north-central and northwestern parts of the state. Currently, Nebraska lies on the eastern edge of the Long-billed Curlew breeding range and, because of the species' range reduction during the last 150 years, understanding their nest survival and nest habitat preferences is of great importance for land management and further conservation efforts.

The Long-billed Curlew is socially monogamous and many return to the breeding grounds in spring already paired (Forsythe 1970, Allen 1980). For unpaired birds, courtship begins upon arrival and both paired and unpaired males quickly establish territories (Allen 1980, Pampush and Anthony 1993). Nest construction begins within one week after pairing

and many nests are initiated by early April (Jenni et al. 1981, Dugger and Dugger 2002). The Long-billed Curlew nests in shallow depressions directly on the ground (Dugger and Dugger 2002) and the nest is lined with various materials such as pebbles, livestock droppings, grass, stems, twigs, and seeds (Jenni et al. 1981). Unlike other grassland shorebird species which conceal their nests in thick vegetation, the curlew nests are often placed in sparse areas with short vegetation (Allen 1980, Jenni et al. 1981). This tendency is thought to assist the adult in detecting approaching predators (Pampush and Anthony 1993) and reduce predator pressure (Redmond and Jenni 1986). The typical clutch size is four eggs (range 2-5) and both parents share incubation duties for the 28-day (range 27-31 days) incubation period (Dugger and Dugger 2002). Curlew chicks hatch synchronously, most within a 4-6 hour period (Allen 1980, Jenni et al. 1981). Curlews are precocial and chicks leave the nest on their own within 4-5 hours of hatching (Allen 1980, Jenni et al. 1981).

Past studies of Long-billed Curlew breeding biology have been conducted in many western states including Idaho, Nevada, Oregon, South Dakota, Utah, Washington, and Wyoming. Clarke (2006) found that nest success decreased from 39% in 2005 to 15% in 2006 due to a large increase in nest depredation in grazed landscapes of western South Dakota. She estimated the constant daily survival rate for nests during 2005 and 2006 as 0.94 (Clarke 2006). The study found that daily nest survival rates were positively related to average visual obstruction readings (VOR) taken at nest sites and negatively related to the bison density in grazed pastures. Hartman and Oring (2009) monitored Long-billed Curlew nests in Northeastern Nevada hay fields from 2003 through 2006. They found that mean nest success was 31% but with considerable inter-annual variation. Research focused on the breeding ecology of the Long-billed Curlew is scarce for Nebraska; only one published study

with this species has been conducted in the state. Bicak (1977) studied the behavioral aspects of curlews at Crescent Lake National Wildlife Refuge (CLNWR) but did not focus on nest survival or habitat assessments.

Conservation of threatened and declining species often relies on a thorough understanding of nest-site selection and subsequent nest survival. I studied the nest survival of Long-billed Curlews in western Nebraska and used program MARK (White and Burnham 1999) to model nest survival as a function of multiple covariates as described by Dinsmore et al. (2002). Nest-site vegetation can affect nest success in some birds (Crabtree et al. 1989), so I modeled nest success as a function of seven vegetation variables (VOR, height of tallest vegetation, litter depth, forb cover, litter cover, grass cover, and bare ground) as well as nest age and within-season variation. I expected to find that nests had increased survival when placed in vegetation with high VOR measurements and in areas of greater forb cover as found by Clarke (2006).

Methods

Study Area

I studied the nesting ecology of the Long-billed Curlew in the Sandhills of Nebraska during spring and summer, 2008-2010. My study site was centered at Crescent Lake NWR, Garden County, Nebraska. This is an 18,615-ha refuge of grass-covered and exposed sand dunes, meadows, and shallow lakes situated in the eastern panhandle of Nebraska (Figure 1). With the numerous shallow alkali lakes and meadows, this area was known to contain a substantial breeding population of curlews (Sharpe et al. 2001). Nearby private land is similarly comprised of lakes, grasslands, and grazed meadows. The topography of this landscape

ranges from choppy and bare sand dunes to low and flat wet meadows. Cattle grazing is the dominant land-use in the Sandhills (Miller 1998).

Nest searching and monitoring

I searched for nests using rope dragging and observations of adults. Rope dragging is a widely used technique to flush incubating birds and it has been successfully used for finding curlew nests (Clarke 2006, M. French, USFWS, personal communication). It involves two people, on foot or using ATVs, dragging a 25-50 ft. weighted rope on the ground through areas where curlews are suspected to nest, e.g., low hills adjacent to wet meadows. The incubating adult will flush and reveal the nest location if the moving rope passes too close. I also used an observation technique to locate nest sites. I witnessed adults swapping nest incubation duties by watching pairs of curlews through a spotting scope from a blind or vehicle. Once a nest was located and marked with flagging and Global Positioning System (GPS) coordinates, eggs were floated to determine development of the embryo and estimate a hatch date (Westerskov 1950, Liebezeit et al. 2007). I attempted to capture both adults on the nest using a modified mist-net technique developed by Redmond and Jenni (1986) and also used by Clarke (2006). Holding an open mist-net horizontally between two poles, two people walked towards the nest and set the open net over the incubating adult. I captured the second adult by returning to the nest later in the day ensuring that the adults had switched incubation duties. Each bird was banded on the right metatarsus with a uniquely numbered USGS metal band and a uniquely numbered green darvic band on the left metatarsus to aid in later identification. The darvic bands were the wrap-around design and needed no additional sealing. To identify the sex of the bird, I measured mass to the nearest gram, and wing, culmen, and total head length to the nearest millimeter. Females are typically heavier (range

568-681 g) with longer culmen lengths (148-180 mm) whereas males have a lower body mass (range 461-541 g) and a shorter culmen (117-137 mm; Clarke 2006). I collected 250 µl of blood from the brachial wing vein and stored it in Queen's Lysis Buffer to be used in possible future genetic or parentage studies (Seutin et al. 1991).

I monitored each nest every 2-3 days, except that I checked nests daily within five days of the predicted hatch date. I visited each nest on hatch day to confirm the nest fate. A nest was called successful if at least one egg hatched. Evidence of depredation included missing eggs, large eggshell fragments or yolk from broken eggs, or disturbed nest cup contents. A nest was categorized as abandoned if no adults were present or defending the nest on multiple consecutive visits. Dusty, sun-bleached, cold, or unattended eggs were additional signs of abandonment.

I took a series of vegetation measurements at two different scales at all nest locations to assess the habitat composition in these areas. Vegetation at nest sites plays an important role in the survival of many species (Martin 1993, Hoekman et al. 2002). Specific nest characteristics may be used for thermal protection, structural protection, or camouflage to aid in predator avoidance (Noel et al. 2005). Vegetative characteristics at the ground level were measured in this study because curlews are ground nesters. Grassland vegetation in western Nebraska can be categorized into grasses, litter, forbs, succulents, woody plants, and bare ground. I used a 100 cm x 50 cm Daubenmire frame placed around each nest site to measure vertical ground cover density and percent cover of the aforementioned vegetation groups (Daubenmire 1959). In addition to four centered frame readings directly around the nest, 16 additional frame readings were taken along 25 m transects in all four cardinal directions from the nest (Figure 2). At the center of each Daubenmire frame, I also measured the visual

obstruction reading (VOR) using a Robel pole (Robel et al. 1970). Vegetation was sampled at nest sites at four sample locations, each 0.5 m from the nest in the four cardinal directions. I did not sample vegetation at the exact nest location due to skewed vegetative readings caused by the open nest cup. Litter depth (cm) and the tallest piece of vegetation (dm) were measured at three locations within each Daubenmire frame and were later averaged for use as covariates. To standardize measurements, all nest vegetation readings were measured within one week after the nest was predicted to hatch regardless of actual nest fate.

I used program MARK to build nest survival models as a function of multiple covariates. They included a constant nest survival model (.), also known as the Mayfield approach (Mayfield 1975), which assumes survival is constant through time. I also included date in season as a linear (T) and quadratic (TT) survival models to investigate seasonal variation in nest survival. I created the covariate "nest age" by coding the age of each nest when found by using egg flotation data. I also used the covariates of VOR (mean of four samples 2 m of nest sites) and outer VOR (mean of 16 samples 2-25 m of nest sites), litter depth (cm), height of the tallest piece of vegetation (dm), forb cover (%), litter cover (%), grass cover (%), and bare ground (%). Finally, I built three additive models combining effects found in the top three models: outer VOR + T, outer VOR + age, outer VOR + TT. I followed the guidelines of Burnham and Anderson (2002) for making model inferences. Models were ranked by Akaike's Information Criterion (AIC); the model with the lowest AIC value was considered best and all models within 2.0 AIC units of that model were considered competitive. I present effects as "strong" when the 95% CL does not overlap zero, "moderate" when it barely overlaps zero but with a strongly off-centered 95% CL range, and "weak" when the 95% CL overlaps zero and the range is only slightly off-

centered. I present estimates of apparent nest success for comparison to earlier estimates for the curlew, and then derived a model-based estimate to minimize the bias associated with apparent nest success (Mayfield 1975). To get this estimate, I used my best nest survival model, started a nest on the mean nest initiation date (11 May), and calculated the probability that a nest would survive the entire incubation period (28 days; Dugger and Dugger 2002) from that date. This extrapolation was straightforward because my best model was very simplistic and used only a constant daily survival rate.

Results

I monitored and measured vegetation at 14 nests (n = 12 active, n = 2 depredated prior to discovery) between 25 April and 18 June during the 3-year study (2008-2010). All nests were found using the observation technique; no nests were found by rope dragging. The mean nest initiation date for all nests was 11 May. Apparent nest survival, classified as a nest producing one or more chicks, was 29% (n = 4 successful nests). My model-based estimate of nest survival was 33% (95% CL: 24%, 93%) and its 95% confidence interval included the apparent survival estimate. The average VOR at nest sites ranged from 0.05 dm to 0.68 dm, the average litter depth ranged from 0 cm to 2.27 cm, and the tallest piece of vegetation within the frames ranged from 5 cm to 75 cm.

I considered 21 models in my nest survival analysis, three of which had ΔAIC values <2.0 (Table 1). The best model indicates there is strong evidence for a negative effect of large-scale VOR on nest survival ($\beta_{outer\ vor}$ = -4.17, SE=1.74, 95% CL: -7.58, -0.77). The effect of VOR at the nest site also suggests a negative influence on nest survival (β_{vor} = -3.57, SE = 1.95, 95% CL: -7.40, 0.26). The forb model showed moderate evidence for a negative influence of forb cover on nest survival (β_{forb} = -12.49, SE = 6.97, 95% CL: -26.14, 1.17)

whereas the bare ground model showed a weak, positive influence of bare ground on survival (β_{bare} = 3.28, SE = 2.20, 95% CL: -1.03, 7.59). Two of the competitive models were additive: a linear seasonal trend + outer VOR model (ΔAIC = 0.55) and age + outer VOR (ΔAIC = 1.53).

None of the time trend models were competitive as stand-alone models. The linear trend model (T) had a ΔAIC of 3.31 and showed a slight trend towards poorer survival as the nesting season progressed (β_T = -0.05, SE = 0.03, 95% CL: -0.12, 0.01). The constant survival model (.) was not competitive (ΔAIC = 3.68). Lastly, the linear nest age model (age) was also not competitive (ΔAIC = 4.08) but still showed a weak trend towards poorer survival with increasing nest age (β_{age} = -0.04, SE = 0.03, 95% CL: -0.09, 0.02). Models that included the effects of grass cover, litter cover, vegetation depth, height of the tallest vegetation, and the quadratic trend model (TT) were not competitive (ΔAIC > 2.0) and I concluded that they had little or no influence on nest survival in this study.

Discussion

Conservation measures often rely on an understanding of nesting ecology, including patterns of nest survival and important vegetative characteristics at nest sites. Those estimates provide an important metric upon which to gauge present population trends and potential future habitat management techniques. My study sought to provide an estimate of the nest survival of the Long-billed Curlew in Nebraska, and then use that information to provide insight into the overall nest success on a larger scale. Below, I discuss some aspects of a modeling approach to estimate curlew nest survival and how Nebraska's nest survival rates compare regionally and nationally.

There are five assumptions that must be met for nest survival models to be unbiased (Dinsmore et al. 2002). They are: 1) nests are correctly aged when they are discovered, 2) nest fates are correctly determined, 3) nest discovery and subsequent nest checks do not influence survival, 4) nest fates are independent, and 5) homogeneity of daily nest-survival rates. I believe my study of curlew nest survival meets these criteria. First, determining the age of nests is possible using egg-flotation, a widely-used technique among ornithologists (Westerskov 1950, Liebezeit et al. 2007). Secondly, nest fates were fairly straightforward to assign because I checked the nests often and floated eggs multiple times to ensure an accurate hatch-date. Finding a nest with no eggs well before that date proves depredation. Ensuring that nest discovery and subsequent nest visits did not influence survival is very difficult to measure. I cannot eliminate the possibility that mammalian nest depredations may have occurred due to researcher visits although I took precautions to avoid leaving scents at nest sites. Likewise, I cannot fully eliminate the possibility that the two abandoned nests were abandoned due to researcher visits. However, I found and monitored other nests in which abandonment was not an issue and I believe this was an unlikely cause of nest failure. Nest fates were almost certainly independent due to the large territory size of curlews and the great distances between nests (>2 km).

Estimates of curlew nest survival have been reported from Idaho, Oregon, South Dakota, Utah, and Wyoming but never from Nebraska, which contains a substantial portion of the continental breeding range (Fellows and Jones 2009). The mean hatching success estimate of 29% is one of the lowest among studies of Long-billed Curlews. Only two other studies have published lower rates; a study in Utah estimated apparent nest success of 20% (n = 10 nests; Paton and Dalton 1994) and a study in South Dakota estimated nest success of

15% (n = 48; Clarke 2006). Other studies found nest success rates between 35% and 69% (Dugger and Dugger 2002). However, Hartman and Oring (2009) estimated nest success of 31% with a substantial sample (n = 215) in Nevada. Mean nest success of other *Numenius* species ranged between 54% and 86% for Whimbrel nests in Manitoba (n = 65; Skeel 1983) and 37% (n = 20; Marks et al. 2002) in a study of Bristle-thighed Curlews in Alaska.

The results in program MARK yielded three competitive models, which suggests that more than one factor is affecting curlew nest survival in Nebraska. All of the competitive models included large-scale VOR suggesting importance of this vegetative characteristic on nest survival. For example, the analyses suggest that more dense vegetation of outer patch levels negatively affects nest survival whereas bare ground positively affects nest survival. Likewise, the analyses suggest that nests placed in areas with less forb cover had greater survival. Although these findings are not in accordance with the findings of Clarke (2006), they confirm what other studies state about curlews using areas with short vegetation and their tendency to use barren areas (Allen 1980, Dugger and Dugger 2002). This tendency is thought to provide nesting curlews with ample visibility and therefore predator avoidance (Pampush and Anthony 1993). Redmond and Jenni (1986) hypothesized that lush vegetation may protect small mammals and that the diet of avian predators would shift more to include curlew chicks which might persuade adults to nest in areas away from thick vegetation. The different conclusions may also be due to predominant vegetation types at the study site. Clarke (2006) study was located in grazed grasslands of South Dakota. The typical plant community, VOR measurements, and predator scheme may be different there compared to the more barren Nebraska Sandhills.

A potential source of bias in this study was the small sample of nests. I intentionally kept models simplistic to avoid over-fitting, although the many competitive models suggest that these data may have been too sparse for even some of these models. There are three primary reasons for the small sample of nests. First, late season blizzards in 2008 and an unusually wet year in 2010 hampered search efforts and were suspected to reduce nest survival. Secondly, wet conditions in 2010 may have created more suitable wet meadow habitats elsewhere resulting in fewer nesting pairs in my study area. Lastly, Long-billed Curlews have large breeding territories and rope-dragging by foot was inefficient. Rope-dragging using ATVs was not permitted in much of the study area and I would suggest future studies use areas that allow ATVs to maximize coverage. The wary nature of curlews together with the very hilly terrain, limited road system, and large territory sizes made it difficult to observe birds without them becoming alarmed and reluctant to switch incubation duties. Collectively, this limited my chances for finding many curlew nests.

My study provides the first estimates of nest survival for Long-billed Curlews in Nebraska, which fulfills one of the Nebraska Natural Legacy Project's stated needs (Schneider et al. 2005). These estimates are statistically acceptable and are within the known range found in other curlew studies. They can be used as a baseline estimate for further study but additional studies with larger samples may improve the accuracy. I affirmed the importance of grasslands with short vegetation, more bare ground, and less forb cover for nesting curlews. This habitat scheme was historically more widespread when bison (*Bison bison*) still grazed the prairies and regular fire regimes maintained shorter vegetation (Risser et al. 1981). Changes in the last century, such as reducing the frequency of naturally occurring fires and converting grazed prairies into cropland, have diminished much of this

habitat (Pampush and Anthony 1993, Oring 2006). Presently, curlews thrive where moderate grazing pressure helps to reduce tall vegetation (Clarke 2006, Askins 2007). However, care should be taken when managing grazing pressure; Clarke (2006) found up to 75% of curlew nest failure due to trampling in South Dakota. Her study recommends reducing livestock density to less than 33 cattle/km^2 and 220 bison/km^2 in pastures during the peak of curlew incubation/hatching (10 April to 25 June). However, the stocking rates in the Sandhills tend to be much lower than those areas and Kempema (2007) found only 3% of grassland bird nests (9 of 287 nests) were trampled by cattle in the Sandhills. A widely used method of maintaining variable habitat characteristics is patch-burn grazing (Fuhlendorf et al. 2006). Studies have shown that patch-burn grazing is a suitable method of managing for a suite of grassland songbird species, many of which use short-grass prairies (Grant et al. 2010). On a large scale (>10 km) and in the correct context, patch-burn grazing may provide the needed habitat for the entire life-cycle of curlews. Many ranchers in the Sandhills avoid the use of fire for management because of fire containment issues resulting from the dry and arid climate. Rotational grazing treatments have been shown to host greater densities of some grassland bird species, e.g. Grasshopper Sparrow, and these systems may be more appropriate for providing similar habitat mosaics without burning areas with dry climates and high fire risks (Kempema 2007).

My study provides a critical baseline understanding of nest survival and the influential factors that affect breeding Long-billed Curlews in Nebraska. The range reduction of curlews during the last 150 years has been attributed to a loss of habitat and this threat still remains today in the Sandhills of Nebraska (Schneider et al 2005). To ensure that Nebraska continues to host a sizeable portion of the curlews' range, future studies are needed

to explore curlew survival as it relates to broad land-use practices, human disturbances, and the conversion of nearby grasslands to agriculture (Dugger and Dugger 2002). Further studies are also needed to better estimate adult survival thus providing information for population growth models and ultimately population trends. The Sandhills are biologically unique and remain an important stronghold for the curlew and other declining grassland species. I am optimistic that land-use managers will use these data to make informed decisions regarding grazing pressures, burning regimes, and grassland preservation for this emblematic prairie species. These findings have important conservation implications, especially if these habitats and the curlews that use them continue to decline.

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Table 3.1. Model selection results for Long-billed Curlew (*Numenius americanus*) nest survival in western Nebraska, 2008-2010. Models are ordered by Akaike's Information Criterion, corrected for small sample size (AIC_c). K is the number of parameters and ΔAIC is the AIC difference from the top model. $S_{(.)}$ represents a model with a constant daily survival rate, $S_{(T)}$ represents a model with a linear time trend, $S_{(TT)}$ represents a model with a quadratic time trend, and $S_{(age)}$ represents a model with an age effect. $S_{(height)}$ represents a model using maximum vegetation height, $S_{(depth)}$ represents a model using litter depth, and $S_{(vor)}$ represents a model using visual obstruction readings. $S_{(bare)}$ represents a model using percent bare ground, $S_{(grass)}$ represents a model using percent grass cover, $S_{(forb)}$ represents a model using percent forb cover, and $S_{(litter)}$ represents a model using percent litter cover. Models with $_{(o.)}$ represent covariates from the outer 16 frames and a lack of $_{(o.)}$ represent covariates from the inner 4 frames.

Model	ΔAIC_c[a]	w_i	K	Deviance
$S_{(o.vor)}$	0.00	0.22	2	35.80
$S_{(T + o.vor)}$	0.55	0.16	3	34.28
$S_{(age + o.vor)}$	1.53	0.10	3	35.26
$S_{(vor)}$	2.17	0.07	2	37.98
$S_{(TT + o.vor)}$	2.24	0.07	4	33.87
$S_{(forb)}$	2.31	0.07	2	38.12
$S_{(T)}$	3.31	0.04	2	39.11
$S_{(o.litter)}$	3.33	0.04	2	39.13
$S_{(.)}$	3.68	0.03	1	41.53
$S_{(bare)}$	3.73	0.03	2	39.53
$S_{(o.depth)}$	3.90	0.03	2	39.71
$S_{(age)}$	4.08	0.03	2	39.88
$S_{(o.forb)}$	4.40	0.02	2	40.21
$S_{(o.height)}$	4.41	0.02	2	40.21
$S_{(grass)}$	4.76	0.02	2	40.56
$S_{(litter)}$	5.02	0.02	2	40.82
$S_{(TT)}$	5.28	0.02	3	39.01
$S_{(depth)}$	5.49	0.01	2	41.29
$S_{(o.grass)}$	5.52	0.01	2	41.33
$S_{(o.bare)}$	5.63	0.01	2	41.43
$S_{(height)}$	5.72	0.01	2	41.52

[a] The AIC_c value of the best model is 39.88.

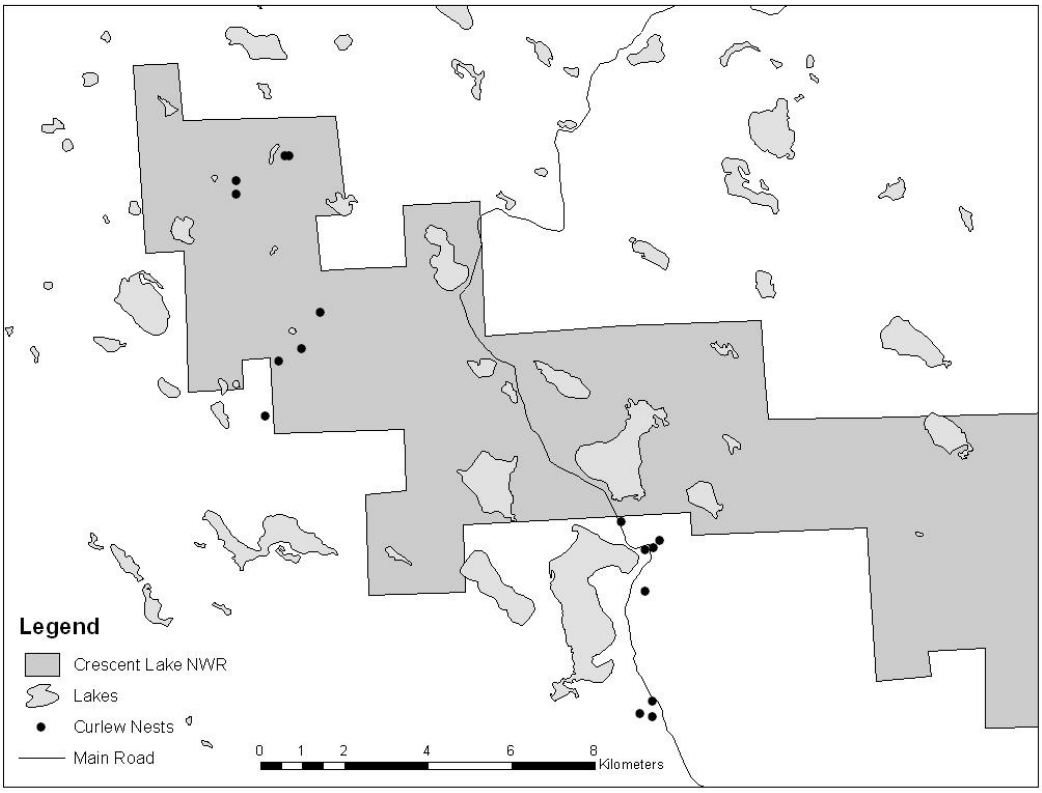

Figure 3.1. The study site at Crescent Lake National Wildlife Refuge, Garden County, Nebraska and Long-billed Curlew (*Numenius americanus*) nest locations for 2008-2010.

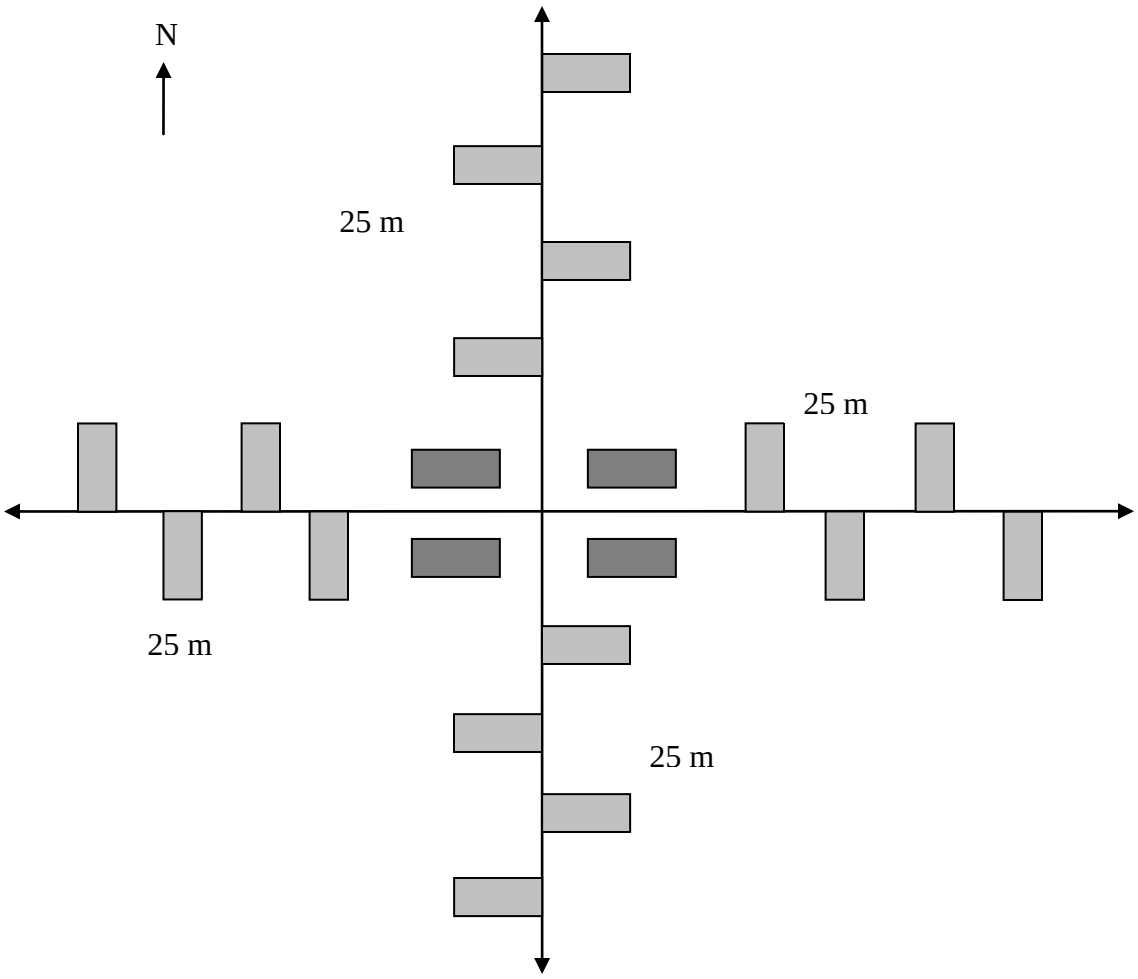

Figure 3.2. The layout of Daubenmire frames and visual obstruction readings (VOR) relative to Long-billed Curlew (*Numenius americanus*) nest locations (in center). Darker shades represent the "inner" scale of measurements and lighter shades represent the "outer" scale of measurements.

Appendix

Long-billed Curlew (*Numenius americanus*) nest locations (X and Y coordinates, UTM zone 13) and discovery date in Western Nebraska, 2008-2010.

Nest coordinates		Date found
0708470	4630974	6 May 2008
0708223	4626062	14 May 2008
0707221	4630384	15 May 2008
0716994	4621556	17 May 2008
0708380	4630983	24 May 2008
0716997	4620552	31 May 2008
0709219	4627225	23 April 2009
0708768	4626348	25 April 2009
0707909	4624747	25 April 2009
0717188	4621605	6 May 2009
0717153	4617547	7 May 2009
0717160	4617943	7 May 2009
0716426	4622210	10 May 2009
0707220	4630044	1 June 2009
0717339	4621775	28 April 2010
0716854	4617629	11 May 2010

CHAPTER IV. CHICK SURVIVAL AND MOVEMENT OF THE LONG-BILLED CURLEW (*NUMENIUS AMERICANUS*) IN NEBRASKA

A paper to be submitted to the *Journal of Field Ornithology*

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Abstract

Populations of the Long-billed Curlew (*Numenius americanus*) have declined dramatically in the last 150 years from the conversion of prairie to agriculture and the curlew is now listed as a "Tier I at-risk" species in Nebraska. I undertook a 3-year study (2008-2010) to measure daily movements and survival of Long-billed Curlew chicks in Nebraska. I measured vegetation characteristics at each chick location and used program MARK to model chick survival as a function of multiple covariates. Apparent fledging success was 4% (n = 1 chick out of 28 total chicks) and my model-based estimate of chick survival for the fledging period was <1% (95% CL: 0%, 13%). These estimates are lower than what other studies of curlew fledging success have found. The best model suggested there was strong evidence for a positive effect of litter cover on chick survival (β_{litter} = 0.32, 95% CL: 0.03, 0.60) but I found no effect of grass cover, forb cover, or visual obstruction on chick survival. Curlew chicks were mobile soon after hatching; two different broods moved >2.6 km in 24 h and on one occasion a 2-day-old chick moved >2 km in 24 h. Long-billed Curlew chicks in Nebraska have low fledging survival, but they were mobile after hatching and were capable of moving

long distances. These findings have implications for habitat management to benefit the curlew, and also suggest appropriate spatial scales where this could occur.

Introduction

Chick survival is a crucial element of the avian life cycle. Precocial chicks leave the nest area to avoid predators, exploit foraging options, and to reduce the competition with conspecifics (Lengyel 2006, Dreitz 2009). The habitat where they forage may affect their survival, but the relationship between precocial chick habitat use and survival is poorly understood in most bird species (Dreitz 2009). Other aspects of precocial chick ecology are also poorly understood, including daily distances moved and movement patterns. Understanding these factors has long been a goal of avian ecologists; population growth models often incorporate estimates of chick survival, so an understanding of these aspects is also important for conservation (Anders et al. 1997, Powell et al. 2000, Colwell et al. 2007).

Many grassland bird populations have declined sharply due to the loss of native prairies and grasslands (Knopf 1994). The Long-billed Curlew (*Numenius americanus*) is a large and distinctive shorebird of western North America that has lost approximately 30% of its historical breeding range (Fellows and Jones 2009). It is one of only nine grassland birds endemic to the North American Great Plains (Dugger and Dugger 2002) and is listed as a bird of conservation concern in five U.S. Fish and Wildlife regions (Fellows and Jones 2009). The Long-billed Curlew is classified as “highly imperiled” by the United States Shorebird Conservation Plan (USSCP; Brown et al. 2001, Fellows et al. 2001) and is listed as vulnerable in Canada. In Nebraska, the Long-billed Curlew is listed as a “Tier I at-risk” species by the Nebraska Natural Legacy Project (Schneider et al. 2005). The decline of this species is attributed to the destruction of suitable breeding habitat and to overharvest by

humans (Dugger and Dugger 2002). Because habitat loss remains a main threat today (Fellows and Jones 2009), further understanding of chick survival and their habitat needs is important. Further research could support broad-scale conservation efforts and this species' recovery (Dugger and Dugger 2002).

Long-billed Curlews are grassland shorebirds and breed in dry short- and mixed-grass prairies. Curlew chicks hatch synchronously and are nidifugous, often leaving the nest within four hours of hatching (Jenni et al. 1981). Long-billed Curlew chick survival has not been well-studied in general, and has not been studied at all in Nebraska. Past studies of Long-billed Curlew biology have been conducted in Idaho, Nevada, Oregon, South Dakota, Utah, Washington, and Wyoming. Redmond and Jenni (1986) studied chick survival in western Idaho and found that success of radio-marked chicks from hatching to fledging (the ability of flight) was 39% but that success varied greatly by year, ranging from 15% to 75% (Redmond and Jenni 1986). Hartman and Oring (2009) also used radio-telemetry and estimated fledging success at 47% for their 4-year study in Nevada. Clarke (2006) used radio-marked adults to study chick survival in grazed landscapes of western South Dakota and estimated chick survival at 30% in 2005 and 40% in 2006. Because newly-hatched curlew chicks have poorly developed thermoregulatory systems (Myhre et al. 1975, Aulie 1976), they are vulnerable to heat exposure. Death due to heat exposure was a leading cause of chick mortality in several studies (Redmond and Jenni 1986, Clarke 2006, Hartman and Oring 2009) and thick vegetation may play a key role in chick survival by providing shade and camouflage (Jenni et al. 1981, Guthery 2002). Most studies suggest that curlew broods prefer tall, dense vegetation (Redmond and Jenni 1986, Hartman and Oring 2009) but Clarke

(2006) found that broods used areas with greater bare ground and less grass cover than random points.

The young of many precocial bird species are capable of moving large distances shortly after hatching. Sadler and Maher (1976) found a Long-billed Curlew brood 6.5 km from where it hatched six days earlier, suggesting that chicks are capable of traveling at least one kilometer per day during their first week of life. Redmond and Jenni (1986) stated that Long-billed Curlew broods remain within 300 m of the nest for 1-5 days and long movements (>1 km) were rare before a chick was 10 days old. The broods of other large, precocial shorebirds can also move substantial distances; Bar-tailed Godwit (*Limosa lapponica*) chicks can move several kilometers from the nest site within a week (Larsen and Moldsvor 1992) and Hudsonian Godwit (*Limosa haemastica*) chicks can move 200 m from the nest within 1.5 h of hatching (Elphick and Klima 2002). Some smaller shorebirds are also capable of large movements; Buff-breasted Sandpiper (*Tryngites subruficollis*) chicks can move as much as 400 m in their first day and daily movements of >0.5 km are common (Lanctot and Laredo 1994). Mountain Plover (*Charadrius montanus*) chicks move progressively farther from their nests and can reach two km in their first 2-3 days (Schneider et al. 2006).

Conservation of threatened and declining species often relies on a thorough understanding of nesting ecology, fledgling ecology, and the scale at which the species operates so that we can manage properly. I studied the survival, habitat use, and movement patterns of Long-billed Curlew chicks in western Nebraska from 2008 to 2010. I expected to find that chicks have increased survival when they are found in thick vegetation which provides shade and camouflage, and that curlew chicks are mobile and move from nest sites.

Together, these findings will provide baseline data that can be used for improved land management and ultimately further conservation of this emblematic prairie species.

Methods

Study Area

I studied the chick ecology of the Long-billed Curlew in the Sandhills of Nebraska during spring and summer, 2008-2010. My study site was centered at Crescent Lake National Wildlife Refuge (CLNWR), Garden County, Nebraska. This is an 18,615-ha refuge of grass-covered and exposed sand dunes, meadows, and shallow lakes situated in the central Panhandle region of Nebraska. With the numerous shallow alkali lakes, this area was known to contain a substantial population of curlews (Sharpe et al. 2001). Nearby private land is similarly comprised of lakes, grasslands, and grazed meadows. The topography of this landscape ranges from choppy and bare sand dunes to low and flat wet meadows. Grazing by cattle is the dominant land-use in the Sandhills due to dry climate and unsuitable sandy soils, which makes farming difficult (Miller 1998). Crescent Lake NWR utilizes cattle grazing and periodic controlled burns to help mimic historical conditions.

Chick searching and monitoring

I used observations of adult curlews swapping nest incubation duties to find nests. Once a nest had been located and marked with flagging and Global Positioning System (GPS) coordinates, eggs were floated to determine development of the embryo and to estimate a hatch date (Westerskov 1950, Liebezeit et al. 2007). I monitored each nest every 2-3 days, except that I checked nests daily within five days of the predicted hatch date. I captured each chick immediately after hatching and banded it on the right metatarsus with a uniquely numbered United States Geological Survey (USGS) metal band and a uniquely numbered

darvic band on the left metatarsus. I measured mass to the nearest gram and culmen and total head length to the nearest millimeter and used measurements of known-age chicks to generate an aging tool for aging chicks found away from nests. I clipped a toenail to collect blood and stored it in 500 μl of Queen's Lysis Buffer, kept it in the dark, and at 5°C (Seutin et al. 1991). I attached a radio-transmitter (ATS A1040 backpack-type, 2.2 gram @ 40 pulses per minute) to chicks by trimming the feathers on their backs and affixing the transmitter using a cyanoacrylate adhesive. I attached a transmitter to all chicks within a brood and later tested for statistical independence of fates. To determine each fate, chicks were tracked and located daily using an ATS R4000 or R410 receiver and a 3-element Yagi antenna. Evidence of depredation included torn off transmitters, chick remains, and nonresponsive adults. I used a Garmin GPS unit and small flags to mark exact locations of chicks so I could return to measure vegetation variables within one week.

I used ArcGIS 9.2 (Environmental Systems Research Institute, Inc., Redlands, California) to map all chick locations. I used the in-program measuring tool to measure distances between subsequent tracking occasions for each chick. To study the age/distance relationship, I used simple linear regression to summarize distances traveled versus chick age. I expected to find that chicks of all ages are mobile and are capable of moving large distances. Additionally, I expected to find that chicks exhibited a pattern of initial large daily movements followed by days or weeks spent in a small area as seen by Allen (1980) and Jenni et al. (1981). I present the movement data of two different chicks from different broods to illustrate contrasting movement patterns exhibited by young curlews.

Many studies suggest that broods of precocial shorebirds move into habitats that provide high chick survival (Lengyel 2006, Dreitz 2009). I took a series of vegetation

measurements at all chick locations to study habitat use and potential correlations with brood survival. Specifically, I used a series of four 100-cm x 50-cm Daubenmire frame readings at each chick location to measure the percent cover of grasses, forbs, litter, and bare ground (Daubenmire 1959). Variables such as bare ground, grass cover, and forb cover have been linked to chick survival in other studies (Clarke 2006, Pleasant et al. 2006). The four frame readings were taken five meters away from the chick location in each of the four cardinal directions (Figure 1). I measured the visual obstruction reading (VOR) using a Robel pole at the center of each Daubenmire frame (Robel et al. 1970). VOR, as an index of relative biomass, should describe how obscured a chick might be at a given location and this may reflect chick visibility by predators. The effect of VOR was found to be an important factor in other chick survival analyses (Clarke 2006). The litter depth (cm) and the height of the tallest piece of vegetation (dm) were measured at three locations within each Daubenmire frame and were later averaged for use as individual covariates. Repeated personal observations of chicks concealed in clumps of vegetation suggested chicks choose those areas for concealment and led me to exclude measurements at the precise chick location from the analyses. To standardize measurements, all vegetation readings were measured one week after the chick was present at that location. I randomly selected one chick from each brood to include in my analyses because I recognized the lack of statistical independence in chick fates within broods.

I used program MARK (White and Burnham 1999) to build chick survival models as a function of multiple covariates. They included a constant survival model (.), which assumes survival is constant through time (c.f. Mayfield 1975). I also included linear (T) and quadratic (TT) survival models for time to investigate within-season variation in chick

survival. I created a "chick age" covariate by using the confirmed hatch date or an estimate of age from mass and culmen measurements of chicks not found at nests. Additionally, I used the covariates of VOR (dm), litter depth (cm), height of the tallest piece of vegetation (dm), forb cover (%), litter cover (%), grass cover (%), and bare ground (%). I took the best two models and combined each with age, linear, and quadratic time trends to create an additional six models.

I followed the general guidelines of Burnham and Anderson (2002) for making model inferences. Models were ranked by Akaike's Information Criterion (AIC); the model with the lowest AIC value was considered best and all models within 2.0 AIC units of that model were considered competitive. I present effects as "strong" when the 95% CL does not overlap zero, "moderate" when it barely overlaps zero but with a strongly off-centered 95% CL range, and "weak" when the 95% CL overlaps zero and the range is only slightly off-centered. I present estimates of apparent chick success for comparison to earlier estimates for the curlew, and then derived a model-based estimate to minimize the bias associated with apparent chick success. To obtain this estimate, I used my best chick survival model, started a chick on the mean hatching date, and calculated the probability that a chick would survive the entire fledgling period (38 days; C. Gregory, personal observation) from that date. This extrapolation was straightforward because my best model was very simplistic and used only a constant daily survival rate.

Results

I captured and measured 28 curlew chicks belonging to 15 different broods during the 3-year study (Table 1). Thirty-two percent of chicks (n = 9) were banded at nest sites and 68% of chicks (n = 19) were found and banded away from nests. I attached a radio-transmitter to 27

chicks between 22 May and 14 June and tracked chicks between 22 May and 4 July (a 44-day period) across all years. Apparent chick fledging success (the proportion of chicks that reached fledging age of 38 days) was 4% (n = 1 chick out of 28 chicks total). My model-based estimate of chick survival for the fledgling period was <1% (95% CL: 0%, 13%) and overlapped the apparent success estimate. Much of the habitat was sparse grass cover and little thick material except in meadows; the average VOR at chick sites was 0.52 dm (SE = 0.55) and the average tallest piece of vegetation was 31 cm (SE = 11). Litter was generally scarce; the average litter depth was 1.00 cm (SE = 1.80) and the average percent litter was 9% (SE = 8%). Bare ground was common; the average percent bare ground was 33% (SE = 18%). Grass was also common and averaged 44% (SE = 19%) of cover. Substantial forb cover was uncommon and the average percent forb cover was only 12% (SE = 10%).

I considered 17 models in my chick survival analysis, eight of which included litter cover or litter depth (Table 2). There were five competitive models (ΔAIC <2) to explain curlew chick survival. The best model suggested there was strong evidence for a positive correlation between litter cover and chick survival (β_{litter} = 0.32, SE = 0.15, 95% CI was 0.03, 0.60). The effect of litter depth in the second best model also suggested a positive influence on chick survival (β_{depth} = 2.55, SE = 1.47, 95% CI was -0.32, 5.43). Three of the six additive models were competitive but the within-season models (age, linear, and quadratic) were not singly competitive. Three of the remaining four competitive models contained a litter effect, which was always positive. No additive models that included litter depth were competitive. The remaining models with effects of bare ground model, height, forb, grass, and VOR did not appear to explain variation in chick survival.

Long-billed Curlew broods were mobile after hatching (Table 3). A linear regression analysis of chick age versus daily distance moved showed a gradual increase of daily movement distances (R^2 = 0.04; Figure 2). Single-day movements >1 km did occur for broods <10 days old (27% of broods) and movements >2 km also occurred but were rare for broods <10 days old (13% of broods). The largest single-day movements were of two different broods moving 2.61 km in 24 h. On one occasion, a 2-day old chick moved 2.01 km in 24 h. There was a wide range of overall movement patterns. One chick moved >15 km in one general direction in 18 days and a non-linear regression analysis showed this chick exhibited a pattern of moving large distances followed by remaining relatively stationary (R^2 = 0.60; Figure 3). A chick from a different brood stayed within a 1 km^2 area for 21 days and a linear regression analysis showed this chick had no clear movement pattern but remained almost stationary (R^2 = <0.01; Figure 4).

Discussion

Avian conservation measures often rely on an understanding of nesting ecology, which includes chick survival for precocial species that leave the nest. These estimates provide an important metric upon which to gauge local population trends and potential future habitat management techniques. My study provides an estimate of chick survival and summarizes the chick movement patterns for the Long-billed Curlew in Nebraska. Below, I discuss some aspects of the modeling approach I used to estimate curlew chick survival, and how Nebraska's chick survival rates and movement patterns compare regionally and nationally.

There are five assumptions that must be met for chick survival models to be unbiased (Dinsmore et al. 2002). They are: 1) chicks are correctly aged when they are discovered, 2) chick fates are correctly determined, 3) chick discovery and subsequent chick tracking does

not influence survival, 4) chick fates are independent, and 5) homogeneity of daily chick-survival rates. I believe my study of curlew chick survival meets these criteria. First, determining the age of chicks was possible using measurements from known birds to extrapolate ages for unknown chicks. Secondly, chick fates were fairly straightforward to assign because I tracked the chicks daily using radio-telemetry. For example, finding a transmitter loose alongside chick remains was evidence of a depredation. Ensuring that chick discovery and subsequent chick tracking did not influence survival is difficult to measure. I cannot eliminate the possibility that mammalian chick depredations may have occurred due to researcher visits, although I took precautions to avoid leaving scents at chick sites by reducing time spent at the location and not kneeling or trampling the vegetation. Chick fates within a brood were not statistically independent; on two occasions, an entire brood was depredated simultaneously in my study. These depredation events were most likely due to a single predator and were possible because chicks are brooded together by the adult, making them an easy target. As with most precocial shorebirds, the brood tends to move as a single unit during the fledgling period (Skeel and Mallory 1996, Lengyel 2006, Colwell et al. 2007, Dreitz 2009). To account for this in my analyses, I randomly selected one chick from each brood and thereby eliminated any dependency in the data.

Estimates of the apparent survival of Long-billed Curlew chicks have been reported from Idaho, South Dakota, Nevada (Redmond and Jenni 1986, Clarke 2006, Hartman and Oring 2009) but never from Nebraska (Fellows and Jones 2009). My apparent chick success estimate of 4% is the lowest reported in studies of Long-billed Curlews. The lowest estimate of success previously reported was 15% during a single season in western Idaho (Redmond and Jenni 1986). However, apparent chick success rates are often biased and a more precise

approach is to use a model-based estimate to reduce those biases. My model-based estimate of <1% is very low but because the confidence intervals overlap the apparent chick success rate, survival may actually be intermediate between the two estimates.

The primary reason for such low survival was the heavy depredation pressure at the study site. Forty-eight percent of chicks in my study were confirmed depredated (n = 13) and some of the unknown-fate chicks were most likely depredated. Studies state that the Swainson's Hawk (*Buteo swansoni*), Coyote (*Canis latrans*), and another mammalian carnivores are the primary predators of curlew broods (Redmond and Jenni 1986, Clarke 2006, Hartman and Oring 2009). These species were common at my field site and were observed being mobbed by adult curlews. A suite of other curlew predators were seen at the study site including American Badger (*Taxidea taxus*), Striped Skunk (*Mephitus mephitis*), and Short-tailed Weasel (*Mustela frenata*). I never directly observed a predator taking a chick but one radio transmitter was tracked to Coyote scat and one nest and the respective adult were depredated by an American Badger. Unlike previous studies where heat exposure and a lack of feeding ability are the leading cause of mortality in chicks 1-5 days old (Redmond and Jenni 1986, Clarke 2006), mammalian predators were suspected as the leading cause of chick mortality in my study.

Another reason for my low survival estimate may have been related to how I sampled chicks to get my estimate. I randomly selected one chick from each brood for analyses to account for the lack of independence of fates. This randomization may have selected chicks that were depredated more quickly than other chicks in the same brood. Although most chicks in a brood were depredated together, occasionally a chick survived substantially longer than its sibling(s) (20% of broods, n = 3). Because of the relatively small number of

chicks for this study, selecting even a couple of individuals that died quickly could have produced survival estimates that were unusually low due to random chance. A short transmitter retention rate was another cause for the small sample of exposure days to estimate chick survival. Despite almost daily confirmations that the transmitters were firmly adhered to the backs of chicks, 48% of chicks (n = 13) prematurely shed their transmitters and were censored from survival analyses. Although this method of transmitter attachment has been used in other bird studies (Johnson et al. 1991, Whittingham 1996, Warnock and Takekawa 2003), I would recommend Hartman and Oring's (2009) method that used epoxy to adhere the transmitter to the metal leg band. A longer retention rate might improve the number of known fates and the subsequent survival estimate.

My chick survival analyses resulted in five competitive models, which suggested that several factors were affecting chick survival in my study. Four of the five best models included litter cover, all with positive correlations, which hinted at the importance of that vegetative characteristic to chick survival. The analyses also suggested that survival increases as litter depth increases, but because litter depth and litter cover may be correlated, I did not create an additive model combining these two characteristics. The litter depth and litter cover models were independently important, which suggested a true positive effect of the presence of litter on chick survival. Contrary to that effect, there was weak evidence of a negative correlation of bare ground on survival. These results agree with previous studies (Jenni et al. 1981, Redmond and Jenni 1986, Hartman and Oring 2009), which note the brood preference for tall, thick vegetation.

I found that Long-billed Curlew chicks were more mobile than previously known, and this was perhaps the most surprising finding in my study. There were no previous

records of curlew chicks traveling >2 km in a 24 h period, especially those as young as two days old. The only other studies that used radio-telemetry to track curlew chicks were Redmond and Jenni (1986), Hoenisch et al. (2008), and Hartman and Oring (2009), but their focus was estimating survival. Moving >15 km from a nest site before being capable of flight is remarkable for any shorebird species; godwits and curlews have been noted to move large distances but never >7 km (Sadler and Maher 1976). Overall, my data weakly suggested that distance moved was positively correlated with chick age but the contrasting patterns of movement may have reduced this effect. For example, some broods moved large distances before becoming relatively stationary whereas others kept a stationary movement pattern from an early age.

Long-billed Curlews may select brood-rearing habitat based on grassland characteristics (Pampush and Anthony 1993) and studies suggest that curlew broods use thick and dense vegetation to aid in camouflage and shading (King 1978, Jenni et al. 1981, Hartman and Oring 2009). Other studies suggest that proximity to wetlands and meadows may be a factor in determining habitat use (Bicak 1977, Clarke 2006, Gratto-Trevor 2006). I found brood habitat ranged from barren dunes to sites adjacent to wetlands but my findings suggest that survival was highest in habitats with high litter content (e.g., meadows). This suggests that curlew broods may move large distances followed by days or weeks of remaining in a small area (Jenni et al. 1981, Allen 1980), but that moving across barren dunes was unavoidable while en route. The small sample of nests and the high depredation rate of chicks may be a result of several poor reproductive seasons with poor food resources. The evidence of chicks almost constantly moving may suggest poor food resources in

meadows thus forcing chicks to spend more time in bare habitats resulting in higher depredation rates.

My study provides the first estimates of chick survival for Long-billed Curlews in Nebraska, which fulfills one of the Nebraska Natural Legacy Project's stated needs (Schneider et al. 2005). These findings suggest that wet meadows are important for curlew chicks but changes in the last century, such as converting grazed prairies into cropland, have diminished much of this habitat (Pampush and Anthony 1993, Oring 2006). Although ranching has played a large role in sustaining the biological diversity in the Sandhills, many of these unique meadows are disappearing due to wetland and wet meadow drainage (Schneider et al. 2005). The early haying of meadows also poses a threat to habitats used by curlew chicks and other grassland species (Schneider et al. 2005, Giovanni 2009). A widely used method of maintaining these variable habitat characteristics is patch-burn grazing (Fuhlendorf et al. 2006). Patch-burn grazing is a suitable method of managing for a suite of grassland bird species, many of which use litter-rich prairies (Grant et al. 2010). Using patch-burn grazing would potentially provide both the short and sparse habitat used by the nesting adults as well as providing tall and thick habitat for better chick survival. On a large scale (>10 km) and in the correct context, patch-burn grazing may provide the needed habitat for the entire life-cycle of curlews. Many ranchers in the Sandhills avoid the use of fire for management because of fire containment issues resulting from the dry and arid climate. Rotational grazing treatments have been shown to host greater densities of some grassland bird species, e.g. Grasshopper Sparrow, and these systems may be more appropriate for providing similar habitat mosaics without burning areas with dry climates and high fire risks (Kempema 2007). The conversion of prairies to agriculture in western Nebraska is reducing

curlew habitat but utilization of a better managed grassland scheme would increase and enhance habitat for curlews.

My study provides a baseline understanding of the survival and movement patterns of Long-billed Curlew chicks in Nebraska. The Sandhills are biologically unique and remain an important stronghold for the curlew (Schneider et al. 2005, C. Gregory, personal observation). I am optimistic that land-use managers will use these data to make informed decisions regarding wet meadow preservation, grazing pressures, and other grassland needs for this emblematic prairie species. By protecting parcels of grassland and avoiding a transition to row-crop agriculture, ranchers and land managers can ensure that the curlew and other grassland species continue to have suitable breeding habitat. Furthermore, adopting a patch-burn or rotational grazing scheme would provide short vegetation for egg-laying and thick, litter-rich meadows for chick-rearing, which would ensure that the habitat needs are met for the entire life-cycle of the curlew. These findings have important conservation implications, especially at the eastern edge of the curlew's range where grassland habitats continue to vanish. My fledgling movement data suggest that multiple landowners may be needed as a group involved in conservation efforts, which may require creative efforts to bring landowners together (Powell 2010, Schutz 2010). Further degradation and disappearance of this habitat will result in the continuation of population decline and reduction that the curlews have suffered for the last 150 years.

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Table 4.1. Total number of Long-billed Curlew (*Numenius americanus*) chicks and broods sampled in Nebraska, 2008-2010.

		No. of chicks	
Year	No. Broods	Radio-tagged	Not radio-tagged
2008	5	7	1
2009	5	13	0
2010	5	7	0
TOTAL	15	27	1

Table 4.2. Model selection results for Long-billed Curlew (*Numenius americanus*) chick survival in western Nebraska, 2008-2010. Models are ordered by Akaike's Information Criterion, corrected for small sample size (AIC_c). K is the number of parameters and ΔAIC is the AIC difference from the best model. $S_{(.)}$ represents a model with a constant daily survival rate, $S_{(T)}$ represents a model with a linear time trend, $S_{(TT)}$ represents a model with a quadratic time trend, and $S_{(age)}$ represents a model with an age effect. $S_{(VOR)}$ represents a model using visual obstruction readings, $S_{(depth)}$ represents a model using litter depth, and $S_{(height)}$ represents a model using maximum vegetation height. $S_{(forb)}$ represents a model using percent cover of forbs, $S_{(bare)}$ represents a model using percent cover of bare ground, $S_{(litter)}$ represents a model using percent cover of litter, and $S_{(grass)}$ represents a model using percent cover of grass.

Model	ΔAIC_c[a]	w_i	K	Deviance
$S_{(litter)}$	0.00	0.24	2	38.34
$S_{(litter + T)}$	1.14	0.14	3	37.38
$S_{(depth)}$	1.44	0.12	2	39.78
$S_{(litter + age)}$	1.67	0.11	3	37.92
$S_{(litter + TT)}$	1.85	0.10	4	35.97
$S_{(depth + T)}$	2.83	0.06	3	39.08
$S_{(depth + age)}$	2.86	0.05	3	39.11
$S_{(depth + TT)}$	3.73	0.04	4	37.85
$S_{(T)}$	4.55	0.03	2	42.90
$S_{(TT)}$	4.66	0.02	3	40.91
$S_{(age)}$	4.79	0.02	2	43.13
$S_{(.)}$	5.06	0.02	1	45.46
$S_{(bare)}$	5.61	0.02	2	43.95
$S_{(height)}$	6.01	0.01	2	44.35
$S_{(forb)}$	6.23	0.01	2	44.57
$S_{(grass)}$	6.98	0.01	2	45.32
$S_{(VOR)}$	7.09	0.01	2	45.43

[a] The AIC_c value for the best model is 42.43.

Table 4.3. Daily distances moved of Long-billed Curlew (*Numenius americanus*) chicks in Nebraska, 2008-2010 ("x" represents the mean distance moved, "±SE" represents the standard error of the mean distance moved, and "range" represents the range of daily distances moved).

Age (in days)	x ±SE (in m)	Range (in m)
≤12	637 ±105	49-2534
13-24	879 ±106	86-2610
≥24	939 ±189	194-1720
All	786 ±70	49-2610

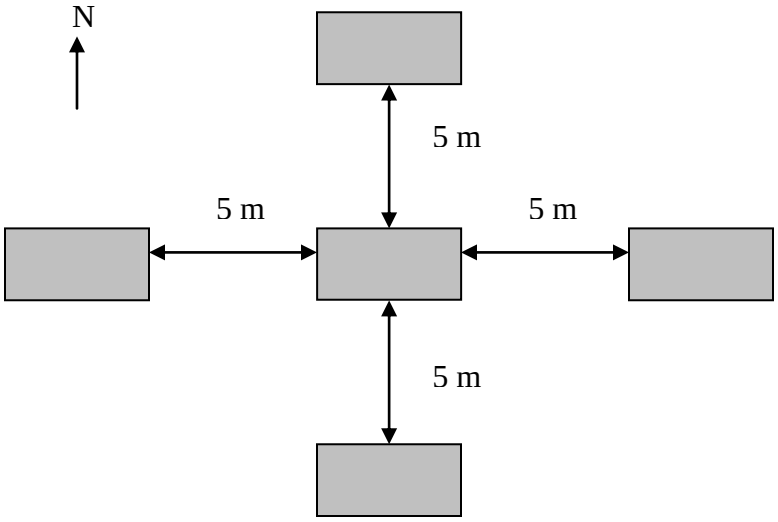

Figure 4.1. The layout of Daubenmire frames and visual obstruction readings (VOR) relative to Long-billed Curlew (*Numenius americanus*) chick locations (in center frame).

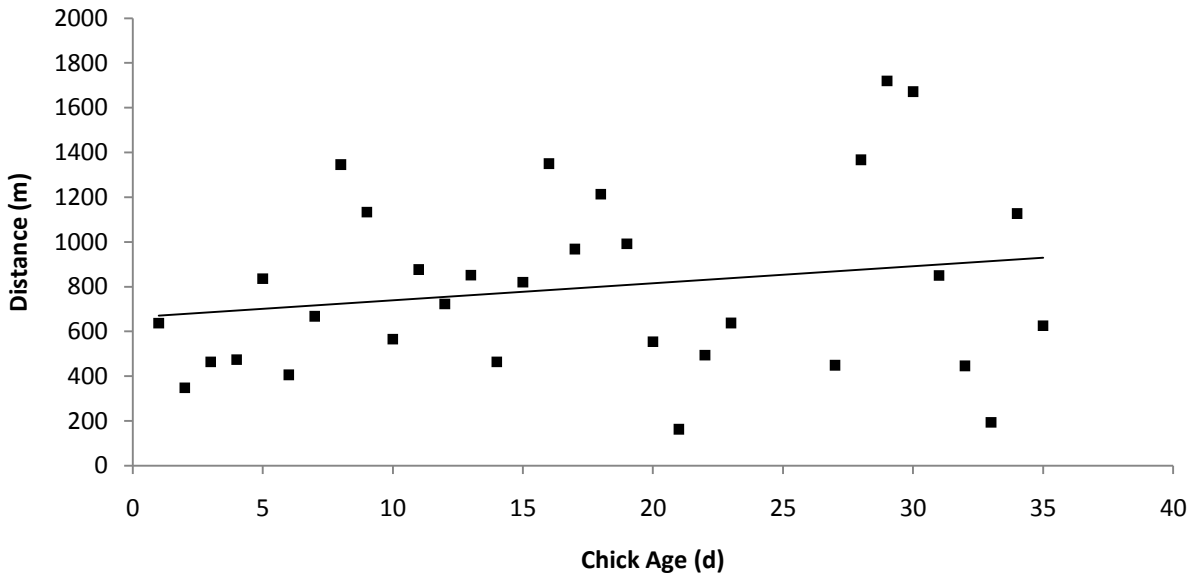

Figure 4.2. The mean daily distance moved by age (in days) of Long-billed Curlew (*Numenius americanus*) chicks in western Nebraska, 2008-2010. Chicks were capable of flight at 38 days old.

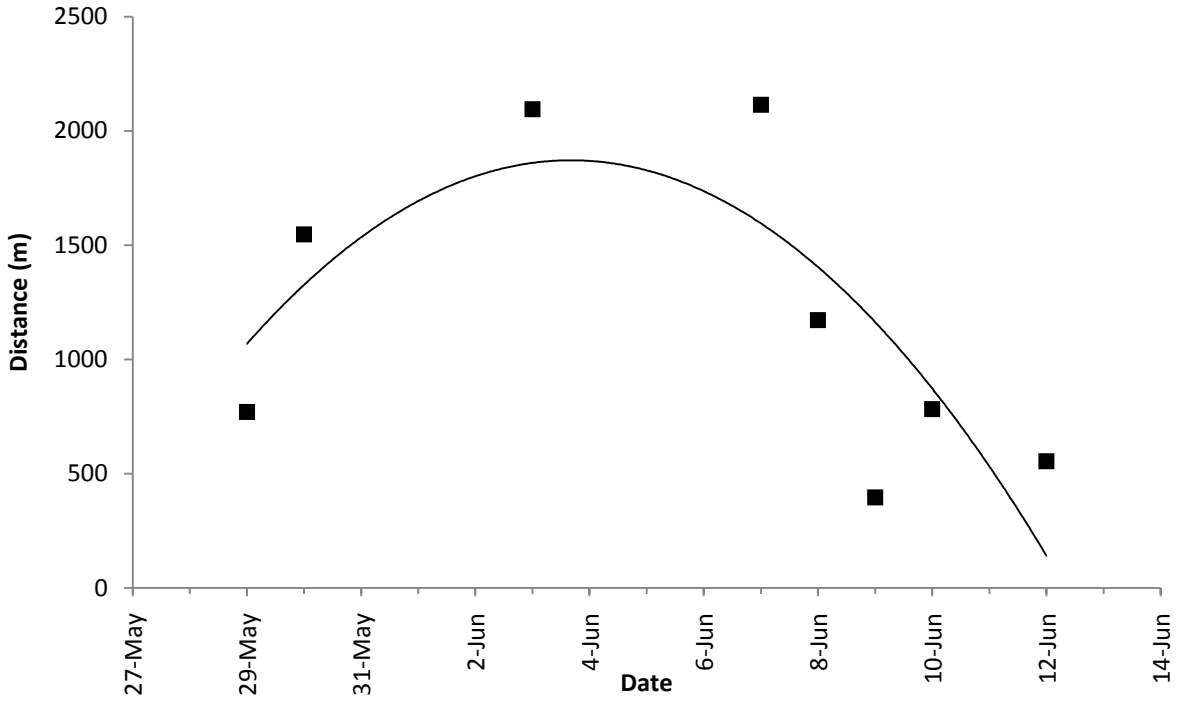

Figure 4.3. Cumulative movements within season by a Long-billed Curlew (*Numenius americanus*) chick in western Nebraska, 29 May to 12 June, 2010. Note that this chick belongs to a different brood than the chick shown in Figure 4.4.

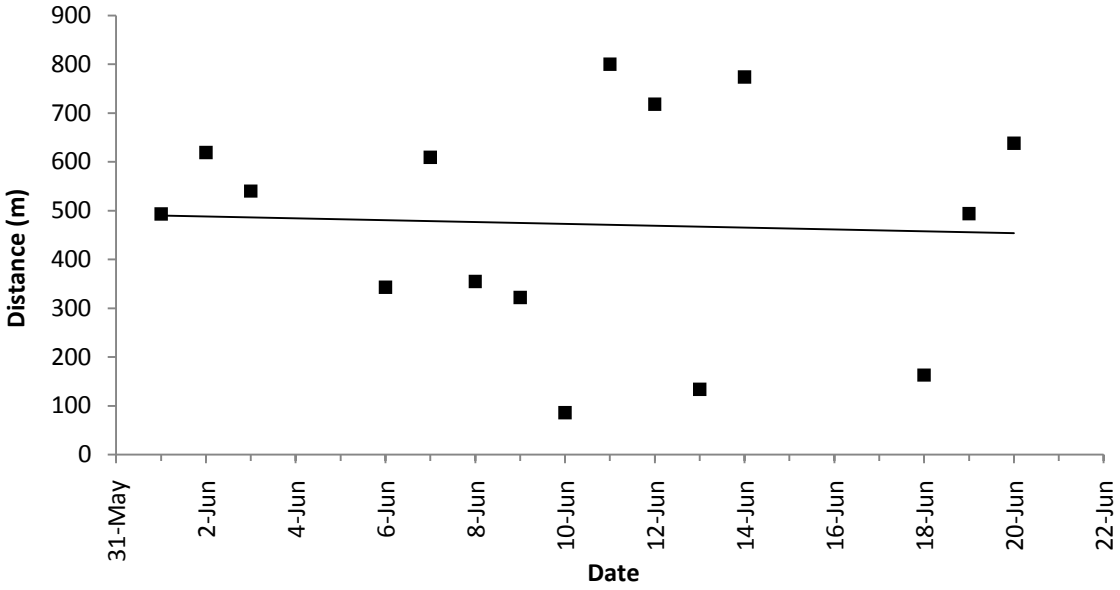

Figure 4.4. Cumulative movements within season by a Long-billed Curlew (*Numenius americanus*) chick in western Nebraska, 1 June to 20 June, 2008. Note that this chick belongs to a different brood than the chick shown in Figure 4.3.

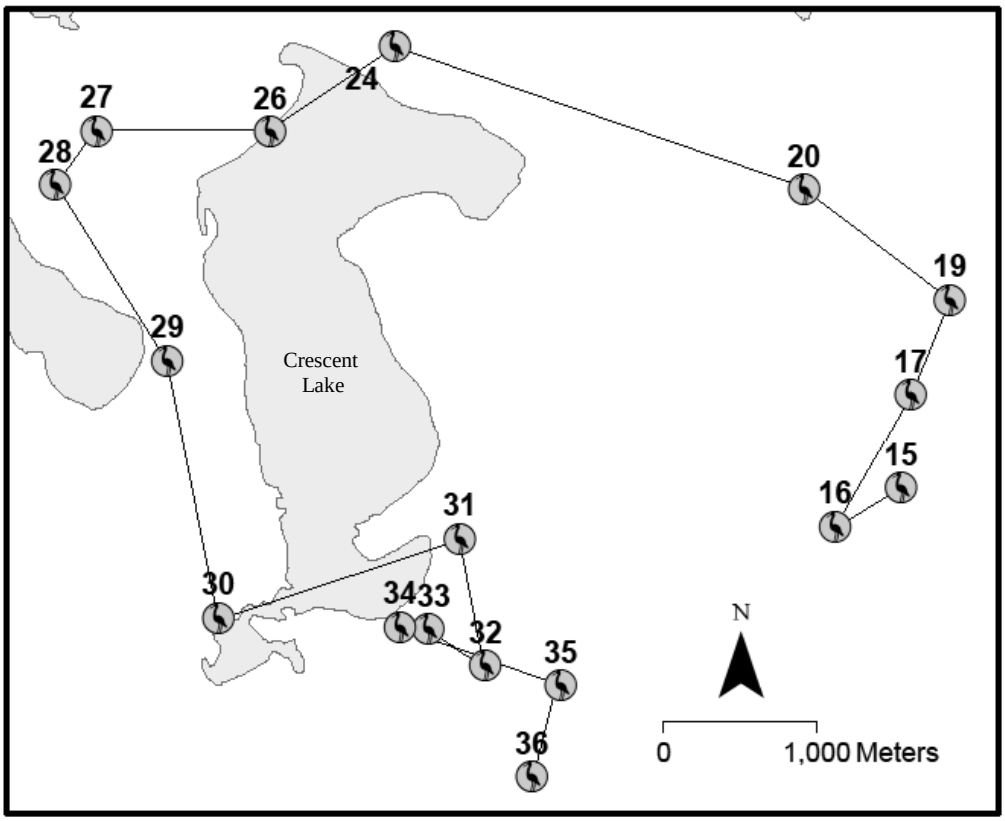

Figure 4.5. Map of movements of a 15 to 36 day old Long-billed Curlew (*Numenius americanus*) chick in western Nebraska, 2008.

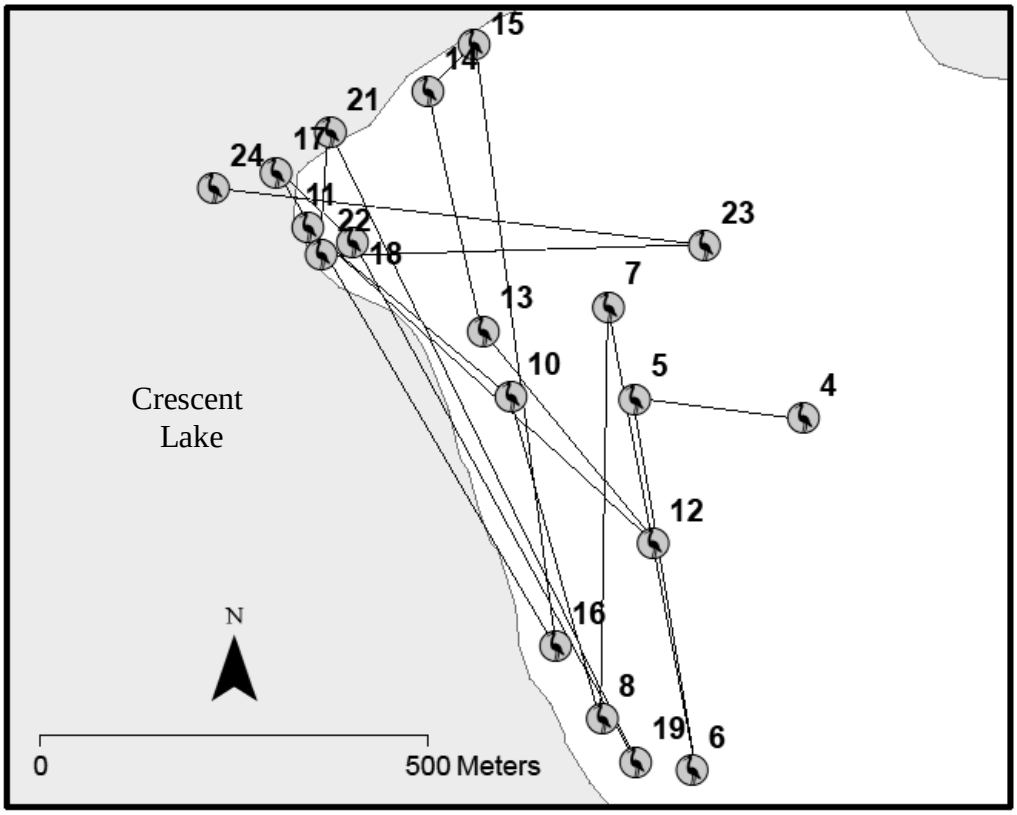

Figure 4.6. Map of movements of a 4 to 24 day old Long-billed Curlew (*Numenius americanus*) chick in western Nebraska, 2008.

Appendix

Chick locations (X and Y coordinates, UTM zone 13), band numbers, and recapture dates for radio-tagged Long-billed Curlew (*Numenius americanus*) chicks in western Nebraska, 2008-2010.

Band number	Date	X	Y
13003	30-May-08	717129	4621247
13003	31-May-08	718009	4621605
13003	1-Jun-08	718329	4620215
13003	2-Jun-08	718334	4619287
13003	6-Jun-08	719565	4618075
13003	7-Jun-08	719731	4618675
13004	31-May-08	716248	4620547
13004	1-Jun-08	716030	4620572
13004	2-Jun-08	716104	4620084
13004	3-Jun-08	715996	4620693
13004	4-Jun-08	715988	4620151
13004	6-Jun-08	715870	4620575
13004	7-Jun-08	715608	4620797
13004	8-Jun-08	716054	4620382
13004	9-Jun-08	715834	4620661
13004	10-Jun-08	715763	4620976
13004	11-Jun-08	715822	4621039
13004	12-Jun-08	715928	4620247
13004	13-Jun-08	715567	4620870
13004	14-Jun-08	715665	4620779
13004	15-Jun-08	716031	4620095
13004	17-Jun-08	715637	4620923
13004	18-Jun-08	715625	4620763
13004	19-Jun-08	716120	4620774
13005	8-Jun-08	719049	4618950
13005	9-Jun-08	719372	4618748
13005	10-Jun-08	719196	4618760
13005	11-Jun-08	719119	4618816
13005	12-Jun-08	719114	4619155
13005	13-Jun-08	719284	4619228
13005	14-Jun-08	718908	4618930
13005	15-Jun-08	719351	4619739
13005	17-Jun-08	719610	4620443
13005	18-Jun-08	718700	4621210
13006	13-Jun-08	719281	4619234
13006	14-Jun-08	718849	4618978
13006	15-Jun-08	719345	4619841

13006	17-Jun-08	719600	4620463
13006	18-Jun-08	718645	4621188
13006	22-Jun-08	715966	4622128
13006	24-Jun-08	715147	4621563
13006	25-Jun-08	714011	4621569
13006	26-Jun-08	713741	4621219
13006	27-Jun-08	714475	4620067
13006	28-Jun-08	714809	4618379
13006	29-Jun-08	716391	4618898
13006	30-Jun-08	716557	4618068
13006	1-Jul-08	716186	4618308
13006	2-Jul-08	715998	4618323
13006	3-Jul-08	717050	4617936
13006	4-Jul-08	716863	4617340
13007	14-Jun-08	716920	4619310
13007	15-Jun-08	718160	4620883
13007	18-Jun-08	719867	4621086
13007	20-Jun-08	722315	4622746
13007	21-Jun-08	721942	4625249
13007	23-Jun-08	725070	4626623
13007	25-Jun-08	725075	4628593
13008	14-Jun-08	716920	4619310
13008	15-Jun-08	718179	4620897
13008	18-Jun-08	719937	4620862
13008	20-Jun-08	722209	4622732
13008	21-Jun-08	721955	4625290
13009	14-Jun-08	716920	4619310
13009	15-Jun-08	718140	4620867
13009	20-Jun-08	722317	4622750
13009	21-Jun-08	721937	4625329
13016	22-May-09	717188	4621605
13016	24-May-09	717272	4621541
13016	25-May-09	717560	4621108
13016	26-May-09	717798	4620970
13016	27-May-09	719730	4620281
13017	22-May-09	717188	4621605
13017	24-May-09	717286	4621552
13017	25-May-09	717546	4621098
13017	26-May-09	717813	4620982
13017	27-May-09	719727	4620291
13017	28-May-09	720154	4619768
13017	29-May-09	720027	4619100
13017	30-May-09	720299	4617931
13017	3-Jun-09	720208	4614873
13017	4-Jun-09	721132	4613973

13017	6-Jun-09	722220	4613294
13017	8-Jun-09	724413	4612214
13018	23-May-09	717188	4621605
13018	24-May-09	717273	4621550
13018	25-May-09	717573	4621096
13018	26-May-09	717831	4620972
13018	27-May-09	719743	4620286
13018	28-May-09	720147	4619756
13018	29-May-09	720026	4619081
13018	30-May-09	720309	4617943
13018	3-Jun-09	720186	4614898
13018	4-Jun-09	721093	4613943
13018	6-Jun-09	722173	4613285
13019	26-May-09	717153	4617547
13019	27-May-09	717111	4617523
13019	28-May-09	716963	4617809
13019	29-May-09	716947	4617731
13019	30-May-09	716937	4617920
13019	31-May-09	716944	4617756
13019	1-Jun-09	716563	4618476
13020	25-May-09	717153	4617547
13020	27-May-09	717120	4617514
13020	28-May-09	716954	4617804
13020	29-May-09	716945	4617725
13020	30-May-09	716938	4617939
13020	31-May-09	716955	4617781
13021	26-May-09	717153	4617547
13021	27-May-09	717112	4617526
13021	28-May-09	716964	4617811
13021	29-May-09	716948	4617726
13021	30-May-09	716939	4617927
13021	31-May-09	716947	4617795
13022	27-May-09	716443	4620630
13022	28-May-09	716093	4620689
13022	29-May-09	715962	4620700
13022	30-May-09	716171	4620917
13022	31-May-09	716538	4620743
13023	31-May-09	716942	4617786
13023	1-Jun-09	716560	4618494
13024	1-Jun-09	716555	4618493
13026	6-Jun-09	717160	4617943
13026	8-Jun-09	717190	4618051
13027	6-Jun-09	717160	4617943
13027	8-Jun-09	717205	4618100
13028	6-Jun-09	717160	4617943

13028	8-Jun-09	717183	4618038
13029	7-Jun-09	717160	4617943
13029	8-Jun-09	717221	4618063
13031	24-May-10	716506	4619070
13031	25-May-10	716278	4619165
13031	26-May-10	716267	4619009
13032	24-May-10	716508	4619067
13032	25-May-10	716268	4619169
13032	26-May-10	716275	4619036
13033	26-May-10	716270	4619010
13034	26-May-10	717767	4621166
13034	27-May-10	718624	4619853
13035	28-May-10	708176	4628401
13035	29-May-10	709135	4627188
13035	30-May-10	709728	4627664
13035	31-May-10	710316	4629098
13035	2-Jun-10	710261	4630652
13035	3-Jun-10	711701	4632176
13035	5-Jun-10	711373	4633029
13035	6-Jun-10	711448	4635146
13035	7-Jun-10	711121	4636273
13035	8-Jun-10	710924	4635936
13035	9-Jun-10	710282	4635497
13035	10-Jun-10	709789	4635263
13035	12-Jun-10	709823	4635974
13035	14-Jun-10	709016	4637043
13036	29-May-10	716509	4620456
13036	30-May-10	716552	4620415
13036	31-May-10	716501	4620723
13036	1-Jun-10	717050	4620963
13036	2-Jun-10	716377	4619757
13036	3-Jun-10	715877	4620608
13036	4-Jun-10	715965	4620260
13036	5-Jun-10	716753	4620484
13036	6-Jun-10	717017	4619799
13036	7-Jun-10	717995	4617711
13036	8-Jun-10	719580	4616506
13036	9-Jun-10	721072	4614370
13037	1-Jun-10	716352	4620782
13037	2-Jun-10	716070	4620987
13037	3-Jun-10	715876	4620612

CHAPTER V. GENERAL CONCLUSIONS

The Long-billed Curlew population decline during the last 150 years has been attributed to a loss of grasslands and overhunting by humans. Many threats still remain today in the Sandhills of Nebraska and my study aimed to provide a critical baseline understanding of the curlew population size in Nebraska, nest and chick survival, and chick movement. By using distance sampling, I estimated that 23,909 curlews were present in Nebraska and that high wind speed during roadside surveys negatively affected the detection rate. I concluded by stating the original range-wide estimate of 20,000 curlews was most likely biased low and that the Sandhills of Nebraska host a substantial portion of the total curlew population. Overall, recent studies of shorebird populations using distance sampling have found that this survey approach offers a precise, defensible, and scientifically-based method for deriving a population estimate.

My study also provided a critical baseline understanding of nest survival and the influential factors that affect breeding Long-billed Curlews in Nebraska. I concluded that bare ground near the nest was an important component of successful nests whereas VOR and tall vegetation generally negatively affected nest survival. My study also provided a baseline understanding of the survival and movement patterns of Long-billed Curlew chicks in Nebraska. I found that chicks found in litter-rich habitats had better survival than chicks found in barren areas. Secondly, I found that chicks were very mobile and were capable of moving distances >2 km in a day. I concluded that adopting a patch-burn or rotational grazing scheme would provide the habitat needs for the entire life-cycle of the curlew; short vegetation for nesting and thick, litter-rich meadows for chick-rearing.

Overall, this study provided valuable information on the breeding ecology of the Long-billed Curlew in Western Nebraska. The insights gained shed further light on population estimates, nest and chick survival, and chick movements of this declining shorebird species.