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Loggerhead Shrike Habitat Selection in South Carolina

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LOGGERHEAD SHRIKE HABITAT SELECTION IN SOUTH CAROLINA

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Wildlife and Fisheries Biology

by
Jennifer L. Froehly
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Accepted by:
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ABSTRACT

The loggerhead shrike (*Lanius ludovicianus*) is a species of concern throughout its range due to severe population declines over the past seven decades. Grassland habitat loss and fragmentation is widely viewed as contributing to the decline. Habitat associations have primarily been studied up to the territory scale, with few studies assessing shrike habitat selection at landscape scales. In Chapter 1 we conducted roadside passive-active point counts for loggerhead shrikes in the coastal plain of South Carolina to evaluate support for several competing hypotheses of how land use and habitat fragmentation at multiple spatial scales influenced the occupancy of loggerhead shrikes. Detection probability increased with fair weather and temperature, and decreased with noise. High probability of detection ($p=0.49$, $SE=0.08$) indicated support for the application of passive point counts in future loggerhead shrike monitoring. Occupancy was best predicted by percentage of pasture at 1 km, where predicted occupancy increased from 2%, when there was 0% pasture in a 1 km radius, to 98%, occupancy when there was 43% pasture in a 1 km radius. There was considerable model selection uncertainty, and our model averaged occupancy estimate was low ($\psi=0.17$, $SE=0.05$). Extrapolation of our averaged model suggested that only 8% of the South Carolina coastal plain was occupied by loggerhead shrikes in the 2016 and 2017 breeding seasons. Our results highlight the importance of habitat beyond breeding territories, and highlight the need for higher concentrations of pasture and grassland at a 1 km scale in order to increase the proportion of area in South Carolina occupied by shrikes.

Identification of factors that influence habitat selection of a nest site can also help managers effectively conserve a species. The Loggerhead Shrike could potentially benefit from fine scale management for nesting habitat, especially where fragmentation and private land ownership impedes conservation at the landscape scale. In Chapter 2 we examined how habitat characteristics at the nest tree and territory core scales influenced nest site selection by Loggerhead Shrikes in the coastal plain of South Carolina. We found 41 Loggerhead Shrike nests and measured characteristics at the nest site and at available sites to model selection factors at the tree and territory core scales. At the territory core scale, we found that low vegetation density heterogeneity, high vegetation height heterogeneity, shorter distances to powerlines, and lower shrub density increased selection. Diameter at breast height increased selection at the tree scale. Overall, Loggerhead Shrikes appeared to select for nest site characteristics that enhanced foraging ease and success, and limited predation risk. For the purpose of increasing optimal nesting habitat for Loggerhead Shrikes, we suggest that private landowners in South Carolina increase grassy habitat on their property and retain large trees in suitable nesting locations.

DEDICATION

I dedicate this thesis to Christopher, my husband, and to my Dad for all their love and support through this project. I also dedicate this thesis to Andrew for his encouragement and friendship.

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TABLE OF CONTENTS

	Page
TITLE PAGE.....	i
ABSTRACT	ii
DEDICATION.....	iii
ACKNOWLEDGMENTS	iv
LIST OF TABLES.....	v
LIST OF FIGURES	vi
CHAPTER	
I. EFFECTS OF SCALE AND LAND COVER ON LOGGERHEAD SHRIKE OCCUPANCY	1
Introduction	1
Study Areas.....	3
Methods	4
Results	12
Discussion.....	13
Management Implications	17
II. NEST SITE SELECTION BY LOGGERHEAD SHRIKES IN A FRAGMENTED LANDSCAPE.....	27
Introduction	27
Methods	29
Results	35
Discussion.....	38
APPENDICES	49
A: Chapter 1 Supplementary Materiel.....	50
B: Chapter 2 Supplementary Materiel.....	53
REFERENCES	56

LIST OF TABLES

Table	Page
1.1 Occupancy covariates and their predicted effect on shrike occupancy.	23
1.2 Model rankings for those retained in the 90% confidence sets for step one and step two	24
1.3 Model averaged covariate estimates, standard errors, and 95% confidence intervals for covariates in the step two 90% confidence model set	25
1.4 Extrapolated area occupied by loggerhead shrike in the South Carolina Coastal Plain	26
2.1 Loggerhead Shrike tree scale and territory core scale (40m radius) nest selection factors used in <i>a priori</i> models	46
2.2 Discrete choice model ranking for Loggerhead Shrike resource selection at the tree and territory core scales in South Carolina during 2016 and 2017	47
2.3 Top model parameter estimates, standard error (SE) and 95% confidence intervals on Loggerhead Shrikes' relative selection of probability at the territory core and tree scales	48
A1.1 Detection <i>a priori</i> hypotheses from step 1	50
A1.2 Occupancy <i>a priori</i> hypotheses	51
A2.1 Territory core scale <i>a priori</i> hypotheses	53
A2.2 Nest tree scale <i>a priori</i> hypotheses	55

LIST OF FIGURES

Figure	Page
1.1 Location of study areas for loggerhead shrike point count surveys in relation to South Carolina geophysical regions	18
1.2 Predicted model averaged covariate effects on detection probability of loggerhead shrike	19
1.3 Predicted model averaged effect of percent pasture at 1 km on occupancy probability for loggerhead shrike	20
1.4 Predicted loggerhead shrike occupancy probability across the South Carolina Coastal Plain using our averaged model	21
2.1 Location of study areas for point count surveys and nest searching in South Carolina, and location of nests from the 2016 and 2017 breeding seasons used in analysis	42
2.2 Territory core ground vegetation height variability (A), territory core ground vegetation density variability (B), and tree scale influence of nest tree diameter at breast height (DBH) (C), on the relative probability of selection by Loggerhead Shrikes in South Carolina during 2016 and 2017	43
2.3 Influence of nest tree diameter at breast height (DBH), on the relative probability of selection at the tree scale by Loggerhead Shrikes in South Carolina during 2016 and 2017	44

CHAPTER ONE

EFFECTS OF SCALE AND LAND COVER ON LOGGERHEAD SHRIKE OCCUPANCY

The loggerhead shrike (*Lanius ludovicianus*), a mid-sized passerine endemic to North America, has exhibited a range-wide decline of at least 74.0% since the 1940's (Cade and Woods 1997, Rosenberg et al. 2016). The Breeding Bird Survey estimated an average annual decline of 3.0% from 1966-2015 (Sauer et al. 2017), although annual population trends in key ecoregions range from -7.3% in the Texan oaks and prairies, to -1.3% in the intermountain west (Rosenberg et al. 2016). The Atlantic Coast has exhibited average annual long-term population declines (-2.9%), but has experienced one of the highest regional total population loss percentages (-89.0%, Rosenberg et al. 2016). In particular, the southeast experienced an average population decline of 6.0% per year prior to 1985 (Luukkonen 1987). Consequently, the loggerhead shrike has become a species of conservation concern and is now listed as a species of conservation priority in numerous State Wildlife Action Plans, including all southeastern and coastal states from Texas to New York.

Despite the extent and longevity of loggerhead shrike declines, the causes are still unknown. One plausible reason for the decline of loggerhead shrike populations is the loss of available habitat (Luukkonen 1987, Smith and Kruse 1992, Gawlik and Bildstein 1993, Prescott and Collister 1993). The loggerhead shrike has been found to have four essential habitat requirements; open grassy areas for foraging, trees or large shrubs for nesting, elevated perches for foraging, and spiky vegetation for prey impalement (Pruitt

2000). These requirements have historically been filled by numerous ecosystems such as sage-steppes, prairies, desert scrubs, pinyon-juniper woodlands, and pine savannas (Pruitt 2000), but these habitats are disappearing. As a result, grasslands, savannas, and barrens represent 55% of all critically endangered ecosystems (identified by having at least a 98% decline in area) in the United States (Noss et al. 1995).

As native grassland habitat has become increasingly rare, researchers have observed shrikes utilizing a variety of human modified habitat, from pasture to croplands (Luukkonen 1987, Esely and Bollinger 2001, Chabot et al. 2001, Walk et al 2006). Indeed, in South Carolina, pasture comprised over half of the area within 100 m of nests (Gawlik and Bildstein 1990). However, it is unclear whether other human modified habitats like row crop agriculture is useful habitat for shrikes. Shrikes have been reported to use fencerows by roads and cropland, and edges of cropland (Stewart 1975, Smith and Kruse 1992), but have also been reported to avoid cropland (DeGeus 1990). Conflicting evidence for selection or avoidance of cropland has even been observed within studies. For example, Gawlik and Bildstein (1990) found no cropland within 100 m of nests, yet they observed shrikes using cropland and pasture equally during the breeding season, and shrike use of cropland increased in the non-breeding season. Additionally, some large grassy areas seemingly ideal for shrikes have remained unoccupied leading some researchers to suggest that habitat is not a limiting factor to shrike populations (Jobin et al. 2005). Collectively, this suggests that researchers still have a poor understanding of what constitutes habitat for shrikes.

The objective of this study was to examine how land use and habitat fragmentation at multiple spatial scales influences the occupancy of loggerhead shrikes in South Carolina. How an individual selects habitat can be an intricate process that occurs on multiple spatial scales (Johnson 1980), yet most shrike studies have only examined habitat selection up to the territory scale (e.g., Luukkonen 1987, Gawlick and Bildsein 1990, Prescott and Collister 1993, Walk et al. 2006). For many avian species, it is increasingly understood that larger scale habitat connectivity is important (Brennan and Kuvlesky 2005), and fragmentation has been shown to negatively affect the occurrence of shrikes in Ontario (A.A.Chabot et al., Queens University, unpublished report). In the southeastern US, landscape composition has become increasingly fragmented, particularly over the past several decades (Griffith et al. 2003). Thus, including landscape scale characteristics in resource selection studies is imperative to building an understanding of how land use change and the patchiness or connectivity of suitable habitat influences shrike populations. To inform future conservation decision-making, our study evaluated support for several competing hypotheses of how land use and habitat fragmentation at multiple spatial scales influenced the occupancy of loggerhead Shrikes.

STUDY AREA

The South Carolina Breeding Bird Atlas (Cely 2003) and ebird records (eBird 2012) suggest that shrikes are most often sighted in the coastal plain and portions of the piedmont regions in South Carolina, with a majority in the coastal plain. Accordingly, we identified two separate study areas in the coastal plain of South Carolina totaling 368,086

ha (Figure 1.1). Both study areas were selected to maximize our ability to collect enough shrike detections and represented a range of land cover conditions that would be suitable for testing our habitat selection hypotheses relative to pasture and cropland cover. Study area one was located in Calhoun and Orangeburg counties and was composed of 42% forest, 22% crop, 14% shrub/scrub, 10% pasture, and 12% other land cover types as determined by the 2011 National Land Cover Database (NLCD) (Homer et al. 2015). Study area two was located in Colleton county and was composed of 61% forest, 15% shrub/scrub, 6% each of pasture and crop, and 12% other land cover types as determined by 2011 NLCD.

METHODS

Data Collection Methods

We conducted point count surveys to determine loggerhead shrike occupancy of selected survey sites. To select survey sites, we used the 2011 NLCD layer (Homer et al. 2015) to create polygons of pasture and cultivated crop cover types in our study areas. We chose to use a roadside survey methodology because our study areas had high road density allowing 90% of all of the pasture and crop polygons to be considered for survey site selection, and because previous research suggests roadside surveys are not likely to affect grassland bird detection probabilities (Lituma and Buehler 2016). Accordingly, only polygons adjacent to non-major roadways were retained. Polygons smaller than 0.5 ha were also eliminated because they would be too small for a loggerhead shrike territory (Pruitt 2000). To ensure that a range of polygon sizes were equally represented in our study, the remaining polygons were separated into four size classes, small (0.5-3.5 ha),

medium (3.5-7.5 ha), large (7.5-11.5 ha), and extra-large (>11.5 ha), with the small size reflecting the minimum territory size of a shrike (Pruitt 2000), the medium and large size classes being representative of different published average shrike territory sizes (Pruitt 2000), and the extra-large size capable of supporting larger than average territories or multiple territories. We then used the Generalized Random Tessellation Stratified (GRTS) sampling design with the *spsurvey* package (Kincaid and Olsen 2016) in Program R version 3.3.3 (R Core Team 2017) to select the final polygons for establishing survey sites. The GRTS sampling allowed for a spatially balanced, random sampling distribution so that each polygon type (pasture and crop) and size was represented in our survey sites across the study area. When first visiting a GRTS selected polygon, we established a roadside point that allowed the maximum viewing area of the polygon, and which was used as the center point for the survey site.

We used previously reported detection and occupancy probability rates to determine the number of survey sites and replicate visits used in our study. Shrikes occurred at an average of 62% of sites in Big Bend National Park (Gutzwiller and Barrow 2001) with an estimated detection probability of 0.24 (which we derived from their reported occupancy and mean abundance of shrikes detected per count per site (Gutzwiller and Barrow 2001, 2002)). Using these estimates and power analyses (as per MacKenzie et al. 2006), we determined that we needed to survey up to 96 sites, 7-10 times each to be 95% confident that we would detect shrikes during at least one survey if they were present at a site. We surveyed a total of 96 points over two years, where 12 points were surveyed adjacent to each polygon type and size class. In an attempt to

ensure independence between sampling sites, we maintained a minimum of 1 km between survey sites based on the diameter of the largest territory size reported (47 ha; A. Chabot et al., unpublished report). To maintain closure within the sampling period, all surveys were conducted during the breeding season when shrikes are highly territorial and most likely to remain in one location (Pruitt 2000). In 2016, we surveyed each site 9 times between 24 March- 16 June. Based on obtaining relatively higher detection estimates than expected during 2016 ($p = 0.50$ in 2016 vs. $p = 0.24$ expected based on literature surveys), we adjusted our survey effort in 2017 to only survey sites 4 times between 24 March - 22 May.

At each survey site we conducted unlimited radius point counts using a combined methodology of a passive point count followed by a call playback period. Before a survey was started, we used a rangefinder to establish visual distance landmarks to ensure accurate distance estimates. Our surveys started with a 10-minute passive point count where all birds seen or heard were recorded, immediately followed by a 6-minute call playback sequence during which we looked and listened for adult loggerhead shrikes. The sequence was as follows: 20 seconds song, 40 seconds silence, 20 seconds begging call, 40 seconds silence, 20 seconds alarm call, 40 seconds silence. This sequence repeated for the second 3 minutes of the callback survey. For shrike and all other avian detections, we recorded distance to the bird and whether the detection was auditory or visual. Detection variables were also recorded at the start of each survey either by a direct measure (temperature, time of day, Julian date) or as an index (noise, wind, sky conditions). Noise was indexed from 0 to 4 where zero was no noise, and four was loud

noise preventing the detection of any birds beyond 50 m (Huff et al. 2000), wind was indexed using the beaufort wind scale from 0 to 5 where zero was calm, and five was 17-21 mph, and sky conditions were indexed by the following; 0: clear, 1: partly cloudy, 2: overcast, 3: fog, 4: drizzle/light rain, 5: rain. All point count surveys were conducted within four hours after sunrise, and were completed by a single observer who varied the time of day between visits to an individual point.

We utilized the 2011 NLCD to obtain spatial data for landscape characteristics (Homer et al. 2015) and calculated percent cover and aggregation index values using the SDMTools package (VanDerWal et al. 2014) in Program R (R Core Team 2017). We estimated vegetation productivity using Normalized difference vegetation index (NDVI) data obtained through the National Air and Space Administration Moderate Resolution Imaging Radiospectrometer (MODIS) data (Didan 2015) and reformatted to the same spatial scale as the NLCD data (30 m). All covariates were standardized using the scale function in program R prior to analysis.

Analytical methods

We used a two-step occupancy modeling approach (MacKenzie's et al. 2006) to evaluate habitat selection at multiple spatial scales. In the first step, we examined how weather (temperature, sky conditions, or wind speed), variability in timing (time of day or Julian date), and ambient noise levels, affected the probability of detection. We hypothesized that increasing temperature, wind, and worsening sky conditions would hinder detection as strong winds, clouds, and extreme temperatures can all decrease activity level of birds due to energy budgeting (Richards 1981, Robbins 1981b). We hypothesized that unlike

most passerine species, shrikes would be more active later in the morning, and therefore, detections would increase with time of day (Robbins 1981a, Chabot 2014). We also hypothesized that more ambient noise would decrease our detection ability due to difficulty of the observer hearing a calling bird, and difficulty of a shrike hearing and reacting to the call-playback. Finally, we hypothesized that detectability of shrikes would peak during the breeding season when most individuals are breeding (Skirvin 1981) and highly territorial (Pruitt 2000). Peak breeding is reported to occur during April and May depending on location (Yosef 1996), so we used a quadratic form ($x + x^2$) of Julian date to represent this hypothesized relationship in our survey time period March-June. We developed 8 *a priori* models to evaluate hypothesized effects of individual and combined covariates on detection while holding occupancy constant (Table A1.1). We tested for correlations between covariates and did not include correlated covariates ($r > 0.7$) in the same model. We ran all occupancy models using the unmarked package (Fiske and Chandler 2011) in Program R (R Core Team 2017). We compared models using the Akaike Information Criterion corrected for small sample sizes (AIC_c) and by examining model weight (Burnham and Anderson 2002). We considered all models within the 90% cumulative model weight to influence detection, and carried over all covariates within this confidence set to the detection portion of our models in step two.

In step two we examined support for hypothesized habitat and landscape variables at four different scales to predict shrike site occupancy. Our smallest scale was a 300 m radius from the center of the survey site. This was the farthest a shrike was detected from a point count and therefore represented the survey site scale and the scale at which we

were able to make occupancy predictions. We also used a 1 km radius scale, which is representative of the maximum distance a shrike would travel in the breeding season (A. A. Chabot et al., unpublished report). Finally, both the 5 km and 15 km scales were analyzed because they were found to be significant in other shrike studies looking at landscape factors (Burton and Whitehead 1990, Chabot 2001, A. A. Chabot et al., unpublished report). We hypothesized that the influence of land cover on occupancy depends on spatial scales (Table 1.1). For example, because shrikes have been found to utilize pastures (Luukkonen 1987, Gawlik and Bildstein 1990, Esely and Bollinger 2001, Walk et al 2006), we hypothesized that percent pasture at the three smaller scales would have a positive effect on occupancy probability. In addition, because shrike occurrence can decline in more productive grasslands (Shen et al. 2013), we hypothesized that as an index for productivity, increasing average maximum breeding season NDVI at the three smaller scales would have a negative effect on occupancy probability. We hypothesized that percent crop cover at the 1 km and 5 km scales would have a negative effect on occupancy probability due to some evidence of row crop avoidance (DeGeus 1990), and we hypothesized that percent forest at all scales would have a negative effect on occupancy probability because Shrike occurrence has also been found to be negatively associated with forest cover (Johnson et al. 2017). We also hypothesized that the aggregation of pasture at the two largest scales, as a measure of connectivity, would have a positive effect on occupancy probability, and that the aggregation of pasture and cropland combined in one “open” habitat type at the 5 km scale would have a positive effect on occupancy probability (A. A. Chabot et al., unpublished report).

We used our 15 occupancy covariates (Table 1.1) to formulate 26 *a priori* occupancy models, evaluating hypothesized effects of land cover, aggregation and primary productivity at each selected scale separately, and between scales on occupancy probability (Table A1.2). We tested for correlations between covariates to determine if any model contained correlated covariates ($r > 0.7$). In instances where correlated covariates occurred in the same model, we ran separate occupancy models with each singular covariate, and retained the covariate that produced the lower AIC_c score. We compared our *a priori* models using AIC_c (Burnham and Anderson 2002). We determined that models carrying any portion of the upper 90% AIC_c cumulative weight were important to occupancy rates and fell within our confidence set of models. We calculated model-averaged occupancy, detection, and covariate estimates and their 95% confidence intervals based on all models in our 90% confidence set. We assumed that covariates with 95% confidence intervals not overlapping zero were important predictors of detection or occupancy.

We used a Pearson chi square test with 10,000 bootstrap replications to determine if our averaged model fit our data (MacKenzie and Bailey 2004). To further assess model performance, we conducted a 10-fold cross validation (Boyce et al. 2002) by randomly separating our data by a 75:25 ratio to establish our training: testing datasets, running our averaged model with the training dataset, and then using the resulting averaged beta coefficients to predict occupancy with the testing data set. Differences between predicted and known occupancy of the testing datasets were assessed using a receiving operator characteristic (ROC) and calculating the area under the curve (AUC) (Boyce et al. 2002).

Model performance was ultimately determined by the AUC value, which could range from 0.0 (predicts opposite of the truth 100% of the time) to 0.5 (no better than a null model) to 1.0 (predicts truth 100% of the time). If our model performed well ($AUC > 0.7$ (Morelli et al. 2017)) in the cross validation analysis, we applied it across a grid of the coastal plain of South Carolina with a resolution equal to the size of our sampling unit (530 m^2 resolution) to predict occupancy probabilities. Since occupancy probability is also a measure of proportion area occupied (MacKenzie et al. 2002), we binned the extrapolated occupancy probability values by tenths, multiplied the bin area by the bin mean occupancy probability, and scaled it to the whole South Carolina coastal plain area to determine the hectares and the proportion area occupied by loggerhead shrikes in each probability bin. Finally, all bins were summed together to get total predicted hectares and proportion area occupied by loggerhead shrikes in the whole coastal plain of South Carolina during the 2016 and 2017 breeding seasons.

Additionally, in order to inform future loggerhead shrike monitoring efforts, we used our model confidence set to determine if our detection and occupancy probabilities would change if a playback period were not included. We removed detection data collected during the playback section of our surveys and ran our confidence set with this modified dataset. We then compared 95% confidence intervals of detection and occupancy probability between the original dataset and the modified dataset to determine if estimates changed when the playback survey period was removed. We determined if occupancy and detection probability estimates were similar when confidence intervals overlapped between datasets.

RESULTS

Loggerhead shrikes were detected at 20 of 94 survey sites. Twelve of the occupied sites were in study area one, and 8 were in study area two. Our detection model confidence set from step one included 5 models (Table 1.2) and included all of our detection covariates. Therefore all of our detection covariates were carried over and used in our second model-fitting step. Five models were retained in our step two model 90% confidence set (Table 1.2). When covariates were held at their mean value, our model averaged results predicted detection at 0.486, SE=0.082, and occupancy at 0.168, SE=0.0465. Within the confidence set, sky conditions was the only model averaged detection covariate whose 95% confidence interval did not overlap zero, though confidence intervals for temperature and noise indicate moderate support as they just barely overlapped zero (Table 1.3). Detection estimates increased from 26%, when skies were cloudy, to 63%, when skies were clear, from 4% at our minimum survey temperature (2° C) to 83% at our maximum survey temperature (28° C), and from 41%, when moderate noise was present, to 63%, when there was no background noise (Figure 1.2). Pasture within 1 km was the only model averaged occupancy covariate with a confidence interval not overlapping zero (Table 1.3). Predicted occupancy increased from 2% when amount of pasture at a 1 km radius was 0%, to 26% at 15% pasture, and leveled off with 99% occupancy at 45% pasture (Figure 1.3).

Our final model from our confidence set
 $(\psi(P1km+NDVI1km+FOR5km+FOR15km+NDVI300m)p(wind+temp+sky+noise+start.$

time+date²)) fit our data ($X^2=220.42$, p value=0.35, $\hat{c}=1.06$). The occupancy portion of this final model set performed well in our cross validation with an AUC of 0.78.

Extrapolation of our model across the coastal plains of South Carolina indicated few areas with high occupancy probability (Figure 1.4), and predicted that the total proportion area occupied by Loggerhead Shrikes in the South Carolina coastal plain was 8% (Table 4).

The detection portion of our averaged model (p(wind+temp+sky+noise+start.time+date²)) did not perform very well in our cross validation with an AUC of 0.57, suggesting it does not have a strong predictive ability. The passive survey period was sufficient to determine occupancy at all but three sites where shrikes were only observed during one survey, and only during the active survey period. Indeed, removing data gathered in the active survey period from the model did not affect detection rates (0.44, SE=0.09 without playback, compared to $p=0.49$, SE=0.08 with playback included), or occupancy rates (0.1, SE=0.04 without playback, compared to $\psi=0.17$, SE=0.05 with playback).

DISCUSSION

Our finding that occupancy of loggerhead shrikes in the South Carolina Coastal Plain was best predicted by the availability of pasture at a 1 km scale suggests that shrikes are sensitive to habitat at a broader spatial scale than previously thought. Previous shrike research has focused on habitat associations within 100-300 m of nest sites (Luukkonen 1987, Gawlik and Bildstein 1990, Esely and Bollinger 2001, Walk et al 2006), or on breeding territories (Yosef and Grubb 1994) that are smaller (4-13ha (Pruitt 2000)) than

our 1 km scale. Our landscape scale findings are consistent with recent findings elsewhere in the southeast that predicted shrike occupancy to decline as percent forest cover increased at the 2.5 km scale (Johnson 2017). Pasture availability at 1 km could be important to shrikes for securing specific resources throughout the year. Shrike territories have been shown to expand due to experimental prey scarcity (Yosef and Deyrup 1998), suggesting that fluctuations in prey availability could explain changes in territory size and selection of more habitat than what is utilized on an average day-to-day basis. Further, territories expand during the post-fledging period (A. A. Chabot et al., unpublished report) suggesting extra buffer habitat around the smaller breeding season territory could provide essential resources during the vulnerable post-fledging period. Thus, to better understand the influence of these moderate scale effects of pasture on site occupancy, further research of shrike space use is likely needed during the fledgling and little-studied non-breeding seasons.

Our lack of support for fragmentation effects on shrike occupancy could be explained by the strength of our percent pasture predictor and by temporal limitations. Simulations testing the importance of habitat variables to extinction thresholds suggest that the abundance of habitat on a landscape has a much larger effect on extinction than does fragmentation (Fahrig 2001), and grassland percentage has been found to be a more consistent predictor of grassland bird abundance than fragmentation (Renfrew and Ribic 2008). Additionally, since fragmentation occurs over time, effects may only appear when analyzing long-term data from when fragmentation occurred. For example, negative effects of large-scale fragmentation on bobolinks (*Dolichonyx oryzivorus*) were found

when analyzing data over 25 years, but when data were analyzed in 5-year increments, no effects of fragmentation were found (Either et al. 2017). Our snapshot analysis suggests that fragmentation was not an important predictor of occupancy during our survey period, though low occupancy probabilities and high fragmentation of pastures in our study areas could indicate that loggerhead shrikes in our study could have already suffered from fragmentation.

While our study only identified pasture as a strong land cover predictor of shrike occupancy (Table 4), it is important to remember that National Land Cover Data lumped rural residential areas, hay, old fields, grassy areas, and pasture into the one pasture category. Delineating land cover data into more specific habitats and monitoring shrike occupancy through time could allow researchers to determine more specific habitat preferences, and how shrikes are responding to land cover change. Further, as occupancy only measures presence, not abundance, it is unknown whether fitness varies between different open habitats. For example, by examining population growth rates in different habitats, Arlt et al. were able to determine that northern wheatears *Oenanthe oenanthe* in pastures and farmyards acted as population sources, but those in crop fields and tall grasslands were population sinks, and that population decline was influenced by the decline of source habitats (2008). Further investigation of shrike populations is needed to determine if different types of open habitats act as population sources or sinks. This is especially important in areas like South Carolina that are primarily composed of small private landholdings. Identification of source and sink habitats will help identify private

land that is most able to provide conservation benefits and thus also identify where agencies should focus on landowner engagement.

Our study illustrates the utility of passive point counts in monitoring shrikes during the breeding season, although poor detection model validation results suggests that more research is needed. Our model suggests that surveying in fair weather, higher temperatures, and low noise levels result in higher detection probability, and that a passive point count is sufficient for detecting shrikes in our study system. This effective use of passive-only point counts to monitor shrike population trends could be beneficial to researchers since other species of interest can also be observed at the same time without biasing shrike specific detection. Currently, shrikes are surveyed differently between researchers, and standardization of survey methodology is needed so that comparisons can be made between or within studies (A. Chabot, loggerhead shrike working group coordinator, personal communication). Our results suggest that passive point counts could be used as part of a standardized survey protocol. Further, in areas like South Carolina that are believed to be host to both residents and over wintering migrants, we suggest that surveying in the non-breeding season could be a vital addition to shrike monitoring. Habitat may be more limited in the non-breeding season due to the influx of migrant individuals (Johnson 2017), and migrants may be settling for more marginal habitat since residents get first pick of the best habitat (Lymn and Temple 1991). Thus, pairing breeding and non-breeding surveys could provide an even better understanding of factors limiting shrike occurrence and abundance.

Overall, our exploration into habitat scale relationships for loggerhead shrike confirms that landscape scale habitat conditions influence shrike breeding habitat selection. The scarcity of suitable habitat in our predictive map of the South Carolina Coastal Plain illustrates the importance of maintaining open pasture habitat in higher concentrations on the South Carolina landscape for the recovery of the shrike population. Maintaining high concentrations of pasture habitat is also likely to benefit other grassland bird species of conservation concern, which as a guild, have experienced more severe declines than any other avian guild in North America (Rosenberg et al. 2016). Savanna sparrow (*Passerculus sandwichensis*), grasshopper sparrow (*Ammodramus savannarum*), and bobolink abundance was found to be best explained by variables including percent forest and percent grassland at the 1.2 km scale (Renfrew and Ribic 2008), and occupancy of 11 out of 19 grassland species was best explained by percent tree cover at the 1.2-1.6 km scales (Cunningham and Johnson 2006). These correlative results suggest that preserving grassland and pasture habitat at a 1 km scale for shrikes could help to protect habitat for numerous grassland bird species. Thus, conservation and restoration of grassland in high densities will contribute to the conservation of loggerhead shrikes as well as many other declining grassland species.

MANAGEMENT IMPLICATIONS

Land-use predictions through 2051 for the southeastern US highlight the susceptibility of open habitats to land use change; predicting a 49.3% loss of pasture and a 24.2% loss of natural rangeland under current land use trends, and 66.7% and 38.6% predicted loss of pasture and rangeland under increased crop demand (Martinuzzi et al. 2015). Our finding

of the importance of pasture habitat at moderate spatial scales, and this predicted loss of grassland habitat, highlight the urgency for further research on how grassland conversion will affect shrike habitat in the future. To further understand shrike habitat, future research should focus on the addition of non-breeding season surveys, as well as understanding the long-term effects of land use change on shrike habitat. Finally, based on our high detection rate, we suggest that researchers use passive point counts to allow for standardization of shrike and other grassland bird survey efforts. We also suggest that in South Carolina, conservation of grasslands and pasture will be most effective on large private lands near areas already occupied by Loggerhead Shrikes.

FIGURES

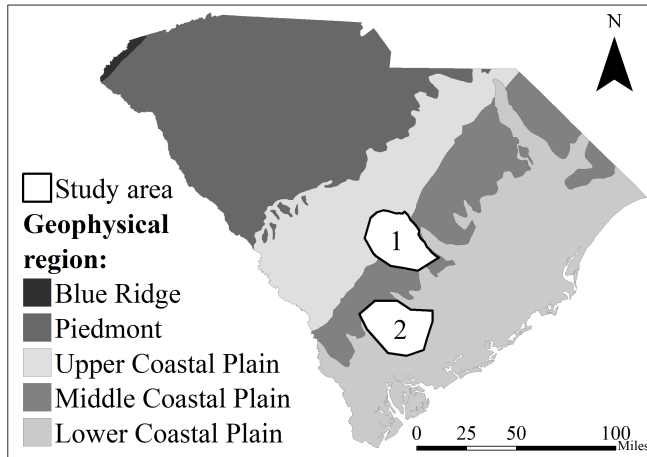


Figure 1.1: Location of study areas for loggerhead shrike point count surveys in relation to South Carolina geophysical regions.

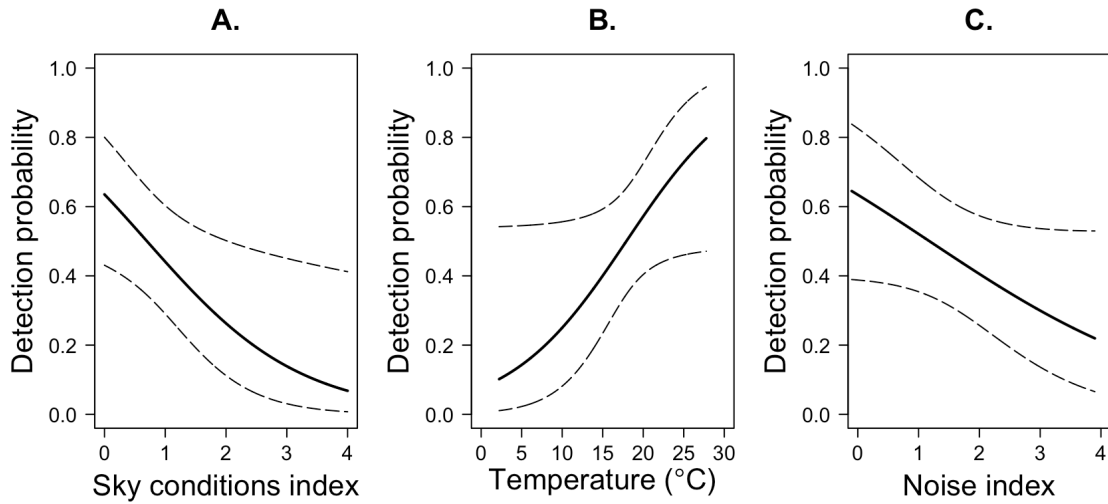


Figure 1.2: Predicted model averaged covariate effects on detection probability of loggerhead shrike. Dashed lines represent 95% confidence interval. **A.** Sky conditions: 0: clear, 1: partly cloudy, 2: overcast, 3: fog, 4: drizzle/light rain **B.** Temperature at time of survey in degrees C. **C.** Ambient noise index: 0: no noise, 1: gentle bubbling brook noise, probably not missing any birds, 2: babbling creek noise, might be missing some distant birds, 3: rushing creek noise, probably detecting only those birds within 50m, 4: roaring creek and river noise, probably detecting only the very loudest calls and songs within 50 m (Huff et al. 2000).

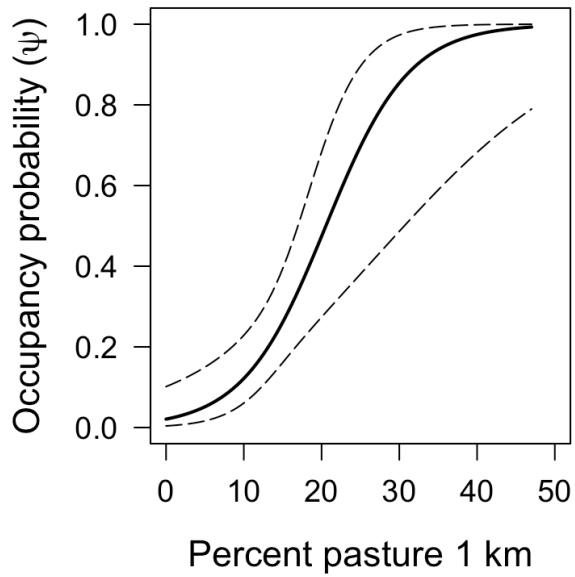


Figure 1.3: Predicted model averaged effect of percent pasture at 1 km on occupancy probability for loggerhead shrike. Dashed lines represent 95% confidence interval.

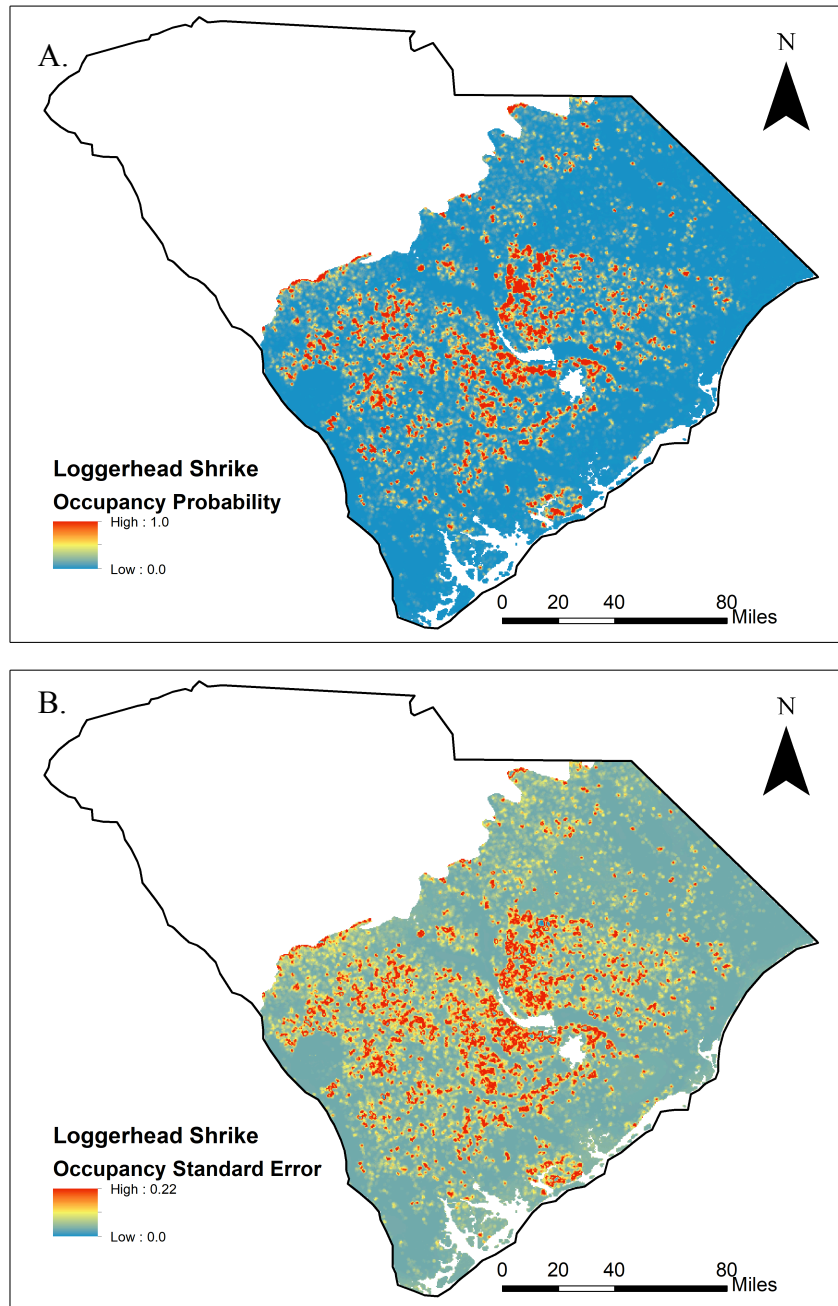


Figure 4: Predicted loggerhead shrike occupancy probability (A) across the South Carolina Coastal Plain using our averaged model:

$(\psi(P1km+ndvi1km+FOR5km+FOR15km+ndvi300m)p(wind+temp+sky+noise+start.time+date^2))$, and the standard error associated with the estimates (B).

TABLES

Table 1.1: Occupancy covariates and their predicted effect on shrike occupancy. X's denote which scales were used in a priori models.

Occupancy Covariate	Covariate name	Predicted effect	Spatial Scales Examined			
			300 m	1 km	5 km	15 km
Percent Pasture	P	(+)	x	x	x	
Percent Crop	C	(-)		x	x	
Percent forest	F	(-)	x	x	x	x
Aggregation of Pasture	AP	(+)			x	x
Aggregation of pasture and crop	AO	(+)			x	
Average maximum breeding density	ndvi	(-)	x	x	x	

Table 1.2: Model rankings for those retained in the 90% confidence sets for step one and step two.

Model	K ^a	AIC _c ^b	ΔAIC_c	w_i^c	Log L.
<i>Detection (step 1) confidence set</i>					
$\psi(\cdot)p(\text{wind+temp+sky})$	5	232.27	0	0.31	-110.80
$\psi(\cdot)p(\text{wind+temp+sky+noise})$	6	322.01	0.73	0.22	-110.02
$\psi(\cdot)p(\text{time})$	3	234.37	2.1	0.11	-114.05
$\psi(\cdot)p(\text{wind+temp+sky+date}^2)$	7	234.52	2.14	0.11	-109.56
$\psi(\cdot)p(\text{wind+temp+sky+time})$	6	235.37	2.25	0.10	-110.78
$\Psi(\cdot)p(\cdot)$	2	235.57	3.29	0.06	-115.72
<i>Occupancy (step 2) confidence set</i>					
$\psi(\text{P1km})p(\text{global})$	10	216.54	0	0.47	-96.94
$\psi(\text{P1km+NDVI1km})p(\text{global})$	11	218.67	2.13	0.16	-96.73
$\psi(\text{P1km+F15km})p(\text{global})$	11	219.10	2.56	0.13	-96.94
$\psi(\text{P1km+F5km})p(\text{global})$	11	219.10	2.56	0.13	-96.94
$\psi(\text{P1km+F15km+NDVI300m})p(\text{global})$	12	220.31	3.77	0.07	-96.23

^a Number parameters in the model

^b Akaike Information Criterion corrected for small sample sizes

^c Akaike weight

Table 1.3: Model averaged covariate estimates, standard errors (SE), and 95% confidence intervals (CI) for covariates in the step two 90% confidence model set for loggerhead shrike detection and occupancy in the South Carolina Coastal Plain.

Model	Estimate	SE	CI
<i>Detection covariates</i>			
Sky	-0.62	0.27	-1.16, -0.09
Wind	0.47	0.3	-0.12, 1.06
Temp	0.69	0.36	-0.01, 1.39
Noise	-0.39	0.22	-0.69, 0.04
Time	-0.27	0.36	-0.98, 0.45
Date ²	0.22	0.22	-0.20, 0.65
Date	-0.42	0.31	-1.04, 0.19
<i>Occupancy Covariates</i>			
Pasture 1 km	1.7	0.5	0.71, 2.69
NDVI 1 km	-0.21	0.31	-0.82, 0.31
Forest 15 km	0.03	0.34	-0.64, 0.69
NDVI 300 m	-0.4	0.33	-1.05, 0.25
Forest 5 km	-0.02	0.31	-0.64, 0.59

Table 1.4: Extrapolated area occupied by loggerhead shrike in the South Carolina Coastal

Plain determined by occupancy probability predicted by our top model of

$(\psi(P1km+ndvi1km+FOR5km+FOR15km+ndvi300m)p(wind+temp+sky+noise$
 $+start.time+date^2))$

Estimated Occupancy	Total ha in bin	Mean ha occupied	Mean proportion area occupied
0.0-0.1	4169342.5	125080.3	0.025
0.1-0.2	367445.3	52177.2	0.010
0.2-0.3	154691.6	37899.4	0.008
0.3-0.4	89270.0	30976.7	0.006
0.4-0.5	62107.0	27886.0	0.006
0.5-0.6	47135.0	25877.1	0.005
0.6-0.7	38370.9	24864.4	0.005
0.7-0.8	31629.3	23722.0	0.005
0.8-0.9	26882.1	22984.2	0.005
0.9-1.0	33033.8	31580.4	0.006
Total	5019907.7	403047.8	0.080

CHAPTER TWO

NEST SITE SELECTION BY LOGGERHEAD SHRIKES IN A FRAGMENTED LANDSCAPE

While landscape-scale habitat conditions are increasingly recognized as an important factor impacting the viability of many avian species (Ribic et al. 2009), fine-scale factors are also important for avian conservation. In particular, fine-scale habitat conditions, such as nesting resources, are often not represented by measures assessed at landscape scales (Johnson 1980). An individual is only able to attempt to produce offspring if nesting habitat needs are met (Walters 1991). Therefore, limited nesting habitat could contribute to a decline in population viability. For example, warm and cool season grass plantings enrolled in the conservation reserve program (CRP) in Missouri provided nesting sites and increased populations of Grasshopper Sparrows (*Ammodramus savannarum*), Eastern Meadowlarks (*Sturnella magna*), Field Sparrows (*Spizella pusilla*), and American Goldfinches (*Spinus tristis*) (McCoy et al. 1999). Even in sink populations (i.e., where population growth is negative) of Dickcissel (*Spiza Americana*) and Red-winged Blackbirds (*Agelaius phoeniceus*), nesting efforts in these CRP fields may reduce the severity of the sink by providing nesting habitat within areas they otherwise would not have nested, increasing the number of individuals that have at least some chance of productivity (McCoy et al. 1999).

Fine-scale management actions can also be easier to implement than at the landscape scale, especially when land ownership is fragmented. For example, in urban areas where natural cavities are limiting, installation of nest boxes can help to increase

population numbers of cavity nesting species like the Eastern Bluebird (*Sialia sialis*) (Newton 1994). Planting native tree and shrub species in residential yards has also been shown to support locally higher densities of insectivorous birds due to increased prey (Narango et al. 2017). Thus, fine-scale management actions like these could be instrumental in conserving avian populations in areas that have otherwise undergone rapid habitat degradation and fragmentation at the landscape scale.

The Loggerhead Shrike (*Lanius ludovicianus*), a mid-sized passerine endemic to North America, is one grassland bird that could potentially benefit from fine-scale management for nesting habitat. The Loggerhead Shrike has exhibited a range-wide decline of at least 74% since the 1940's (Cade and Woods 1997, Rosenberg et al. 2016) with the Atlantic coast experiencing one of the highest regional population declines (-89%, Rosenberg et al. 2016). Consequently, the Loggerhead Shrike is a species of conservation concern in many state wildlife action plans. Recent findings predicted that Loggerhead Shrikes in South Carolina were more likely to occur in areas with high pasture percentages within 1 km of the individual (Froehly et al. in review) suggesting that high concentrations of pasture will be important for the conservation of the species. In addition to maintaining relatively large open grassland habitats, Loggerhead Shrikes are also likely selecting for finer scale factors like the number of foraging perches and the availability of nest trees to establish a nest site in the breeding season (Gawlik and Bildstein 1990, Esely and Bollinger 2001, Michaels and Cully 1998, Chabot et al. 2001). Thus, information on how Loggerhead Shrikes select nesting habitat could guide fine scale management actions to promote both occupation and breeding.

The objective of this study was to examine how fine-scale habitat characteristics within the breeding territory influence nest site selection by Loggerhead Shrikes in the coastal plain of South Carolina. We examine selection at the territory core scale to provide insight into the critical resources required during the nesting season and also examine selection at the tree scale to inform managers as to what Loggerhead Shrikes considered a suitable nesting location. Collectively, our study can provide recommendations for land managers and individual land-owners on how to enhance nesting habitat for Loggerhead Shrikes across the fragmented southeast coastal plain.

METHODS

Study Area

We conducted our study within the South Carolina Coastal Plain where Loggerhead Shrike occupancy is known to be relatively high (see Froehly et al. in review). The South Carolina Coastal Plain is composed of 51% forest, 12% crop, 4% pasture, 8% developed, 24% other (Homer et al. 2015). Land in South Carolina is 90% privately owned (Vincent et al. 2017, South Carolina Department of Administration 2018) though private property sizes range from plantations of thousands of acres, to residential houses on less than an acre of land. We selected 2 study areas in the coastal plain of South Carolina totaling 368,086 ha (Figure 2.1). One study area one was located in Calhoun and Orangeburg counties, while the other was located in Colleton County. These study areas were chosen so that we were able to maximize shrike detections and because they represented a range of land cover conditions that suitable for testing our fine scale habitat selection hypotheses across the South Carolina Coastal Plain.

Data Collection Methods

In March-June 2016 and 2017 we used three techniques to locate Loggerhead Shrike nests within the South Carolina Coastal Plain. First, we conducted unlimited radius point counts using a 10-minute passive point count followed by a 6-minute call playback period. We selected point count locations from roadside crop and pasture polygons using a Generalized Random Tessellation Stratified (GRTS) sampling design in the *spsurvey* package (Kincaid and Olsen 2016) in Program R version 3.3.3 (R Core Team 2017) so that survey points represented a range of sizes of crop and pasture polygons in our study area as defined by the National Landcover Database (NLCD)(Homer et al. 2015)(see methods in Froehly et al. in review). When a Loggerhead Shrike was observed during a survey, we remained after the survey to make extended visual observations to determine if the individual may be nesting and to locate the nest. Second, we made extended observations where there had been eBird sightings (particularly spring sightings) from the last 10 years since Loggerhead Shrikes are known to reuse territories (Pruitt 2000). Lastly, we made extended observations at locations from expert sightings within the current field season, including sightings by state biologists and our own incidental sightings that were made while driving between point-count survey locations.

Once a Loggerhead Shrike was observed at a location, we obtained landowner permission to further search for and locate the nest. Nests were confirmed by visual observations of an individual building a nest, incubating eggs, or feeding chicks. We collected a GPS location of the nest, then to minimize disturbance to the birds, we

returned to the nest after it had failed or fledged to collect data on nest tree and territory core habitat characteristics. Other Loggerhead Shrike studies have analyzed territory characteristics anywhere from 2.5 m to 100 m from the nest (Chabot et al. 2001, St-Louis et al. 2009, Galwik and Bildstein 1990). We defined the territory core as a 40 m radius circle around the nest tree, which is equal to the smallest reported Loggerhead Shrike territory size (Yosef and Grubb 1994). Within the territory core we counted the number of shrubs (woody stems <2 m in height), the number of trees (woody stems >2 m in height), and the number of artificial posts (Table 2.1). We measured ground cover vegetation structure in two transects radiating out from the nest tree at random directions using a modified “Weins” pole method to quantify vegetation structure (Michaels and Cully 1998, Rotenberry and Wiens 1980). Specifically, we placed a 6 mm diameter rod vertically at 10, 20, 30, 40 meters and recorded the number of times a piece of vegetation hit the rod (separated by type: grass, forb, standing dead), height of the tallest live vegetation, and litter presence and depth. We used these ground cover data to calculate the probability of each grass, forb, standing dead, and litter occurring at the territory core as well as vertical and horizontal heterogeneity (Table 2.1). We calculated vertical heterogeneity by finding the coefficient of variation of all the maximum live vegetation heights. Likewise, we calculated horizontal heterogeneity by finding the coefficient of variation of all the number of vegetation pole hits. Using a laser rangefinder, we also measured distance from the nest tree to the nearest road, the nearest artificial perch, the nearest tree, the nearest bush, the nearest powerline, the nearest building, and the nearest crop field (Table 2.1). These distances were not confined to the 40 m radius territory

core. We also collected data on characteristics of the nest tree itself. We recorded tree species, nest height, the distance from the nest to the trunk of the tree, height of the tree, height of the lowest branch, diameter at breast height in cm (DBH), and calculated the percent canopy openings from spherical convex densiometer readings at each cardinal direction taken with the observer's back against the trunk of the tree (Table 2.1).

To compare used nest sites to available nest sites, we also collected the same territory core and nest tree data on two nearby trees that were available for nesting. We chose nearby available trees by following a random compass bearing from the nest tree. We used the first woody structure (tree or shrub) encountered outside of 40 m as the unused available tree to ensure that we were sampling at least partially different territory core areas than the used territory core. We collected all nest tree and territory core data near the end of the breeding season and within a month's time as to minimize the potential confounding effects of vegetation growth throughout the season.

Analytical Methods:

We used a discrete choice modeling framework, where paired choice sets of used and available resources were analyzed to provide the utility, or usefulness, of a location to an individual compared to the resources available to that individual (Cooper and Millsaugh 1999). We developed and evaluated support for 12 *a priori* models representing our hypotheses on territory core selection factors (Table A2.1). These territory core models were subset into three groups of factors we hypothesized to influence ground cover type and structure, tree and shrub structure, and proximity to manmade structures. We hypothesized that ground cover type and structure influenced

prey diversity and density, and ease of foraging by Loggerhead Shrikes in grassland systems (Rotenberry and Wiens 1980). We predicted that the occurrence of grass, bare ground, forbs and standing dead vegetation would increase selection while litter and litter depth would decrease selection by Loggerhead Shrikes (Gawlik and Bildstein 1990, Michaels and Cully 1998, Rotenberry and Weins 1980, DeGeus 1990, Chabot et al. 2001). The influence of ground cover structure on Loggerhead Shrike habitat use has differed between studies, as studies occurring mainly in pasture report selection of short, uniform grass (Gawlik and Bildstein 1990, Chabot et al. in prep), but studies occurring in more natural prairie landscapes report selection of high structural diversity (Michaels and Cully 1998, St-Louis et al. 2010, Prescott and Collister 1993, Rotenberry and Wiens 1980). Since there is little natural prairie habitat in South Carolina, we predicted that selection would occur for short, uniform ground vegetation structure.

We hypothesized that tree and shrub structure influences core territory selection through the balance of predator evasion and perch density factors. In Ontario, isolated trees were more often selected as nest trees than non-isolated trees (Chabot et al. in prep), and areas with a higher density of trees, like along fencerows, have led to higher nest predation rates in several Loggerhead Shrike populations (Gawlik and Bildstein 1990, Yosef 1994, Walk et al. 2006). Thus, we predicted that low tree and shrub density and greater distances to the nearest tree and shrub would increase selection.

We hypothesized that human modified habitat factors including perch availability and human disturbance could influence territory core selection. Shrikes are sit and wait predators and are known to benefit by a high density of perches (Yosef and Grubb 1994),

therefore, we predicted that low distance to powerline and nearest post, as well as post density would increase selection as Loggerhead. Shrikes have also been observed nesting in fencerows along roads (Stewart 1975, Smith and Kruse 1992) so we predicted that Loggerhead Shrikes would select for areas near roads due to the foraging opportunity that fencerows and mowed corridors commonly found along roadsides provide. Past research suggests that the influence row crop agriculture on Loggerhead Shrike habitat selection may differ between populations, as Loggerhead Shrikes have been found to both use (Gawlik and Bildstein 1990) and avoid (DeGeus 1990) cropland. Since croplands do not offer any woody vegetation for nesting, we predicted that Loggerhead Shrikes would select for areas to nest away from cropland. Finally, we developed a global model and 6 sub-global *a-priori* models to evaluate how multiple hypothesized factors influenced nest site selection at the territory core scale (Table A2.1).

We developed 5 *a priori* models representing our hypotheses that nest tree selection would be influenced by predation risk (Martin 1993), environmental exposure (Luukkonen 1987, Gawlik and Bildstein 1990), and structural preference (Chabot et al 2001) (Table A2.2). Specifically, we predicted that selection would occur for denser, larger trees with higher bottom branches because they offer more protection from predation and weather, and offer sturdy branches for nest building (Gawlik and Bildstein 1990, Chabot et al. in prep).

We tested for correlations between covariates and did not include correlated covariates ($r > 0.65$) in the same model. In instances where correlated covariates occurred in the same model, we ran separate occupancy models with each singular covariate, and

retained the covariate that produced the lower AIC_c score. We fit models in Program R using discrete choice modeling with the *mlogit* package (Croissant 2013). We extracted the Log Likelihood from each model to calculate Akaike Information Criterion for small sample size (AIC_c) values and model weights (Burnham and Anderson 2002). We evaluated nest tree and territory core models separately and considered models within 2 Δ AIC_c units of the highest ranked model to influence selection, and further investigated effects of covariates within these models. We validated each scales' top model(s) using k-fold cross validation (Boyce et al. 2002). For each of 5 validation replications we randomly separated data so that 75% of choice sets (the nest and the two paired available points) made up the training dataset, and the remaining 25% of the choice sets made up the testing dataset. We ran the top models with the training data and used the resulting fitted models to calculate the relative probability of selection within each choice set. In each choice set, the model predicted correctly if the relative probability of the used site was higher than the relative probabilities of the available sites. We determined final model accuracy as the percentage of correctly predicted choice sets out of the 5 testing datasets.

RESULTS

We found 15 nests between 4 April and 26 May 2016 and 30 nests between 17 March and 31 May 2017, and collected habitat measurements on these nests and their paired points between 5 June and 18 June 2016 and between 21 May and 5 June in 2017. Nests were mostly located within the primary study area boundaries, though 2 nests were located just southeast of the northern study area (Figure 2.1). All nests were located on

private property with the exception of 2 nests that occurred in a town park and at a county recycling facility. We found 10 nests in loblolly pine (*Pinus taeda*), 9 nests in live oak (*Quercus Virginiana*), 4 nests in water oak (*Quercus nigra*), 3 nests in laurel oak (*Quercus laurifolia*), 2 nests in each of longleaf pine (*Pinus palustris*), black cherry (*Prunus serotina*), and sweetgum (*Liquidamber styraciflua*), and a nest in each of 9 additional tree, shrub or vine species. Nests were located at an average height of 6.9 ± 4.9 m and 3.8 ± 2.8 m out from the main trunk of the tree or bush.

Our modeling results indicate that Loggerhead Shrike habitat selection at the territory core scale was best explained by the 2 top models (Table 2.2). The highest ranked model included covariates of shrub and tree density, vegetation density heterogeneity, and vegetation height heterogeneity and held 40% of the model weight (Table 2.2). Based on this top model, vegetation height heterogeneity, and vegetation density heterogeneity most influenced probability of selection (Table 2.3). Vegetation density heterogeneity had a negative effect on relative selection probability. As variation increased from 0.0 to 2.0, selection probability decreased from 16% to 0.0% (Figure 2.2A). In contrast, vegetation height heterogeneity had a positive effect, where predicted selection probability increased from 0.0 to 14% as variation increased from 1 to 3 (Figure 2.2B). Cross validation resulted in a 43% chance that the model would correctly predict the used territory. The second ranked model included covariates of grass presence, post density, distance to powerline, shrub and tree density, vegetation density heterogeneity, vegetation height heterogeneity, and distance to crop and held 39% of the model weight (Table 2.2). In this model, effects of vegetation density and vegetation height

heterogeneity were similar to the first model, though this model was more complex, and also indicated a negative effect of both distance to powerline, and shrub density though 95% confidence intervals for these variables did overlap zero (Table 2.3). Relative probability of selection increased as distance to powerline decreased, as there was a only a 1% relative selection probability for a nest being 180m from a powerline, but a 5% probability at 70m, and a maximum 18% probability at zero meters from a powerline (Figure 2.2C). Additionally, relative probability of selection decreased from 18% to 5% to 0% as shrub density increased from zero to 24 to 72 shrubs in the territory core (Figure 2.2D). Cross validation resulted in only a 52% chance that this second model would correctly predict the used territory.

Our modeling results indicate that Loggerhead Shrike habitat selection at the tree scale was also explained by 2 top models (Table 2.2). The top nest tree model included only DBH as a covariate and held 62% of the model weight, while the second ranked model included DBH and canopy openings and held 31% of the model weight, though canopy openings had a standard error larger than the estimate and therefore was likely not influencing selection (Table 2.3). We found that DBH had a relatively slight, positive influence on selection probability, where trees with a 100 cm DBH had a relative selection probability of 3% and our maximum measured DBH of 165cm had a relative selection probability of 10% (Figure 2.3). Cross validation resulted in a 40% chance that the 1st ranked model would correctly predict the used tree, and a 32% chance that the second ranked model would predict correctly.

DISCUSSION

Our findings suggest that, like other avian species, nest site selection by Loggerhead Shrike in South Carolina is driven by factors that enhance foraging ease and success and by factors that reduce predation risk. Selection of factors that reduce predation risk are congruent with nest selection by other grassland and passerine birds (Pearson and Knapp 2016, Eggers et al. 2006, Hoover 2003). Likewise, characteristics affecting foraging success are important in many grassland and farmland birds as fragmentation and pesticide use in agricultural areas diminishes insect and prey populations (Stanton et al. 2016, Inselman et al. 2015). Indeed, Shrikes in this region generally occupy areas with high pasture or grassland concentration within 1km (Froehly et al. in review). However, despite this sensitivity, Loggerhead Shrikes appear to be taking advantage of nesting habitats that are characteristic of both natural and human modified landscapes.

Similar to previous studies of Loggerhead Shrike nest selection in other portions of their range, ground vegetation structure was an important factor in territory core selection. Studies in South Carolina and Ontario have noted that Loggerhead Shrikes nesting in pasture preferred short, uniform vegetation (Gawlik and Bildstein 1990, Chabot et al. in prep), but Loggerhead Shrikes nesting in native prairie prefer higher diversity in vegetation structure (Michaels and Cully 1998, St-Louis et al. 2010, Prescott and Collister 1993, Rotenberry and Wiens 1980). Our prediction that Loggerhead Shrikes would select for nest sites in short, uniform ground vegetation structure was only partly

supported, where individuals preferred to nest where territory cores contained low variation of ground vegetation density, but higher variation in vegetation heights. This result is likely a function of the habitat conditions specific to our study area. First, raw data from all used and available territories indicated that all ground cover was short (average maximum heights= 9.03 ± 8.77 cm) and sparse (average hits= 1.48 ± 0.99). Therefore, it is likely Loggerhead Shrikes preferred consistently sparse ground vegetation that was also variable in height while still being short. Second, selection for nesting in areas with higher vegetation height diversity was likely a function of Loggerhead Shrikes selecting pasture-lands for nesting rather than manicured lawns. Lastly, higher height diversity may be preferred by Loggerhead Shrikes because it likely has greater prey availability that could provide more prey items for foraging (St-Louis et al. 2010, Chabot et al. 2001). Additionally, Loggerhead Shrikes showed some preference for territory cores with fewer shrubs, likely to maximize the amount of grassy foraging area close to the nest and to minimize predation risk. To provide higher vegetation height diversity and improve foraging conditions in nesting territories for Loggerhead Shrikes, we suggest that residential landowners could wait longer to mow their lawns, rotate mowing different sections of lawn, or establish a “meadow” section that is not mown.

Loggerhead Shrikes also showed some selective preference for territory cores closer to powerlines, which is likely indicative of their propensity to use powerlines as unobstructed perches. In South Carolina, Loggerhead Shrikes were most often observed when perched on utility lines rather than on posts or natural perches (Gawlik and Bildsein 1993). Similarly, Loggerhead Shrikes in Texas preferentially perched on partially dead

trees, dead trees, or bare perches, all which like powerlines, offer unobstructed views, over fully foliated trees (Becker et al. 2009). Therefore, our findings suggest that nest trees that are closer to powerlines are preferred because parents are likely able to utilize an ideal perch with an unobstructed view for foraging, but also be close to the nest.

Loggerhead Shrikes occupied a variety of tree species in our study, but overall, trees with larger DBH measurements were selected for. Trees with larger DBH not only likely provide more, higher perches for detecting prey and potential nest predators (DeGeus 1990, Bekoff et al. 1987), but may be preferred by Loggerhead Shrikes because they could offer more defenses against snake predation since it is difficult for snakes to climb large trees (Rudolph et al. 1990). Further, given that Loggerhead Shrikes show high site fidelity and have been known to reoccupy previously used nest sites (Pruitt 2000, Chabot et al. in prep), relatively older, large diameter trees are likely critically important for nesting. In our study, an extreme case of nest site fidelity was observed when one pair decided to nest in a brush pile that contained their previous year's nest, even though there were other trees available in their territory. While a large DBH is not preferred in this example, it does demonstrate to what lengths a shrike will go to maintain a preferred nesting site. Overall, we suggest that landowners retain large trees in grassy habitat. Further, given evidence of high nest site fidelity, landowners should examine trees they are considering cutting down and conserve those that hold nests.

Our results reflect what Loggerhead Shrikes chose for nesting locations, but may not reflect the fitness value of those locations. Selection of nests sites is thought to be adaptive so that preferred sites offer high reproductive success (Martin 1998). However,

sometimes seemingly ideal locations can act as ecological traps and decrease fitness (Dwernychuk and Boag 1972). For example, at the Savannah River Site, Indigo Buntings (*Passerina cyanea*) selected winged habitat patches that had 50% more edge than simple rectangular patches, but produced more fledglings from nests in the rectangular patches with less edge, possibly due to increased predation pressure in patches with more edge (Weldon and Haddad 2005). Indeed several researchers have observed a high rate of Loggerhead Shrike car strikes (Pruitt 2000), which could indicate an ecological trap associated with nests near powerlines. Therefore, it is essential for future work to determine how nesting success relates to selected nest sites. Additionally, we measured habitat variables after nests fledged or failed to reduce disturbance to the birds, though selection of a nest site occurs earlier, at nest initiation. This temporal difference between selection and measuring habitat variables could potentially have led to a misrepresentation of some of our variables like grass height (Gibson et al. 2016). Thus, either measuring habitat at a more standard “nest hatch” date or examining how variables change through the breeding season will be important in future Loggerhead Shrike research to ensure that data is accurately portrayed.

Overall, while Loggerhead Shrike distribution and occupancy may be more strongly influenced by larger scale habitat requirements like the amount of pasture and grassland in an area (Froehly et al. in review), suitable nesting sites are still necessary for population recruitment. Ideally, both large and small scales should be managed so that all habitat requirements are met, but in areas with highly fragmented ownership, like in South Carolina, small-scale actions may be the only management option. Fine scale

nesting characteristics are not only more easily managed, but can also have the ability to influence larger scale factors through the cumulative effects of many landowners carrying out the same management actions (Jennings et al. 1999). Many landowners taking action to preserve specific habitat characteristics at small scales can help to increase natural habitat abundance and connectivity, and thereby decrease the severity of fragmentation and habitat loss at even the landscape scale (Marzluff and Ewing 2001). In order to promote nesting and to increase available habitat for Loggerhead Shrikes in the Southeast coastal plain, we recommend that private landowners maximize the amount of grassy habitat on their property which will provide essential grassland habitat, retain large trees in open habitat to provide nesting substrate, and increase diversity in ground vegetation height to provide more natural and high quality grassland cover.

FIGURES

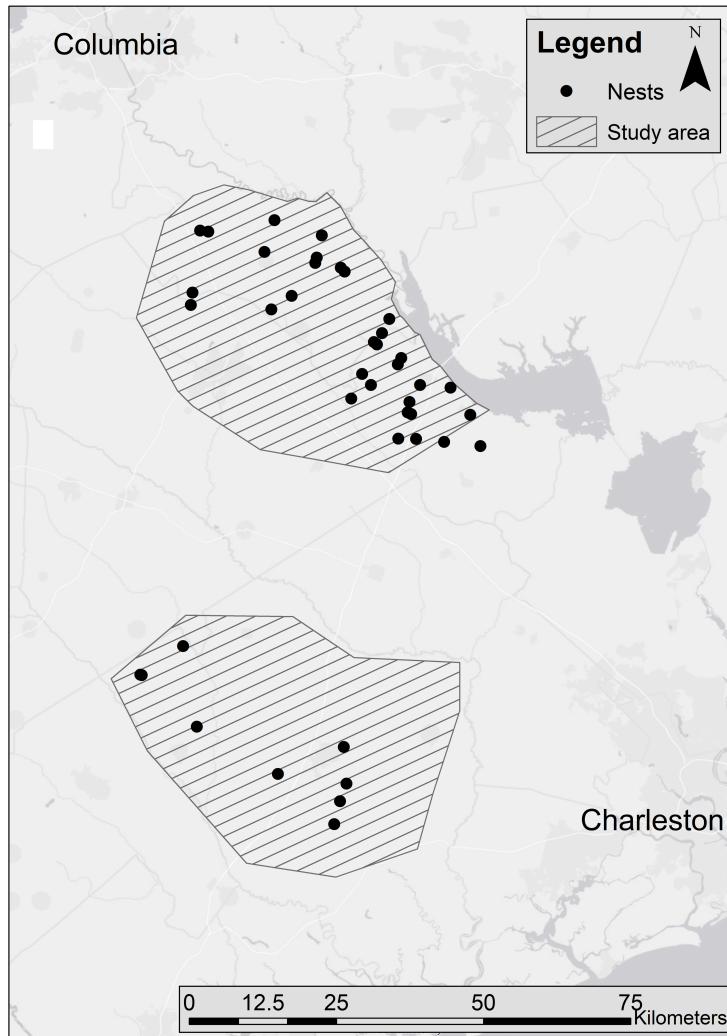


Figure 2.1: Location of study areas for point count surveys and nest searching in South Carolina, and location of nests from the 2016 and 2017 breeding seasons used in analysis.

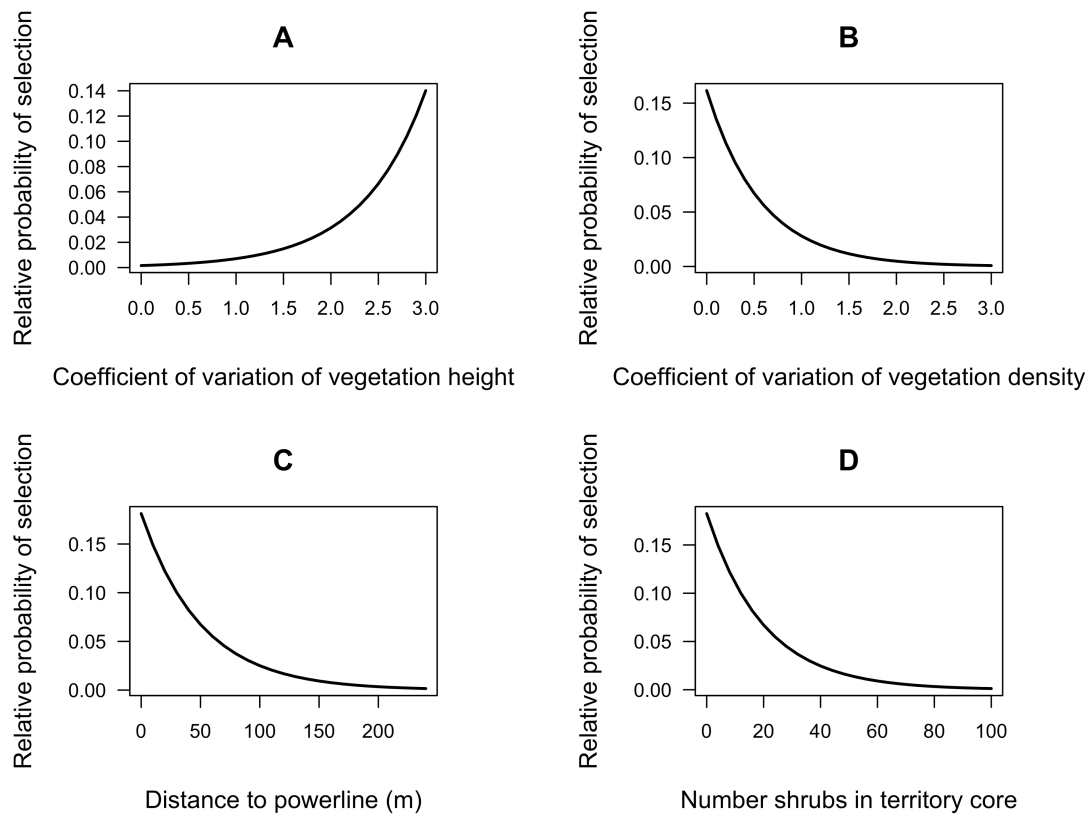


Figure 2.2: Influence of ground vegetation height variability (A), territory core ground vegetation density variability (B), nest distance to the nearest powerline (C), and shrub density (D), on the relative probability of selection at the territory core scale by Loggerhead Shrikes in South Carolina during 2016 and 2017.

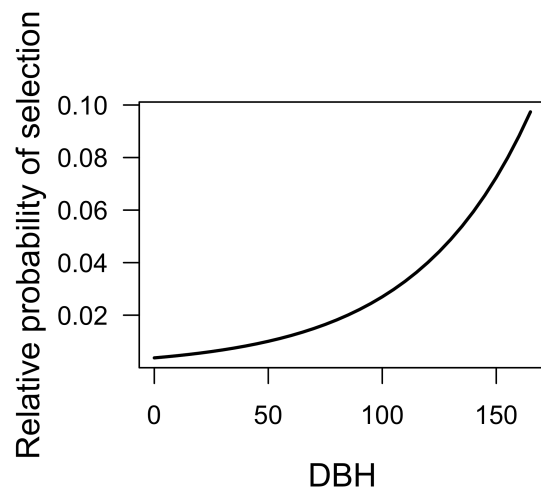


Figure 2.3. Influence of nest tree diameter at breast height (DBH), on the relative probability of selection at the tree scale by Loggerhead Shrikes in South Carolina during 2016 and 2017.

TABLES

Table 2.1: Loggerhead Shrike tree scale and territory core scale (40m radius) nest selection factors used in *a priori* models:

Tree Scale

Variable	Description
DBH	Diameter at breast height (cm)
l.branch	Distance from the ground to the lowest branch on the tree (m)
c.open	Average canopy opening percentage from densiometer readings at the trunk in each cardinal direction

Territory Core Scale

Variable	Description
H.Het	Maximum ground cover height heterogeneity. Coefficient of variation of maximum vegetation heights.
D.Het	Ground cover density heterogeneity. Coefficient of variation of vegetation total hits.
Grass	Probability of grass presence
Forb	Probability of forb presence
Litter	Probability of litter presence
Standing.dead	Probability of standing dead vegetation presence
Litter.depth	Average litter depth
dist.shrub	Distance to the nearest woody stem >2m in height (m)
dist.tree	Distance to the nearest woody stem <2 (m)
Shrubs	Number of woody stems <2m in height within 40m radius
Trees	Number of woody stems >2m in height within 40m radius
Posts	Number posts within 40m radius
dist.post	Distance to the nearest post (m)
dist.powerline	Distance to the nearest utility line (m)
dist.building	Distance to the nearest building (m)
dist.road	Distance to the nearest road (m)
dist.crop	Distance to nearest row crop (m)

Table 2.2: Discrete choice model ranking for Loggerhead Shrike resource selection at the tree and territory core scales in South Carolina during 2016 and 2017. Models listed are those that contributed to the 90% cumulative model weight. K is the number parameters in the model. ΔAIC_c is the change in Akaike Information Criterion value corrected for small sample sizes from the top model. W_i is the Akaike weight.

Model	K	ΔAIC_c	W_i	Log L.
<i>Territory Core Scale</i>				
1. $\beta(\text{Shrub}) + \beta(\text{Trees}) + \beta(\text{D.Het}) + \beta(\text{H.Het})$	4	0.00 ^a	0.40	-32.73
2. $\beta(\text{grass}) + \beta(\text{posts}) + \beta(\text{dist.poweline}) + \beta(\text{Shrub}) + \beta(\text{Trees}) + \beta(\text{D.Het}) + \beta(\text{H.Het}) + \beta(\text{dist.crop})$	8	0.03	0.39	-30.33
3. $\beta(\text{Shrub}) + \beta(\text{Trees}) + \beta(\text{grass})$	3	3.27	0.08	-34.93
<i>Tree Scale</i>				
1. DBH	1	0.00 ^b	0.62	-40.13
2. DBH+c.open	2	1.39	0.31	-39.79

^a Territory core scale lowest AIC_c value was 68.79

^b Tree scale lowest AIC_c value was 82.29

Table 2.3: Top model parameter estimates, standard error (SE) and 95% confidence intervals on Loggerhead Shrikes' relative selection of probability at the territory core and tree scales.

Covariate	Estimate	SE	95% CI
Territory Core Model 1			
Shrub	-0.692	0.46	-1.630, 0.246
Trees	-0.657	0.43	-1.524, 0.211
D.Het	0.892	0.49	-0.100, 1.884
H.Het	-1.085	0.54	-2.175, 0.004
Territory Core Model 2			
dist.crop	-2.514	2.16	-6.842, 1.813
grass	0.440	0.40	-0.376, 1.257
posts	-0.307	0.33	-0.984, 0.370
dist.poweline	-0.948	0.53	-2.009, 0.112
Shrub	-0.974	0.54	-2.055, 0.107
Trees	-0.193	0.50	-1.192, 0.806
D.Het	0.860	0.49	-0.131, 1.851
H.Het	-0.940	0.56	-2.073, 0.192
Tree Model 1			
DBH	0.62513	0.24	0.140, 1.110
Tree Model 2			
DBH	0.58891	0.25	0.083, 1.094
c.open	0.15732	0.22	-0.284, 0.598

APPENDICES

Appendix A

Chapter 1 Supplemental Materiel

Table A1.1: Detection *a priori* hypotheses from step 1

Hypothesis	Model Formula
1. Detection probability will not be affected by any of these variables.	$\psi(.)p(.)$
2. Time of day will increase detectability	$\psi(.)p(\text{time})$
3. Increasing ambient noise level will decrease detectability	$\psi(.)p(\text{noise})$
4. Detectability will maximize at peak breeding	$\psi(.)p(\text{date}^2)$
5. Increasing wind and temperature, and worsening sky conditions will decrease detectability	$\psi(.)p(\text{wind} + \text{temp} + \text{sky})$
6. Increasing wind, temperature, and ambient noise, and worsening sky conditions will decrease detectability	$\psi(.)p(\text{wind} + \text{temp} + \text{sky} + \text{noise})$
7. Increasing wind and temperature, and worsening sky conditions will decrease detectability. Detectability will also maximize at peak breeding	$\psi(.)p(\text{wind} + \text{temp} + \text{sky} + \text{date}^2)$
8. Increasing wind and temperature, and worsening sky conditions will decrease detectability. Time of day will increase detectability.	$\psi(.)p(\text{wind} + \text{temp} + \text{sky} + \text{time})$
8. Increasing wind and temperature, and worsening sky conditions will decrease detectability. Time of day will increase detectability. Detectability will also maximize at peak breeding	$\psi(.)p(\text{wind} + \text{temp} + \text{sky} + \text{noise} + \text{date}^2 + \text{time})$

Table A1.2: Occupancy *a priori* hypotheses

Hypothesis	Model formula
<i>300 m</i>	
1. Higher proportions of pasture at 300 m will increase occupancy probability	$\psi(\text{pasture } 300 \text{ m})p(\text{covariates from step 1})$
2. Higher NDVI values at 300 m will decrease occupancy probability	$\psi(\text{NDVI } 300 \text{ m})p(\text{covariates from step 1})$
3. Higher proportions of forest at 300 m will decrease occupancy probability	$\psi(\text{forest } 300 \text{ m})p(\text{covariates from step 1})$
4. Higher proportions of pasture at 300 m will increase occupancy probability and NDVI values at 300 m will decrease occupancy probability	$\psi(\text{pasture } 300 \text{ m} + \text{NDVI } 300 \text{ m})p(\text{covariates from step 1})$
<i>1 km</i>	
5. Higher proportions of pasture at 1 km will increase occupancy probability	$\psi(\text{pasture } 1 \text{ km})p(\text{covariates from step 1})$
6. Higher NDVI values at 1 km will decrease occupancy probability	$\psi(\text{NDVI } 1 \text{ km})p(\text{covariates from step 1})$
7. Higher proportions of crop at 1 km will decrease occupancy probability	$\psi(\text{crop } 1 \text{ km})p(\text{covariates from step 1})$
8. Higher proportions of forest at 1 km will decrease occupancy probability	$\psi(\text{pasture } 1 \text{ km})p(\text{covariates from step 1})$
8. Higher proportions of pasture at 1 km will increase occupancy probability and higher NDVI values 1 km will decrease occupancy probability	$\psi(\text{pasture } 1 \text{ km} + \text{NDVI } 1 \text{ km})p(\text{covariates from step 1})$
<i>5 km</i>	
9. Higher proportions of pasture at 5 km will increase occupancy probability	$\psi(\text{Pasture } 5 \text{ km})p(\text{covariates from step 1})$
10. Higher NDVI values at 5 km will decrease occupancy probability	$\psi(\text{NDVI } 5 \text{ km})p(\text{covariates from step 1})$
11. Higher proportions of pasture and pasture aggregation at 5 km will increase occupancy probability	$\psi(\text{pasture } 5 \text{ km} + \text{pasture aggregation } 5 \text{ km})p(\text{covariates from step 1})$
11. Higher pasture aggregation at 5 km will increase occupancy probability and higher NDVI values at 5 km will decrease occupancy probability	$\psi(\text{pasture aggregation } 5 \text{ km} + \text{NDVI } 5 \text{ km})p(\text{covariates from step 1})$

12. Higher proportions of pasture at 5 km will increase occupancy probability and higher NDVI values at 5 km will decrease occupancy probability	$\psi(\text{Pasture 5 km} + \text{NDVI 5 km})p(\text{covariates from step 1})$
13. Higher proportions of pasture and pasture aggregation at 5 km will increase occupancy probability and higher NDVI values at 5 km will decrease occupancy probability	$\psi(\text{Pasture 5 km} + \text{NDVI 5 km} + \text{open aggregation 5 km})p(\text{covariates from step 1})$
14. Higher proportion of crop at 5 km will decrease occupancy probability	$\psi(\text{crop 5 km})p(\text{covariates from step 1})$
14. Higher proportions of pasture and pasture aggregation at 5 km will increase occupancy probability and higher NDVI values at 5 km will decrease occupancy probability	$\psi(\text{pasture 5 km} + \text{NDVI 5 km} + \text{pasture aggregation 5 km})p(\text{covariates from step 1})$
<i>15 km</i>	
15. Higher proportion of forest at 15 km will decrease occupancy probability	$\psi(\text{forest 15 km})p(\text{covariates from step 1})$
16. Higher proportion of forest at 15 km will decrease occupancy probability and higher pasture aggregation at 15 km will increase occupancy probability	$\psi(\text{forest 15 km} + \text{pasture aggregation 15 km})p(\text{covariates from step 1})$
<i>multiple scales</i>	
17. Higher proportions of pasture at 300 m will increase occupancy probability and higher NDVI values at 1 km and high proportion of forest at 15 km will decrease occupancy probability	$\psi(\text{pasture 300 m} + \text{NDVI 1 km} + \text{Forest 15 km})p(\text{covariates from step 1})$
18. Higher proportions of pasture at 300 m will increase occupancy probability and higher proportions of forest at 1 km will decrease occupancy probability	$\psi(\text{pasture 300 m} + \text{forest 1 km})p(\text{covariates from step 1})$
19. Higher proportions of pasture at 1 km will increase occupancy probability and higher NDVI values at 300 m will decrease occupancy probability	$\psi(\text{NDVI 300 m} + \text{pasture 1 km} + \text{forest 15 km})p(\text{covariates from step 1})$
20. Higher proportions of pasture at 5 km will increase occupancy probability and higher proportions of forest at 15 km will decrease occupancy probability	$\psi(\text{pasture 5 km} + \text{forest 15 km})p(\text{covariates from step 1})$
21. Higher proportions of pasture at 1 km will increase occupancy probability and higher proportions of forest at 5 km will decrease occupancy probability	$\psi(\text{pasture 1 km} + \text{forest 5 km})p(\text{covariates from step 1})$
22. Higher proportions of pasture at 1 km and pasture aggregation at 5 km will increase occupancy probability and higher NDVI values at 300 m will decrease occupancy probability	$\psi(\text{NDVI 300 m} + \text{pasture 1 km} + \text{pasture aggregation 5 km} + \text{forest 15 km})p(\text{covariates from step 1})$
23. Higher proportions of pasture at 1 km will increase occupancy probability and higher proportions of forest at 15 km will decrease occupancy probability	$\psi(\text{Pasture 1 km} + \text{forest 15 km})p(\text{covariates from step 1})$

Appendix B

Chapter 2 Supplemental Material

Table A2.1: Territory core scale *a priori* hypotheses

Hypothesis	Model Formula
<i>Ground Cover</i>	
1. Negative effect of vegetation density and height heterogeneity, positive effect of grass, forbs, negative effect of litter and litter depth, and positive effect of standing	$\beta(\text{D.Het}) + \beta(\text{H.Het}) + \beta(\text{grass}) + \beta(\text{forb}) + \beta(\text{litter}) + \beta(\text{litter.depth}) + \beta(\text{standing.dead})$
2. Positive effect of grass, forbs, negative effect of litter and litter depth, and positive effect of standing dead.	$\beta(\text{grass}) + \beta(\text{forb}) + \beta(\text{litter}) + \beta(\text{litter.depth}) + \beta(\text{standing.dead})$
3. Negative effect of vegetation density and height heterogeneity	$\beta(\text{D.Het}) + \beta(\text{H.Het})$
4. Positive effect of grass.	$\beta(\text{grass})$
<i>Tree and shrub</i>	
5. Negative effect of tree and shrub density, and distance to the nearest tree and shrub	$\beta(\text{dist.tree}) + \beta(\text{dist.shrub}) + \beta(\text{Trees}) + \beta(\text{Shrub})$
6. Negative effect of distance to the nearest tree and shrub	$\beta(\text{dist.tree}) + \beta(\text{dist.shrub})$
7. Negative effect of tree and shrub density	$\beta(\text{Trees}) + \beta(\text{Shrub})$
<i>Proximity to manmade</i>	
8. Negative effect of distance to powerlines and nearest post, positive effect of distance to building, road, and crop, and post density	$\beta(\text{dist.powerline}) + \beta(\text{dist.building}) + \beta(\text{dist.road}) + \beta(\text{dist.perch}) + \beta(\text{dist.crop}) + \beta(\text{posts})$
9. Positive effect of post density, negative effect of distance to powerline.	$\beta(\text{posts}) + \beta(\text{dist.powerline})$
10. Positive effect of post density and distance to buildings	$\beta(\text{posts}) + \beta(\text{dist.building})$
11. Positive effect of post density	$\beta(\text{posts})$
12. Positive effect of distance to crop	$\beta(\text{d.crop})$
<i>Combined</i>	
13. Positive effect of grass, and post density, negative effect of distance to powerlines, tree and shrub density, vegetation density and height heterogeneity, and positive effect of	$\beta(\text{grass}) + \beta(\text{posts}) + \beta(\text{dist.powerline}) + \beta(\text{Shrub}) + \beta(\text{Trees}) + \beta(\text{D.Het}) + \beta(\text{H.Het}) + \beta(\text{dist.crop})$

14. Positive effect of grass, and post density, negative effect of tree and shrub density	$\beta(\text{grass}) + \beta(\text{posts}) + \beta(\text{Trees}) + \beta(\text{Shrub})$
15. Negative effect of tree and shrub density, and vegetation density and height heterogeneity	$\beta(\text{Shrub}) + \beta(\text{Trees}) + \beta(\text{D.Het}) + \beta(\text{H.Het})$
16. Negative effect of tree and shrub density, positive effect of grass	$\beta(\text{Shrub}) + \beta(\text{Trees}) + \beta(\text{grass})$
17. Positive effect of grass and post density	$\beta(\text{grass}) + \beta(\text{posts})$
18. Positive effect of grass, forbs, negative effect of litter and litter depth, and positive effect of standing dead, positive effect of post density, negative effect of distance to the nearest tree and shrub, tree and shrub density, distance to powerlines and nearest post, positive effect of distance to building, road, and crop, negative effect of vegetation density and height heterogeneity	$\beta(\text{grass}) + \beta(\text{forb}) + \beta(\text{litter}) + \beta(\text{litter.depth})$ $+ \beta(\text{standing.dead}) + \beta(\text{posts})$ $+ \beta(\text{dist.powerline}) + \beta(\text{Shrub}) + \beta(\text{Trees})$ $+ \beta(\text{dist.tree}) + \beta(\text{dist.shrub})$ $+ \beta(\text{dist.building}) + \beta(\text{dist.road})$ $+ \beta(\text{dist.perch}) + \beta(\text{D.Het})$ $+ \beta(\text{H.Het}) + \beta(\text{dist.crop})$

Table A2.2: Nest tree scale *a priori* hypotheses

Hypothesis	Model Structure
1. Positive influence of DBH	$\beta_1(\text{DBH})$
2. Positive influence of height of the lowest branch	$\beta_1(\text{l.branch})$
3. Negative influence of canopy openings	$\beta_1(\text{c.open})$
4. Positive influence of height of the lowest branch and negative influence of canopy openings	$\beta_1(\text{l.branch}) + \beta_2(\text{open})$
5. Positive effect of DBH and negative influence of canopy openings	$\beta_1(\text{DBH}) + \beta_2(\text{c.open})$

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