

BREEDING SEASON OCCUPANCY OF LONG-BILLED CURLEWS AND SANDHILL CRANES IN GRAZED HABITATS AT RED ROCK LAKES NATIONAL WILDLIFE REFUGE, MONTANA

Jennifer Stadum, Department of Intercollege Programs for Science Education,
Montana State University, Bozeman, MT 59717

Jeffrey M. Warren, Red Rock Lakes National Wildlife Refuge, U.S. Fish and Wildlife Service,
Lima, MT 59739

Jay J. Rotella, Montana State University, Department of Ecology, 310 Lewis Hall,
Bozeman, MT 59717

ABSTRACT

Long-billed curlew (*Numenius americanus*) and sandhill crane (*Grus canadensis*) are species of concern at state and federal levels. The concern is largely due to declines in population resulting from loss and degradation of wetland and grassland habitats that have reduced the amount of available breeding habitat for both species. Red Rock Lakes National Wildlife Refuge (RRLNWR) in southwestern Montana encompasses one of the largest wetland complexes in the Intermountain West, providing important breeding habitat for cranes and curlews in the region. We explored landscape- and plot-scale drivers of curlew and crane breeding-season occupancy (ψ) in grazed grassland and wet meadow habitats at RRLNWR. Distance to palustrine emergent marsh was the best landscape-scale predictor of curlew and crane occupancy. Mean breeding season occupancy of curlews across sites was 0.68 (95% CI = 0.39–0.87) and increased with distance from emergent marsh, ranging from 0.37 (95% CI = 0.24–0.52) to 0.80 (95% CI = 0.56–0.93) as distance to emergent marsh went from 64 m to 629 m. Conversely, crane mean breeding season occupancy was 0.38 (95% CI = 0.17–0.64) and decreased as distance from emergent marsh increased, ranging from 0.58 (95% CI = 0.27–0.58) to 0.28 (95% CI = 0.11–0.56) as distance to emergent marsh went from 64 m to 629 m. Plot-scale vegetation characteristics available from a reduced data set indicated curlew occupancy was positively related to the ratio of vegetation 5–15 cm tall to vegetation >15cm ($\beta = 4.92$, SE = 2.53).

Key Words: cattle grazing, grassland, *Grus canadensis*, *Numenius americanus*, wetland, wet meadow, habitat management

INTRODUCTION

Grazing is an important disturbance in many grassland systems from arid savannah to wetlands. Grazing affects the structure of a grassland proximately, through consumption and trampling of vegetation, and ultimately by altering plant community composition (Augustine and McNaughton 1998). Grazing-related disturbance can result in decreased vegetation height, increased soil water infiltration

(Abdel-Magid et al. 1987), redistribution of litter, and improved grass production (Austin et al. 2007, Watts et al. 1987). Additionally, ungulate hoof action disturbs the soil, altering seedbeds and aiding in the transportation of seeds (Vavra et al. 2007). Wild ungulates such as elk (*Cervus elaphus*) and American bison (*Bison bison*) have evolved symbiotically with grassland ecosystems (Vavra et al. 2007). They

contribute to the nitrogen cycle by fertilizing grassland plant species with their feces and urine. Grazing also interacts with fire, another key grassland disturbance, affecting fire frequency, intensity, and distribution on the landscape (Coppedge et al. 2008). Where native herbivory no longer provides these grassland disturbances, domestic livestock are commonly used as a primary tool in grassland management.

Grasslands provide nesting, foraging, and brooding habitat for a diverse group of avian species. Long-billed curlew (*Numenius americanus*) (hereafter, curlew) and sandhill crane (*Grus canadensis*) (hereafter, crane) are two species that preferentially select grazed grasslands during the breeding season (Pampush and Anthony 1993, Gerber et al. 2014). The Long-billed curlew is an upland nesting shorebird species of management concern at international, national, regional, and state levels (Brown et al. 2001). For example, curlew has been extirpated from five states and is a species of concern in at least eighteen states, including Montana (Fellows and Jones 2009).

Like many other grassland birds, curlew numbers have declined significantly across their range (Fellows and Jones 2009). Vegetation type and height play an important role in breeding territory selection of curlews (Saalfeld et al. 2010). Curlews preferentially select grazed native grasslands for nesting (Saalfeld et al. 2010). Redmond and Jenni (1986) observed that curlews chose nesting sites that had been grazed within the previous year and selected nesting territories based on structural attributes of vegetation over the availability of forage items. Grassland structural attributes selected by breeding curlews include grassland swards relatively homogenous in vertical height (Pampush and Anthony 1993), and with vegetation heights measuring 4–15 cm (Saalfeld et al. 2010).

Sandhill cranes prefer open grasslands and freshwater marshes (Gerber et al. 2014). Cranes differ from curlews in their utilization of wet meadow habitat for nesting and brooding. Cranes prefer

to nest in shallowly flooded wetlands and meadows (Drewien and Bizeau 1974), returning annually in monogamous pairs to nest (Baker et al. 1995; Drewien et al. 1999). Cranes tend to nest in habitat that is isolated from human activity (Drewien 1973), has standing water with adjacent emergent aquatic vegetation (Gerber et al. 2014), and includes tracts of intact adjacent upland habitat (Austin and Pyle 2004). Grassland and wet meadow habitats adjacent to nesting territories are utilized during brood rearing (Bennett 1978; Downs 2004). Downs (2004) observed that cranes nested in marshy areas ≤ 100 m from grasslands that were used extensively for brood rearing, forage and cover. Grassland habitats, including wet meadows, contain macroinvertebrates and other protein and lipid rich foods (e.g., rodents, frogs, eggs and nestlings) that provide forage items for cranes during the breeding season (Walkinshaw 1973; Armbruster 1987).

We undertook the current study to explore the relative contribution of local-scale habitat attributes influenced by grazing and broader-scale landscape attributes (e.g., distance to palustrine emergent marsh) on breeding season occupancy of long-billed curlews and sandhill cranes. This is in contrast to other studies on these species that considered local- and landscape-scale attributes in isolation. Moreover, this study examined occupancy of both species simultaneously, providing insight into how these two species with potentially conflicting breeding season habitat needs could be used to dynamically manage disturbance of wet meadow and grassland habitat with cattle grazing.

STUDY AREA

Red Rock Lakes National Wildlife Refuge (RRLNWR) (19,334 ha) is located in the Centennial Valley of southwestern Montana. The elevation ranges between 2,013 m above mean sea level (msl) to 2,926 m msl. The average annual precipitation is 49.5 cm, as recorded at refuge headquarters at 2,039 m msl. Twenty-seven percent of the precipitation received annually occurs in the

months of May and June. The annual mean temperature is 1.7°C; mean maximum July and mean minimum January temperatures are 24.8°C and -17.9°C, respectively.

Grassland habitat comprises >800 ha of RRLNWR. Dominant grasses include Idaho fescue (*Festuca idahoensis*), needle and thread grass (*Hesperostipa comata*), tufted hairgrass (*Deschampsia caespitosa*), and basin wildrye (*Leymus cinereus*). Non-native grasses smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*) are also present in the grassland habitat (USFWS 2009).

Wet meadow habitat comprises ~2,869 ha of RRLNWR and is the most commonly grazed habitat on the refuge (USFWS 2009). This habitat is seasonally flooded during most springs and sub-irrigated by groundwater during the summer, resulting in a highly productive habitat. Sedge (*Carex* spp.) and rush (*Juncus* spp.) dominate wet meadow habitat, which also includes common forbs such as lupine (*Lupinus* spp.), fleabane (*Erigeron* spp.), phlox (*Phlox* spp.), and cinquefoil (*Potentilla* spp.) (USFWS 2009). Vegetation height is highly dependent upon moisture gradients and can range from <30 cm to >60 cm in height.

RRLNWR contains 21 active grazing units varying in size from 123 to 1,327 ha. With few exceptions, late-season (i.e., after 10 July) grazing treatments are followed by two full growing seasons of rest. Stocking rates (Animal Units per Month [AUM]) were determined and implemented for each grazing unit by a Natural Resources Conservation Service (NRCS) range condition survey conducted in 1987 (USFWS, unpubl. data).

METHODS

Avian Surveys

Sample plots ($n = 102$) within wet meadow and grassland habitats on RRLNWR were randomly selected using ArcGIS 9.3 Geographic Information System (GIS) software (ESRI, Redlands, California). Plots were 16 ha in size, which was determined based on published

estimates of crane and curlew breeding territory sizes; 6–14 ha for curlews (Stanley and Skagen 2007) and 10–23 ha for cranes (Gerber et al. 2014).

Plots were surveyed three times during the nesting and early brood rearing periods for both species to allow estimation of ψ (MacKenzie et al. 2004). For logistical reasons, plots were grouped and the order that groups were surveyed was randomly selected. Surveys were conducted from sunrise to 4 hours after sunrise and from 4 hours before sunset to sunset. Each plot was surveyed at least once during a morning survey and once during an afternoon/early evening survey.

Plots were surveyed by a single observer following an 800-m U-shaped transect that began and ended at a plot boundary and ran parallel to, and 100-m inside of, the remaining three boundary edges. Surveys were not conducted during periods of high winds or heavy rain. For each observation species, detection type (call, flyover, flew into plot, visual, visual/call), social status (lone, paired, group, nest, brood), and numbers of individuals were recorded. Auditory only detections were also recorded (Tipton et al. 2008).

Habitat Characteristics

We quantified vegetation characteristics in each avian survey plot using the point-line intercept method (Bonham 1989) along two randomly placed 50-m transects. A transect was placed along a random bearing from a random point within the plot. Bearings that resulted in the transect crossing a road, extending into open water, or exiting the plot were eliminated and another random bearing selected. A 5-mm diameter, 1-m long dowel marked in 5-cm increments was used to record physiognomic class in 5-cm height categories every other meter along each transect. Vegetation physiognomic classes included: bunchgrass, rhizomatous grass, sedge/rush, and forb. Ground cover class (plant physiognomic class, bare soil, rock, moss, cow pie, water) was recorded at each point along each transect where the dowel contacted the ground. Mean plot percent

ground cover by class was calculated as the number of hits per class divided by 50 (2 transects \times 25 samples per transect). Litter depth was measured (± 1.0 cm) every fourth meter along each transect for a total of 12 measurements per transect and used to calculate mean litter depth for a plot ($n = 24$). We calculated the ratio of preferred height vegetation (5–15 cm) to vegetation >15 cm as a predictor of curlew ψ , and the sum of vegetation hits >15 cm as predictors of crane ψ . Lastly, the ratio of sedge/rush hits to grass hits (rhizomatous and bunchgrass hits combined) was calculated as a proxy measure of within-plot sub-irrigated wet meadow habitat. We believe this metric was sensitive to subtle hydrological gradients within areas classified as wet meadow by remotely sensed wetland data (Cowardin et al. 1979, Richards 2012). Moreover, we considered the sedge/rush to grass ratio a measure of plant productivity; the ratio should decline with the hydrological gradient from mesic wet meadow to xeric grassland. The vegetation height ratio was included as a proxy for plant biomass, and resultant crane forage availability; invertebrate diversity and abundance (Morris 2000, Kruess and Tschardtke 2002), and small mammal biomass (Grant et al. 1982) are generally positively correlated with plant height and biomass.

Other habitat characteristics hypothesized to affect curlew and crane ψ recorded for each sample plot included: years since last grazed, proportion of palustrine emergent marsh, distance from palustrine emergent marsh, and distance to road. The latter two covariates were estimated using GIS software as the distance (± 1 m) from the plot centroid to the nearest emergent wetland edge or road, respectively. Proportion of palustrine emergent marsh within each plot was quantified using palustrine emergent marsh as classified by the National Wetlands Inventory (Cowardin et al. 1979).

Data Analysis

We modeled variation in ψ using plot-scale vegetation characteristics (e.g.,

litter depth) and landscape-scale habitat attributes (e.g., distance to emergent marsh) using Program PRESENCE version 2.3 (MacKenzie 2002). Based on a review of pertinent literature, we created two a priori model suites for each species – one comprising all plots surveyed ($n = 102$) and a reduced set ($n = 47$) that included covariates for plot-scale vegetation structure. For the former, distance to emergent marsh (DEM), distance from road (DRD), proportion of palustrine emergent marsh (PEM), and years since last grazed (YLG) were covariates considered. For the latter, plot-scale vegetation characteristic covariates included the ratio of preferred-height vegetation (6–15 cm) to taller vegetation (>15 cm) (HeightRatio), mean litter depth (LitDpth), sum of vegetation hits >15 cm (Sum15cm) and the ratio of sedge/rush to grass (both rhizomatous and bunch grass) (SRGrRatio). The distance to emergent marsh habitat (DEM) was also included in these model suites as it was the best predictor of curlew and crane ψ from the full model suites. Detection probability, p , was held constant ($p(.)$) or allowed to vary among survey periods ($p(t)$) for each ψ model structure described above.

We employed methods developed by MacKenzie et al. (2002) to estimate single-season occupancy rates based on presence-absence data when detection probabilities were <1 . A key assumption of occupancy modeling is that the occupancy state of a site is constant within the season surveyed (e.g., breeding season). The territoriality of cranes and curlews during the breeding season should lead to minimal violation of this assumption.

We tested model goodness-of-fit for each model suite using the parametric bootstrap procedure ($n = 1,000$ simulations) in Program PRESENCE. We used Akaike's Information Criterion corrected for small sample size (AIC_c) to evaluate the amount of support for each model in each suite. Where overdispersion was evident (i.e., $\hat{c} > 1.0$) we accounted for this by using quasi-likelihood AIC_c ($QAIC_c$). We calculated ΔAIC_c (the difference in AIC_c values between a candidate model and the most supported

model) to determine strength of support for each model. Models within $2 \Delta AIC_c$ units of the best model (i.e., that with the lowest AIC_c score) were well supported (Burnham and Anderson 2002), assuming models differ by more than an uninformative parameter (Arnold 2010).

RESULTS

A total of 102 plots were surveyed for ψ of curlews and cranes during 14 May–18 June 2009; 86 plots were surveyed three times, 15 twice, and a single plot was only surveyed once. Vegetation transects ($n = 94$) were completed on 47 plots from 25 June–28 July 2009, providing data on plot-level vegetation characteristics. Plots varied considerably in the four habitat attributes used to model the full data set ($n = 102$ plots); distance to palustrine emergent marsh, distance to road, proportion of palustrine emergent marsh and years since last grazed (Table 1).

Mean litter depth was variable within grazing units (Table 1) and not dependent upon years since last grazed. The estimated slope of the relationship between litter depth and YLG was -0.054 (SE = 0.185,

$P = 0.77$). Other plot-scale attributes quantified were similarly variable, providing strong gradients to assess curlew and crane breeding season occupancy within grazed grassland and wet meadow habitat (Table 1).

Avian Surveys

We detected curlews and cranes on 62 and 23 plots, respectively. There were 135 recorded observations of curlews; 63% ($n = 85$) were of lone birds, 31% ($n = 42$) pairs, and 6% ($n = 8$) were groups ranging from 3–10 birds. Of the 38 total observations of cranes, 53% ($n = 20$) were lone birds, 45% ($n = 17$) pairs, and 3% were groups (a single group of 5 birds). Based on models from the full data set, breeding season ψ of curlews and cranes was best predicted by a plot's distance to emergent marsh, and the nature of the response differed between species. The importance of distance to emergent marsh in crane ψ was corroborated with the plot-scale model suite. However, the proportion of preferred vegetation height in a plot was the best predictor of curlew ψ in the plot-scale model suite. Goodness-of-fit tests demonstrated a modest level of over-dispersion in the full curlew model

Table 1. Summary of predictor variables used to model breeding season occupancy of long-billed curlew and sandhill crane at Red Rock Lakes National Wildlife Refuge, 2009. Variables are distance to emergent marsh (DEM), distance to road (DRD), proportion emergent marsh (PEM), years since last grazed (YLG), litter depth (LitDpth), sedge/rush to grass ratio (SRGrRatio), preferred height (6–15 cm) vegetation to taller (>15 cm) vegetation ratio (HeightRatio), and the sum of vegetation hits >15 cm (Sum>15cm). HeightRatio was only used to model curlew occupancy; Sum15cm was used exclusively to model crane occupancy.

Variable	\bar{x}	SE	Range
DEM (m)	0	51	0 – 1985
DRD (m)	438	95	0 – 4144
PEM	0.08	0.01	0.0 – 0.47
YLG	3 ^a	—	1 – 17
LitDpth (cm)	8.1	0.61	0.5 – 19
SRGrRatio	8.3	5.42	0 – 256
HeightRatio ^b	1.8	0.33	0 – 13.5
Sum15cm ^c	123	13.61	2 – 474

^a Most frequent number of years since last grazing.

^b Curlew analysis only.

^c Crane analysis only.

suite only ($\hat{c} = 1.85$); results presented for that model suite were adjusted accordingly using QAIC_c. As there was no evidence of over-dispersion in the crane data sets we used only AIC_c.

Landscape-scale Models

Long-billed Curlew—The most parsimonious model in our a priori suite of landscape-scale models indicated that curlew ψ increased with increasing distance from palustrine emergent marsh (DEM) habitat (Tables 2 and 3). There was considerable support for the top model $\psi(\text{DEM}), p(\cdot)$, with a model weight of 0.58 and nearly 2 QAIC_c units between this model and the second-best model

(Table 2). Moreover, DEM was in each of the top three models. For example, based on the top model, $\hat{\psi}$ for a plot at a distance of 64 m (1st quartile) from the nearest emergent marsh was 0.37 (95% CI = 0.24–0.52), which increased to 0.80 (95% CI = 0.56–0.93) for a plot 629 m (3rd quartile) from an emergent marsh (Table 3; Fig. 1). Detection probability, p , was constant among surveys in the top model ($\hat{p} = 0.52$, 95% CI = 0.43–0.61). The second best model differed from the best model only by inclusion of years since last grazed (YLG). However, YLG was an uninformative parameter (Arnold 2010) with a confidence interval that broadly overlapped zero ($\hat{\beta} = 0.03$, SE = 0.080).

Table 2. Model results from the long-billed curlew landscape-scale model suite ($n = 102$ plots) with covariates distance to emergent marsh (DEM), distance to road (DRD), proportion emergent marsh (PEM), and years since last grazed (YLG). Model rankings were corrected for over dispersed data ($\hat{c} = 1.85$). Detection probability is p , occupancy is ψ , Red Rock Lakes National Wildlife Refuge, 2009.

Model	K^a	w^b	ΔQAIC_c
$\psi(\text{DEM}), p(\cdot)$	3	0.58	0.00
$\psi(\text{DEM}+\text{YLG}), p(\cdot)$	4	0.22	1.93
$\psi(\text{DEM}), p(t)$	5	0.16	2.64
$\psi(\text{DRD}), p(\cdot)$	3	0.02	6.86
$\psi(\text{PEM}), p(\cdot)$	3	0.01	8.86
$\psi(\cdot), p(\cdot)$	2	<0.01	8.90
$\psi(\text{YLG}), p(\cdot)$	3	<0.01	10.87
$\psi(\cdot, \text{PEM}), p(t)$	5	<0.01	11.63
$\psi(\text{YLG}), p(t)$	5	<0.01	13.60

^aNumber of parameters

^bNormalized relative weight likelihood

^cDifference between model's quasi-likelihood Akaike's Information Criterion corrected for small sample size and the lowest QAIC_c value

Table 3. Coefficient estimates, standard errors (SE), and 95% confidence intervals (CI) for the most parsimonious long-billed curlew breeding season occupancy model from the landscape-scale model suite, Red Rock Lakes National Wildlife Refuge, 2009.

Model Parameter	$\hat{\beta}$	SE	95% CI	
			LCI	UCI
Occupancy (ψ ; intercept)	0.74	0.41	-0.06	1.54
Distance to emergent marsh (m)	1.75	0.61	0.55	2.94
Detection probability (p)	0.08	0.18	-0.27	0.43

Note: Coefficients are presented based on a logit link to the real parameter.

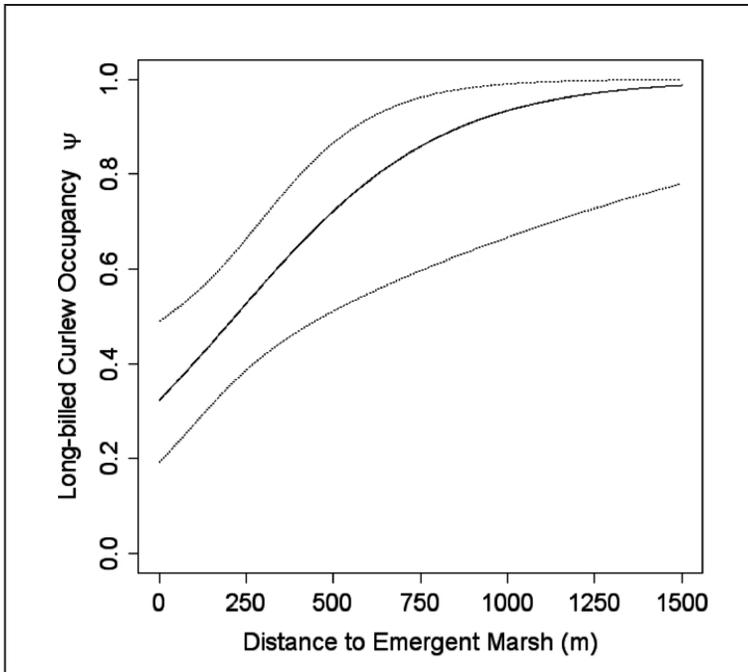


Figure 1. Predicted long-billed curlew occupancy rate, ψ (solid line), and 95% confidence intervals (dotted lines), in relation to distance to emergent marsh habitat on Red Rock Lakes National Wildlife Refuge, 2009.

The high QAICc score for the YLG-only model further demonstrated no support for this attribute.

Sandhill Crane.—We found support for the hypothesis that crane ψ in grassland habitats would increase with proximity to palustrine emergent marsh habitats preferred for nesting. Landscape-scale-models containing distance to palustrine emergent marsh (DEM) were strongly supported, with the covariate occurring in the top three models (Tables 4 and 5). For example, ψ for a plot at a distance of 64 m (1st quartile) from the nearest emergent marsh was 0.58 (95% CI = 0.27-0.58), whereas ψ for a plot 629 m (3rd quartile) from an emergent marsh was 0.28 (95% CI = 0.11-0.56) (Fig. 2). Detection probability, p , was constant among surveys in the top model ($\hat{p} = 0.24$, 95% CI = 0.13– 0.41). The second-best model provided weak support for the hypothesis that crane ψ would be positively related to number of years a unit had been rested from grazing, but the effect of rest from

grazing was imprecisely estimated ($\hat{\beta} = 1.30$, SE = 1.17).

The hypothesis that distance to road (DRD) would be positively related to crane ψ was clearly not supported by the data (Table 4). Similarly, a hypothesized positive relationship between crane ψ and the proportion of palustrine emergent marsh in a plot was not supported (Table 4).

Plot-Scale Models

Long-billed Curlew.—Results from models investigating curlew ψ relative to plot-scale vegetation characteristics (Table 6) supported our hypothesis of preference for habitats with vegetation heights between 5 and 15 cm. For curlew, ψ was positively related to the proportion of vegetation 5–15 cm in height in a plot. For example, on a plot with a relatively low proportion of preferred-height vegetation (1st quartile vegetation height ratio of 0.70), ψ was estimated to be 0.47 (95% CI = 0.26–0.69) (Fig. 3).

Table 4. Model results from the full sandhill crane landscape-scale model suite ($n = 102$ plots) with covariates distance to emergent marsh (DEM), distance to road (DRD), proportion emergent marsh (PEM), and years since last grazed (YLG). Detection probability is p , occupancy is ψ , Red Rock Lakes National Wildlife Refuge, 2009.

Mode	k^a	w^b	ΔAIC_c
ψ (DEM), p (.)	3	0.36	0
ψ (DEM+YLG), p (.)	4	0.29	0.38
ψ (DEM), p (t)	5	0.16	1.65
ψ (YLG), p (t)	6	0.12	2.12
ψ (YLG), p (.)	3	0.02	5.71
ψ (.), p (.)	2	0.01	6.42
ψ (YLG), p (t)	5	<0.01	7.58
ψ (PEM), p (.)	3	<0.01	8.29
ψ (DRD), p (.)	3	<0.01	8.42
ψ (PEM), p (t)	5	<0.01	10.11
ψ (DRD), p (t)	5	<0.01	10.23

^aNumber of parameters

^bNormalized relative weight likelihood

^cDifference between model's quasi-likelihood Akaike's Information Criterion corrected for small sample size and the lowest AIC value

Table 5. Coefficient estimates, standard errors (SE), and 95% confidence intervals (CI) for the most parsimonious sandhill crane breeding season occupancy model from the landscape-scale model suite, Red Rock Lakes National Wildlife Refuge, 2009.

Model Parameter	$\hat{\beta}$	SE	95% CI	
			LCI	UCI
Occupancy (ψ)	-0.51	0.56	-1.61	0.59
Distance to emergent marsh (m)	-1.18	0.53	-2.22	-0.14
Detection probability (p)	-1.14	0.41	-1.94	-0.34

Note: Coefficients are presented based on a logit link to the real parameter.

Estimated occupancy rate increased twofold to 0.94 (95% CI = 0.50–1.00) for a plot with a high proportion of preferred-height vegetation (3rd quartile vegetation height ratio of 2.0). The model including vegetation height was a better predictor of curlew ψ than distance to emergent marsh (Table 5). Detection probability, p , was constant among surveys in the top model ($\hat{p} = 0.51$, 95% CI = 0.39–0.63), and similar to the estimate from the landscape scale model suite top model.

Sandhill Crane.—We did not find strong support for the hypothesis that crane ψ was positively related to vegetation height (i.e., vegetation hits >15 cm), amount of wet meadow (i.e., ratio of sedge/rush hits to grass hits), or litter depth within a plot (Table 7). Models including litter depth failed to converge and therefore were not presented in table 7. Results from the plot-scale model suite corroborated results from the landscape scale model suite, with distance to palustrine emergent

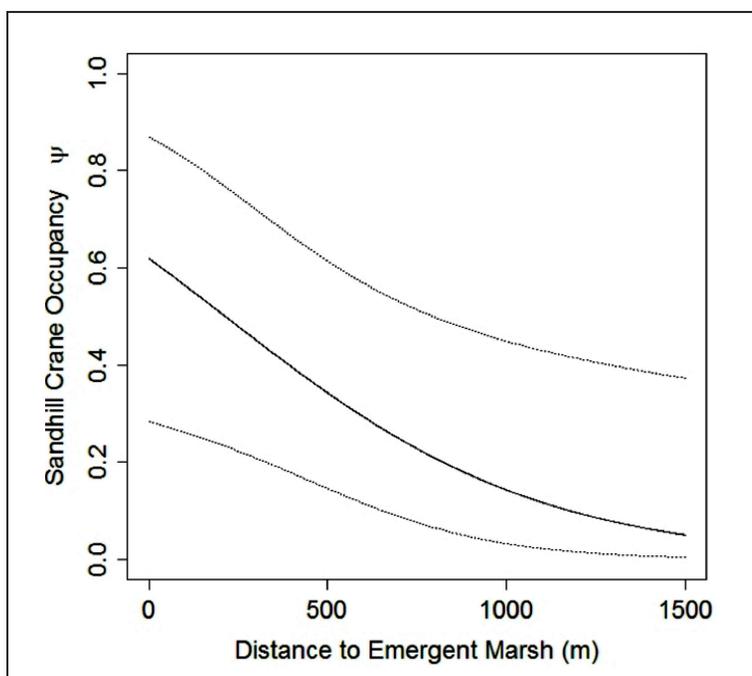


Figure 2. Predicted sandhill crane occupancy rate, ψ (solid line), and 95% confidence intervals (dotted lines), in relation to distance to emergent marsh habitat on Red Rock Lakes National Wildlife Refuge, 2009.

Table 6. Model selection results investigating the relationship between long-billed curlew breeding season occupancy and plot-scale vegetation characteristics ($n = 47$ plots). Covariates included the ratio of preferred-height vegetation (6–15 cm) to taller vegetation (>15cm) (HeightRatio), mean litter depth (LitDpth), and the ratio of sedge/rush to grass (both rhizomatous and bunch grass) (SRGrRatio). The distance to emergent marsh habitat (DEM) was also included as it was the best predictor of curlew occupancy from the landscape-scale suite, Red Rock Lakes National Wildlife Refuge, 2009.

Model	K^a	w^b	ΔAIC_c
ψ HeightRatio, $p(\cdot)$	3	0.49	0.00
ψ (DEM), $p(\cdot)$	3	0.29	1.06
ψ (HeightRatio), $p(t)$	5	0.13	2.66
ψ (DEM), $p(t)$	5	0.08	3.71
ψ (LitDpth), $p(\cdot)$	3	0.01	7.28
ψ (\cdot), $p(\cdot)$	2	<0.01	9.10
ψ (LitDepth), $p(t)$	5	<0.01	10.04
ψ (SRGrRatio), $p(\cdot)$	3	<0.01	10.08
ψ (SRGrRatio), $p(t)$	5	<0.01	12.85

^aNumber of parameters

^bNormalized relative weight likelihood

^cDifference between model's Akaike's Information Criterion corrected for small sample size and the lowest AIC_c value

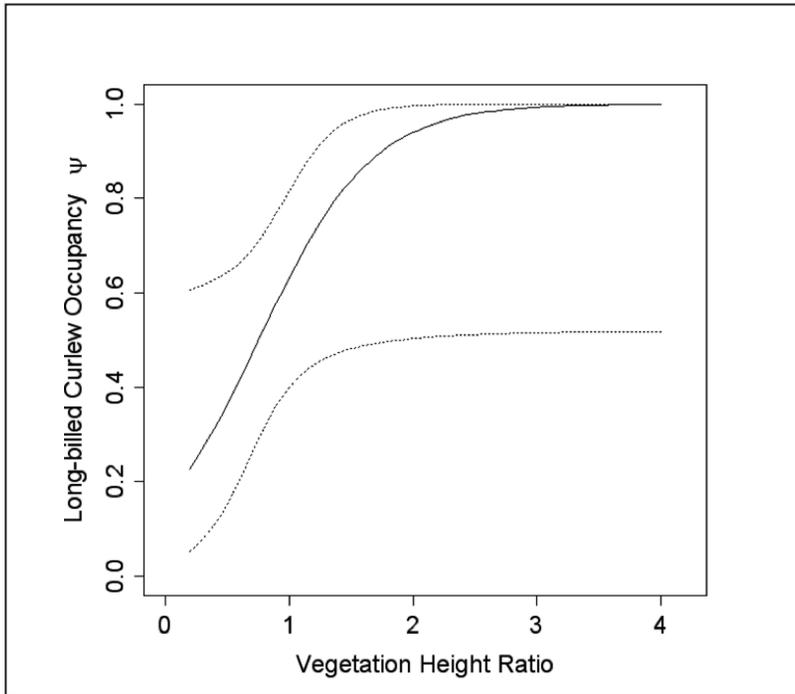


Figure 3. Predicted relationship between long-billed curlew occupancy rate, ψ (solid line), and 95% confidence intervals (dotted lines), in relation to vegetation height ratio during the breeding season, Red Rock Lakes National Wildlife Refuge, 2009. Height ratio was calculated as the ratio of transect hits of preferred height vegetation (6-15 cm) to taller vegetation (>15 cm).

Table 7. Model results from the sandhill crane and plot-scale vegetation characteristics ($n = 47$ plots). Covariates included the number of vegetation hits above 15 cm (Sum15cm), mean litter depth (Mean), and the ratio of sedge/rush hits to grass (both rhizomatous and bunch grass) hits (SRGrRatio). The distance to emergent marsh habitat (DEM) was also included as it was the best predictor of crane occupancy from the landscape-scale suite. Detection probability is p , occupancy is ψ on Red Rock Lakes National Wildlife Refuge.

Model	K^a	w^b	ΔAIC_c
ψ (DEM), p (.)	3	0.41	0.00
ψ (.), p (.)	2	0.25	0.99
ψ (Sum15cm), p (.)	3	0.12	2.44
ψ (DEM), p (t)	5	0.08	3.41
ψ (SRGrRatio), p (.)	3	0.05	4.11
ψ (.), p (t)	4	0.04	4.45
ψ (Sum15cm), p (t)	5	0.02	5.90
ψ (SRGrRatio), p (t)	5	0.02	6.27

^aNumber of parameters

^bNormalized relative weight likelihood

^cDifference between model's Akaike's Information Criterion corrected for small sample size and the lowest AIC_c value

marsh appearing in the top model (Table 7). Plot vegetation height was the most-supported vegetation-characteristic model with a ΔAICc score of 2.44 (Table 7). The small sample size of the reduced data set, coupled with the relatively low number of crane observations, likely limited our ability to detect relationships between crane ψ and habitat characteristics.

DISCUSSION

Our results provide insights into the relative role of plot- and landscape-scale attributes of grazed grasslands and wet meadows on breeding season occupancy of long-billed curlews and sandhill cranes, and how those responses differed between species. For example, curlew ψ increased with increasing distance to palustrine emergent marsh, whereas for crane ψ , estimates decreased as distance to palustrine emergent marsh increased. Moreover, for curlew, estimates of ψ responded positively to vegetation heights demonstrated in other studies to be preferred nesting habitat (Pampush and Anthony 1993, and Saalfeld et al. 2010). We did not find support for models in which crane ψ was related to plot-scale vegetation characteristics, although the number of crane observations in the reduced data set used in the plot-scale model suite was small, and therefore limited this analysis. Alternatively, our selection of sedge/rush to grass ratio may not have been a suitable metric for predicting crane ψ , although we believe it was a relatively sensitive measure of hydrological gradient in more mesic wet meadow habitat, where we predicted higher crane occupancy due to greater foraging opportunities, compared to drier adjacent grassland habitat.

Long-billed curlews preferentially select grazed grassland habitat for nesting. Redmond and Jenni (1986) observed that curlews chose nesting sites that had been grazed within the previous year. For curlew, estimates of ψ during this study increased with increasing amounts of preferred height vegetation, corroborating earlier work that found curlews preferred nesting in vegetation 4–15 cm in height (Saalfeld et

al. 2010). However, our results for curlew did not demonstrate a strong relationship between how recently a grazing unit was grazed and ψ . This may be due to the inconsistency of vegetation and litter in grazing units post-grazing treatment. Current grazing levels are relatively light, resulting in high sward heterogeneity with respect to vegetation structure and height due to localized grazing patterns within a unit. For example, we did not find a relationship between years since last grazed and mean litter depth at the grazing unit scale during this study. Moreover, variation in litter depth within grazing units was high, with standard deviations ranging from 2.9 – 8.5 cm during 2009. This structural heterogeneity could benefit curlews. Having taller grass habitat juxtaposed with more recently grazed nesting habitat supports both nesting and brooding activities of curlews (Redmond and Jenni 1982).

Sandhill cranes prefer to nest over water in shallowly flooded wetlands and meadows (Austin et al. 2007). Our results consistently demonstrated a positive relationship between crane ψ and proximity to palustrine emergent marsh habitat. These results corroborate those of Downs et al. (2008) who found that cranes nested in marshy areas ≤ 100 m from grasslands that were used extensively for brood rearing, foraging, and cover. Grassland and wet meadow habitats adjacent to nesting territories are preferred by cranes during brood rearing (Gerber et al. 2014). Our results for crane provided only weak support for a relationship between ψ and vegetation structure, i.e., years since last grazed in the landscape-scale model suite, and sum of vegetation hits > 15 cm and the ratio of sedge/rush to grass in the plot-scale model suite.

This study underscores the differences of habitat needs for nesting and brood-rearing cranes and curlews. Large tracts of grassland and wet meadow habitats are necessary for both species' nesting, brood rearing, forage and cover needs (Gerber et al. 2014). Curlews and cranes similarly utilize grasslands in conjunction with emergent wetlands for nesting and foraging

(Austin et al. 2007, Saalfeld et al. 2010). Curlews utilize sparse grassland, preferably grazed within the previous year, for nesting (Stanley and Skagen 2007). Conversely, cranes prefer to nest on or near water where vegetation density is high (Gerber et al. 2014, McWethy and Austin 2009).

The current grazing plan for RRLNWR creates disturbance that provides the vegetation structure preferred by nesting curlews within a matrix of taller vegetation that may benefit broods. The rotational aspect of the current grazing plan also provides areas with taller vegetation preferred by nesting, foraging and brood-rearing cranes. This illustrates how prescriptive livestock grazing can be used to provide structurally diverse grassland and wet meadow habitats for species with seemingly disparate structural preferences within the same habitat type. Managing grassland and wet meadow habitat for species that exist on opposite ends of a disturbance preference gradient presumably incorporates the needs of species with intermediate preferences.

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