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Habitat Selection Across the Reproductive Cycles of Grassland Songbirds in the Northern Great Plains

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HABITAT SELECTION ACROSS THE REPRODUCTIVE CYCLE OF GRASSLAND SONGBIRDS IN THE NORTHERN GREAT PLAINS

By

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An Abstract of the Thesis Presented
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Grassland birds are declining precipitously in North America. Many grassland birds use the Northern Great Plains during their reproductive cycle, where much of their breeding habitat has been converted for agricultural use. Grassland landscapes that remain are sustained by management routines. Understanding habitat conditions that support multiple life stages throughout the entire reproductive cycle is essential for developing effective management strategies to lessen and reverse population declines in grassland bird populations. However, there is limited knowledge for habitat selection in grassland specialists, especially during the post-fledging stage. To address this information gap and to better inform managers with information than can support grassland birds during their breeding season, we measured habitat selection in both adults and juveniles of grassland bird specialized to the Northern Great Plains. We characterized nest site selection in four grassland specialists: Baird's Sparrow (*Centronyx bairdii*), grasshopper Sparrow (*Ammodramus savannarum*), chestnut-collared longspur (*Calcarius ornatus*), and Sprague's pipit (*Anthus spragueii*). We also examined habitat use of juveniles in Baird's and grasshopper sparrows throughout the post-fledging phase using radio-tracking data. We analyzed habitat selection for adults and juveniles with parameters measured from the ground and from spectral data collected via Unmanned Aircraft System (UAS) at juvenile used points, random points, and adult nest sites. We found that adults of all four grassland specialists placed nests in intermediate ranges of vegetation height and density compared with habitat available on the landscape, demonstrating a community-level trend. Nest sites were also characterized by other habitat parameters though varied by species and spatial scales, indicating species-specific habitat selection as well. We found that juvenile birds used habitat that differed from both habitat available on the landscape and from adult nest sites. Particularly, high forb cover was influential for juveniles of both sparrow species and that with age, juveniles of both species moved toward lower elevations and that juvenile Baird's sparrows moved towards densely vegetated areas (e.g. wetland areas). Additionally, we found that high-resolution Green Normalized Vegetation Index (GNDVI) was an informative habitat parameter for fine-scale habitat selection in grassland specialists and shows promise for UAS as an innovative tool for habitat assessment. Based on our findings, we recommend managers consider both community-level habitat selection to provide habitat that supports a suite of grassland birds and species-specific habitat selection to target particularly threatened species or those experiencing local declines. Further, we recommend consideration of all life stages for grassland birds that breed in the Northern Great Plains when strategizing a habitat management plan, particularly that wetland areas be regarded for the management of Baird's sparrows.

DEDICATION

This is for my grandparents Nicola and Giovanna Comes.

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All animal care, nest monitoring, and capture activities were approved by Montana, Fish, Wildlife & Parks (MTFWP) Institutional Animal Care and Use Committee (IACUC) protocol #FWP02-2015. We were issued state collection permits by North Dakota Game and Fish, and MTFWP, as well as a federal banding permit by the USGS Breeding Bird Laboratory (BBL; #22415).

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1.1. Abstract

Grassland birds are declining dramatically in North America. Many of these birds breed in the Northern Great Plains, where their habitat is either disappearing or being fragmented by agricultural use and cropland conversion. To better support grassland birds during their breeding season in the Northern Great Plains, we characterized nest site selection in four grassland specialists: Baird's sparrow (*Centronyx bairdii*), grasshopper sparrow (*Ammodramus savannarum*), chestnut-collared longspur (*Calcarius ornatus*), and Sprague's pipit (*Anthus spragueii*). We recorded ground habitat parameters and made novel use of a small unmanned aircraft system (UAS) to obtain fine-scale spectral data at nest sites (habitat use) and randomly selected sites (habitat availability). We found that all species selected for intermediate ranges of vegetation height and density compared to available habitat, indicating a community-level trend. Habitat selection was also explained by bare ground, forb, dead grass, and litter but direction and strength of those relationships varied by species. Additionally, we found that high-resolution Green Normalized Vegetation Index (GNDVI) was an informative habitat parameter for nest site selection in the grassland specialist community and in three of four grassland species observed, showing promise for a novel tool in habitat assessment. Based on our findings, we suggest managers maintain vegetation heights at a fine scale ($0.5m^2$) and vegetation densities at a slightly large scale ($78.54m^2$) within the optimal values we measured for each species to provide habitat that supports a community of grassland birds. We

recommend these optimal ranges be managed for jointly with regulating coverage of forbs, litter, and bare ground to address the species-specific habitat needs comprising this community, or to target a particular species in the Northern Great Plains.

1.2. Introduction

Grassland bird populations are imperiled, showing more consistent and dramatic declines than any other bird guild in North America (Knopf, 1994; Sauer et al., 2017). These losses are likely linked to habitat loss; grasslands in the Northern Great Plains of southern Canada and the north-central US have diminished by 53% since European colonization of North America (Zhang et al., 2011) and remaining habitat is heavily threatened by cropland conversion (Coppedge et al., 2001; Gage et al., 2016; Rashford et al., 2011), mismanaged grazing (Richardson et al., 2014), and invasive vegetation (Jones et al., 2010). Grassland specialists are experiencing particularly steep declines (Rosenberg et al., 2019), in part due to reduced habitat on wintering grounds as a result of agricultural conversion (Pool et al., 2014) and homogenization of vegetation on breeding grounds in the Northern Great Plains due to uniform grazing regimes and the introduction and spread of non-native grasses (Derner et al., 2009). Because these declines are closely associated with habitat loss, identification of habitat conditions influencing reproduction and survival are critical for the management and long-term viability of grassland bird populations.

The mixed-grass prairie region of the Northern Great Plains comprises the breeding grounds for many of these declining species. Management techniques in this region that have shown promise for increasing nesting habitat in grassland land birds including patch graze burning (Hovick et al., 2015; McNew et al., 2015), altered haying frequency (Davis et al., 2017; Pintaric et al., 2019), and preservation of continuous tracts of grasslands (Herse et al., 2017; Lockhart and Koper, 2018). Livestock, in particular, may be used by landowners to shape grassland ecosystems by modifying vegetation structure that is suitable for grassland bird habitat while simultaneously providing desired provisioning of food for livestock (Derner et al., 2009). A thorough understanding of the habitat needs of grassland birds is critical to provide landowners with recommendations that allow them to balance bird conservation with other desired outcomes.

Nest site selection by grassland birds can be driven by various factors, many of which are associated with habitat that can be influenced by management action. These factors include predation (Keyel et al., 2013), interspecific and intraspecific competition for territories (Ahlering et al., 2006), and microclimate thermoregulation of ground nests (Hartman and Oring, 2003; Nelson and Martin, 1999; With and Webb, 1993; Zuckerberg et al., 2018). These factors are often correlated with habitat structure and composition; for example, grassland birds have been shown to place nests in dense vegetation that reduces visual, auditory, and olfactory cues to predators (Fogarty et al., 2017; Martin, 1993). The amount of bare ground, live grass, dead grass, litter (dead, detached vegetation), forbs, shrubs, and exotic vegetation have all explained adult occupancy (Ahlering and Merkord, 2016; Green et al., 2019) and survival (Perlut et al., 2008; Perlut and Strong, 2011) in grassland birds of the Northern Great Plains. However, vegetation is often not a strong driver of nest success in grassland specialists (Bernath-Plaisted et al., *in review*; Bernath-Plaisted and Koper, 2016; Davis, 2005; Lusk and Koper, 2013) thus habitat structure and composition may be more important during a different life phase such as the nest site selection process. Though, nest site selection studies are limited, and, the ones available tend to focus on only one species rather than a full assessment for the requirements of several birds specialized to the Northern Great Plains. This may in part be due to the time and costs associated with sufficiently examining habitat selection which includes measuring habitat used by birds and habitat available across the landscape.

Habitat selection studies in much of the Northern Great Plains has been hampered by the size and accessibility of the area and the large scale at which some species use the landscape. Unmanned aircraft systems (UAS) are an emergent technology for these circumstances (Chabot and Bird, 2015; Hodgson et al., 2016; Scobie and Hugenholtz, 2016). Data collected via UAS is especially promising for collecting high-resolution (up to 2.5cm pixels) spectral data compared to other methods (e.g. satellite platforms, Laliberte et al., 2011), which is helpful in understanding fine-scale habitat use such as nest selection in grassland birds. For small grassland-nesting songbirds, important predictors of nest placement often occur at a scale that is too fine to be detected by many other remote-sensing platforms. Spectral vegetation indices (SVIs) can also produce metrics from remotely sensed data that measure a variety of conditions potentially important to nesting birds. For example, certain SVIs can successfully quantify biomass and delineate areas that are vegetated versus unvegetated (Von Bueren et al., 2015), both observed to influence nest site selection of grassland birds (Davis, 2005; Fisher and Davis, 2010).

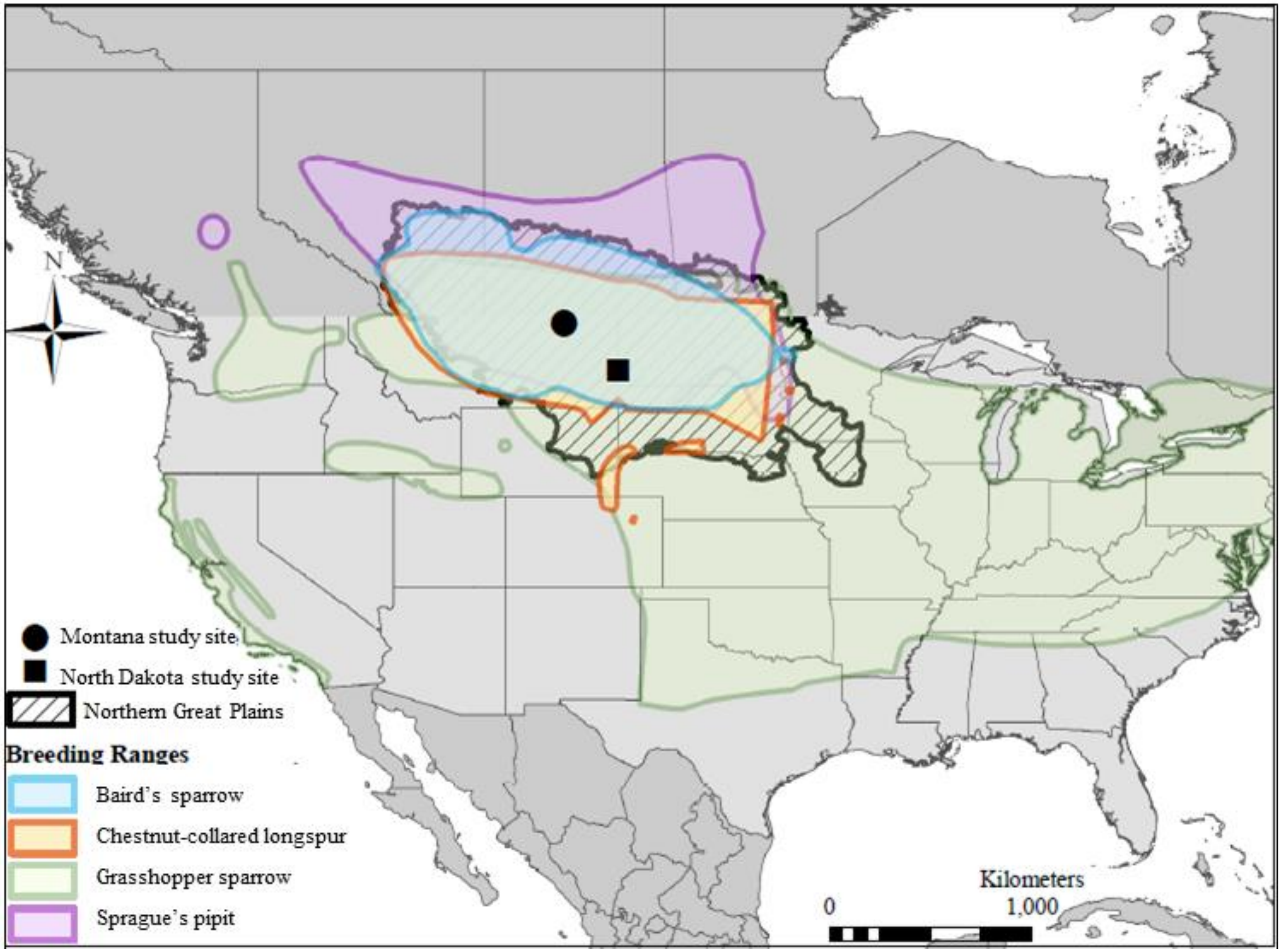

Figure 1.1. Study sites and breeding ranges for four grassland birds in the Northern Great Plains, USA.

We characterized nest sites on native mixed-grass prairies to identify microhabitat features important in nest site selection in four species of grassland birds that are highly specialized to grasslands of the Northern Great Plains (Correll et al., 2019) and overlap in breeding ranges (Fig. 1.1): Baird's sparrow (*Centronyx bairdii*), grasshopper sparrow (*Ammodramus savannarum*), chestnut-collared longspur (*Calcarius ornatus*), and Sprague's pipit (*Anthus spragueii*). We collected both ground and UAS-derived habitat data associated with nests and randomly-selected, non-nest points, to 1) identify habitat characteristics at two spatial scales important for nest site selection for each species and for the specialist grassland bird community as a whole and 2) to compare the predictive power of ground and UAS-derived data in nesting habitat selection studies in this ecosystem. We predicted that 1) habitat requirements for nest sites vary across spatial scales and species and 2) high-resolution spectral vegetation indices (SVIs) collected via UAS are informative for measuring fine-scale habitat selection in grassland birds. Our findings provide rangeland managers with an informed description of suitable habitat that can support a community of breeding grassland specialists that will inform management and an assessment of a promising new tool that would more easily allow for broad characterization of habitat than traditional methods.

1.3. Methods

1.3.1. Study ecosystem and sites

We monitored four study sites in the Northern Great Plains where ranges of grassland specialists overlap (Fig. 1.1). Two study sites were located in Valley County, Montana (48°39'51"N, 106°33'48"W; elevation ~923m) in an area subject to low disturbance and moderate grazing. One of these sites was on fenced private ranch property surrounded by cropland and state pastureland, and the other site was on a parcel within a larger fenced in area managed by the Bureau of Land Management. The remaining two study sites were located in Golden Valley County, North Dakota (46°37'47"N, 103°58'54"W; elevation ~915m) in the Little Missouri National Grasslands and grazed by local producers that lease the property and practice twice-annual rotational grazing regimes. Data collection occurred over three breeding seasons from 2016-2018. In 2018, one of the site locations was changed due to a fire that burned most of the original site. We partially shifted the 2018 site to unburned prairie that had comparable habitat characteristics and grazing impact and was adjacent to the original study site.

The areas from which we conducted our study are composed of flat landscapes with moderate hills, few small wetlands, and sparse patches of shrub cover. Composition and structure of these prairies historically has been determined by precipitation, fire, grazing by ungulates, and soil disturbance by small mammals (Richardson et al., 2014) and are dominated by a mixture of native and non-native grasses, cool-season and warm-season grasses, and a variety of forb species. Native grasses include cool-season grasses like western wheatgrass (*Pascopyrum smithii)* and needlegrass (*Stipa comata*) and warm-season grasses like blue grama (*Bouteloua gracilis)*, buffalograss (*Buchloe dactyloides)*, and bluestems (*Schizachrium scoparium*) (Singh et al., 2010). Non-native cool-season grasses primarily include Kentucky bluegrass (*Poa pratensis)* and crested wheatgrass (*Agropyron cristatum)* (Ellis-Felege et al., 2013).

1.3.2. Field Data Collection

1.3.2.1. Nest searching and monitoring

We searched for nests daily from May through August using a combination of rope-drag (Giovanni et al., 2011) and behavioral cues (e.g. adult bird carrying nesting material or food directly to the nest; Rodewald, 2004) to find grassland specialist nests within our study sites (following methods in Bernath-Plaisted et al. 2019). We searched for nests primarily during early morning hours from sunrise through 0900 when birds are expected to be active on or near their nests. We avoided rope dragging during inclement weather or when grass was wet from over-night moisture accumulation. We recorded nest locations with GPS units to relocate for habitat measurements once the nest was complete. Upon locating nests, we limited trampling vegetation near the nest by taking variable paths to nest each time it was relocated.

1.3.2.2. Habitat measurements

We measured habitat at nest sites and random points at two spatial scales. We randomly generated non-nest sampling points (hereafter "random points") across each study site using ArcMap version 10.6 (ESRI, Redlands, CA) and surveyed a random point for each nest found at the same study site and at a similar time as the nest point was measured (Table A.1). To minimize disturbance to recently fledged nests, we collected measurements for nest points and their associated random points within three days after nest completion. We measured habitat immediately surrounding each survey point (nest or random) using a Daubenmire frame (0.2 x 0.5m quadrat) to quantify percent cover of vegetation composition (Daubenmire, 1959, hereafter “0.5m scale”). We also measured vegetation within a 10m diameter plot centered on the nest or random point, using a rapid assessment survey to measure vegetation cover types and a Robel pole to measure vegetation density (hereafter "10m scale"). We recorded percent cover of bare ground, shrubs, live grass, dead grass, litter, forbs and exotic vegetation cover at both spatial scales (0.5m, 10m). We considered crested wheatgrass (*Agropyron cristatum*), Kentucky bluegrass (*Poa pratensis*), western goatsbeard (*Tragopogon dubius*), yellow sweet clover (*Melilotus officinalis*), and smooth brome (*Bromus inermis*) as exotic vegetation (Ellis-Felege et al., 2013). We determined visual obstruction with a Robel pole, a commonly used measurement of vegetation density in grasslands, to assess concealment by recording the height the pole was completely obscured by vegetation at the four cardinal directions (Smith, 2008). We later calculated vegetation density by averaging these four cardinal-direction measurements (Robel et al., 1970). We report vegetation density in terms of visual obstruction (centimeters).

1.3.2.3. Imagery Processing

We piloted an eBee Plus, fixed-wing drone (senseFly, Switzerland) equipped with specialized cameras over all study sites to collect spectral reflectance data during our 2018 season to complement our ground-collected habitat dataset. We recorded spectral data that includes bandwidths within the visible light spectrum (red, green, blue) using a Sensor Optimized for Drone Applications (SODA; senseFly, Switzerland), which rendered rasters produced from collected imagery at a resolution of 2-4 cm depending on altitude flown. We also recorded data containing four spectral bands including visible green, visible red, red edge, and near infrared (ranging from wavelengths 550-790 nm) using a Parrot Sequoia (Parrot SA, Paris, France) sensor, which rendered rasters produced from collected imagery at a resolution of 11-15 cm depending on altitude flown. We collected data at least three times during the season at each study site (approximately every 30 days) from mid-May through early August in 2018 to control for phenological changes in the habitat (Cunliffe et al., 2016; Lu and He, 2017). We used Pix4D imagery processing software (version 4.1, Pix4D SA, Lausanne, Switzerland) to align georeferenced images (raster images associated with spatial locations), generate point clouds, create orthomosaics, and create Digital Surface Models (DSM) from these UAS-collected data. We used a Trimble R2 (Trimble, Sunnyvale, California) to collect ground control points that were later included in the photogrammetry process to correct georeferenced images to sub-decimeter accuracy.

We calculated three different vegetation indices to compare SVI performance to ground-collected data in the ability to differentiate nest from random points: the normalized difference vegetation index (NDVI), green normalized difference vegetation index (GNDVI), and red-edge inflection point (REIP). Measurements from these SVIs can evaluate the amount of live vegetation on the ground by measuring chlorophyll content using algorithms of specific bandwidths and infrared light reflectance in a particular pixel. We calculated NDVI ($[R_{NIR}-R_{VISR}] / [R_{NIR}+R_{VISR}]$; Rouse et al., 1973), REIP ($[R_{NIR}-R_{RRED}] / [R_{NIR}+R_{RRED}]$; Guyot et al., 1992), and GNDVI ($[R_{NIR}-R_{VISG}] / [R_{NIR}+R_{VISG}]$; Gitelson et al., 1996) using ArcMap 10.6 (ESRI, Redlands, CA). Low values therefore correspond to unvegetated or dead vegetation cover, and high values correspond to the presence of live vegetation (Beeri et al., 2007; Geipel and Korsaeth, 2017).

We then extracted the mean SVI values for each nest or random point at our 10m habitat evaluation scale using ArcMap 10.6 (ESRI, Redlands, CA) by creating a 5m radius buffer around all nests and non-nest points. We assigned spectral values with the nearest date to the measurement of the associated ground survey measurements to each survey point.

1.3.3. Statistical Analysis

We performed all data management and statistical analyses using Program R 3.6.2 (R Development Core Team 2018). Because spectral data and some ground habitat measurements were only collected in 2018, we characterized nest-site selection using two datasets: one included ground-collected habitat data at both spatial scales collected between 2016-2018, and the other included ground-collected 10m scale measurements and SVIs from 2018 only. We then identified the best models to describe the difference in habitat conditions between nest and random points for each of the four species observed and the community as a whole.

We reduced the number of candidate predictors in two ways before model selection. First, we eliminated uninformative percentage-cover categories (where ≥80% of observations measured zero). Second, we tested for correlation between continuous variables using Pearson correlation coefficient (r) and removed the less informative variable if $r > 0.6$ between two variables. We assessed each parameter's informative power using univariate logistic regression and Akaike's Information Criterion corrected for small sizes (AIC_C; Akaike, 1974). If the two parameters were equally informative ($\Delta AIC_C < 2.0$), we retained the variable present in the other dataset to increase our ability to directly compare the output of our two model selections.

Grassland birds often require intermediate or threshold amounts of certain habitat characteristics (Ruth and Skagen, 2017; Schaub et al., 2010; Sliwinski and Koper, 2015; Williams and Boyle, 2018; Winter et al., 2005). To accommodate these non-linear relationships between habitat characteristics and nest site selection, we compared univariate linear and quadratic models of each retained variable as predictors of nest site selection (using AIC_C) before our full model selection. For each variable, we retained the linear and quadratic form together as a candidate predictor if the latter exhibited Δ AIC_C > 2.0. If the linear term performed better or both linear and quadratic models performed within two AIC_C units, we included only the linear term as a candidate predictor in our model selections.

For each dataset, we created generalized linear models (GLMs) in a fully balanced candidate model set to test which combinations of our predictor variables best explain differences between nest and random points using the MuMIn package (R package version 3.6.2). We used an information theoretic approach to compare all candidate models using Δ AIC_C and Akaike weights (w_i) to evaluate the strength of models. We considered models Δ $AIC_C < 2$ as our top models (Burnham & Anderson, 2002). We reported parameter estimates (β) with standard errors (SE) and 95% confidence intervals (CI) for top models. We considered variables appearing in the top models to be informative only where confidence intervals did not overlap zero in a model (Arnold, 2010). We only discuss results for variables that fit these criteria. For each species and the community, we plotted predicted relative probabilities of use across the range of observed values for variables that fit the criteria mentioned above to demonstrate habitat-relationships. Where top model identified significant quadratic relationships, we calculated the optimal value for those habitat variables at the inflection point where the probability of a given variable being a nest was at its maximum.

To test which ground-collected habitat variables best predicted the most informative SVI, we followed the same information theoretic model selection approach using linear models to construct a candidate model set. For these linear models we evaluated the strength of the models with R^2 values to estimate the variance of SVIs explained by ground-measured variables. Finally, to better understand the performance of including drone-collected SVIs in our nest site selection analysis, we used classification error to compare the accuracy rate (%) of predicting nest sites and non-nest sites correctly between a GLM with only the best-performing SVI as a predictor variable to a GLM with only the best-performing ground-collected habitat variables for the entire grassland bird community.

Table 1.1. Summary of available habitat characteristics for grassland specialist birds in the Northern Great Plains, USA 2016-2018. Values are provided according to spatial scale at which they were measured. Measurements were taken from non-nest, random points, distributed throughout the landscape.

Habitat measurement	**Mean (μ) (min-max)**
Daubenmire scale (0.5m scale)	
Bare ground cover (% cover)	19 % ± 24 % (0 % – 95 %)
Litter cover (% cover)	13 % ± 18 % (0 % – 90 %)
Forb cover (% cover)	9 % ± 11 % (0 % – 90 %)
Shrub cover (% cover)	1 % ± 5 % (0 % – 75 %)
Vegetation height (cm)	19 cm ± 5 cm (0 cm – 75 cm)
Rapid Assessment scale (10m scale)	
Bare ground cover (% cover)	15 % ± 16 % (0 % – 88 %)
Litter cover (% cover)	7 % ± 7 % (0 % – 48 %)
Forb cover (% cover)	13 % ± 10 % (0 % – 65 %)
Shrub cover (% cover)	2 % ± 7 % (0 % – 60 %)
Exotic vegetation cover (% cover)	32 % ± 27 % (0 % – 94 %)
Dead grass cover (% cover)	19 % ± 15 % (0 % – 74 %)
Forb height (cm)	17 cm ± 9 cm (0 cm – 80 cm)
Grass height (cm)	24 cm ± 10 cm (0 cm – 95 cm)
Vegetation density (cm)	8 cm ± 7 cm (0 cm – 61 cm)
GNDVI (index 0-1)	0.46 index (0.30 – 0.68 index)
Elevation (m)	895 m ± 22 m (861 m – 933 m)

1.4. Results

1.4.1. Field data collection

From 2016-2018, we discovered and monitored 865 nests (Table A.1). Chestnut-collared longspur nests dominated the sample (*n* = 470), followed by grasshopper sparrow (*n* = 201), Baird's Sparrow (*n* = 150), and Sprague's pipit (*n* = 44). On average, the landscape was dominated by grass species with an average height of 24 cm (range: 0 – 95cm) with variable patches of bare ground, litter cover, dead grass, forb cover, and shrub cover (range: 2 – 19%) at both spatial scales (Table 1.1). Shrubs occupied the least amount of space on this landscape, with less than 7% cover at either spatial scale (Table 1.1). Exotic vegetation (e.g., crested wheatgrass, Kentucky bluegrass) covered an average of 32% percent of the area at the 10m scale, although cover was highly variable among points (range: 0 – 94%; Table 1.1).

1.4.2. Statistical analysis

1.4.2.1. 2016 – 2018 Datasets: Ground-collected habitat variables

In our tests for correlation among predictors, we found that bare ground and total grass cover were highly correlated at both the 0.5m and 10m scales (r = -0.68 and r = -0.75, respectively). We included bare ground and excluded live grass cover in our model comparisons because bare ground outperformed live grass cover at the 0.5m scale and performed within Δ $AIC_C \leq 2$ at the 10m scale. We did not find strong correlations between any given parameter measured at the 0.5m scale and the 10m scale. In our tests for threshold effects of each predictor, the quadratic relationship performed better than their linear counterparts (Δ $AIC_C > 2$) for bare ground, litter cover and height at the 0.5m

Table 1.2. Summary of nest site selection model comparisons. Results of generalized linear model comparisons assessing nest site selection in grassland specialist birds in the Northern Great Plains, USA 2016-2018. Measurement codes are as follows: bare ground cover (BG), litter cover (LC), forb cover (FC), forb height (FH), vegetation height (VH), vegetation density (VD), grass height (GH), dead grass (DG), exotic vegetation cover (EX), elevation (EL), Green Normalized Vegetation Index (GV). Symbols and shading represent the level of significance of a given covariate in relation to the response variable, nest site selection.

Ground-measured habitat variables 2016-2018

	fine-scale measurements [b]							coarse-scale measurements [c]										model selection	
Species[a]	BG	BG^2	LC	LC^2	FC	VH	VH^2	BG	LC	VD	VD^2	FC	FH	FH^2	GH	GH^2	number of top models	$\sum(w_i)$ [d]
Community	++	---	+	-	.	+++	---	+	.	+++	---	+	--	--	.	.	4	0.57
BAIS	-	---	---	+	---	++	--	--	+++	+++	---	.	.	.	.	.	2	0.40
CCLO	+	---	.	.	+++	+++	---	+++	.	+++	---	.	-	---	.	.	1	0.77
GRSP	+/-	-	+	-	--	+++	---	-	+	+++	---	-	.	.	-	-	26	0.42
SPPI	.	.	.	.	+	.	.	+	.	+++	---	+	.	.	.	.	4	0.67

Ground-measured and drone-collected habitat variables 2018

	coarse-scale measurements											drone measurements			model selection	
Species	BG	LC	LC^2	VD	VD^2	FC	FH	GH	DG	DG^2	EX	EL	GV	GV^2	number of top models	$\sum(w_i)$
Community	+	.	.	+++	---	+	-	-	+	---	.	-	---	---	16	0.41
BAIS	--	.	.	+++	---	.	++	.	.	.	-	-	.	.	7	0.25
CCLO	+++	.	.	+++	---	++	--	--	-	---	++	.	---	--	8	0.42
GRSP	--	.	.	+++	---	-	.	.	.	.	-	-	--	-	9	0.28
SPPI	--	.	.	.	.	.	.	.	.	.	++	.	-	---	2	0.55

[a] community and species-specific datasets: Baird's sparrow (BAIS), chestnut-collared longspur (CCLO), grasshopper sparrow (GRSP), Sprague's pipit (SPPI)
[b] measured at 0.5m scale
[c] measured at 10m scale
[d] sum of AIC weights across top models

+++	significant positive relationship in all top models
---	significant negative in all top models
++	significant positive in at least one of the top models
--	significant negative in at least one of the top models
+	insignificant positive in at least one of the top models (CIs overlap zero)
-	insignificant negative in at least one of the top models (CIs overlap zero)
.	included in candidate model list, though not in any top models

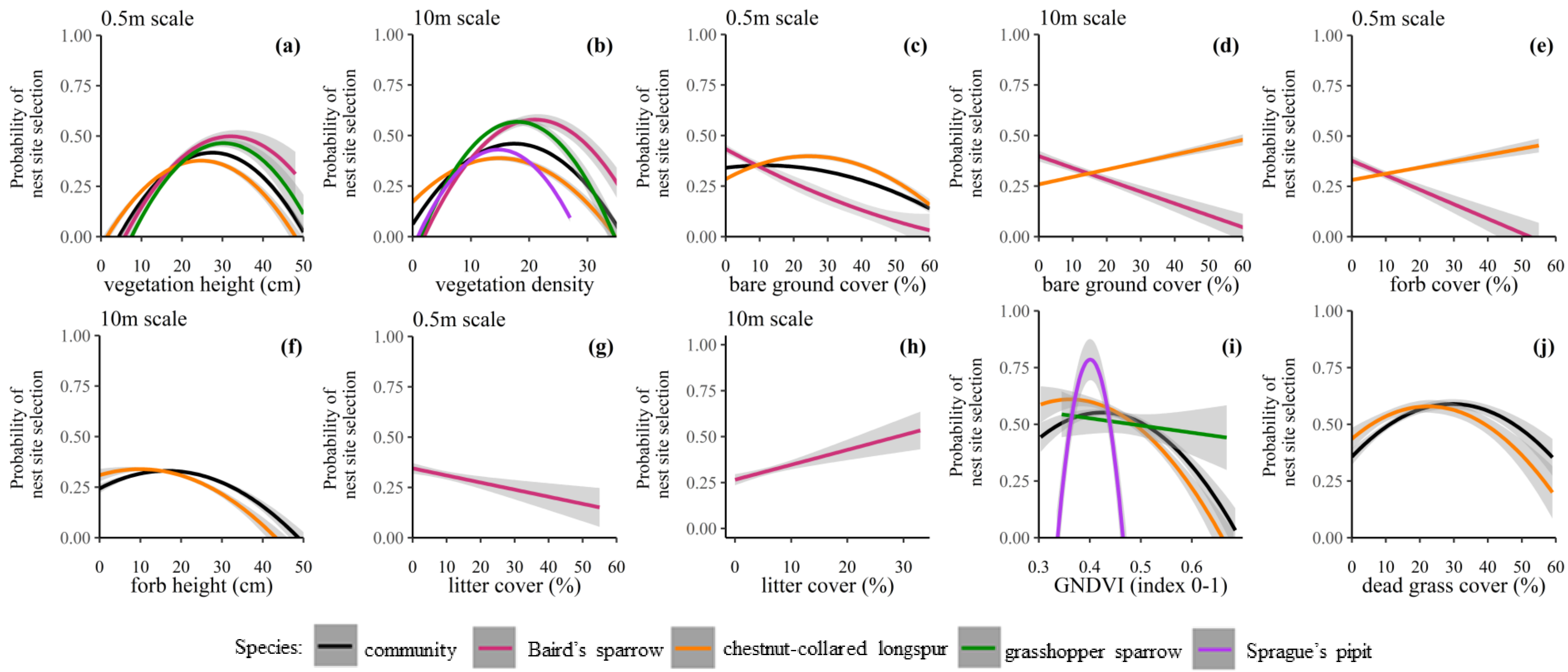

Figure 1.2. Probability of selection of habitat conditions at 0.5m and 10m scale for (a) vegetation height, (b) vegetation density, (c, d) bare ground cover, (e) forb cover, (f) forb height, (g, h) litter cover, (i) Green Normalized Difference Vegetation Index (GNDVI), and (j) dead grass cover for nest sites at the community and species levels for Baird's sparrows, grasshopper sparrows, chestnut-collared longspurs and Sprague's pipit**.**

Table 1.3. Inflection points of quadratic habitat conditions for nest sites. Inflection points for maximum values of habitat characteristics having quadratic, parabolic habitat relationships with nest site selection by grassland specialist birds in the Northern Great Plains. Inflection points represent the value at which a given habitat characteristic has the maximum probability of being used as a nest site by a given species. Ranges for values used by each species for nest sites are in parenthesis. Community refers to the four grassland birds included in the table.

Species	Vegetation height (cm)	Vegetation density (cm)
Baird's sparrow	26.4 cm (8.0 cm – 40.0 cm)	18.0 cm (2.0 cm – 25.5 cm)
grasshopper sparrow	32.2 cm (11 cm – 46 cm)	17.2 (0.0 – 22.0)
chestnut-collared longspur	27.4 cm (0 cm – 46 cm)	10.6 cm (1.5 cm – 28.8 cm)
Sprague's pipit	-	14.5 cm (2.0 cm – 26.5 cm)
Community	30.2 cm (0 cm – 46 cm)	13.3 cm (0.0 cm – 28.8 cm)

scale, and for vegetation density, grass height, and forb height at the 10m scale in our full 2016-18 dataset. We included quadratic effects for dead grass in our 2018-only dataset. These quadratic effects (with their linear counterpart) were included as candidate predictors in our final model selections.

We present summarized results of our full set of model comparisons and candidate models in Table 1.2 and parameter estimates (β) with standard errors (SE) and 95% confidence intervals (CI) for all top models from this dataset are available in appendices Tables A.2-6. Results for ground measurements were similar across both datasets (2016-18 and 2018 only) and are reported from the 2016-18 dataset, apart from the effect of particular variables including dead grass and exotic vegetation cover which are reported only from the 2018 dataset (Tables A.7-11).

Across the grassland specialist community and in three of four species, nests were more likely to be found at intermediate vegetation heights at the 0.5m scale (Fig. 1.2A) and vegetation densities at the 10m scale (Fig. 1.2B). The inflection points of vegetation height used at nest sites were similar between species, ranging from 26.4 – 32.2cm (Table 1.3). The inflection points of vegetation density varied between species, where chestnut-collared longspurs, the community level, and Sprague's pipits used lower vegetation densities (respectively 10.6, 13.3, and 14.5 cm; Table 1.3); and grasshopper and Baird's sparrows used slightly higher densities (respectively 17.2 and 18.0 cm; Table 1.3).

Other habitat measurements evaluated in our models (bare ground cover, forb cover, forb height, litter cover, and dead grass) had significant, yet variable effects on nesting between species, the community, and spatial scales (Fig. 1.2 C-H & J). For each habitat variable, at least one or more of the species-specific results differed from the community (Table 1.2) and for some variables where there was not a community effect there was a species-specific effect occurring in opposite directions (e.g. bare ground cover at the 10m scale; Fig. 1.2D and forb cover at the 0.5m scale; Fig. 1.2E). Percent cover of bare ground and forbs predicted nest sites in Baird's sparrows and chestnut-collared longspurs (Table 1.2). At both spatial scales, Baird's sparrows were more likely to nest in areas with low percentages of bare ground cover while chestnut-collared longspurs were more likely to nest in areas with higher coverage of bare ground (Fig. 1.2C & D). Similarly, at the 0.5m scale, Baird's sparrows were more likely to nest in areas with low forb cover while chestnut-collared longspurs were more likely to nest in areas with high forb cover (Fig. 1.2 E). Litter cover predicted nest-site selection at both spatial scales only for

Baird's sparrows (Fig. 1.2 G & H). Intermediate coverage of dead grass predicted nest sites for the grassland bird community and chestnut-collared longspurs (Fig. 1.2 J).

For some variables, selection occurred in opposite directions across spatial scales within a community or species level. Litter cover affected nesting in Baird's sparrows at both spatial scales, though in opposite directions; negatively at the 0.5m scale (Fig. 1.2 G), and positively at the 10m scale (Fig. 1.2H). Similarly, in chestnut-collared longspurs nests were placed in sites with increased forb cover at the 0.5m scale (Fig. 1.2E), but decreased forb height at the 10m scale increased the probability of nesting (Fig. 1.2F). For some species the relationship between the habitat variable and nest site selection differed between linear and quadratic effects across spatial scales. For example, in chestnut-collared longspurs and Baird's sparrows, bare ground cover has a quadratic effect at the 0.5m scale (Fig. 1.2C) and a linear effect at the 10m scale (Fig. 1.2D).

1.4.2.2. 2018 Dataset: Drone and ground-collected habitat variables

The three SVI values we acquired (NDVI, GNDVI, REIP) were strongly correlated with each other (r = 0.9, r = 0.7, r = 0.8, respectively). In univariate model comparisons predicting nest site selection, GNDVI performed better than REIP and NDVI. We therefore only included GNDVI as a candidate variable to predict nest-site selection. Further, we found no correlations between any of the SVIs and the ground-collected habitat variables. Quadratic terms for the 2018 dataset included dead grass, litter cover, vegetation density, and GNDVI. All other candidate variables were included as linear terms (bare ground, forb cover, forb height, grass height, exotic vegetation cover, and elevation).

The GNDVI, in combination with other ground-collected variables, predicted nest sites at the community level and for three of the four grassland specialists assessed, apart from Baird's sparrow. Nest sites were associated with lower amounts of GNDVI for the community, chestnut-collared longspurs, and grasshopper sparrows (Fig. 1.2I); nests were associated with intermediate ranges of GNDVI values with an inflection point of 0.40 (range: 0.37 – 0.44; Table 1.3) for Sprague's pipit (Fig. 1.2I). For grasshopper sparrows, nests were most likely to be found at locations with low GNDVI values, intermediate vegetation density, and low bare ground coverage (Table 1.2). For chestnut-collared longspurs, nests were more likely at points with low GNDVI values, intermediate vegetation density, high coverage of bare ground, intermediate dead grass cover, and high coverage of forbs of low heights (Table 1.2). For the community level, nests were more likely at points with low GNDVI values, intermediate vegetation density, and intermediate dead grass cover (Table 1.2). From our classification errors to test the predictive power of including GNDVI in our models, the accuracy rate of correctly predicting nest sites and non-nest sites in a model with GNDVI as the only predictor variable was 53% (95% CI = 47 – 58%). In a model with only the best-performing ground-collected data (bare ground, dead grass, forb cover, and vegetation density) as predictor variables, the accuracy rate of correctly predicting nest sites and non-nest sites was 64% (95% CI = 57 – 69%).

The combination of exotic vegetation cover, bare ground cover, dead grass cover, forb height, grass height, and vegetation density best predicted GNDVI values (Table A.12). Each of the top models included all seven ground-collected variables and had R^2 values of 0.37. The GNDVI had a negative relationship with bare ground, dead grass, and grass height and a positive relationship with exotic vegetation cover, forb height, and vegetation density. Though, exotic vegetation cover (β = 0.208 – 0.225, CIs = 0.135 – 0.295), bare ground cover (β = -0.320 – -0.291, CIs = -0.405 – -215), dead grass cover (β = -0.337 – -0.312, CIs = -0.409 – -0.248) and vegetation density (β = 0.210-0.213, CIs = 0.133 –0.286) had the largest effects on GNDVI.

1.5. Discussion

1.5.1. Nest site selection: community and species-specific needs

Our analysis of nest site selection revealed that grassland birds as a community nested in an intermediate range of vegetation height and density of which can be prioritized when managing for this community of birds. This is the first study to show community-level selection in these grassland specialist species. In addition, we found that bare ground, litter, dead grass and forb cover were influential for nest sites, though the relationship with these habitat characteristics varied by species and should be managed for respectively.

Grassland specialists examined in this study shared similar nesting patterns for vegetation height and density, preferring intermediate ranges, resulting in a rare target for managers wishing to support multiple species with a single management goal (Fig. 1.2A & B). Our findings for vegetation height and density are consistent with previous research in Baird’s sparrows, Sprague’s pipits, and grasshopper sparrows (Davis, 2005; Fisher and Davis, 2011a; Ruth and Skagen, 2017). However, it is important to note that for vegetation height, all species shared similar patterns and optimal ranges (Fig. 1.2A; Table 1.3). Sprague’s pipit did not show a relationship with vegetation height in our findings, though others have found a strong relationship between this species and intermediate vegetation height at nest sites (Fisher and Davis, 2011a). This disparity could be due to small sample size for this species in our study (n = 44) when compared with other species in our dataset (n = 150-470). For vegetation density, all species only shared similar patterns but greater variation in optimal values (maximum probability of nest site) (Fig. 2B; Table 1.3).

Grassland birds may be selecting vegetation density and height as optimal ground cover to protect nests from exposure to the elements (Hartman and Oring, 2003; Nelson and Martin, 1999) and predators (Fogarty et al., 2017; Martin and Roper, 1988). In the Northern Great Plains, there is minimal shade apart from that provided by ground vegetation cover, making ground nests vulnerable to extreme heat and sun exposure. Consequently, adult birds may nest in tall, dense vegetation to utilize shade as a form of nest thermoregulation to benefit nest survival (Carroll et al., 2015) by avoiding developmental abnormalities in offspring caused by thermal stress (Salaberria et al., 2014). Though increased vegetation height and density are beneficial to grassland birds, our results show that grassland birds are not selecting the tallest and densest vegetation as nest sites. Taller or denser vegetation on this landscape may adversely affect foraging efficiency while hunting for arthropods on the ground (Ahlering et al., 2006; Schaub et al., 2010) or, serves as a physical barrier when birds must escape predatory encounters (Götmark et al., 1995).

Contrary to the similar selection patterns for vegetation height and density that we found across the grassland bird community, each species-specific output from our results identified unique habitat selected for nesting. Each bird species selected for different amounts of bare ground, forbs, dead grass and litter between species and spatial scales.

For instance, Baird's sparrows nested in sites with higher litter cover and Chestnut-collared longspurs nested in sites with higher bare ground and forb cover compared with the other species. These characteristics can be targeted by managers if the intent is to optimize breeding habitat for a particular grassland species and combined with vegetation height and density optimal for the community as a whole.

Chestnut-collared longspurs selected for more bare ground at nest sites, a pattern consistent with previous findings (Davis 2005). Bare ground may be a particular characteristic of importance because of the foraging opportunities it affords small-bodied birds by increasing access to invertebrate communities (Ahlering et al., 2009; Davis, 2005; Schaub et al., 2010). Locating prey items in open areas has an advantage over moving through and disturbing vegetation which may cause prey to easily escape. Alternatively, the use of increased bare ground at nest sites for this species may be associated with an adaptation to reduce interspecies competition with other ground-nesting birds that tend to avoid areas of bare ground. Thus, it is plausible that chestnut-collared longspurs place nests in open areas to avoid predators that have developed a search pattern to target the nests of other species in densely covered vegetation (Martin T. E., 1996).

Chestnut-collared longspurs and the grassland bird community also selected for increased forb cover and lower forb height, although these associations were weak. Forbs increase vegetative interspersion and provide camouflage by creating high contrast patterns that potentially disrupt visual cues used by aerial predators increasing nest survival in grassland birds that produce open-cup nests (Bowman and Harris, 1980; Fogarty et al., 2017; Pearson and Knapp, 2016), which may be particularly effective for chestnut-collared longspur nests that are also often placed near bare ground. The preference for lower forb heights may also be reflective of the available forb species. Native forbs in this ecoregion include lupines (*Lupinus spp*), pussytoes (*Antennaria plantaginifolia*), yarrow (*Achillea millefolium*), and western sagewort (*Artemisia ludoviciana*), are all shorter than some common invasive forbs like yellow sweet clover (*Melilotus officialis*) (Charboneau, 2013; Singh et al., 2010). It is possible that anthropogenic changes to grassland habitat, including the introduction of tall forb species, have occurred far too rapidly for grassland birds to adopt nesting patterns associated with this exotic, introduced vegetation.

While we found that grassland specialists selected similarly for vegetation height and density across species, future work should consider whether this includes other grassland species that breed in this region like savannah sparrow (*Passerculus sandwichensis*), bobolink (*Dolichonyx oryzivorus*), lark buntings (*Calamospiza melanocorys*), western meadowlarks (*Sturnella neglecta*), and horned larks (*Eremophila alpestris*) which are also part of the declining bird community in the Northern Great Plains. A complete interpretation of nest site selection for all breeding grassland songbirds of this region will make management feasible for a larger set of breeding birds. Additionally, we were unable to assess the effect of dead grass or litter depth across all three breeding seasons. These characteristics warrant further exploration for nesting patterns in grassland birds; dead vegetation may have more biological relevance to nesting because it likely provides their only source of cover at the beginning of the breeding season (Ahlering et al., 2009).

1.5.2. Incorporating UAS methods in habitat assessment for grassland birds

Measuring habitat via UAS is a promising new tool to compliment traditional methods in fine-scale habitat studies. Our results indicate that high-resolution GNDVI collected vis UAS alone does not outperform ground measurements for fine-scale habitat selection, however three of four grassland specialists (chestnut-collared longspurs, grasshopper sparrows, and Sprague's pipit) showed some amount of selection for GNDVI. Further, measuring GNDVI could be more efficient than collecting multiple types of data on the ground; the combination of top-performing ground-collected variables (bare ground cover, dead grass cover, forb cover, and vegetation density) performed better by only 11% in correctly predicting nests and non-nests sites compared with GNDVI alone.

It is important to note that GNDVI outperformed other SVIs including NDVI, which is by far the most commonly used vegetation index in grassland bird studies and those conducted in other ecosystems (Ahlering et al., 2009; Green et al., 2019; Iens, 2006; Lipsey and Naugle, 2017; Macías-Duarte et al., 2018). In the Northern Great Plains, however, NDVI can be a poor indicator of biomass because of the confounding reflectance values of dead versus live grass (Guo et al., 2005). The GNDVI outperforms NDVI in other herbaceous ecosystems (Taddeo et al., 2019b) likely because GNDVI displays a greater sensitivity to chlorophyll concentrations than NDVI (Geipel and Korsaeth, 2017; Gitelson et al., 1996). Chlorophyll content is dependent on both

Table 1.4. Habitat measured at nest sites. Mean, standard deviation, and ranges of habitat characteristics measured at nest sites of grassland specialist birds in the Northern Great Plains, USA 2016-2018. Measurements for two spatial scales surrounding nest points are provided (0.5 meter diameter, 10 meter diameter). Dashes indicate characteristic was not measured within a certain spatial scale.

Habitat variable	**Baird's sparrow**		**chestnut-collared longspur**		**grasshopper sparrow**		**Sprague's pipit**	
	0.5m	**10m**	**0.5m**	**10m**	**0.5m**	**10m**	**0.5m**	**10m**
Bare ground (%)	6 ± 11 (0 – 55)	10 ± 11 (0 – 55)	16 ± 17 (0 – 80)	17 ± 16 (0 – 78)	5 ± 10 (0 – 60)	8 ± 11 (0 – 60)	10 ± 16 (0 – 75)	13 ± 8 (1 – 32)
Forb cover (%)	6 ± 7 (0 – 40)	12 ± 8 (1 – 40)	11 ± 13 (0 – 70)	13 ± 10 (1 – 54)	7 ± 8 (0 – 40)	11 ± 8 (1 – 41)	10 ± 11 (0 – 45)	16 ± 9 (2 – 39)
Shrub cover (%)	0 ± 1 (0 – 10)	1 ± 2 (0 – 12)	0 ± 2 (0 – 45)	1 ± 2 (0 – 28)	0 ± 1 (0 – 15)	1 ± 2 (0 – 16)	0 ± 1 (0 – 5)	0 ± 1 (0 – 4)
Litter cover (%)	8 ± 10 (0 – 75)	7 ± 6 (1 – 31)	11 ± 14 (0 – 85)	7 ± 7 (0 – 61)	15 ± 20 (0 – 90)	9 ± 9 (0 – 60)	8 ± 7 (0 – 30)	5 ± 4 (1 – 20)
Vegetation height (cm)	22 ± 7 (8 – 40)	-	19 ± 6 (0 – 46)	-	22 ± 6 (11 – 46)	-	21 ± 7 (9 – 42)	-
Vegetation density (cm)	-	12 ± 5 (2 – 26)	-	8 ± 4 (0 – 22)	-	10 ± 4 (2 – 29)	-	11 ± 5 (2 – 27)
Dead grass cover (%)	-	25 ± 16 (3 – 62)	-	18 ± 12 (1 – 51)	-	22 ± 12 (3 – 62)	-	29 ± 15 (10 – 55)
Exotic cover (%)	-	24 ± 28 (0 – 91)	-	31 ± 26 (0 – 89)	-	44 ± 25 (0 – 85)	-	25 ± 27 (0 – 72)
Grass height (cm)	-	27 ± 9 (11 – 54)	-	23 ± 8 (6 – 52)	-	26 ± 7 (6 – 50)	-	24 ± 8 (9 – 42)
Forb height (cm)	-	18 ± 8 (4 – 43)	-	15 ± 6 (3 – 36)	-	17 ± 7 (6 – 43)	-	16 ± 7 (5 – 30)
Shrub height (cm)	-	3 ± 8 (0 – 39)	-	2 ± 7 (0 – 39)	-	4 ± 9 (0 – 39)	-	2 ± 7 (0 – 38)
GNDVI (index)	-	0.44 ± 0.07 (0.34 – 0.69)	-	0.44 ± 0.06 (0.30 – 0.61)	-	0.47 ± 0.06 (0.37 – 0.60)	-	0.41 ± 0.02 (0.37 – 0.44)
Elevation (m)	-	907 ± 23 (874 – 932)	-	890 ± 17 (869 – 929)	-	906 ± 20 (871 – 932)	-	920 ± 18 (877 – 933)

precipitation and nutrient availability and may be a better measure of habitat characteristics selected by grassland birds.

Unfortunately, our understanding of what GNDVI is measuring on the ground is uncertain and requires additional work outside the scope of our study. Our results show that GNDVI is not well represented by a single vegetative metric that we measured from the ground (Table A.12). It is possible that GNDVI is measuring interspersion, or the degree of combined live grass, dead grass, bare ground (Yang and Guo, 2014). Interspersion varies between species of grass; certain species like exotic sod-forming grasses including Kentucky bluegrass are much more interspersed compared to grasses that grow in bunches like needle grasses, blue grama, June grass, fescues, and wheat grass. Thus, it is unsurprising that exotic vegetation cover was most influential of the covariates that predicted GNDVI (Table A.12). Furthermore, GNDVI predicted nest site selection in grasshopper sparrows, which on average placed nests in higher amounts of exotic cover compared with Baird's sparrows (Table 1.4) whose nests were not predicted by GNDVI. Alternatively, GNDVI may measure habitat characteristics that we did not measure on the ground that have been well-predicted by GNDVI in other studies (e.g. moisture or lichen/moss cover; (Taddeo et al., 2019a; Xu et al., 2014).

Next steps in remote sensing of grassland bird habitat via UAS should involve further exploration of indices that better detect photosynthetic vegetation and senescent vegetation together to accurately describe ground conditions, (e.g. soil adjusted total vegetation index, or SATVI; Guo et al., 2005; Marsett et al., 2019; Song et al., 2017; Yang and Guo, 2014). This SVI has shown a tight relationship with grass biomass in these ecosystems. Because our results demonstrate that grassland birds select nest sites associated with bare ground and dead grass cover for nest habitat, we recommend collecting spectral data that best measures these habitat characteristics.

1.5.3. Conclusions

The declining grassland specialists discussed here maintain breeding ranges largely occurring on private land in the Northern Great Plains. We found that all the species we measured selected for a similar range of vegetation height and density. We recommend a heterogeneous mixture of vegetation heights between 26.4 – 32.2cm and of vegetation densities between 10.6 – 18.0cm to encompass the range of optimal values of these conditions used for nest sites each species observed in our study that represent the grassland bird community of the Northern Great Plains (see Table 1.3 for species-specific optimal values). Vegetation height is potentially a rangeland characteristic that producers can target through grazing strategies (Derner et al., 2009). Livestock managers seeking to improve conditions for a community of grassland birds should consider designing grazing intensity and pattern targeting our vegetative height and density results (Table 1.3).

Our study also revealed other vegetative cover that is important for nesting. Bare ground cover, litter cover, forb cover, and dead grass cover were all selected on across our four grassland specialists. Thus, we recommend managers aim to maintain a diversity of these cover types available on their landscape to support a diversity of grassland birds (Fuhlendorf et al., 2006; Hovick et al., 2015). Management practices that yield heterogenous landscapes include rotational grazing, varied stocking rates, and prescribed fire when practiced at optimal frequencies (Davis et al., 2017; Lwiwski et al., 2015; Sandercock et al., 2014).

It is important to mention that grasslands can undergo dramatic interannual changes that vary regionally which all affect grassland bird demographic rates accordingly (Ahlering and Merkord, 2016; George et al., 1992; Gorzo et al., 2016; Lipsey and Naugle, 2017; Perlut and Strong, 2011). When making long-term management plans for grassland birds, any prescriptions or methods of management should reflect local and regional differences in vegetation types, climate, and soil type in addition to interannual variability such as precipitation and snow melt.

Finally, we found the use of UAS was helpful for predicting nest sites in the Northern Great Plains. While our ground-measured metrics did outperform UAS metrics for our study, the difference in performance was small. Thus, land managers can better balance the cost of collecting bird information (hiring field technicians to find nests, radio-tag birds, re-sight efforts) or measuring a large number of vegetation characteristics from the ground with the cost and time effectiveness of utilizing UASs without a major loss of important information. Rangeland managers often use methods similar to assess important bird habitat to monitor grassland condition for their ranching and agricultural businesses (Puri et al., 2017). Thus, UAS-collected data can provide a unique opportunity to leverage a tool already used by landowners as a monitoring instrument to improve breeding habitat for grassland birds.

CHAPTER 2: HABITAT USE OF POST-FLEDGING BAIRD'S SPARROWS *(CENTRONYX BAIRDII)* AND GRASSHOPPER SPARROWS *(AMMODRAMUS SAVANNARUM)* IN THE NORTHERN GREAT PLAINS

2.1. Abstract

Habitat loss and alteration are linked to population decline in grassland birds, but there is limited knowledge of how juvenile grassland birds use habitat during the post-fledging stage. Understanding how birds use habitat during this life stage is essential for developing effective management strategies to lessen and reverse decline. We tracked radio-tagged fledglings and collected habitat data on the ground and using spectral collected via a drone to characterize juvenile habitat use data for two grassland specialists, Baird's sparrow and grasshopper sparrow, in western North Dakota and northeastern Montana. We analyzed post-fledgling habitat use with variables measured from the ground and from spectral data collected via Unmanned Aircraft System at juvenile used points, random points, and adult nest sites to identify habitat conditions specified to the post-fledge stage. We found that both species selected for high forb cover and that juvenile Baird's sparrows moved towards densely vegetated areas (e.g. wetland areas) after they leave the nest. Patterns of selection of dead grass cover, grass height, and exotic vegetation varied between species but were also influential in juvenile habitat selection. We found that juveniles of both species selected for habitat cover types that differed substantially from those present at nest sites. We demonstrate that habitat use varies between different life stages within the breeding period and between species of juvenile grassland specialists co-existing in the Northern Great Plains. Generally, we emphasize consideration of all life stages when developing a management plan for a

certain area. Particularly, we present a novel recommendation that wetland areas be considered for the management of Baird's sparrows on breeding grounds in mixed-grass prairies.

2.2. Introduction

Habitat selection is a fundamental component of natural history, population ecology, and habitat management for a species (Johnson, 1980; Matthiopoulos et al., 2015; Morris, 2003; Pulliam, 1988). However, habitat selection studies are largely limited to investigating conditions important for adults (Nelson et al., 2017; Shahan et al., 2017). As a result, little is known about habitat selection by juveniles. The juvenile life stage is generally understudied across taxa (Agrain et al., 2015; Ogutu et al., 2011; Orgeret et al., 2016) including many species of songbirds (Streby and Andersen, 2011; Xiao et al., 2017). However, juvenile demographic parameters are often highly influential in population growth (Anders et al., 1997; Grüebler et al., 2014; van Oosten et al., 2017) and are often driven by habitat quality (Jenkins et al., 2017; Streby et al., 2015; Young et al., 2019), emphasizing the importance of considering the juvenile life stage in reproductive ecology studies and resulting management recommendations.

Post-fledgling habitat use differs substantially from adult nesting habitat in some songbird species (King et al 2006; Anders et al., 2018; Bulluck & Beuhler, 2008; Jenkins et al., 2017; Streby and Andersen, 2011), but because there is a much larger body of literature related to nest site selection, management strategies are often based only on habitat requirements at the nesting stage. Management of habitat based only on one life stage could have population-level consequences. For example, shrub-dominated clear cuts were an important determinant of juvenile survival of ovenbirds (*Seirus aurocapilla)* despite higher nesting survival within interior forests (Streby and Andersen, 2011). In this scenario, management of oven bird populations may not be effective if management actions optimize only interior forest.

Despite its influence on population growth, the post-fledgling period remains the least studied of the life stages for birds in particular (Cox et al., 2014), likely due to the difficulty of tracking young after they leave the nest (Streby et al., 2015); young birds remain silent and immobile in the presence of larger animals (including human observers). There are strong reasons to believe, however, that habitat selection might differ at this stage. Fledglings are more limited than adults in their ability to escape from predators and forage independently (Fisher and Davis, 2011b; Streby et al., 2015). Instead, young birds likely rely more heavily on vegetation structure because dense or tall plants provide protection from predators or inclement weather (Berkeley et al., 2007; Fisher and Davis, 2011b; Small et al., 2015). To fully assess suitable habitat, it is important to measure how juveniles use habitat compared with habitat available to them on a given landscape.

Grassland specialists like Baird's sparrows *(Centronyx bairdii)* and grasshopper sparrows *(Ammodramus savannarum)* are declining precipitously in North America (Correll et al., 2019; Gorzo et al., 2016; Knopf, 1994; Sauer et al., 2017, Rosenberg et al., 2019) and may benefit from conservation actions inclusive of all life stages to lessen this decline. Both species occupy mixed-grass prairie regions in the Northern Great Plains during the breeding season; Baird's sparrows are highly specialized to grasslands within this region, while grasshopper sparrows have more expansive ranges (Fig. 2.1). Population declines in both of these species have been linked with habitat loss and alteration on grassland landscapes occupied throughout their annual cycle on the breeding grounds (Gage et al., 2016; Rashford et al., 2011) and the wintering grounds in the Chihuahuan Desert (Macías-Duarte and Panjabi, 2013; Pool et al., 2014). These species are a prime example of those in need of effective conservation actions inclusive of species' needs in all life stages. Conservation efforts for grassland birds are mainly implemented through habitat management because vegetative structure on these landscapes are already predominantly determined by human management practices for livestock production (Derner et al., 2009; Hovick et al., 2015; McNew et al., 2015). Specifying the physical attributes of habitats that birds select throughout their life cycle will better inform those management practices.

While habitat selection for these species has been explored in adults (Macias-Duarte et al., 2017; Macías-Duarte and Panjabi, 2013. Davis, 2005; Jones et al., 2010), little has been done to understand habitat selection in juveniles. Grassland birds display age-specific vital rates; adult survival in Baird's and grasshopper sparrows is high (79% and 74%, respectively) compared with low juvenile survival (23% and 54%, respectively; Ahlering et al., 2009; Hovick et al., 2011; Bernath-Plaisted et al. *in review*). Adult survival rates are not strongly associated with specific habitat conditions, however, juvenile survival rates are influenced by vegetation height, vegetation density, exotic vegetation cover, and dead grass cover (Bernath-Plaisted et al *in review*, Small et al., 2015). Because vital rates for juveniles are influenced by habitat conditions, further exploration of habitat selection is warranted at this life stage in these species. Furthermore, because some habitat conditions are known to determine survival for only juveniles and not adults, it is worth investigating other habitat features on the landscape that are currently not known to be used by adults.

Adult Baird's and grasshopper sparrows typically use upland grass areas for nest placement and foraging (Jones et al., 1998), and the use of wetland areas is uncommon despite the potential for higher food availability in these regions (Barnett and Facey, 2016). Adults of both sparrow species in the Northern Great Plains tend to occupy ungrazed to moderately grazed tracts of native prairie with sparse shrub cover. There is some evidence that adult Baird's and grasshopper sparrows occupy wetland meadows or shallow dry ponds in excessively dry years in this region (Faanes, 1982), though they generally prefer well-drained sites (Kantrud and Kologiski, 1983). Certain subspecies of grasshopper sparrow utilize semi-wet areas as their ranges include native palmetto (*Serenoa repens*)-wiregrass (*Aristida stricta*) prairie in Florida, coastal dunes, and outskirts of saltmarsh wetlands (Vickery 2020). The above criteria are based upon adult habitat occupancy and use. However, habitat use corresponds with an animals' anticipated resource. For adults, these resources are likely attributed to establishing territories and building nests in sites safe from predators. However, for juvenile birds, in addition to predator avoidance, developmental growth fueled by quality food is also a highly desirable resource.

The relationship between juvenile habitat use and wetlands areas is worthy of investigation because wetlands are potentially sources for high-quality food in concentrated areas. Vegetation surrounding wetlands are composed of denser, taller, and increased live grass cover than surrounding cover type on mixed-grass prairies (Dahl, 2014), features that are linked to increased biomass of insects in grasslands (Barnett and

Facey, 2016). Wetland areas are available within upland grassland systems scattered throughout the Northern Great Plains predominantly as a result of historic glacial activity (Tiner, 2003) and often serve as an important refugia for many other groups of birds (Elliott et al., 2019). However, these highly productive wetlands have been altered or removed due to increased agricultural development (30,100 hectare loss since 1997 from this region; Dahl, 2014). Wetlands have not yet been documented as important habitat for Baird's or grasshopper sparrows, though they might be considered management purposes if typically selected for by juvenile sparrows. We are limited in knowledge about wetland use among other habitat that may be used by juveniles because currently no studies have observed juvenile habitat selection in Baird's sparrow or grasshopper sparrow in the Northern Great Plains.

We explored juvenile habitat selection in two grassland songbird species of the Northern Great Plains to inform management of grasslands for this important life stage. Specifically, we (1) compared habitat used by post-fledge juveniles with habitat available on the landscape to characterize juvenile habitat selection, (2) compared habitat used by adult sparrows for nesting and habitat used by fledgling sparrows to test for differences by life stage within the breeding period, and (3) tested whether juveniles moved toward wetland areas after fledging from their nests. We expected that (1) prior to independence from parents, post-fledgling birds select habitat that provides increased vegetation cover and height to avoid predators and inclement weather conditions (Suedkamp et al., 2007; Small et al., 2015); (2) habitat use of juvenile birds during the post-fledging stage differs from nesting habitat used by adult birds because mechanisms for thermoregulation and predator avoidance likely also differ for nests and juveniles as they do in other migrant songbirds (Jenkins et al., 2017) ; and (3) Juvenile sparrows use densely vegetated areas surrounding wetlands to optimize foraging opportunities as they begin to gain independence from adults. This study is the first to explore habitat use by both juveniles and adults of these two threatened grassland songbirds in the Northern Great Plains. Our findings will better inform grassland management with recommendations for the entire breeding period inclusive of habitat suitable for both nests and juveniles. Without attention to both stages, it is unclear what managers must provide to encourage successful nesting that leads up to surviving juveniles capable of migration to complete the reproductive cycle.

2.3. Methods

2.3.1. Study ecosystem and sites

The mixed-grass prairies of the Northern Great Plains are a combination of tall and short grass prairies subject to semi-arid climates (Charboneau, 2013). Our study sites are composed of generally flat landscapes, with mild elevational variability, sporadic patches of shrub cover (*Symphoricarpos occidentalis*), and pockets of small natural or artificial wetlands. Vegetation cover is dominated by a blend of native, non-native, cool- and warm-season grasses. Native, cool-season grasses include western wheatgrass (*Pascopyrum smithii)* and needlegrass (*Stipa comata*).Native, warm-season grasses include blue grama (*Bouteloua gracilis)*, buffalograss (*Buchloe dactyloides)*, and bluestems (*Schizachrium scoparium*) (Singh et al., 2010). Non-native, cool-season

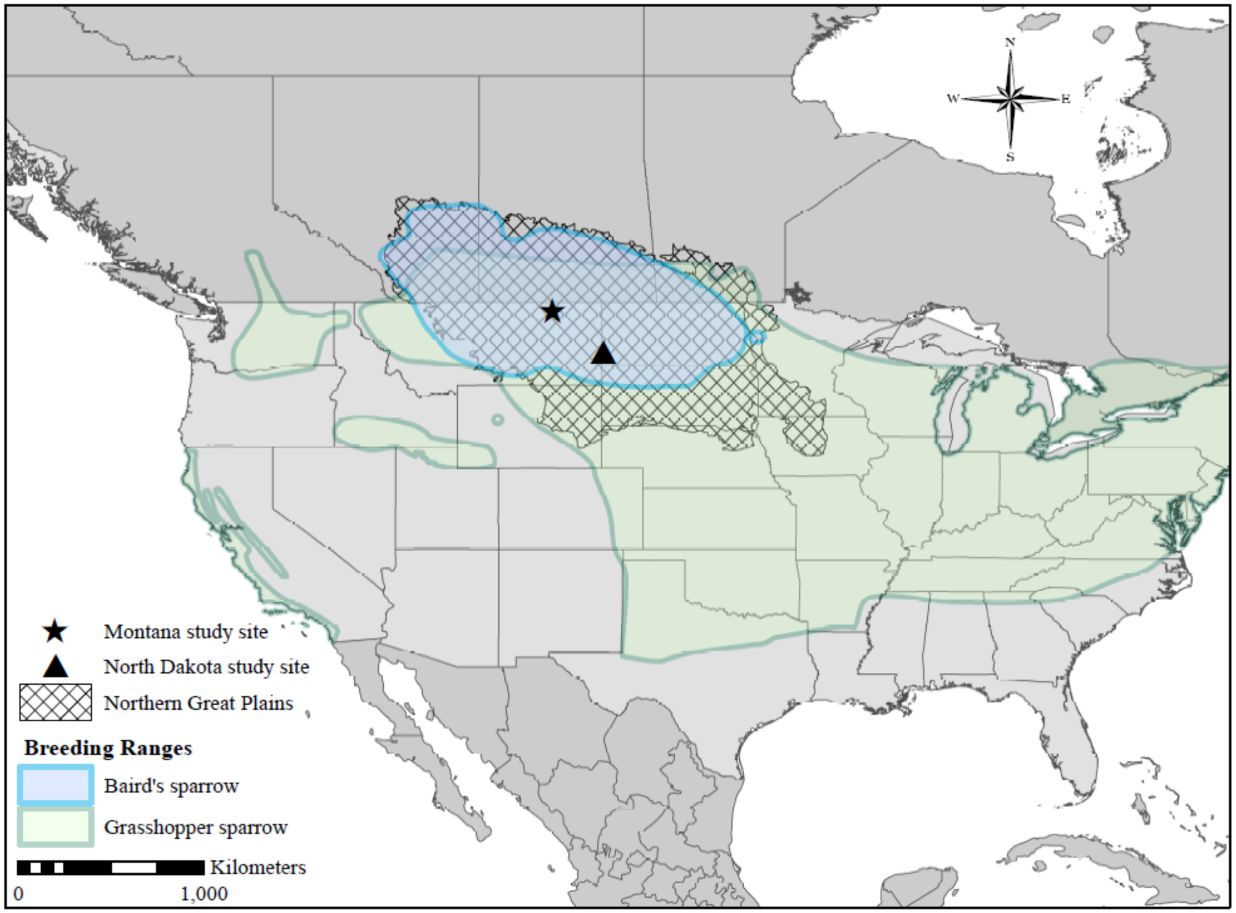

Figure 2.1. Breeding ranges of Baird's and grasshopper sparrows in the Northern Great Plains, USA. Black icons show site locations for a demographic study of grassland birds in 2018.

grasses include Kentucky bluegrass (*Poa pratensis)* and crested wheatgrass (*Agropyron cristatum)* (Ellis-Felege et al., 2013).

We conducted our research at two study sites on mixed-grass prairies in the Northern Great Plains where breeding ranges of several grassland specialist birds overlap (Fig. 2.1). We visited two plots within each study site. One study site was located in Valley County, Montana (48°39’51”N, 106°33’48”W; elevation ~923m) on a landscape with moderate grazing and little other anthropogenic disturbance. One plot at this site was on private ranch property, enclosed by fences and surrounded by agricultural and state pastureland, and the other was located on a tract of continuous prairie managed by the Bureau of Land Management. Our other site was located in Golden Valley County, North Dakota in the Little Missouri National Grasslands (46°37’47”N, 103°58’54”W; elevation ~915m). Both plots in North Dakota were located on leased properties that were grazed twice per year. Plot sizes ranged from 128-177 ha ($\bar{x}$ = 150.5, SD = 17.6).

2.3.2. Field Data Collection

2.3.2.1. Telemetry data

We used radio telemetry to track fledgling Baird’s and grasshopper sparrows from nests monitored during spring and summer of 2018. We located nests with a combination of systematic rope-dragging techniques (Giovanni et al., 2011), behavioral observation (Rodewald, 2004), and opportunistic finds while conducting other research activities. We conducted nest searching efforts from sunrise through 0900 to more easily locate nests when adult birds are most active and to avoid flushing adults off their nests during midday hours when temperatures are highest. We did not conduct nest searching efforts

Table 2.1. Habitat measured at juvenile locations and random points. Mean, standard deviation, and ranges of habitat characteristics measured at juvenile Baird's and Grasshopper sparrow locations and random points in the Northern Great Plains, USA 2016-2018.

	Baird's sparrow	**Grasshopper sparrow**	**Random points**
Ground habitat measurements	**Mean (min-max)**	**Mean (min-max)**	**Mean (min-max)**
Bare ground (% cover)	21% ± 18% (0% – 78%)	10% ± 11% (0% – 61%)	19% ± 24% (0% – 95%)
Litter cover (% cover)	5% ± 4% (1% – 31%)	5% ± 4% (0% – 33%)	7% ± 7% (0% – 48%)
Forb cover (% cover)	13% ± 8% (1% – 40%)	20% ± 13% (2% – 74%)	13% ± 10% (0% – 65%)
Shrub cover (% cover)	2% ± 6% (0% – 33%)	2% ± 7% (0% – 60%)	2% ± 7% (0% – 60%)
Exotic vegetation (% cover)	8% ± 13% (0% – 80%)	42% ± 22% (0% – 85%)	32% ± 27% (0% – 94%)
Dead grass cover (% cover)	25% ± 14% (3% – 60%)	12% ± 10% (0% – 55%)	19% ± 15% (0% – 74%)
Forb height (cm)	19 cm ± 6 cm (7 cm – 38 cm)	21 cm ± 7 cm (7 cm – 58 cm)	17 cm ± 9 cm (0 cm – 80 cm)
Grass height (cm)	24 cm ± 8 cm (8 cm – 44 cm)	29 cm ± 8 cm (13 cm – 58 cm)	24 cm ± 10 cm (0 cm – 95 cm)
UAS-collected measurements	**Mean (min-max)**	**Mean (min-max)**	**Mean (min-max)**
GNDVI (index 0-1)	0.41 ± 0.05 (0.32 – 0.63)	0.51 ± 0.08 (0.30 – 0.68)	0.46 ± 0.07 (0.30 – 0.68)
Elevation (m)	914 m ± 21 m (865 m – 933 m)	914 m ± 17 m (872 m – 931 m)	895 m ± 22 m (865 m – 933 m)
Slope (degrees)	5° ± 4° (0° – 25°)	6° ± 4° (0° – 22°)	5° ± 4° (0° – 37°)

at any time when temperatures were below 10° C, during severe weather, or when grass was wet with moisture accumulated from the previous night.

We banded all nestlings in Baird’s and grasshopper sparrow nests with a USGS aluminum band approximately two days before expected fledging to decrease risk of forced fledging. We also fitted two randomly selected nestlings from each nest with a VHF radio transmitter (PicoPip Ag337; 0.29 g, ~20-30-day battery-life; Lotek Wireless), using a leg-loop harness (Rappole and Tipton, 1991). We only attached transmitters to nestlings weighing more than 11 grams to ensure that the transmitter represented less than 5% percent of body weight (Aldridge & Brigham, 1988). Radio-tagged nestlings were tracked with a hand-held Yagi 3-element antennae and Lotek receivers (Lotek Wireless Inc., New Market, Canada). We then tracked each bird daily and recorded its location with a GPS unit. We tracked each individual until the bird died, the transmitter battery-life died, or until the bird departed from the study site for migration. We returned to recorded locations within two days to perform a habitat survey.

2.3.2.2. Habitat measurements

We completed habitat surveys at juvenile locations identified by radio telemetry, adult nesting locations, and random points. We measured vegetation at two random points within a realistic buffer for each location to define available habitat (Northrup et al., 2013). The distance of random points from used locations were assigned by a random draw from an age-specific lognormal distribution of movement distances defined by the average of observed distances between telemetry resightings on these sites in previous years from 2016 – 2017 (Fig. B.1). We used two different age-specific distributions to define availability (see results): 1-10 days out of the nest and >10 days out of the nest.

We generated random points with a random bearing at a random distance within the age-appropriate availability buffer for each day the bird was alive and out of the nest. To avoid risk of injury to fledglings with limited mobility (ages 1-10 days out of the nest), observers returned two days after the bird was located to perform habitat surveys. We only included bird locations where the bird was confirmed as live and out of the nest in analysis. We did not include data points where a bird was found dead because of potential displacement of the carcass by a predator following a depredation event. We also did not include juvenile locations where a bird was found dead due to exposure or unknown causes because of the risk of alternative habitat selection behaviors nearing death.

We collected 11 ground measurements within a 5-m radius of each bird or random location, including percent cover and height for live grass, dead grass, shrubs, and forbs; and percent cover for bare ground, vegetative litter, and exotic vegetation (Table 2.1). We considered crested wheatgrass (*Agropyron cristatum*), Kentucky bluegrass (*Poa pratensis*), western goatsbeard (*Tragopogon dubius*), yellow sweet clover (*Melilotus officinalis*), smooth brome (*Bromus inermis*), and vetches (*Vicia spp.*) to be invasive to this area (Ellis-Felege et al., 2013).

To investigate use of wetland areas by juveniles, we explored juvenile movement toward wetlands in each of the sparrow species through high-resolution spectral imagery collected from a small unmanned aircraft system (UAS) to identify areas of dense vegetation surrounding wetlands. We piloted an eBee Plus fixed-wing drone (senseFly, Switzerland) equipped with specialized cameras over all study sites to collect spectral reflectance data. Spectral data included bandwidths within the visible light spectrum (red, green, blue) using a Sensor Optimized for Drone Applications (SODA; senseFly, Switzerland), which rendered rasters produced from collected imagery at a resolution of 2-4 cm depending on altitude flown. We also recorded data containing four spectral bands including visible green, visible red, red edge, and near infrared (ranging from wavelengths 550-790 nanometers) using a Parrot Sequoia (Parrot SA, Paris, France) sensor, which rendered rasters produced from collected imagery at a resolution of 11-15 cm depending on altitude flown. We collected data three times during the season at each study site (approximately every 30 days) from mid-May through early August in 2018 to control for phenological changes in the habitat (Cunliffe et al., 2016; Lu and He, 2017). We used Pix4D imagery processing software, (version 4.1, Pix4D SA, Lausanne, Switzerland) to align georeferenced images (raster images associated with spatial locations), generate point clouds, create orthomosaics and create Digital Surface Models (DSM) from these UAS-collected data. We used a Trimble R2 (Trimble, Sunnyvale, California) to collect ground control points that were later included in the photogrammetry process to correct georeferenced images to sub-decimeter accuracy.

2.3.2.3. Imagery processing

With UAS-derived data, we calculated elevation, slope, and the green normalized difference vegetation index (GNDVI) to evaluate the amount of live vegetation on the ground using the formula $(R_{NIR}-R_{VISG}) / (R_{NIR}+R_{VISG})$ (Gitelson et al., 1996). The GNDVI correlates with the amount of infrared and green light reflected by chlorophyll. Low GNDVI values therefore correspond to unvegetated or dead vegetation cover, and high values correspond to the presence of live vegetation (Beeri et al., 2007; Geipel and Korsaeth, 2017). Certain SVIs can successfully quantify moisture and delineate areas that are vegetated versus unvegetated (Von Bueren et al., 2015). We used the Green

Normalized Vegetation Index (GNDVI) as a proxy for measuring densely vegetated areas surrounding wetlands due to its high performance in predicting wetland vegetation in similar habitat types (Taddeo et al., 2019a, 2019b). We extracted the mean GNDVI values for each data point (juvenile used points, random points, and adult nest sites) by creating a 5m radius buffer around all points using ArcMap 10.6 (ESRI, Redlands, CA). To make spectral data comparable with ground-collected data for juvenile use and random points, we extracted spectral data collected closest to the date that ground measurements were collected. For nest sites, we used spectral data collected at the time nests were initiated by adults. Initiation dates were determined by back dating from hatch date, nestling age, clutch size, and lay period. For nests with inconclusive hatch dates or nestling age, we defined nest initiation date as the last date prior to nest failure minus the maximum interval for laying and incubation (~13 days). We calculated elevation and slope at each point from flights conducted during the beginning of the season to minimize inaccuracy introduced by vegetation.

2.3.3. Statistical Analyses

We characterized juvenile habitat selection using three datasets for each species. 1) We characterized juvenile habitat selection by comparing juvenile used points with random points available on the landscape (hereafter referred to as the use-availability datasets); 2) we compared habitat use during different stages of the breeding period by comparing pools of juvenile used points with those of nest sites selected by adults (hereafter referred to as the juvenile-adult use datasets); and 3) we tested whether juveniles disperse toward wetlands following fledging using only juvenile locations. We used Program R 3.6.2 (R Development Core Team 2018) for all data management purposes and subsequent statistical analyses.

Prior to model selection on all three data sets, we eliminated uninformative variables and tested for multicollinearity and quadratic effects among our candidate predictors. We considered variables uninformative if >80% of data points were equal to zero. To reduce issues posed by collinearity in our model comparisons, we quantified Variance Inflation Factors (VIF) for all variables in the global model for each dataset and considered variables collinear if they surpassed a threshold of VIF = 2. Where pairs of variables had VIF values > 2, we removed the variable from that pair having the highest VIF (O'Brien 2007). As grassland birds may select habitat at intermediate values or beyond a certain threshold (Ruth and Skagen, 2017; Schaub et al., 2010; Sliwinski and Koper, 2015; Williams and Boyle, 2018; Winter et al., 2005) the relationship between use and habitat characteristics may be curvilinear. To test for these non-linear relationships, we compared univariate and quadratic models of each variable as predictors of habitat selection using Akaike's Information Criterion corrected for small sizes (AIC_C; Akaike, 1974) prior to our complete model selection. For each variable, we retained the linear and quadratic form as candidate variables in the full model selection if the quadratic outperformed the linear by 2.0 AIC_C. If the linear and quadratic models were equivalent or the linear outperformed the quadratic by 2.0 AIC_C units, we included only the linear term in our full model set.

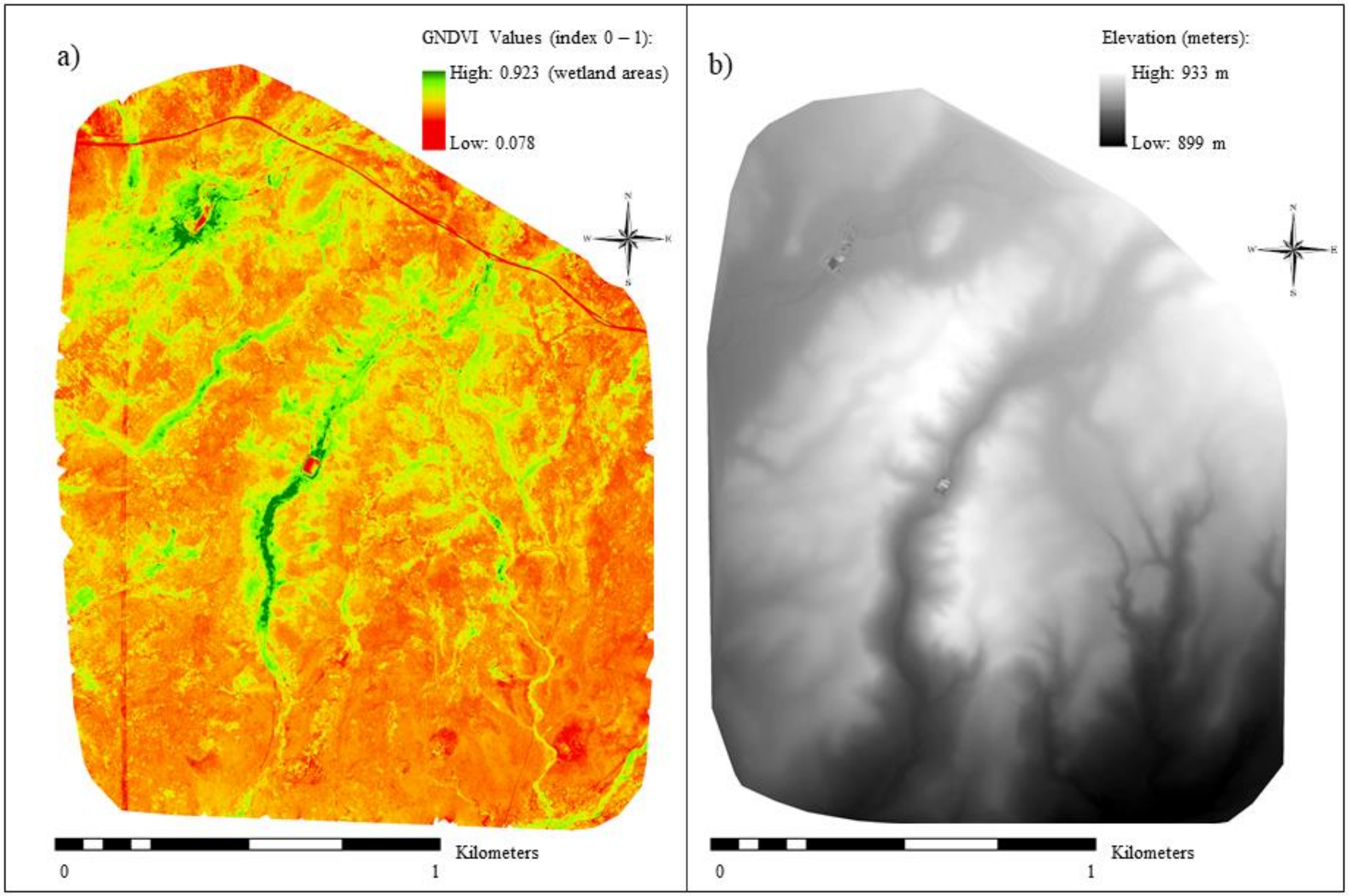

Figure 2.2. Wetland areas at study site in the Northern Great Plains, USA. An example of raster imagery produced using Unmanned Aircraft Systems measuring the Green Normalized Vegetation Index (GNDVI: a) and elevation (b) of grasslands on the Bureau of Land Management, Montana, USA 2018. Wetland vegetation and areas with the highest GNDVI values are shown in dark green. Red spots centered within dark green areas are water bodies.

For the use-availability and juvenile-adult use datasets, we used an information theoretic approach AIC_C to test which combinations of our predictor variables best explain variation in habitat use in juvenile Baird's and grasshopper sparrows. We created generalized linear models (GLMs) in fully balanced candidate model sets using the MuMIn package (R package version 3.6.2.). We considered models within 2.0 AIC_C as equivalent and interpreted Akaike weights (w_i; Burnham & Anderson, 2002). We considered variables in our top model sets to be informative only where confidence intervals do not overlap zero. We reported parameter estimates (β), standard errors (SE) and 95% confidence intervals for each model included in top models sets. We interpreted our results based on the top model ($\Delta AIC_C = 0$) when model comparisons produced only one top model for the criteria we chose, or, where only the top model included informative variables where confidence intervals did not overlap zero. For model comparisons where models aside from the top model set included informative variables that differed from the top model, we discuss support for each model in terms of AIC model weights (w_i).

To evaluate the relationship between juvenile dispersal patterns and wetland areas, we used a linear model to test whether fledgling age (in days) was predicted by GNDVI values used as a proxy for wetlands (Fig. 2.2). The model included an interaction term between GNDVI and elevation to test whether effects of wetland areas varied with high or low elevations. To perform analysis with normally distributed independent variables, we scaled and centered elevation and GNDVI values separately for each study plot.

2.4. Results

2.4.1. Field Data Collection

We located 150 Baird's sparrow and 201 grasshopper sparrow nests and fitted 43 fledgling Baird's sparrows and 31 fledgling grasshopper sparrows with radio transmitters. Our final dataset included 385 used data points (173 and 212 for Baird's and grasshopper sparrows, respectively) and 770 random data points (346 and 424 for Baird's and grasshopper sparrows, respectively). Daily movement distances of recently fledged sparrows increased with age (Fig. B.1). We calculated and used two age-dependent buffers to assign random points based from average movements for birds 1-10 days fledged from the nest and for birds >10 days fledged from the nest (Fig. B.1). From days 1-10, juvenile sparrows on average moved 40 m per day (SD = 27m; range = 2 – 142 m). From days 11-20, juvenile sparrows on average moved 93m per day (SD = 75m; range = 2 – 351m).

2.4.2. Statistical Analyses

We did not include shrub or shrub height in our analyses because these measurements were uninformative, and we removed live grass cover because it produced elevated VIF values that indicated multicollinearity with bare ground when combined in the same model for each dataset (live grass cover: VIF = 11 in use-availability and VIF = 55 in juvenile-adult use for Baird's sparrow; bare ground: VIF = 8 in use-availability and VIF = 18 in juvenile-adult use for grasshopper sparrow). When only bare ground cover was included in the above-mentioned models, VIF values were < 2 for all variables included in global models for each dataset. In the univariate comparisons for each habitat variable, the quadratic relationship performed better than their linear counterparts ($\Delta AIC_C \geq 2$) for dead grass, litter cover, forb cover, bare ground, grass height and GNDVI in the Baird's sparrow use-availability dataset and litter cover and GNDVI in the Grasshopper juvenile-adult use dataset. We report parameter estimates, standard errors, 95% CIs, AIC_C values, ΔAIC_C values, and AIC model weights (w_i) for the top models included in model comparisons performed for each dataset (Tables 2.2 – 2.3).

Table 2.2. Model selection results for habitat selection of juvenile sparrows. Probability of habitat use of juvenile Baird's sparrows and grasshopper sparrows is compared with habitat available in the Northern Great Plains, USA, 2018.

Species	Model parameter	Estimate	SE	LCL	UCL	*K*	AIC$_c$	Δ AIC$_c$	w_i
						Model Selection*			
Baird's sparrow	1					7	692.997	0.000	0.201
	intercept	-0.304	0.152	-0.601	-0.003				
	GNDVI	0.322	0.131	0.068	0.582				
	GNDVI^2	-0.162	0.070	-0.310	-0.034				
	dead grass cover	0.425	0.124	0.185	0.673				
	dead grass cover^2	-0.238	0.094	-0.427	-0.059				
	forb cover	0.400	0.142	0.125	0.682				
	forb cover^2	-0.269	0.103	-0.486	-0.085				
Grasshopper sparrow	1					3	830.098	0.000	0.070
	intercept	-0.803	0.084	-0.970	-0.639				
	forb cover	0.229	0.084	0.065	0.394				
	grass height	0.302	0.086	0.135	0.472				
	2					4	831.758	1.660	0.030
	intercept	-0.804	0.085	-0.971	-0.640				
	bare ground	-0.056	0.094	-0.244	0.124				
	forb cover	0.222	0.084	0.057	0.388				
	grass height	0.286	0.090	0.111	0.463				
	3					4	831.943	1.844	0.028
	intercept	-0.803	0.084	-0.970	-0.639				
	forb cover	0.227	0.084	0.064	0.392				
	grass height	0.297	0.087	0.128	0.468				
	slope	0.035	0.084	-0.130	0.199				
	4					4	832.023	1.924	0.027
	intercept	-0.803	0.084	-0.970	-0.639				
	forb cover	0.233	0.084	0.067	0.399				
	grass height	0.301	0.086	0.134	0.471				
	litter cover	0.027	0.084	-0.143	0.190				
	5					4	832.043	1.944	0.026
	intercept	-0.803	0.084	-0.970	-0.639				
	exotic vegetation	-0.026	0.091	-0.204	0.154				
	forb cover	0.222	0.087	0.053	0.393				
	grass height	0.307	0.088	0.136	0.481				

*The model selection metrics are the number of parameters (K), Akaike Information Criterion adjusted for sample size (AIC$_c$), difference between model and minimum AIC$_c$ values (Δ AIC$_c$) and AIC$_c$ weight (w_i). Models with Δ AIC$_c$ < 2 are shown.

Table 2.3. Model selection results for juvenile use and nest sites. Habitat use of juvenile Baird's sparrows and grasshopper sparrows is compared with adult nest sites in the Northern Great Plains, USA in 2018.

Species	Model parameter	Estimate	SE	LCL	UCL	Model Selection* *K*	AIC$_c$	Δ AIC$_c$	w_i
Baird's sparrow	1					5	182.550	0.000	0.130
	intercept	1.861	0.238	1.427	2.369				
	GNDVI	-0.504	0.199	-0.915	-0.127				
	forb cover	0.690	0.306	0.131	1.346				
	grass height	0.695	0.243	0.249	1.207				
	2					5	182.656	0.106	0.124
	intercept	1.844	0.238	1.411	2.352				
	GNDVI	-0.398	0.186	-0.777	-0.042				
	exotic vegetation	-0.383	0.170	-0.732	-0.056				
	bare ground	0.955	0.298	0.422	1.601				
	forb cover	0.550	0.244	0.101	1.062				
	3					5	184.471	1.921	0.050
	intercept	1.746	0.214	1.349	2.193				
	GNDVI	-0.550	0.200	-0.961	-0.173				
	exotic vegetation	-0.340	0.169	-0.682	-0.011				
	forb cover	0.423	0.231	-0.006	0.907				
	grass height	-0.682	0.198	-1.085	-0.301				
	4					5	184.489	1.940	0.050
	intercept	1.869	0.243	1.429	2.390				
	elevation	-0.409	0.226	-0.870	0.021				
	GNDVI	-0.511	0.199	-0.916	-0.128				
	bare ground	0.970	0.296	0.439	1.612				
	forb cover	0.571	0.245	0.120	1.087				
Grasshopper sparrow	1					5	197.853	0.000	0.96
	intercept	1.828	0.279	1.310	2.410				
	elevation	1.240	0.233	0.811	1.730				
	GNDVI	2.150	0.403	1.436	3.024				
	GNDVI^2	0.634	0.273	0.146	1.231				
	exotic vegetation	-1.099	0.254	-1.628	-0.628				

*The model selection metrics are the number of parameters (K), Akaike Information Criterion adjusted for sample size (AIC$_c$), difference between model and minimum AIC$_c$ values (Δ AIC$_c$) and AIC$_c$ weight (w_i). Models with Δ AIC$_c$ < 2 are shown.

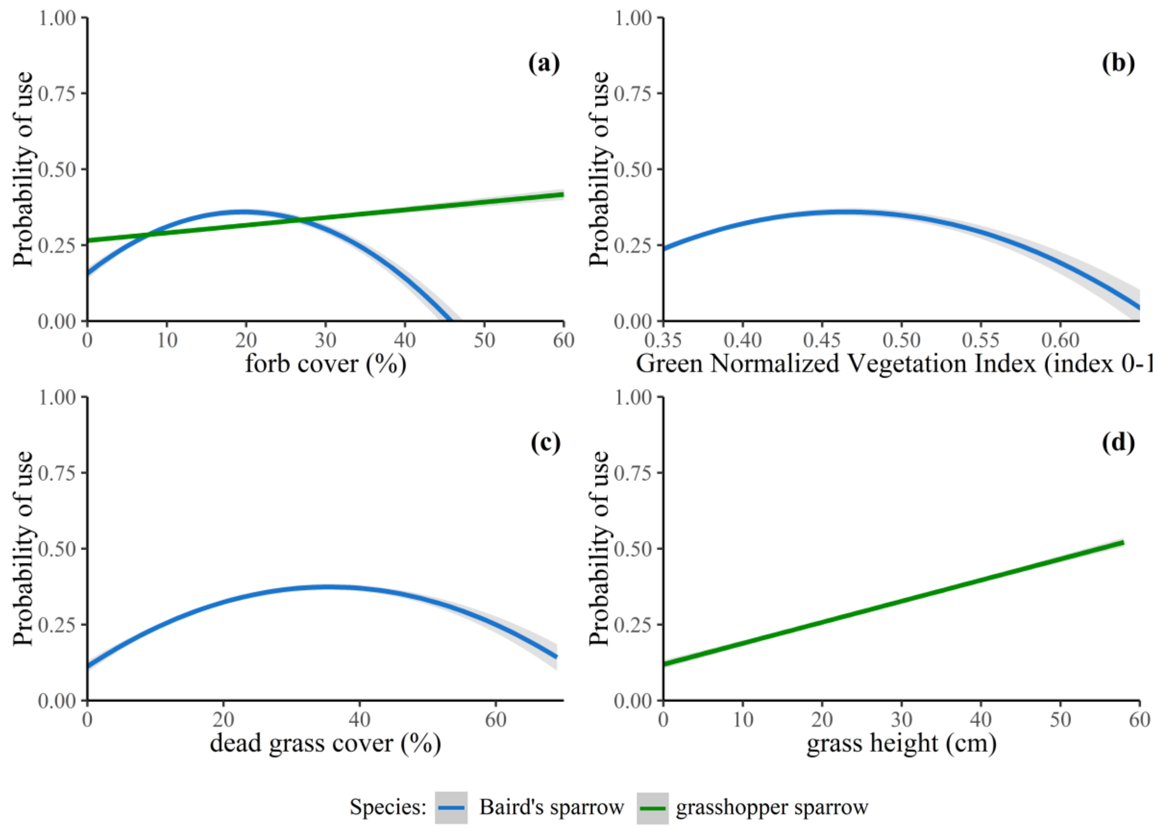

Figure 2.3. Habitat selection by juvenile Baird’s and grasshopper sparrows. Probability of habitat use compared with habitat available by juvenile Baird’s and grasshopper sparrows in the Northern Great Plains, USA, 2018.

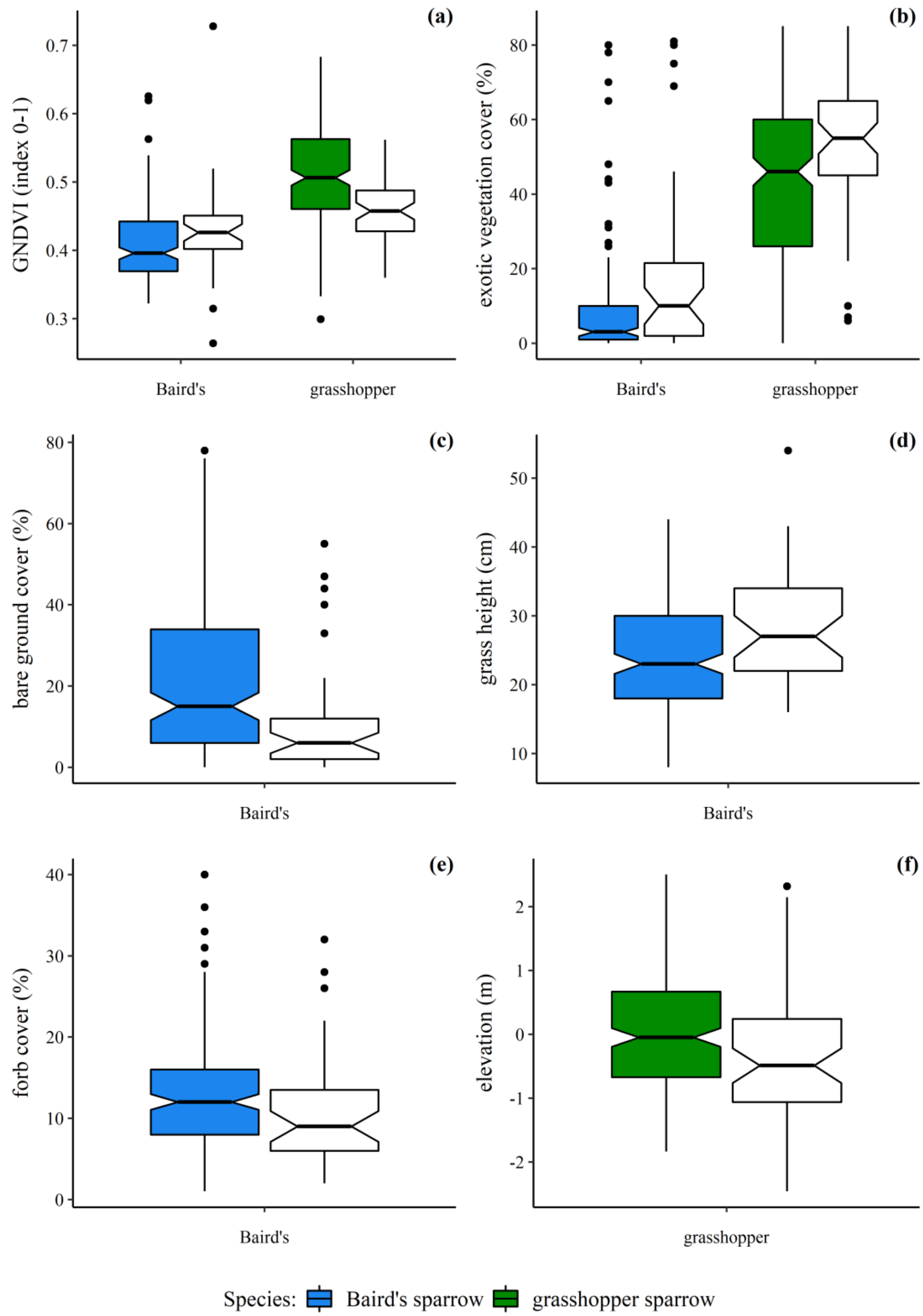

Figure 2.4. Comparison of juvenile and adult habitat use. Colored boxplots represent juvenile used locations and white boxplots represent nest sites.

2.4.2.1. Juvenile habitat selection

We found that juvenile Baird's sparrows selected for an intermediate range of forb cover, dead grass, and GNDVI (all quadratic effects; Table 2.2). Dead grass cover had the largest effect on probability of habitat use followed by forb cover and GNDVI (Fig. 2.3A-C). Juveniles were most likely to be found in 36% cover forbs, 20% cover dead grass, and a GNDVI value of 0.46 (range; 0 – 1) (Fig. 2.3A – C). We found that juvenile grasshopper sparrows selected for increased amounts of forb cover and grass height (Table 2.2). Grass height had the largest effect size and appeared in every top model in combination with forb cover (Table 2.2). Probability of habitat use by juveniles increased as forb cover and grass height increased (Fig. 2.3A & 2.3E).

2.4.2.2. Juvenile habitat use and nest site selection

For Baird's sparrows, our top model demonstrates that juveniles used points with lower GNDVI values, shorter grass heights, and more forb cover compared to nest sites selected by adults (Table 2.3; Fig. 2.3A, 2.3D & 2.3E). The second top model in our top model set has nearly equivalent support (w_i = 0.12) with our first top model (w_i = 0.13) and indicates that juveniles used less exotic vegetation cover and more bare ground (Table 2.3; Fig. 2.3B & 2.3C) in combination with more forb cover and less GNDVI compared with nest sites. Our third and fourth models each had equivalent, yet relatively little support (w_i = 0.05), thus we did not consider variables for either model as informative. For grasshopper sparrows, juveniles used higher GNDVI values, less exotic vegetation cover, and higher elevation than were present at nest sites (Table 2.3; Fig. 2.3A, 2.3B, & 2.3F). For both species, dead grass cover, litter cover, and forb height did not vary between juvenile locations and nest sites (Table 2.3). Additionally, for grasshopper sparrows there were no differences in coverage of bare ground and grass height, and for Baird's sparrows there were no differences in elevation (Table 2.3).

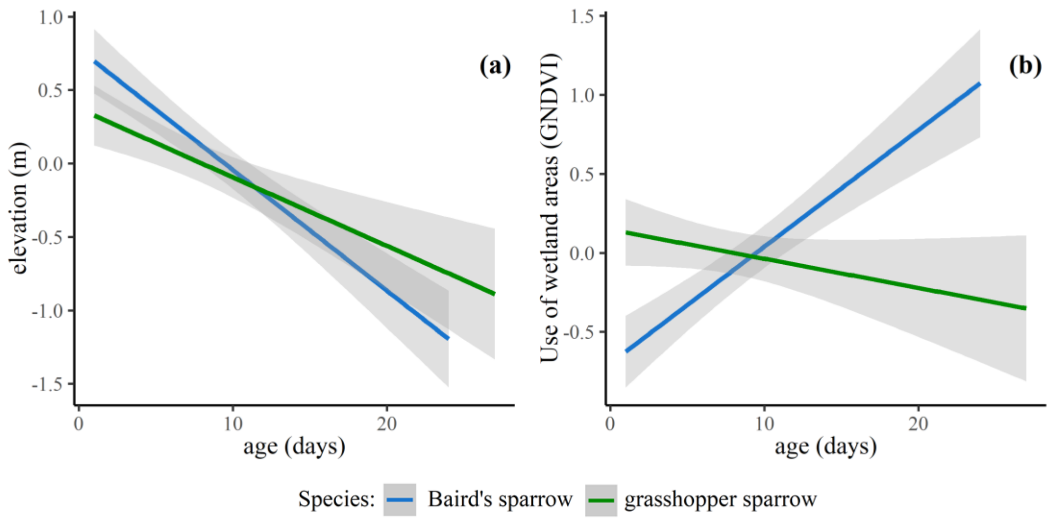

Figure 2.5. Juvenile sparrow movements associated with wetlands and elevation.

2.4.2.3. Juvenile dispersal patterns

After leaving their nests, juvenile Baird's and grasshopper sparrows moved toward areas of lower elevation and only juvenile Baird's sparrows moved toward wetland areas (Fig. B.3 – B.4) Our models for greenness, or GNDVI, combined with elevation were related to juvenile bird age in both Baird's ($P < 0.0001$, $R^2 = 0.34$) and grasshopper sparrows ($P < 0.0001$, $R^2 = 0.16$). Greenness increased with increasing juvenile age in Baird's sparrows (β = 1.682, 95% CI = 0.748 – 2.615, $P = 0.0005$; Fig. 2.5) but decreased in grasshopper sparrows (β = -1.586, 95% CI = -2.427 – -0.745, $P = 0.0003$; Fig. 2.5). Elevation decreased with increasing juvenile age in both Baird's sparrows (β = -2.501, 95% CI = -3.383 – -1.618, $P < 0.0001$; Fig. 2.5) and grasshopper sparrows (β = -2.019, 95% CI = -2.932 – -1.105, $P < 0.0001$; Fig. 2.5). The interaction term between GNDVI and elevation was not significant in Baird's sparrows (β = -0.320, 95% CI = -1.181 – 0.541, $P = 0.4640$) and only marginally significant in grasshopper sparrows (β = 0.691, 95% CI = 0.011 – 1.369, *P* = 0.0462). The majority of our grasshopper sparrow juvenile sample were in North Dakota where average GNDVI of used (x = 0.509, SD = 0.077, range: 0.299 – 0.683) and random points (x = 0.500, SD = 0.072, range: 0.288 – 0.688) were slightly higher than our Baird's sparrow juvenile sample (Fig. B.2), which occurred only in Montana (used points: x = 0.408, SD = 0.053, range: 0.322 – 0.628; random points: x = 0.402, SD = 0.061, range: 0.314 – 0.665).

2.5. Discussion

Understanding habitat use across multiple life stages is necessary to lessen and reverse decline in grassland bird populations. We found that in Baird's and grasshopper sparrows in the Northern Great Plains, juveniles selected sites with intermediate to high forb cover and that Baird's sparrows also moved towards densely vegetated areas (e.g. wetlands) after they left the nest. Further, juveniles of both species selected habitat different from 1) what was available on the landscape, and 2) nest sites of the same species, demonstrating that juveniles use habitat specific to this life stage. Juvenile selection for dead grass cover, grass height, greenness (GNDVI), elevation, bare ground cover, and exotic vegetation varied between species but were also influential. We found that, unlike other life stages, habitat is influential for the post-fledge stage in the life cycle for Baird's and grasshopper sparrows. Fortunately, management for habitat is one of the most accessible methods of improving vital rates for grassland birds, thus should be well-considered by managers. However, if habitat for only one stage is managed for in these two species, then managers are not optimizing successful breeding for birds. Attention to these two stages of the reproductive cycle that together produce successful young will strengthen management practices that aim to provide suitable breeding habitat for grassland birds in the Northern Great Plains.

Forb cover was influential for habitat selection in juvenile sparrows of both species. Juvenile Baird's sparrows used locations with intermediate forb cover, while grasshopper sparrows used locations with higher forb cover. Both species likely use forb cover because it increases habitat complexity. Forbs, compared with other vegetation on this landscape, offer considerably more camouflage because their leaf arrangements generate high contrast patterns and cast shadows that possibly disturb visual cues used by aerial predators (Bowman and Harris, 1980; Fogarty et al., 2017; Pearson and Knapp, 2016). Using forbs for camouflage may be a strategy particularly effective for juvenile birds that have reduced mobility and are extremely vulnerable to predators. Our results are consistent with juveniles of the eastern grasshopper sparrow *(Ammodramus savannarum pratensis)* subspecies and juveniles of other grassland birds including Henslow's sparrow *(Ammodramus henslowii)* and Sprague's pipit *(Anthus spragueii)* that selected for high forb cover as well (Fisher and Davis, 2011b; Small et al., 2015; Young et al., 2019). Juvenile Baird's sparrows only used intermediate ranges of forb cover. Forbs that are ubiquitous on this landscape include short perennials like pussytoes (*Antennaria plantaginifolia*) having leaves that are compressed to the ground and do not provide enough cover to protect young Baird's sparrows from predators. Conversely, forbs that are too tall may be problematic for mobility of young Baird's sparrows of that are reliant on locomotion from the ground.

Juvenile Baird's sparrows used only intermediate ranges for all vegetation cover that was influential for habitat selection (e.g. forbs and dead grass) compared with grasshopper sparrows that used increasing amounts of vegetation cover (e.g. high forb cover and tall grass). This disparity implies that juvenile Baird's sparrows use a narrower range of habitat features compared with what is available, where juvenile grasshopper sparrows use these habitat features as it increasingly becomes available to them. The discrepancy may be reflective of habitat use patterns in adults for each of these species. Although we did not measure habitat used by adults of either species at our own study sites, it has been shown in the Northern Great Plains that adult Baird's sparrows prefer grasslands with patchy bare ground and adult grasshopper sparrows prefer areas with taller vegetation and less bare ground (Ahlering, 2005; Ahlering et al., 2009; Jones et al., 2010), though habitat use quite variable for grasshopper sparrow depending on the region they are found. Baird's sparrows are highly specialized and range restricted to the Northern Great Plains during the breeding season, however grasshopper sparrows are much more widely distributed (Fig. 2.1) across North America utilizing shrub steppe, native fields, non-native, fields, palmetto-wiregrass prairie, coastal dunes, and other herbaceous landscapes (Vickery 2020). We found that habitat selection by juvenile grasshopper sparrows was similar to adult grasshopper sparrows in the Northern Great Plains preferring areas with taller vegetation. Similarly, juvenile Baird's sparrows were found in areas with more bare ground and shorter grass, habitat features also characteristic of areas used by adult Baird's sparrows during the breeding season. It is possible that juvenile Baird's sparrow use of intermediate vegetation cover mirrors the narrower constraints of preferred habitat at the species range scale and the adult microhabitat use scale compared with grasshopper sparrows.

Juvenile Baird's sparrows may also use intermediate ranges of vegetation as means of thermoregulation in response to increased sun exposure or wet, cold conditions from storms. Baird's sparrows selected for intermediate dead grass cover and values of

GNDVI, a measure of the composition of live and non-photosynthetic material on the landscape (Yang and Guo, 2014, Chapter 1). Weather can shift dramatically in grasslands, ranging from extreme heat to heavy precipitation to high winds, all within a matter of hours. Dead grass and other non-photosynthetic features retain more heat than live grass (Lagouarde et al., 1995; Mihalakakou, 2002; Monteith and Szeicz, 1961; Parton et al., 1993). Thus, juvenile birds may use intermediate ranges of dead grass or GNDVI as means of using the environment to adjust their own body temperatures in response to inclement weather that is highly variable.

Juvenile sparrows of both species also used certain habitat features differently compared with adult nest sites, demonstrating that within the reproductive cycle alone, habitat selection varies with specific life stages in these grassland species. Further, while both juvenile species selected for less exotic cover than nest sites, each species otherwise used different habitat characteristics than adults used at nest sites (Fig. 2.4). Juvenile grasshopper sparrows selected for less exotic vegetation cover, lower elevation, and higher GNDVI, while Baird’s sparrows selected for less exotic vegetation cover, higher cover of bare ground and forbs, shorter grass, and lower values of GNDVI. Juvenile Baird’s sparrows used more bare ground than was present at nest sites, perhaps because a nest placed near bare ground faces increased exposure to predators, but foraging for insects on bare ground is easier (for adults) than in dense grass (Ahlering et al., 2009; Schaub et al., 2010). Furthermore, juvenile Baird’s sparrows were found in shorter grass, which may also maximize their mobility compared with areas having tall grass. Means of food availability and predator avoidance likely influence habitat selection by juvenile sparrows during the post-fledging period. As juvenile birds shift from dependence on adults to independence, they must successfully forage on their own, which may explain juvenile Baird's sparrow increased use of shorter grass and open areas like bare ground where foraging may be more accessible (Fisher and Davis, 2011b).

Adult birds are typically thought to select nest sites for the purpose of nest survival, though some select sites to optimize post-fledgling survival, and some select nest sites to balance survival of both the nest and fledglings (Streby et al., 2014). Nest survival is lower in grasshopper sparrows (17%) compared with Baird's sparrows (41%) yet juvenile survival is higher in grasshopper sparrows (54%) compared with Baird's sparrows (23%) (Bernath-Plaisted et al., 2020, *in review*). Because we find some differences in habitat between juvenile used sites and nest sites, it is possible that those differences are selected for by adult Baird's and grasshopper sparrow to increase nest survival. However, our analysis for both species also showed that not all habitat features differed between juvenile locations and nest sites. Because nest survival is lower than juvenile survival in grasshopper sparrows and because apart from three habitat conditions, there were not many differences between juvenile habitat and nest sites (Fig. 2.4), it is possible that adult grasshopper sparrows select nest sites to increase juvenile survival. Contrarily, for Baird's sparrows where nest survival is higher than juvenile survival and where there are several habitat features that differ between adult nest sites and juvenile locations (Fig. 2.4), it is possible that adult selection pressure for nest sites is largely driven by increasing nest survival.

2.5.1. Importance of wetlands for juvenile grassland birds

We found strong patterns associated with juvenile movement towards wetlands and low elevation areas as fledglings aged and become independent from their parents.

Both juvenile Baird's and grasshopper sparrows moved towards lower elevations as they dispersed from the nest (Fig. 2.5A, Fig. B.3 – B.4), but only Baird's sparrows moved towards wetland areas (Fig. 2.5B, Fig. B.3), often eventually arriving at the dense, tall, and live vegetation immediately surrounding wetlands (Fig. 2.2).

Adults sparrows likely avoid placing nests near wetland or lowland areas because they are often frequented by meso-mammalian predators (Fogarty et al., 2017; Pietz and Granfors, 2000) even though wetlands are likely a rich food source because insect abundance is linked to primary productivity and moisture in grasslands (Barnett and Facey, 2016; Branson and Vermeire, 2016). Because our results show that juvenile Baird's sparrows use wetland areas as they grow older and can fly, the optimized foraging opportunities provided by wetlands (Dahl, 2014) likely outweigh the risks associated with meso-mammalian predation. Similarly, it is possible that juveniles of both species use lower elevations because the risk of predation by mammalian predators is outweighed by foraging opportunities or the ability to hide from aerial predators at higher elevations. There are several explanations for the dissimilar patterns of juvenile movement toward wetlands in particular. One explanation refers to the concept that both species vary in degrees of habitat specialism to this region (Correll et al., 2019). Alternatively, species were heavily associated with study site where most grasshopper juveniles were monitored in North Dakota and all Baird's sparrows were monitored in Montana, thus habitat availability may have influenced dispersal patterns.

Specialists are often limited by certain aspects of their natural history including diet and morphology which subsequently influence habitat selection in many bird species (Hansen and Urban, 1992; Hanzelka and Reif, 2015; Julliard et al., 2006). For example, adults of both Baird's and grasshopper sparrows incorporate seeds and insects in their diet, however grasshopper sparrows are known to include a much higher degree of diversity within these food groups because their larger bills grant them accessibility to larger items compared with the smaller bill size of Baird's sparrows (Titulaer et al., 2018, 2017). Thus, even though the diets of juveniles in both of these species are largely comprised of insects (Maher, 1979), juvenile grasshopper sparrows may have a more diverse diet that is reflective of adults. We found that only juvenile Baird's sparrows move towards wetland areas as they age, likely because these areas provide an abundance of insects (Dahl, 2014) from which they may feed on insects specific to what their potentially narrower diet is comprised of. Conversely, the tendency for juvenile grasshopper sparrows to move toward wetlands is likely not as pertinent if grasshopper juveniles have increased foraging options given that they have a less constrained diet.

Alternatively, species was largely confounded with study site during the time we conducted our study. While we standardized greenness values across each plot, raw greenness values were higher at North Dakota sites where we monitored grasshopper sparrows than Montana sites where we monitored Baird's sparrows (Fig. B.2). Therefore, GNDVI may not have been as limiting at the North Dakota sites, and therefore not as limiting in our grasshopper sparrow dataset. We associate the highest GNDVI values with the dense, live vegetation surrounding wetlands (Fig. 2.2) also equivalent to these areas having higher biomass (Wang et al., 2005). Insect abundance is positively associated with increased biomass (Barnett and Facey, 2016), thus wetland areas (and areas with high GNDVI) are likely a rich food source in a semi-arid grassland landscape (Branson and Vermeire, 2016). However, at our Montana study site, areas with the highest GNDVI were centered around sparse wetland areas (Fig. B.3.A), whereas areas with higher GNDVI values were more available throughout the North Dakota study site (Fig. B.4.A). Thus, if increased GNDVI corresponds with potentially more food sources, it is likely that grasshopper sparrows in North Dakota do not have to seek wetland areas to forage where GNDVI is highest compared with how Baird's sparrow juveniles might do to optimize foraging in Montana.

Though Baird's sparrows may be found in these wetland areas, it is important to speculate whether wetlands are conducive for survival. Often, habitat that is frequently occupied or used by animals can be misleading and is not representative of the negative demographic consequences associated with those habitats (e.g. ecological traps; Bernath-Plaisted and Koper, 2016; Herse et al., 2017; Latif et al., 2011; Perlut et al., 2008; Pintaric et al., 2019). Juvenile survival is lower in Baird's sparrows compared with grasshopper sparrows (Bernath-Plaisted et al., *in review*) in the Northern Great Plains. We found that only Baird's sparrows moved toward wetland areas during the post-fledge period. However, we find that juveniles Baird's sparrows frequent wetlands (areas with the highest GNDVI values; > 0.7) when they are at least 15 days old (Fig. 2.5). Mortality is highest in juveniles approximately within the first six days of leaving the nest (Fig. B.5), a common pattern consistent with fledgling of other grassland birds (Berkeley et al., 2007; Hovick et al., 2011; van Vliet et al., 2020; Young et al., 2019). Thus, during these first few days when fledglings are most susceptible to mortality, they are still within the vicinity of their nest sites (Fig. B.6), none of which were located in or near wetland areas. At the age juveniles are found in wetland areas, survival is high suggesting that increasing or maintaining these habitat features are a promising consideration for management strategies that aim to promote population growth for Baird's sparrows.

Maintenance of wetland areas for management purposes should be considered jointly with habitat that is also important for multiple grassland species and stages of the reproductive cycle. Because much of the important habitat described for breeding birds is based from nesting habitat, wetland and lowland areas are not currently highlighted in any management protocols for either species (Jones et al., 1998; Sliwinski and Koper, 2015). Wetland areas exist sporadically throughout the Northern Great Plains and should be maintained as such to prevent removal of the semi-arid, heterogenous areas used by many adult grassland birds for nesting (Davis, 2005), and should not be dramatically increased for the purpose of juvenile survival. Rather, it is important that these sparse wetlands are not altered or removed from this region, as they have been increasingly subject to since 1997 (Dahl, 2014). A defined amount of wetland areas that provides habitat for juvenile sparrows and also does not encroach on important habitat for adult birds and juveniles of other bird species is unknown and should be considered for future research efforts.

2.5.2. Conclusions

Our results emphasize the importance of considering the habitat needs of all life stages of songbirds breeding in the Northern Great Plains. We demonstrate that habitat use varies between different life stages and species of juvenile grassland birds co-existing in the Northern Great Plains. We therefore suggest that managers maintain heterogeneity on their land where habitat cover important to juveniles are available within a patch size of at least 10m to support the juvenile life stage of grassland birds. To support juvenile

Baird's sparrows specifically, managers should aim to maintain intermediate ranges of native forb cover, dead grass cover, and pockets of wetland areas. To support juvenile grasshopper sparrows, managers should aim to maintain ample forb cover and patches of taller grass. Because forb cover was important for juveniles of both species, we recommend that forb cover be prioritized to increase survival of multiple juvenile grassland birds. Patch-graze burning and rotational grazing have been shown to promote new growth of native grass and forb species in grasslands (Guttery et al., 2017; McNew et al., 2015; Sandercock et al., 2014).

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APPENDIX A: SUPPLEMENTARY MATERIAL FOR CHAPTER 1

Table A.1. Summary of nests discovered from 2016-2018.

Species	2016	**Year** 2017	2018	**Total**
Baird's sparrow	43	60	47	***150***
Grasshopper sparrow	78	48	75	***201***
Chestnut-collared longspur	107	150	213	***470***
Sprague's pipit	13	16	15	***44***

Table A.2. Model comparison of nest site selection in grassland bird community 2016 – 2018. The model selection metrics are the number of parameters (K), Akaike Information Criterion adjusted for sample size (AIC_c), difference between model and minimum AIC_c values (Δ AIC_c) and AIC_c weight (w_i). Models with Δ $AIC_c < 2$ are shown. Parameter estimates, standard errors (SE) and lower and upper 95% confidence limits (LCL and UCL, respectively) are included.

Model parameter	Estimate	SE	LCL	UCL	*K*	AIC_c	Δ AIC_c	w_i
1					11	3158.81	0.00	0.24
intercept	-0.147	0.082	-0.307	0.015				
bare ground$_{0.5m}$	0.141	0.088	-0.031	0.313				
bare ground$_{0.5m}^2$	-0.238	0.060	-0.359	-0.123				
vegetation height$_{0.5m}$	0.435	0.073	0.293	0.579				
vegetation height$_{0.5m}^2$	-0.166	0.041	-0.252	-0.089				
litter cover$_{0.5m}$	0.031	0.097	-0.159	0.221				
litter cover$_{0.5m}^2$	-0.054	0.034	-0.122	0.013				
forb height$_{10m}$	-0.147	0.058	-0.260	-0.034				
forb height$_{10m}^2$	-0.064	0.036	-0.140	-0.001				
vegetation density$_{10m}$	0.580	0.087	0.411	0.752				
vegetation density$_{10m}^2$	-0.391	0.058	-0.508	-0.281				
2					11	3160.31	1.50	0.12
intercept	-0.161	0.080	-0.317	-0.004				
bare ground$_{0.5m}$	0.178	0.086	0.011	0.346				
bare ground$_{0.5m}^2$	-0.248	0.060	-0.370	-0.133				
vegetation height$_{0.5m}$	0.438	0.075	0.293	0.585				
vegetation height$_{0.5m}^2$	-0.151	0.041	-0.237	-0.075				
forb height$_{10m}$	-0.111	0.062	-0.233	0.011				
forb height$_{10m}^2$	-0.052	0.037	-0.130	0.013				
grass height$_{10m}$	-0.083	0.062	-0.206	0.039				
grass height$_{10m}^2$	-0.039	0.036	-0.114	0.026				

Table A.2 Continued

	vegetation density$_{10m}$	0.644	0.084	0.481	0.809				
	vegetation density$_{10m}^2$	-0.411	0.057	-0.526	-0.302				
3						10	3160.36	1.55	0.11
	intercept	-0.176	0.077	-0.327	-0.024				
	bare ground$_{0.5m}$	0.146	0.088	-0.026	0.318				
	bare ground$_{0.5m}^2$	-0.244	0.060	-0.365	-0.129				
	vegetation height$_{0.5m}$	0.420	0.072	0.280	0.562				
	vegetation height$_{0.5m}^2$	-0.162	0.041	-0.247	-0.085				
	bare ground$_{10m}$	0.093	0.050	-0.006	0.191				
	forb height$_{10m}$	-0.127	0.058	-0.241	-0.012				
	forb height$_{10m}^2$	-0.067	0.036	-0.142	-0.003				
	vegetation density$_{10m}$	0.644	0.084	0.481	0.810				
	vegetation density$_{10m}^2$	-0.415	0.058	-0.531	-0.305				
4						11	3160.73	1.92	0.09
	intercept	-0.178	0.077	-0.329	-0.026				
	bare ground$_{0.5m}$	0.139	0.088	-0.033	0.311				
	bare ground$_{0.5m}^2$	-0.240	0.060	-0.362	-0.125				
	vegetation height$_{0.5m}$	0.427	0.072	0.286	0.569				
	vegetation height$_{0.5m}^2$	-0.162	0.041	-0.248	-0.086				
	bare ground$_{10m}$	0.095	0.050	-0.004	0.193				
	forb cover$_{10m}$	0.058	0.045	-0.031	0.145				
	forb height$_{10m}$	-0.137	0.059	-0.253	-0.022				
	forb height$_{10m}^2$	-0.068	0.036	-0.144	-0.005				
	vegetation density$_{10m}$	0.639	0.084	0.475	0.805				
	vegetation density$_{10m}^2$	-0.415	0.058	-0.531	-0.305				

Table A.3. Model comparison of nest site selection in Baird's sparrows 2016 – 2018. The model selection metrics are the number of parameters (K), Akaike Information Criterion adjusted for sample size (AIC_c), difference between model and minimum AIC_c values (ΔAIC_c) and AIC_c weight (w_i). Models with $\Delta AIC_c < 2$ are shown. Parameter estimates, standard errors (SE) and lower and upper 95% confidence limits (LCL and UCL, respectively) are included.

Model parameter	Estimate	SE	LCL	UCL	*K*	AIC_c	ΔAIC_c	w_i
1					10	481.123	0.000	0.279
intercept	-0.457	0.226	-0.900	-0.009				
bare ground$_{0.5m}$	-0.124	0.283	-0.684	0.429				
bare ground$_{0.5m}^2$	-0.606	0.295	-1.294	-0.117				
forb cover$_{0.5m}$	-0.493	0.149	-0.802	-0.217				
litter cover$_{0.5m}$	-0.824	0.234	-1.295	-0.374				
litter cover$_{0.5m}^2$	0.105	0.059	-0.015	0.219				
bare ground$_{10m}$	-0.343	0.152	-0.653	-0.056				
litter cover$_{10m}$	0.299	0.127	0.055	0.554				
vegetation density$_{10m}$	1.044	0.222	0.621	1.497				
vegetation density$_{10m}^2$	-0.433	0.120	-0.701	-0.233				
2					11	482.883	1.759	0.116
intercept	-0.275	0.244	-0.750	0.211				
bare ground$_{0.5m}$	-0.055	0.290	-0.629	0.511				
bare ground$_{0.5m}^2$	-0.600	0.310	-1.309	-0.089				
forb cover$_{0.5m}$	-0.498	0.149	-0.806	-0.219				
vegetation height$_{0.5m}$	0.542	0.242	0.071	1.025				
vegetation height$_{0.5m}^2$	-0.316	0.147	-0.614	-0.035				
litter cover$_{0.5m}$	-0.861	0.236	-1.336	-0.408				
litter cover$_{0.5m}^2$	0.098	0.060	-0.025	0.215				
litter cover$_{10m}$	0.356	0.128	0.112	0.616				
vegetation density$_{10m}$	0.860	0.240	0.400	1.344				
vegetation density$_{10m}^2$	-0.315	0.129	-0.598	-0.092				

Table A.4. Model comparison of nest site selection in chestnut-collared longspurs 2016 – 2018. The model selection metrics are the number of parameters (K), Akaike Information Criterion adjusted for sample size (AIC_c), difference between model and minimum AIC_c values (ΔAIC_c) and AIC_c weight (w_i). Models with $\Delta AIC_c < 2$ are shown. Parameter estimates, standard errors (SE) and lower and upper 95% confidence limits (LCL and UCL, respectively) are included.

Model parameter	Estimate	SE	LCL	UCL	*K*	AIC_c	ΔAIC_c	w_i
1					11	1707.31	0.00	0.77
intercept	-0.064	0.105	-0.269	0.144				
bare $ground_{0.5m}$	0.134	0.102	-0.067	0.334				
bare $ground_{0.5m}^2$	-0.273	0.076	-0.427	-0.127				
forb $cover_{0.5m}$	0.198	0.058	0.084	0.313				
vegetation $height_{0.5m}$	0.385	0.095	0.201	0.572				
vegetation $height_{0.5m}^2$	-0.124	0.053	-0.240	-0.028				
bare $ground_{10m}$	0.326	0.066	0.197	0.455				
forb $height_{10m}$	-0.255	0.084	-0.420	-0.091				
forb $height_{10m}^2$	-0.109	0.066	-0.247	0.007				
vegetation $density_{10m}$	0.449	0.118	0.220	0.682				
vegetation $density_{10m}^2$	-0.648	0.108	-0.872	-0.446				

Table A.5. Model comparison of nest site selection in grasshopper sparrows 2016 – 2018. The model selection metrics are the number of parameters (K), Information Criterion adjusted for sample size (AIC_c), difference between model and minimum AIC_c values (ΔAIC_c) and AIC_c weight (w_i). Models with $\Delta AIC_c < 2$ are shown. Parameter estimates, standard errors (SE) and lower and upper 95% confidence limits (LCL and UCL, respectively) are included.

Model parameter	Estimate	SE	LCL	UCL	K	AIC_c	ΔAIC_c	w_i
1					9	691.965	0.000	0.029
intercept	-0.459	0.126	-0.707	-0.213				
forb cover$_{0.5m}$	-0.172	0.100	-0.374	0.021				
vegetation height$_{0.5m}$	0.472	0.155	0.174	0.783				
vegetation height$_{0.5m}^2$	-0.214	0.084	-0.390	-0.060				
bare ground$_{10m}$	-0.229	0.131	-0.497	0.017				
grass height$_{10m}$	-0.101	0.135	-0.364	0.165				
grass height$_{10m}^2$	-0.098	0.083	-0.269	0.058				
vegetation density$_{10m}$	1.019	0.159	0.714	1.339				
vegetation density$_{10m}^2$	-0.271	0.068	-0.410	-0.143				
2					9	692.107	0.142	0.027
intercept	-0.393	0.162	-0.709	-0.073				
bare ground$_{0.5m}$	0.078	0.257	-0.428	0.582				
bare ground$_{0.5m}^2$	-0.237	0.167	-0.614	0.054				
forb cover$_{0.5m}$	-0.185	0.101	-0.387	0.009				
vegetation height$_{0.5m}$	0.383	0.154	0.084	0.691				
vegetation height$_{0.5m}^2$	-0.220	0.085	-0.398	-0.066				
bare ground$_{10m}$	-0.198	0.133	-0.472	0.053				
vegetation density$_{10m}$	1.010	0.166	0.691	1.343				
vegetation density$_{10m}^2$	-0.275	0.069	-0.416	-0.145				
3					11	692.134	0.169	0.027
intercept	-0.347	0.171	-0.682	-0.010				
bare ground$_{0.5m}$	0.073	0.258	-0.435	0.578				
bare ground$_{0.5m}^2$	-0.226	0.166	-0.599	0.065				
forb cover$_{0.5m}$	-0.187	0.101	-0.391	0.008				
vegetation height$_{0.5m}$	0.410	0.161	0.098	0.731				
vegetation height$_{0.5m}^2$	-0.191	0.085	-0.371	-0.034				
bare ground$_{10m}$	-0.212	0.136	-0.491	0.045				
grass height$_{10m}$	-0.083	0.135	-0.347	0.183				
grass height$_{10m}^2$	-0.102	0.084	-0.274	0.056				
vegetation density$_{10m}$	1.016	0.167	0.696	1.350				
vegetation density$_{10m}^2$	-0.265	0.069	-0.405	-0.135				
4					7	692.366	0.401	0.024
intercept	-0.506	0.115	-0.731	-0.282				
forb cover$_{0.5m}$	-0.169	0.100	-0.369	0.023				

Table A.5 Continued

vegetation height$_{0.5m}$	0.446	0.147	0.164	0.743				
vegetation height$_{0.5m}{}^2$	-0.246	0.083	-0.420	-0.095				
bare ground$_{10m}$	-0.213	0.127	-0.474	0.026				
vegetation density$_{10m}$	1.009	0.159	0.705	1.328				
vegetation density$_{10m}{}^2$	-0.281	0.068	-0.420	-0.152				
5					8	692.411	0.446	0.024
intercept	-0.391	0.162	-0.707	-0.072				
bare ground$_{0.5m}$	-0.010	0.250	-0.503	0.481				
bare ground$_{0.5m}{}^2$	-0.214	0.166	-0.589	0.074				
forb cover$_{0.5m}$	-0.194	0.100	-0.395	0.000				
vegetation height$_{0.5m}$	0.403	0.154	0.106	0.710				
vegetation height$_{0.5m}{}^2$	-0.228	0.083	-0.403	-0.077				
vegetation density$_{10m}$	1.020	0.166	0.701	1.354				
vegetation density$_{10m}{}^2$	-0.279	0.069	-0.420	-0.149				
6					10	692.635	0.670	0.021
intercept	-0.331	0.171	-0.664	0.006				
bare ground$_{0.5m}$	-0.015	0.252	-0.512	0.478				
bare ground$_{0.5m}{}^2$	-0.205	0.165	-0.576	0.084				
forb cover$_{0.5m}$	-0.195	0.101	-0.398	-0.001				
vegetation height$_{0.5m}$	0.421	0.161	0.109	0.742				
vegetation height$_{0.5m}{}^2$	-0.199	0.083	-0.375	-0.046				
grass height$_{10m}$	-0.045	0.132	-0.301	0.216				
grass height$_{10m}{}^2$	-0.117	0.084	-0.289	0.041				
vegetation density$_{10m}$	1.025	0.167	0.704	1.359				
vegetation density$_{10m}{}^2$	-0.269	0.069	-0.409	-0.138				
7					8	692.945	0.980	0.018
intercept	-0.446	0.125	-0.692	-0.200				
vegetation height$_{0.5m}$	0.491	0.154	0.195	0.801				
vegetation height$_{0.5m}{}^2$	-0.211	0.083	-0.386	-0.059				
bare ground$_{10m}$	-0.245	0.130	-0.512	0.000				
grass height$_{10m}$	-0.091	0.134	-0.353	0.174				
grass height$_{10m}{}^2$	-0.102	0.084	-0.273	0.055				
vegetation density$_{10m}$	0.954	0.154	0.659	1.264				
vegetation density$_{10m}{}^2$	-0.282	0.068	-0.422	-0.152				
8					8	693.208	1.243	0.016
intercept	-0.406	0.121	-0.644	-0.168				
forb cover$_{0.5m}$	-0.185	0.100	-0.385	0.007				
vegetation height$_{0.5m}$	0.491	0.155	0.194	0.802				
vegetation height$_{0.5m}{}^2$	-0.225	0.082	-0.398	-0.074				
grass height$_{10m}$	-0.053	0.131	-0.308	0.205				
grass height$_{10m}{}^2$	-0.118	0.083	-0.288	0.038				
vegetation density$_{10m}$	1.049	0.158	0.746	1.368				

Table A.5 Continued

vegetation density$_{10m}^{2}$	-0.280	0.068	-0.419	-0.151				
9					6	693.282	1.317	0.015
intercept	-0.495	0.114	-0.720	-0.272				
vegetation height$_{0.5m}$	0.469	0.147	0.188	0.763				
vegetation height$_{0.5m}^{2}$	-0.243	0.082	-0.416	-0.094				
bare ground$_{10m}$	-0.231	0.127	-0.491	0.008				
vegetation density$_{10m}$	0.946	0.154	0.651	1.255				
vegetation density$_{10m}^{2}$	-0.292	0.068	-0.432	-0.162				
10					9	693.312	1.347	0.015
intercept	-0.387	0.162	-0.703	-0.067				
bare ground$_{0.5m}$	0.026	0.253	-0.472	0.522				
bare ground$_{0.5m}^{2}$	-0.225	0.166	-0.599	0.064				
forb cover$_{0.5m}$	-0.188	0.101	-0.390	0.006				
vegetation height$_{0.5m}$	0.404	0.154	0.106	0.711				
vegetation height$_{0.5m}^{2}$	-0.224	0.083	-0.399	-0.073				
litter cover$_{10m}$	0.102	0.094	-0.085	0.286				
vegetation density$_{10m}$	1.037	0.167	0.715	1.372				
vegetation density$_{10m}^{2}$	-0.279	0.069	-0.421	-0.149				
11					9	693.328	1.363	0.015
intercept	-0.453	0.126	-0.700	-0.207				
vegetation height$_{0.5m}$	0.488	0.155	0.191	0.799				
vegetation height$_{0.5m}^{2}$	-0.212	0.083	-0.387	-0.060				
bare ground$_{10m}$	-0.242	0.129	-0.507	0.003				
forb cover$_{10m}$	-0.123	0.096	-0.316	0.062				
grass height$_{10m}$	-0.098	0.135	-0.363	0.168				
grass height$_{10m}^{2}$	-0.100	0.084	-0.271	0.057				
vegetation density$_{10m}$	0.966	0.155	0.670	1.277				
vegetation density$_{10m}^{2}$	-0.280	0.068	-0.419	-0.150				
12					6	693.342	1.377	0.015
intercept	-0.470	0.112	-0.689	-0.251				
forb cover$_{0.5m}$	-0.183	0.099	-0.382	0.008				
vegetation height$_{0.5m}$	0.477	0.147	0.196	0.772				
vegetation height$_{0.5m}^{2}$	-0.257	0.081	-0.429	-0.110				
vegetation density$_{10m}$	1.041	0.158	0.739	1.359				
vegetation density$_{10m}^{2}$	-0.290	0.068	-0.429	-0.161				
13					10	693.426	1.461	0.014
intercept	-0.462	0.126	-0.710	-0.215				
forb cover$_{0.5m}$	-0.146	0.106	-0.358	0.057				
vegetation height$_{0.5m}$	0.473	0.155	0.175	0.785				
vegetation height$_{0.5m}^{2}$	-0.214	0.083	-0.390	-0.061				
bare ground$_{10m}$	-0.229	0.130	-0.496	0.017				
forb cover$_{10m}$	-0.078	0.101	-0.281	0.117				
grass height$_{10m}$	-0.104	0.135	-0.369	0.163				

Table A.5 Continued

grass height$_{10m}^{2}$	-0.097	0.083	-0.268	0.059				
vegetation density$_{10m}$	1.016	0.159	0.711	1.336				
vegetation density$_{10m}^{2}$	-0.271	0.068	-0.410	-0.142				
14					8	693.536	1.571	0.013
intercept	-0.413	0.160	-0.726	-0.096				
bare ground$_{0.5m}$	0.016	0.254	-0.485	0.512				
bare ground$_{0.5m}^{2}$	-0.197	0.161	-0.561	0.085				
vegetation height$_{0.5m}$	0.410	0.153	0.114	0.715				
vegetation height$_{0.5m}^{2}$	-0.218	0.083	-0.394	-0.066				
bare ground$_{10m}$	-0.212	0.133	-0.484	0.038				
vegetation density$_{10m}$	0.931	0.160	0.623	1.251				
vegetation density$_{10m}^{2}$	-0.285	0.069	-0.427	-0.153				
15					10	693.547	1.582	0.013
intercept	-0.395	0.162	-0.713	-0.075				
bare ground$_{0.5m}$	0.073	0.257	-0.434	0.577				
bare ground$_{0.5m}^{2}$	-0.238	0.168	-0.617	0.054				
forb cover$_{0.5m}$	-0.159	0.106	-0.371	0.045				
vegetation height$_{0.5m}$	0.383	0.155	0.084	0.691				
vegetation height$_{0.5m}^{2}$	-0.220	0.084	-0.398	-0.066				
bare ground$_{10m}$	-0.197	0.133	-0.469	0.053				
forb cover$_{10m}$	-0.079	0.101	-0.282	0.116				
vegetation density$_{10m}$	1.006	0.166	0.686	1.339				
vegetation density$_{10m}^{2}$	-0.274	0.069	-0.415	-0.145				
16					10	693.582	1.617	0.013
intercept	-0.390	0.162	-0.706	-0.070				
bare ground$_{0.5m}$	0.096	0.258	-0.413	0.602				
bare ground$_{0.5m}^{2}$	-0.242	0.167	-0.619	0.049				
forb cover$_{0.5m}$	-0.182	0.101	-0.384	0.013				
vegetation height$_{0.5m}$	0.385	0.155	0.086	0.694				
vegetation height$_{0.5m}^{2}$	-0.218	0.084	-0.396	-0.064				
bare ground$_{10m}$	-0.177	0.136	-0.455	0.080				
litter cover$_{10m}$	0.074	0.096	-0.117	0.263				
vegetation density$_{10m}$	1.024	0.167	0.702	1.359				
vegetation density$_{10m}^{2}$	-0.276	0.069	-0.417	-0.146				
17					10	693.596	1.631	0.013
intercept	-0.363	0.169	-0.695	-0.030				
bare ground$_{0.5m}$	0.012	0.255	-0.491	0.510				
bare ground$_{0.5m}^{2}$	-0.186	0.161	-0.547	0.095				
vegetation height$_{0.5m}$	0.434	0.160	0.125	0.753				
vegetation height$_{0.5m}^{2}$	-0.190	0.084	-0.367	-0.035				
bare ground$_{10m}$	-0.224	0.135	-0.502	0.031				
grass height$_{10m}$	-0.074	0.134	-0.337	0.191				

Table A.5 Continued

grass height$_{10m}$^{2}	-0.106	0.084	-0.278	0.053				
vegetation density$_{10m}$	0.936	0.160	0.628	1.258				
vegetation density$_{10m}$^{2}	-0.275	0.069	-0.416	-0.143				
18					11	693.772	1.807	0.012
intercept	-0.365	0.170	-0.698	-0.030				
bare ground$_{0.5m}$	0.020	0.255	-0.485	0.519				
bare ground$_{0.5m}$^{2}	-0.197	0.163	-0.564	0.088				
vegetation height$_{0.5m}$	0.430	0.161	0.119	0.750				
vegetation height$_{0.5m}$^{2}	-0.191	0.084	-0.368	-0.035				
bare ground$_{10m}$	-0.221	0.135	-0.497	0.034				
forb cover$_{10m}$	-0.132	0.097	-0.327	0.055				
grass height$_{10m}$	-0.082	0.135	-0.346	0.185				
grass height$_{10m}$^{2}	-0.103	0.084	-0.276	0.055				
vegetation density$_{10m}$	0.949	0.161	0.640	1.273				
vegetation density$_{10m}$^{2}	-0.272	0.069	-0.413	-0.140				
19					7	693.779	1.814	0.012
intercept	-0.501	0.114	-0.725	-0.277				
vegetation height$_{0.5m}$	0.464	0.147	0.182	0.759				
vegetation height$_{0.5m}$^{2}	-0.244	0.082	-0.416	-0.095				
bare ground$_{10m}$	-0.226	0.126	-0.485	0.011				
forb cover$_{10m}$	-0.117	0.096	-0.309	0.067				
vegetation density$_{10m}$	0.956	0.154	0.661	1.266				
vegetation density$_{10m}$^{2}	-0.289	0.068	-0.429	-0.160				
20					11	693.807	1.842	0.012
intercept	-0.345	0.161	-0.662	-0.030				
forb cover$_{0.5m}$	-0.176	0.102	-0.381	0.021				
vegetation height$_{0.5m}$	0.492	0.155	0.193	0.803				
vegetation height$_{0.5m}$^{2}	-0.221	0.084	-0.398	-0.066				
litter cover$_{0.5m}$	0.095	0.218	-0.334	0.522				
litter cover$_{0.5m}$^{2}	-0.119	0.112	-0.341	0.098				
bare ground$_{10m}$	-0.230	0.131	-0.499	0.018				
grass height$_{10m}$	-0.100	0.135	-0.364	0.166				
grass height$_{10m}$^{2}	-0.105	0.084	-0.277	0.053				
vegetation density$_{10m}$	0.967	0.162	0.657	1.293				
vegetation density$_{10m}$^{2}	-0.255	0.069	-0.396	-0.125				
21					9	693.808	1.843	0.012
intercept	-0.412	0.161	-0.727	-0.094				
bare ground$_{0.5m}$	0.025	0.254	-0.477	0.522				
bare ground$_{0.5m}$^{2}	-0.208	0.164	-0.578	0.077				
vegetation height$_{0.5m}$	0.404	0.154	0.107	0.710				
vegetation height$_{0.5m}$^{2}	-0.219	0.083	-0.395	-0.066				
bare ground$_{10m}$	-0.208	0.132	-0.478	0.041				

Table A.5 Continued

forb cover$_{10m}$	-0.127	0.096	-0.321	0.058				
vegetation density$_{10m}$	0.943	0.161	0.635	1.265				
vegetation density$_{10m}^2$	-0.282	0.069	-0.424	-0.151				
22					11	693.817	1.852	0.012
intercept	-0.305	0.188	-0.673	0.065				
bare ground$_{0.5m}$	-0.039	0.256	-0.544	0.463				
bare ground$_{0.5m}^2$	-0.205	0.165	-0.576	0.082				
forb cover$_{0.5m}$	-0.194	0.102	-0.400	0.002				
vegetation height$_{0.5m}$	0.427	0.154	0.129	0.735				
vegetation height$_{0.5m}^2$	-0.233	0.084	-0.410	-0.081				
litter cover$_{0.5m}$	0.023	0.223	-0.416	0.459				
litter cover$_{0.5m}^2$	-0.117	0.110	-0.337	0.097				
litter cover$_{10m}$	0.168	0.105	-0.039	0.373				
vegetation density$_{10m}$	0.961	0.171	0.631	1.303				
vegetation density$_{10m}^2$	-0.257	0.070	-0.400	-0.125				
23					8	693.829	1.864	0.012
intercept	-0.509	0.115	-0.734	-0.285				
forb cover$_{0.5m}$	-0.165	0.100	-0.365	0.028				
vegetation height$_{0.5m}$	0.449	0.148	0.166	0.746				
vegetation height$_{0.5m}^2$	-0.243	0.082	-0.417	-0.093				
bare ground$_{10m}$	-0.190	0.130	-0.457	0.056				
litter cover$_{10m}$	0.074	0.096	-0.116	0.260				
vegetation density$_{10m}$	1.020	0.160	0.715	1.341				
vegetation density$_{10m}^2$	-0.281	0.068	-0.421	-0.153				
24					9	693.831	1.866	0.012
intercept	-0.394	0.162	-0.710	-0.074				
bare ground$_{0.5m}$	-0.015	0.251	-0.509	0.476				
bare ground$_{0.5m}^2$	-0.215	0.167	-0.592	0.074				
forb cover$_{0.5m}$	-0.168	0.105	-0.379	0.035				
vegetation height$_{0.5m}$	0.403	0.154	0.105	0.710				
vegetation height$_{0.5m}^2$	-0.228	0.083	-0.403	-0.077				
forb cover$_{10m}$	-0.080	0.101	-0.282	0.115				
vegetation density$_{10m}$	1.016	0.166	0.696	1.349				
vegetation density$_{10m}^2$	-0.278	0.069	-0.419	-0.148				
25					8	693.885	1.920	0.011
intercept	-0.507	0.115	-0.733	-0.283				
forb cover$_{0.5m}$	-0.145	0.105	-0.355	0.058				
vegetation height$_{0.5m}$	0.447	0.148	0.164	0.744				
vegetation height$_{0.5m}^2$	-0.246	0.082	-0.420	-0.096				
bare ground$_{10m}$	-0.213	0.127	-0.473	0.026				
forb cover$_{10m}$	-0.073	0.100	-0.274	0.121				
vegetation density$_{10m}$	1.006	0.159	0.702	1.325				

Table A.5 Continued

vegetation $density_{10m}^2$	-0.281	0.068	-0.420	-0.152				
26					10	693.927	1.962	0.011
intercept	-0.462	0.126	-0.710	-0.214				
forb $cover_{0.5m}$	-0.170	0.101	-0.372	0.023				
vegetation $height_{0.5m}$	0.472	0.155	0.174	0.783				
vegetation $height_{0.5m}^2$	-0.214	0.084	-0.390	-0.061				
bare $ground_{10m}$	-0.218	0.135	-0.494	0.037				
grass $height_{10m}$	-0.096	0.136	-0.361	0.172				
grass $height_{10m}^2$	-0.095	0.084	-0.267	0.061				
litter $cover_{10m}$	0.032	0.098	-0.164	0.223				
vegetation $density_{10m}$	1.023	0.160	0.717	1.344				
vegetation $density_{10m}^2$	-0.272	0.068	-0.411	-0.143				

Table A.6. Model comparison of nest site selection in Sprague's pipit 2016 – 2018. The model selection metrics are the number of parameters (K), Akaike Information Criterion adjusted for sample size (AIC_c), difference between model and minimum AIC_c values (ΔAIC_c) and AIC_c weight (w_i). Models with $\Delta AIC_c < 2$ are shown. Parameter estimates, standard errors (SE) and lower and upper 95% confidence limits (LCL and UCL, respectively) are included.

Model parameter	Estimate	SE	LCL	UCL	*K*	AIC_c	ΔAIC_c	w_i
1					3.00	173.51	0.00	0.25
intercept	-0.347	0.227	-0.797	0.096				
vegetation $density_{10m}$	0.908	0.385	0.176	1.701				
vegetation $density_{10m}^2$	-1.235	0.416	-2.188	-0.502				
2					4.00	173.74	0.23	0.23
intercept	-0.333	0.229	-0.786	0.115				
forb $cover_{10m}$	0.264	0.193	-0.113	0.648				
vegetation $density_{10m}$	0.943	0.386	0.208	1.736				
vegetation $density_{10m}^2$	-1.282	0.423	-2.259	-0.54				
3					4.00	175.43	1.92	0.10
intercept	-0.355	0.228	-0.806	0.089				
forb $cover_{0.5m}$	-0.086	0.198	-0.499	0.286				
vegetation $density_{10m}$	0.887	0.387	0.153	1.683				
vegetation $density_{10m}^2$	-1.216	0.413	-2.165	-0.488				
4					4.00	175.46	1.95	0.10
intercept	-0.338	0.228	-0.79	0.107				
bare $ground_{10m}$	0.08	0.197	-0.32	0.462				
vegetation $density_{10m}$	0.923	0.387	0.187	1.717				
vegetation $density_{10m}^2$	-1.253	0.419	-2.213	-0.514				

Table A.7. Model comparison of nest site selection in grassland bird community, 2018. The model selection metrics are the number of parameters (K), Akaike Information Criterion adjusted for sample size (AIC_c), difference between model and minimum AIC_c values (ΔAIC_c) and AIC_c weight (w_i). Models with $\Delta AIC_c < 2$ are shown. Parameter estimates, standard errors (SE) and lower and upper 95% confidence limits (LCL and UCL, respectively) are included.

Model parameter	Estimate	SE	LCL	UCL	*K*	AIC_c	ΔAIC_c	w_i
1					8	841.128	0.000	0.047
intercept	0.552	0.129	0.303	0.809				
$GNDVI_{10m}$	-0.437	0.105	-0.646	-0.233				
$GNDVI_{10m}^2$	-0.102	0.066	-0.235	0.024				
dead grass $cover_{10m}$	0.026	0.112	-0.194	0.245				
dead grass $cover_{10m}^2$	-0.163	0.068	-0.300	-0.031				
grass $height_{10m}$	-0.151	0.096	-0.341	0.037				
vegetation $density_{10m}$	1.095	0.132	0.841	1.360				
vegetation $density_{10m}^2$	-0.270	0.070	-0.416	-0.150				
2					9	841.492	0.364	0.039
intercept	0.568	0.130	0.317	0.825				
elevation	-0.113	0.088	-0.286	0.057				
$GNDVI_{10m}$	-0.446	0.106	-0.656	-0.241				
$GNDVI_{10m}^2$	-0.111	0.066	-0.245	0.016				
dead grass $cover_{10m}$	0.032	0.112	-0.189	0.252				
dead grass $cover_{10m}^2$	-0.167	0.069	-0.305	-0.035				
grass $height_{10m}$	-0.150	0.097	-0.340	0.039				
vegetation $density_{10m}$	1.126	0.135	0.868	1.396				
vegetation $density_{10m}^2$	-0.274	0.069	-0.419	-0.154				
3					7	841.551	0.422	0.038
intercept	0.540	0.128	0.292	0.795				
$GNDVI_{10m}$	-0.452	0.105	-0.661	-0.248				
$GNDVI_{10m}^2$	-0.097	0.065	-0.229	0.028				
dead grass $cover_{10m}$	0.008	0.111	-0.211	0.226				
dead grass $cover_{10m}^2$	-0.160	0.068	-0.297	-0.028				
vegetation $density_{10m}$	1.022	0.122	0.787	1.267				
vegetation $density_{10m}^2$	-0.263	0.069	-0.407	-0.145				
4					8	841.867	0.738	0.032
intercept	0.556	0.129	0.307	0.812				
elevation	-0.115	0.087	-0.287	0.056				
$GNDVI_{10m}$	-0.461	0.105	-0.670	-0.256				
$GNDVI_{10m}^2$	-0.107	0.066	-0.240	0.020				
dead grass $cover_{10m}$	0.015	0.112	-0.205	0.233				
dead grass $cover_{10m}^2$	-0.165	0.068	-0.302	-0.033				
vegetation $density_{10m}$	1.055	0.125	0.814	1.306				

Table A.7 Continued

vegetation density$_{10m}^2$	-0.267	0.068	-0.410	-0.149				
5					8	842.159	1.030	0.028
intercept	0.562	0.130	0.311	0.821				
GNDVI$_{10m}$	-0.404	0.112	-0.627	-0.187				
GNDVI$_{10m}^2$	-0.106	0.066	-0.238	0.021				
forb cover$_{10m}$	0.128	0.107	-0.081	0.340				
dead grass cover$_{10m}$	0.039	0.114	-0.185	0.263				
dead grass cover$_{10m}^2$	-0.158	0.068	-0.294	-0.026				
vegetation density$_{10m}$	1.082	0.133	0.826	1.348				
vegetation density$_{10m}^2$	-0.283	0.072	-0.432	-0.157				
6					9	842.568	1.440	0.023
intercept	0.550	0.129	0.301	0.807				
GNDVI$_{10m}$	-0.440	0.105	-0.650	-0.236				
GNDVI$_{10m}^2$	-0.100	0.066	-0.233	0.027				
dead grass cover$_{10m}$	0.050	0.116	-0.178	0.278				
dead grass cover$_{10m}^2$	-0.165	0.069	-0.302	-0.033				
forb cover$_{10m}$	0.070	0.089	-0.104	0.245				
grass height$_{10m}$	-0.154	0.097	-0.344	0.035				
vegetation density$_{10m}$	1.091	0.132	0.837	1.355				
vegetation density$_{10m}^2$	-0.267	0.069	-0.413	-0.148				
7					8	842.573	1.444	0.023
intercept	0.549	0.128	0.301	0.804				
GNDVI$_{10m}$	-0.441	0.106	-0.651	-0.236				
GNDVI$_{10m}^2$	-0.103	0.066	-0.236	0.024				
dead grass cover$_{10m}$	0.014	0.112	-0.205	0.233				
dead grass cover$_{10m}^2$	-0.163	0.068	-0.301	-0.031				
forb height$_{10m}$	-0.094	0.093	-0.277	0.088				
vegetation density$_{10m}$	1.055	0.127	0.811	1.311				
vegetation density$_{10m}^2$	-0.264	0.068	-0.407	-0.147				
8					10	842.596	1.467	0.022
intercept	0.566	0.130	0.316	0.824				
elevation	-0.126	0.088	-0.300	0.047				
GNDVI$_{10m}$	-0.451	0.106	-0.661	-0.246				
GNDVI$_{10m}^2$	-0.109	0.066	-0.243	0.018				
dead grass cover$_{10m}$	0.063	0.117	-0.166	0.292				
dead grass cover$_{10m}^2$	-0.171	0.069	-0.308	-0.038				
forb cover$_{10m}$	0.088	0.090	-0.088	0.265				
grass height$_{10m}$	-0.153	0.097	-0.343	0.036				
vegetation density$_{10m}$	1.124	0.135	0.866	1.394				
vegetation density$_{10m}^2$	-0.270	0.069	-0.416	-0.152				
9					9	842.606	1.478	0.022
intercept	0.565	0.130	0.313	0.825				
GNDVI$_{10m}$	-0.407	0.112	-0.630	-0.190				

Table A.7 Continued

GNDVI$_{10m}^2$	-0.107	0.066	-0.240	0.020				
bare ground$_{10m}$	0.085	0.113	-0.135	0.307				
dead grass cover$_{10m}$	0.044	0.114	-0.181	0.268				
dead grass cover$_{10m}^2$	-0.161	0.069	-0.298	-0.029				
grass height$_{10m}$	-0.128	0.101	-0.327	0.070				
vegetation density$_{10m}$	1.124	0.138	0.859	1.400				
vegetation density$_{10m}^2$	-0.282	0.072	-0.433	-0.157				
10					9	842.791	1.663	0.020
intercept	0.566	0.130	0.314	0.825				
GNDVI$_{10m}$	-0.393	0.112	-0.616	-0.175				
GNDVI$_{10m}^2$	-0.104	0.066	-0.237	0.023				
bare ground$_{10m}$	0.172	0.113	-0.049	0.396				
dead grass cover$_{10m}$	0.088	0.122	-0.150	0.327				
dead grass cover$_{10m}^2$	-0.160	0.068	-0.297	-0.028				
forb cover$_{10m}$	0.112	0.094	-0.072	0.297				
vegetation density$_{10m}$	1.093	0.134	0.837	1.361				
vegetation density$_{10m}^2$	-0.284	0.072	-0.434	-0.159				
11					9	842.815	1.687	0.020
intercept	0.574	0.130	0.322	0.834				
elevation	-0.104	0.088	-0.277	0.068				
GNDVI$_{10m}$	-0.418	0.113	-0.641	-0.199				
GNDVI$_{10m}^2$	-0.113	0.066	-0.247	0.014				
bare ground$_{10m}$	0.113	0.108	-0.098	0.326				
dead grass cover$_{10m}$	0.041	0.114	-0.184	0.265				
dead grass cover$_{10m}^2$	-0.162	0.068	-0.299	-0.030				
vegetation density$_{10m}$	1.104	0.134	0.846	1.373				
vegetation density$_{10m}^2$	-0.283	0.072	-0.433	-0.159				
12					9	842.886	1.757	0.019
intercept	0.556	0.129	0.307	0.813				
GNDVI$_{10m}$	-0.432	0.106	-0.642	-0.227				
GNDVI$_{10m}^2$	-0.105	0.066	-0.238	0.022				
dead grass cover$_{10m}$	0.028	0.112	-0.193	0.247				
dead grass cover$_{10m}^2$	-0.165	0.069	-0.302	-0.032				
forb height$_{10m}$	-0.053	0.098	-0.246	0.139				
grass height$_{10m}$	-0.134	0.102	-0.334	0.065				
vegetation density$_{10m}$	1.106	0.134	0.849	1.374				
vegetation density$_{10m}^2$	-0.270	0.069	-0.415	-0.150				
13					9	843.042	1.914	0.018
intercept	0.555	0.129	0.305	0.811				
elevation	-0.127	0.088	-0.301	0.046				
GNDVI$_{10m}$	-0.466	0.106	-0.675	-0.261				
GNDVI$_{10m}^2$	-0.104	0.066	-0.237	0.023				
dead grass cover$_{10m}$	0.044	0.116	-0.184	0.272				

Table A.7 Continued

dead grass cover$_{10m}^2$	-0.168	0.069	-0.305	-0.036				
forb cover$_{10m}$	0.084	0.090	-0.091	0.260				
vegetation density$_{10m}$	1.052	0.125	0.811	1.302				
vegetation density$_{10m}^2$	-0.264	0.068	-0.407	-0.148				
14					8	843.053	1.925	0.018
intercept	0.538	0.128	0.290	0.792				
GNDVI$_{10m}$	-0.455	0.105	-0.664	-0.251				
GNDVI$_{10m}^2$	-0.095	0.066	-0.227	0.031				
dead grass cover$_{10m}$	0.031	0.115	-0.196	0.257				
dead grass cover$_{10m}^2$	-0.162	0.068	-0.299	-0.030				
forb cover$_{10m}$	0.065	0.089	-0.108	0.240				
vegetation density$_{10m}$	1.017	0.122	0.782	1.262				
vegetation density$_{10m}^2$	-0.261	0.068	-0.404	-0.143				
15					9	843.085	1.957	0.018
intercept	0.563	0.129	0.314	0.820				
elevation	-0.109	0.088	-0.282	0.063				
GNDVI$_{10m}$	-0.450	0.106	-0.661	-0.245				
GNDVI$_{10m}^2$	-0.111	0.066	-0.245	0.016				
dead grass cover$_{10m}$	0.020	0.112	-0.200	0.239				
dead grass cover$_{10m}^2$	-0.168	0.069	-0.305	-0.035				
forb height$_{10m}$	-0.085	0.093	-0.269	0.098				
vegetation density$_{10m}$	1.083	0.130	0.834	1.343				
vegetation density$_{10m}^2$	-0.267	0.067	-0.410	-0.151				
16					10	843.097	1.969	0.017
intercept	0.579	0.131	0.326	0.839				
elevation	-0.117	0.089	-0.292	0.056				
GNDVI$_{10m}$	-0.408	0.113	-0.631	-0.188				
GNDVI$_{10m}^2$	-0.112	0.066	-0.245	0.015				
bare ground$_{10m}$	0.161	0.114	-0.062	0.385				
dead grass cover$_{10m}$	0.097	0.122	-0.142	0.335				
dead grass cover$_{10m}^2$	-0.166	0.069	-0.303	-0.034				
forb cover$_{10m}$	0.126	0.094	-0.059	0.312				
vegetation density$_{10m}$	1.120	0.135	0.860	1.391				
vegetation density$_{10m}^2$	-0.285	0.072	-0.435	-0.161				

Table A.8. Model comparison of nest site selection in Baird's sparrow, 2018. The model selection metrics are the number of parameters (K), Akaike Information Criterion adjusted for sample size (AIC_c), difference between model and minimum AIC_c values (ΔAIC_c) and AIC_c weight (w_i). Models with $\Delta AIC_c < 2$ are shown. Parameter estimates, standard errors (SE) and lower and upper 95% confidence limits (LCL and UCL, respectively) are included.

Model parameter	Estimate	SE	LCL	UCL	*K*	AIC_c	ΔAIC_c	w_i
1					4	86.478	0.000	0.062
intercept	0.067	0.328	-0.591	0.709				
bare ground$_{10m}$	-0.793	0.361	-1.543	-0.112				
vegetation density$_{10m}$	1.783	0.505	0.931	2.956				
vegetation density$_{10m}^2$	-0.500	0.343	-1.190	0.210				
2					5	87.040	0.562	0.047
intercept	0.077	0.330	-0.583	0.724				
bare ground$_{10m}$	-0.624	0.374	-1.404	0.079				
forb height$_{10m}$	0.457	0.361	-0.228	1.210				
vegetation density$_{10m}$	1.635	0.508	0.774	2.814				
vegetation density$_{10m}^2$	-0.447	0.338	-1.134	0.245				
3					5	87.550	1.072	0.036
intercept	0.098	0.334	-0.569	0.753				
elevation	-0.325	0.304	-0.948	0.259				
bare ground$_{10m}$	-0.732	0.364	-1.485	-0.046				
vegetation density$_{10m}$	1.888	0.532	0.999	3.145				
vegetation density$_{10m}^2$	-0.530	0.359	-1.259	0.202				
4					4	87.797	1.319	0.032
intercept	0.184	0.313	-0.431	0.806				
forb height$_{10m}$	0.633	0.337	0.007	1.347				
vegetation density$_{10m}$	1.776	0.485	0.966	2.916				
vegetation density$_{10m}^2$	-0.511	0.316	-1.168	0.120				
5					6	88.245	1.767	0.026
intercept	0.098	0.334	-0.570	0.756				
elevation	-0.320	0.311	-0.958	0.276				
bare ground$_{10m}$	-0.576	0.375	-1.356	0.129				
forb height$_{10m}$	0.456	0.369	-0.244	1.222				
vegetation density$_{10m}$	1.749	0.535	0.848	3.007				
vegetation density$_{10m}^2$	-0.481	0.353	-1.204	0.232				
6					5	88.339	1.861	0.025
intercept	0.088	0.329	-0.572	0.734				
exotic vegetation$_{10m}$	-0.164	0.265	-0.692	0.363				
bare ground$_{10m}$	-0.829	0.367	-1.593	-0.137				
vegetation density$_{10m}$	1.807	0.502	0.954	2.967				
vegetation density$_{10m}^2$	-0.504	0.336	-1.184	0.192				
7					6	88.450	1.972	0.023

Table A.8 Continued

intercept	0.182	0.345	-0.500	0.871
elevation	-0.504	0.355	-1.256	0.158
exotic vegetation$_{10m}$	-0.362	0.311	-1.008	0.235
bare ground$_{10m}$	-0.784	0.366	-1.546	-0.094
vegetation density$_{10m}$	1.985	0.534	1.081	3.230
vegetation density$_{10m}^2$	-0.575	0.348	-1.286	0.139

Table A.9. Model comparison of nest site selection in chestnut-collared longspur, 2018. The model selection metrics are the number of parameters (K), Akaike Information Criterion adjusted for sample size (AIC_c), difference between model and minimum AIC_c values (ΔAIC_c) and AIC_c weight (w_i). Models with $\Delta AIC_c < 2$ are shown. Parameter estimates, standard errors (SE) and lower and upper 95% confidence limits (LCL and UCL, respectively) are included.

Model parameter	Estimate	SE	LCL	UCL	*K*	AIC_c	ΔAIC_c	w_i
1					11	499.417	0.000	0.093
intercept	0.769	0.182	0.419	1.133				
$GNDVI_{10m}$	-0.550	0.163	-0.877	-0.236				
$GNDVI_{10m}^2$	-0.198	0.099	-0.397	-0.007				
exotic $vegetation_{10m}$	0.301	0.148	0.013	0.596				
bare $ground_{10m}$	0.461	0.164	0.142	0.788				
dead grass $cover_{10m}$	0.032	0.174	-0.309	0.373				
dead grass $cover_{10m}^2$	-0.190	0.100	-0.395	-0.002				
forb $cover_{10m}$	0.260	0.137	-0.005	0.534				
grass $height_{10m}$	-0.341	0.142	-0.625	-0.066				
vegetation $density_{10m}$	1.060	0.195	0.688	1.452				
vegetation $density_{10m}^2$	-0.440	0.117	-0.684	-0.224				
2					9	500.382	0.966	0.057
intercept	0.601	0.158	0.297	0.916				
$GNDVI_{10m}$	-0.515	0.151	-0.817	-0.225				
$GNDVI_{10m}^2$	-0.213	0.098	-0.411	-0.024				
exotic $vegetation_{10m}$	0.354	0.141	0.081	0.636				
bare $ground_{10m}$	0.561	0.147	0.276	0.856				
forb $cover_{10m}$	0.327	0.124	0.089	0.576				
grass $height_{10m}$	-0.346	0.140	-0.626	-0.075				
vegetation $density_{10m}$	1.063	0.193	0.695	1.452				
vegetation $density_{10m}^2$	-0.434	0.116	-0.677	-0.219				
3					10	500.532	1.116	0.053
intercept	0.805	0.182	0.455	1.169				
$GNDVI_{10m}$	-0.431	0.156	-0.743	-0.128				
$GNDVI_{10m}^2$	-0.208	0.099	-0.409	-0.020				
bare $ground_{10m}$	0.453	0.151	0.159	0.754				
dead grass $cover_{10m}$	-0.010	0.171	-0.346	0.325				
dead grass $cover_{10m}^2$	-0.206	0.100	-0.411	-0.019				
forb $cover_{10m}$	0.229	0.131	-0.024	0.490				
forb $height_{10m}$	-0.266	0.126	-0.516	-0.020				
vegetation $density_{10m}$	1.050	0.192	0.684	1.437				
vegetation $density_{10m}^2$	-0.436	0.117	-0.679	-0.220				
4					10	500.883	1.467	0.045
intercept	0.619	0.159	0.313	0.936				

Table A.9 Continued

GNDVI$_{10m}$	-0.493	0.151	-0.797	-0.201				
GNDVI$_{10m}^2$	-0.232	0.100	-0.434	-0.039				
exotic vegetation$_{10m}$	0.332	0.143	0.055	0.616				
bare ground$_{10m}$	0.571	0.148	0.285	0.868				
forb cover$_{10m}$	0.358	0.128	0.113	0.615				
forb height$_{10m}$	-0.168	0.133	-0.430	0.092				
grass height$_{10m}$	-0.285	0.148	-0.580	0.003				
vegetation density$_{10m}$	1.089	0.195	0.717	1.483				
vegetation density$_{10m}^2$	-0.433	0.117	-0.677	-0.216				
5					11	500.938	1.522	0.043
intercept	0.794	0.183	0.443	1.160				
GNDVI$_{10m}$	-0.477	0.161	-0.800	-0.165				
GNDVI$_{10m}^2$	-0.208	0.100	-0.410	-0.017				
exotic vegetation$_{10m}$	0.182	0.139	-0.091	0.457				
bare ground$_{10m}$	0.530	0.163	0.214	0.855				
dead grass cover$_{10m}$	0.030	0.174	-0.312	0.371				
dead grass cover$_{10m}^2$	-0.199	0.100	-0.406	-0.011				
forb cover$_{10m}$	0.292	0.140	0.022	0.573				
forb height$_{10m}$	-0.264	0.127	-0.516	-0.017				
vegetation density$_{10m}$	1.031	0.192	0.663	1.418				
vegetation density$_{10m}^2$	-0.437	0.117	-0.682	-0.220				
6					11	500.943	1.526	0.043
intercept	0.811	0.183	0.460	1.178				
GNDVI$_{10m}$	-0.443	0.157	-0.756	-0.138				
GNDVI$_{10m}^2$	-0.214	0.099	-0.415	-0.025				
bare ground$_{10m}$	0.391	0.158	0.083	0.706				
dead grass cover$_{10m}$	-0.009	0.171	-0.346	0.327				
dead grass cover$_{10m}^2$	-0.210	0.100	-0.416	-0.022				
forb cover$_{10m}$	0.209	0.131	-0.045	0.472				
forb height$_{10m}$	-0.215	0.132	-0.476	0.042				
grass height$_{10m}$	-0.180	0.139	-0.455	0.090				
vegetation density$_{10m}$	1.094	0.196	0.720	1.490				
vegetation density$_{10m}^2$	-0.437	0.117	-0.680	-0.221				
7					10	501.003	1.586	0.042
intercept	0.765	0.181	0.417	1.127				
GNDVI$_{10m}$	-0.559	0.162	-0.884	-0.248				
GNDVI$_{10m}^2$	-0.190	0.100	-0.392	0.001				
exotic vegetation$_{10m}$	0.198	0.137	-0.068	0.468				
bare ground$_{10m}$	0.338	0.151	0.045	0.637				
dead grass cover$_{10m}$	-0.092	0.161	-0.409	0.222				
dead grass cover$_{10m}^2$	-0.189	0.099	-0.393	-0.002				
grass height$_{10m}$	-0.318	0.140	-0.598	-0.047				

Table A.9 Continued

	vegetation density$_{10m}$	1.057	0.193	0.687	1.447				
	vegetation density$_{10m}^2$	-0.445	0.116	-0.688	-0.230				
8						9	501.021	1.605	0.042
	intercept	0.774	0.180	0.428	1.133				
	GNDVI$_{10m}$	-0.497	0.154	-0.805	-0.199				
	GNDVI$_{10m}^2$	-0.187	0.097	-0.385	0.000				
	bare ground$_{10m}$	0.304	0.148	0.016	0.597				
	dead grass cover$_{10m}$	-0.110	0.160	-0.424	0.202				
	dead grass cover$_{10m}^2$	-0.194	0.099	-0.398	-0.009				
	grass height$_{10m}$	-0.254	0.132	-0.516	0.002				
	vegetation density$_{10m}$	1.062	0.193	0.694	1.451				
	vegetation density$_{10m}^2$	-0.443	0.115	-0.685	-0.229				

Table A.10. Model comparison of nest site selection in grasshopper sparrow, 2018. The model selection metrics are the number of parameters (K), Akaike Information Criterion adjusted for sample size (AIC_c), difference between model and minimum AIC_c values (ΔAIC_c) and AIC_c weight (w_i). Models with $\Delta AIC_c < 2$ are shown. Parameter estimates, standard errors (SE) and lower and upper 95% confidence limits (LCL and UCL, respectively) are included.

Model parameter	Estimate	SE	LCL	UCL	*K*	AIC_c	ΔAIC_c	w_i
1					6	163.765	0.000	0.050
intercept	0.335	0.272	-0.187	0.882				
$GNDVI_{10m}$	-0.639	0.252	-1.155	-0.161				
$GNDVI_{10m}^2$	-0.151	0.178	-0.515	0.192				
bare $ground_{10m}$	-0.573	0.304	-1.209	-0.001				
vegetation $density_{10m}$	1.607	0.336	0.992	2.318				
vegetation $density_{10m}^2$	-0.342	0.157	-0.678	-0.112				
2					7	163.798	0.033	0.049
intercept	0.352	0.274	-0.175	0.903				
elevation	-0.326	0.226	-0.785	0.105				
$GNDVI_{10m}$	-0.666	0.250	-1.179	-0.192				
$GNDVI_{10m}^2$	-0.192	0.176	-0.549	0.152				
bare $ground_{10m}$	-0.698	0.322	-1.376	-0.098				
vegetation $density_{10m}$	1.654	0.344	1.026	2.385				
vegetation $density_{10m}^2$	-0.331	0.156	-0.668	-0.102				
3					8	164.749	0.984	0.030
intercept	0.425	0.283	-0.118	0.997				
elevation	-0.335	0.228	-0.800	0.101				
$GNDVI_{10m}$	-0.563	0.265	-1.103	-0.056				
$GNDVI_{10m}^2$	-0.261	0.189	-0.650	0.105				
exotic $vegetation_{10m}$	-0.280	0.250	-0.783	0.202				
bare $ground_{10m}$	-0.772	0.331	-1.468	-0.154				
vegetation $density_{10m}$	1.649	0.344	1.021	2.380				
vegetation $density_{10m}^2$	-0.317	0.156	-0.656	-0.086				
4					7	164.762	0.997	0.030
intercept	0.405	0.281	-0.134	0.973				
$GNDVI_{10m}$	-0.540	0.267	-1.083	-0.030				
$GNDVI_{10m}^2$	-0.216	0.190	-0.610	0.148				
exotic $vegetation_{10m}$	-0.265	0.243	-0.756	0.206				
bare $ground_{10m}$	-0.634	0.311	-1.281	-0.051				
vegetation $density_{10m}$	1.598	0.334	0.986	2.307				
vegetation $density_{10m}^2$	-0.328	0.156	-0.665	-0.097				
5					7	164.875	1.110	0.029
intercept	0.341	0.273	-0.184	0.892				
$GNDVI_{10m}$	-0.610	0.253	-1.127	-0.129				

Table A.10 Continued

	$GNDVI_{10m}^2$	-0.168	0.178	-0.531	0.176				
	bare $ground_{10m}$	-0.629	0.314	-1.287	-0.043				
	forb $cover_{10m}$	-0.216	0.208	-0.636	0.190				
	vegetation $density_{10m}$	1.631	0.340	1.008	2.353				
	vegetation $density_{10m}^2$	-0.344	0.161	-0.683	-0.111				
6						8	165.212	1.447	0.024
	intercept	0.361	0.276	-0.168	0.917				
	elevation	-0.309	0.228	-0.773	0.128				
	$GNDVI_{10m}$	-0.642	0.251	-1.156	-0.163				
	$GNDVI_{10m}^2$	-0.205	0.177	-0.564	0.140				
	bare $ground_{10m}$	-0.743	0.329	-1.437	-0.130				
	forb $cover_{10m}$	-0.187	0.208	-0.607	0.219				
	vegetation $density_{10m}$	1.673	0.347	1.039	2.409				
	vegetation $density_{10m}^2$	-0.333	0.160	-0.674	-0.102				
7						8	165.227	1.462	0.024
	intercept	0.433	0.285	-0.111	1.010				
	$GNDVI_{10m}$	-0.479	0.269	-1.025	0.041				
	$GNDVI_{10m}^2$	-0.252	0.191	-0.649	0.114				
	exotic $vegetation_{10m}$	-0.344	0.255	-0.861	0.145				
	bare $ground_{10m}$	-0.733	0.327	-1.415	-0.123				
	forb $cover_{10m}$	-0.285	0.218	-0.730	0.134				
	vegetation $density_{10m}$	1.625	0.341	1.003	2.348				
	vegetation $density_{10m}^2$	-0.329	0.161	-0.669	-0.093				
8						5	165.453	1.688	0.021
	intercept	0.501	0.261	0.000	1.026				
	$GNDVI_{10m}$	-0.481	0.232	-0.952	-0.038				
	$GNDVI_{10m}^2$	-0.220	0.172	-0.576	0.107				
	vegetation $density_{10m}$	1.769	0.327	1.176	2.466				
	vegetation $density_{10m}^2$	-0.398	0.165	-0.736	-0.147				
9						9	165.576	1.811	0.020
	intercept	0.456	0.287	-0.093	1.036				
	elevation	-0.315	0.232	-0.786	0.129				
	$GNDVI_{10m}$	-0.508	0.269	-1.053	0.010				
	$GNDVI_{10m}^2$	-0.292	0.191	-0.686	0.075				
	exotic $vegetation_{10m}$	-0.354	0.261	-0.883	0.147				
	bare $ground_{10m}$	-0.858	0.346	-1.584	-0.216				
	forb $cover_{10m}$	-0.258	0.218	-0.703	0.162				
	vegetation $density_{10m}$	1.671	0.348	1.036	2.411				
	vegetation $density_{10m}^2$	-0.319	0.161	-0.661	-0.083				

Table A.11. Model comparison of nest site selection in Sprague's pipit, 2018. The model selection metrics are the number of parameters (K), Akaike Information Criterion adjusted for sample size (AIC_c), difference between model and minimum AIC_c values (ΔAIC_c) and AIC_c weight (w_i). Models with $\Delta AIC_c < 2$ are shown. Parameter estimates, standard errors (SE) and lower and upper 95% confidence limits (LCL and UCL, respectively) are included.

Model parameter	Estimate	SE	LCL	UCL	*K*	AIC_c	ΔAIC_c	w_i
1					4	30.679	0.000	0.315
intercept	2.632	1.094	0.889	5.423				
$GNDVI_{10m}$	-0.440	0.808	-2.080	1.244				
$GNDVI_{10m}^2$	-3.996	1.661	-8.353	-1.623				
bare $ground_{10m}$	-1.246	0.613	-2.734	-0.192				
2					4	31.240	0.562	0.238
intercept	2.958	1.302	0.989	6.269				
$GNDVI_{10m}$	0.202	0.892	-1.484	2.350				
$GNDVI_{10m}^2$	-3.860	1.584	-8.185	-1.578				
exotic $vegetation_{10m}$	2.173	1.401	0.188	5.930				

Table A.12. Model comparison of GNDVI and ground measurements, 2018. The model selection metrics are the number of parameters (K), Akaike Information Criterion adjusted for sample size (AIC_c), difference between model and minimum AIC_c values (ΔAIC_c) and AIC_c weight (w_i). Models with $\Delta AIC_c < 2$ are shown. Parameter estimates, standard errors (SE) and lower and upper 95% confidence limits (LCL and UCL, respectively) are included.

Model parameter	Estimate	SE	LCL	UCL	*K*	AIC_c	ΔAIC_c	w_i
1					9	1622.103	0.000	0.290
intercept	0.000	0.031	-0.061	0.061				
exotic $vegetation_{10m}$	0.209	0.037	0.136	0.282				
bare $ground_{10m}$	-0.317	0.042	-0.399	-0.234				
dead grass $cover_{10m}$	-0.337	0.036	-0.409	-0.266				
forb $cover_{10m}$	-0.058	0.036	-0.129	0.013				
forb $height_{10m}$	0.097	0.036	0.026	0.169				
grass $height_{10m}$	-0.092	0.040	-0.170	-0.013				
vegetation $density_{10m}$	0.210	0.037	0.138	0.283				
2					8	1622.629	0.525	0.223
intercept	0.000	0.031	-0.061	0.061				
exotic $vegetation_{10m}$	0.225	0.036	0.154	0.295				
bare $ground_{10m}$	-0.291	0.039	-0.367	-0.215				
dead grass $cover_{10m}$	-0.312	0.033	-0.377	-0.248				
forb $height_{10m}$	0.090	0.036	0.019	0.161				
grass $height_{10m}$	-0.087	0.040	-0.166	-0.009				
vegetation $density_{10m}$	0.213	0.037	0.141	0.286				
3					10	1624.052	1.949	0.110
intercept	0.000	0.031	-0.061	0.061				
exotic $vegetation_{10m}$	0.208	0.037	0.135	0.281				
bare $ground_{10m}$	-0.320	0.043	-0.405	-0.235				
dead grass $cover_{10m}$	-0.335	0.037	-0.408	-0.263				
forb $cover_{10m}$	-0.060	0.037	-0.132	0.012				
forb $height_{10m}$	0.096	0.037	0.024	0.168				
grass $height_{10m}$	-0.094	0.041	-0.174	-0.014				
litter $cover_{10m}$	-0.011	0.034	-0.078	0.055				
vegetation $density_{10m}$	0.211	0.037	0.138	0.284				

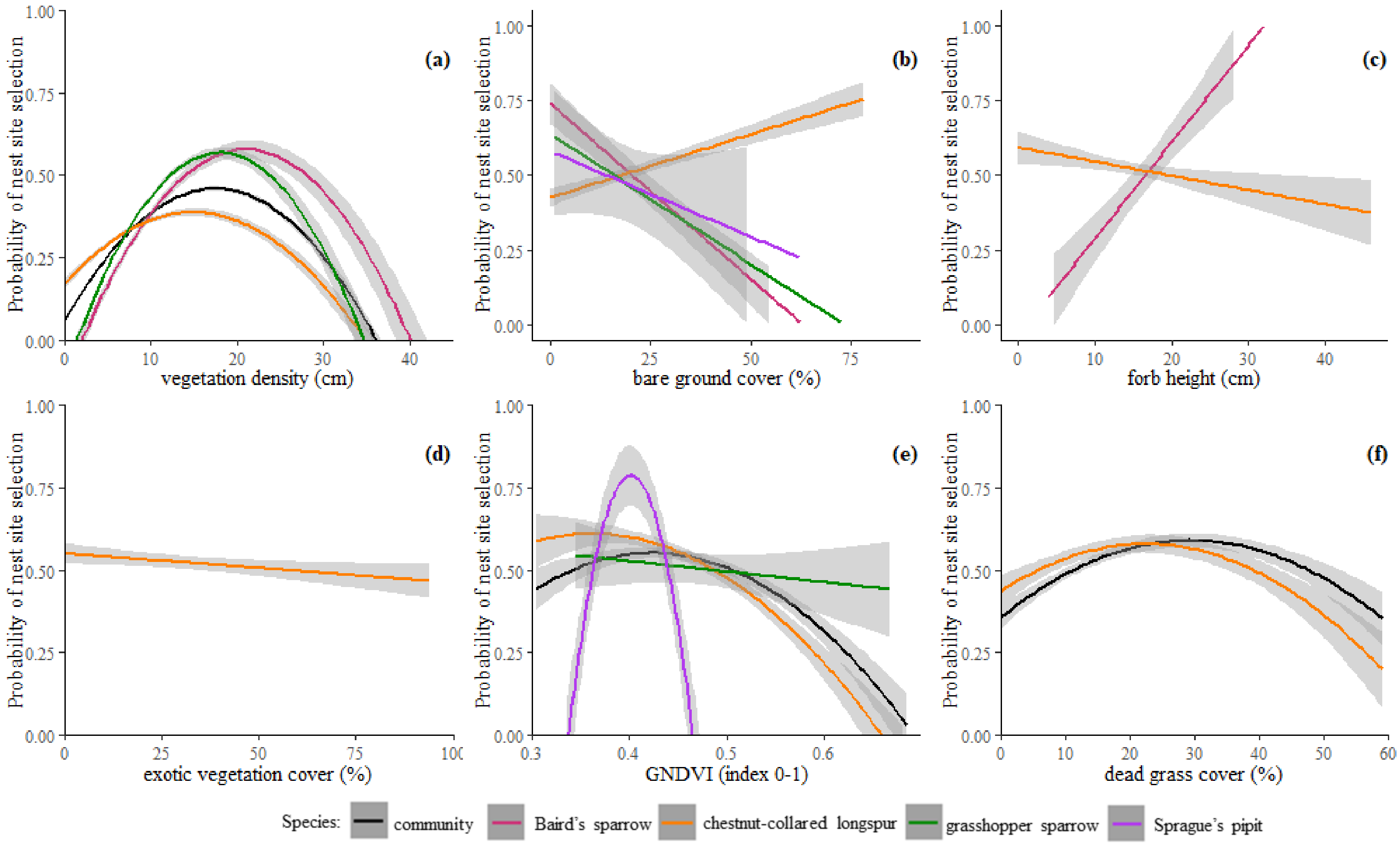

Figure A.1. Predicted probabilities of nest site selection, 2018. Probability of selection of habitat conditions at 10m scale for (a) vegetation density, (b) bare ground cover, (c) forb height, (d) exotic vegetation cover, and (e) Green Normalized Difference Vegetation Index (GNDVI), and (f) dead grass cover for nest sites at the community and species levels for Baird's sparrows, grasshopper sparrows, chestnut-collared longspurs and Sprague's pipit**.**

APPENDIX B: SUPPLEMENTARY MATERIAL FOR CHAPTER 2

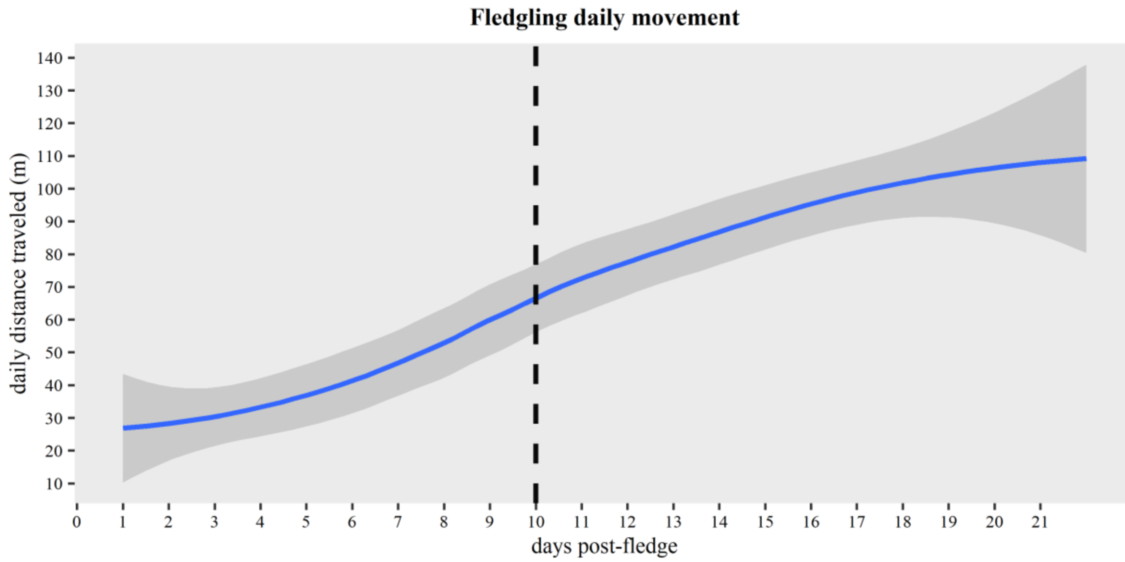

Figure B.1 Juvenile sparrow daily movement data collected from 2016 – 2017 in the Northern Great Plains, USA. Values are based on the average daily movement for juvenile sparrows for each day after leaving the nest. The vertical dotted line divides the two age-dependent categories (days 1-10 out of the nest and days >11 out of the nest) used to delineate appropriate buffer sizes that represent available areas for juveniles to choose locations from.

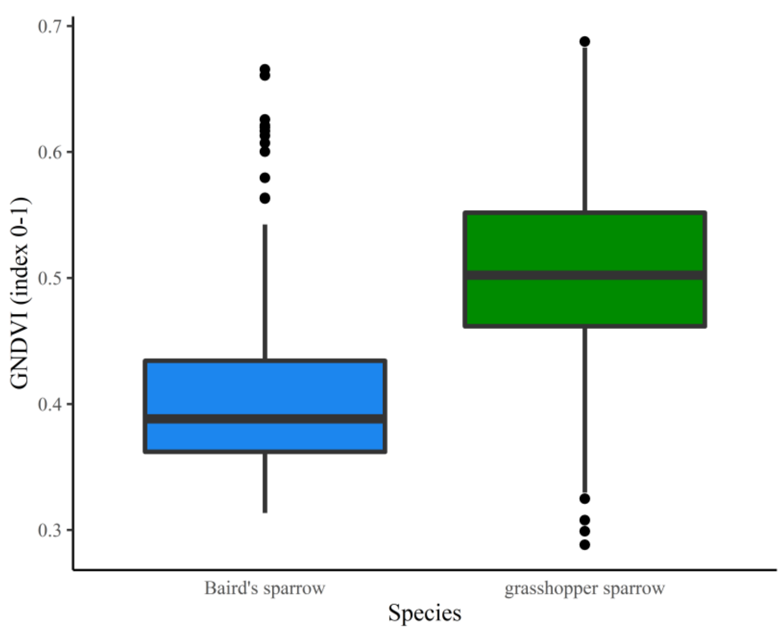

Figure B.2. Variation in Green Normalized Difference Vegetation Index (GNDVI) values measured at used locations between species of juvenile grassland birds in the Northern Great Plains, USA 2018.

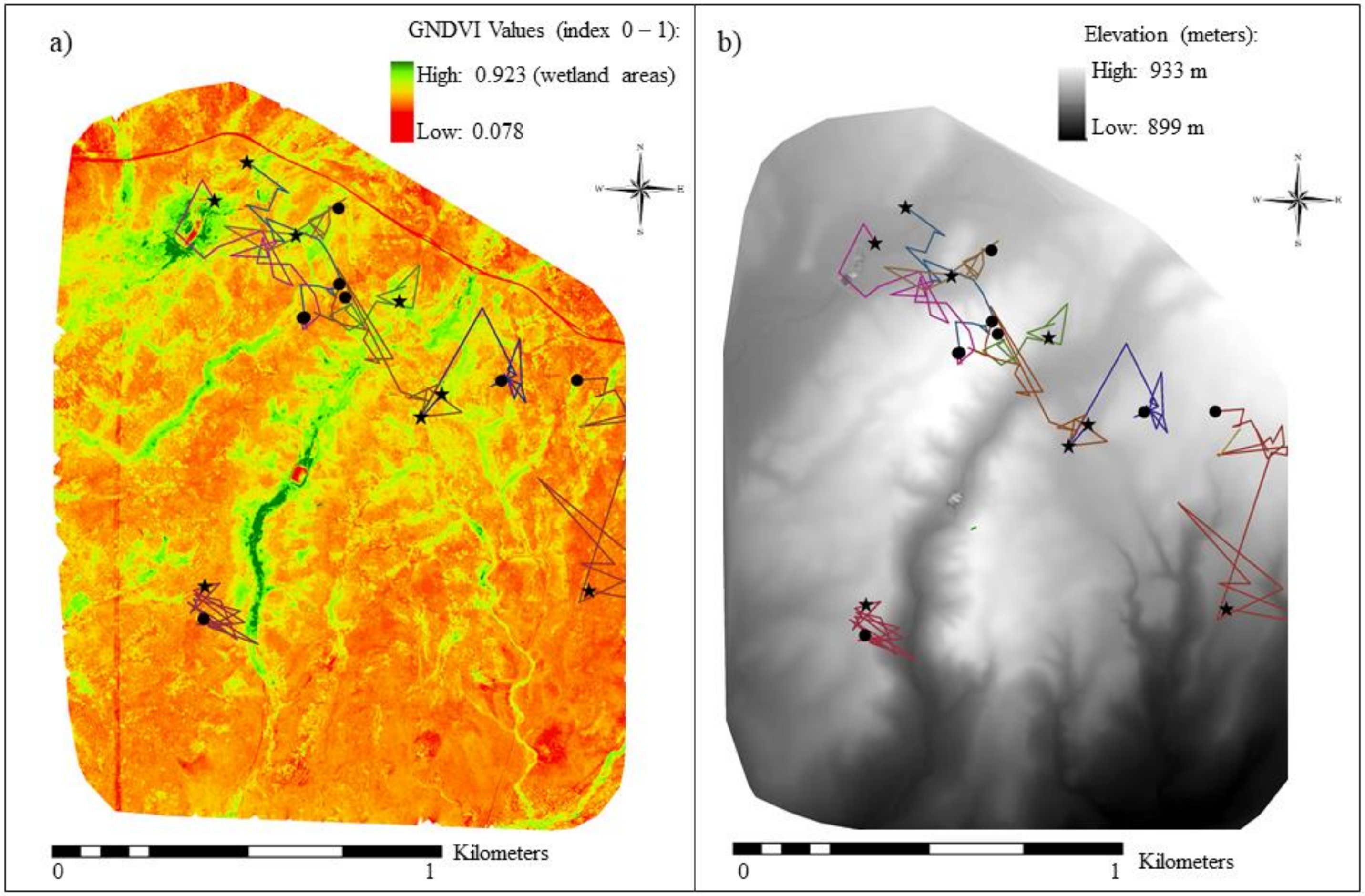

Figure B.3. Juvenile Baird's sparrow movements in Montana, USA 2018. Black circles represent the first day juveniles left their nest, black starts represent the last day the sparrow was radio-tracked until. Each colored line represents an individual bird. Juvenile movement is displayed on top of a map that measures variation in greenness on the landscape using the Green Normalized Difference Vegetation Index (GNDVI; a) and a map that measures elevation (b).

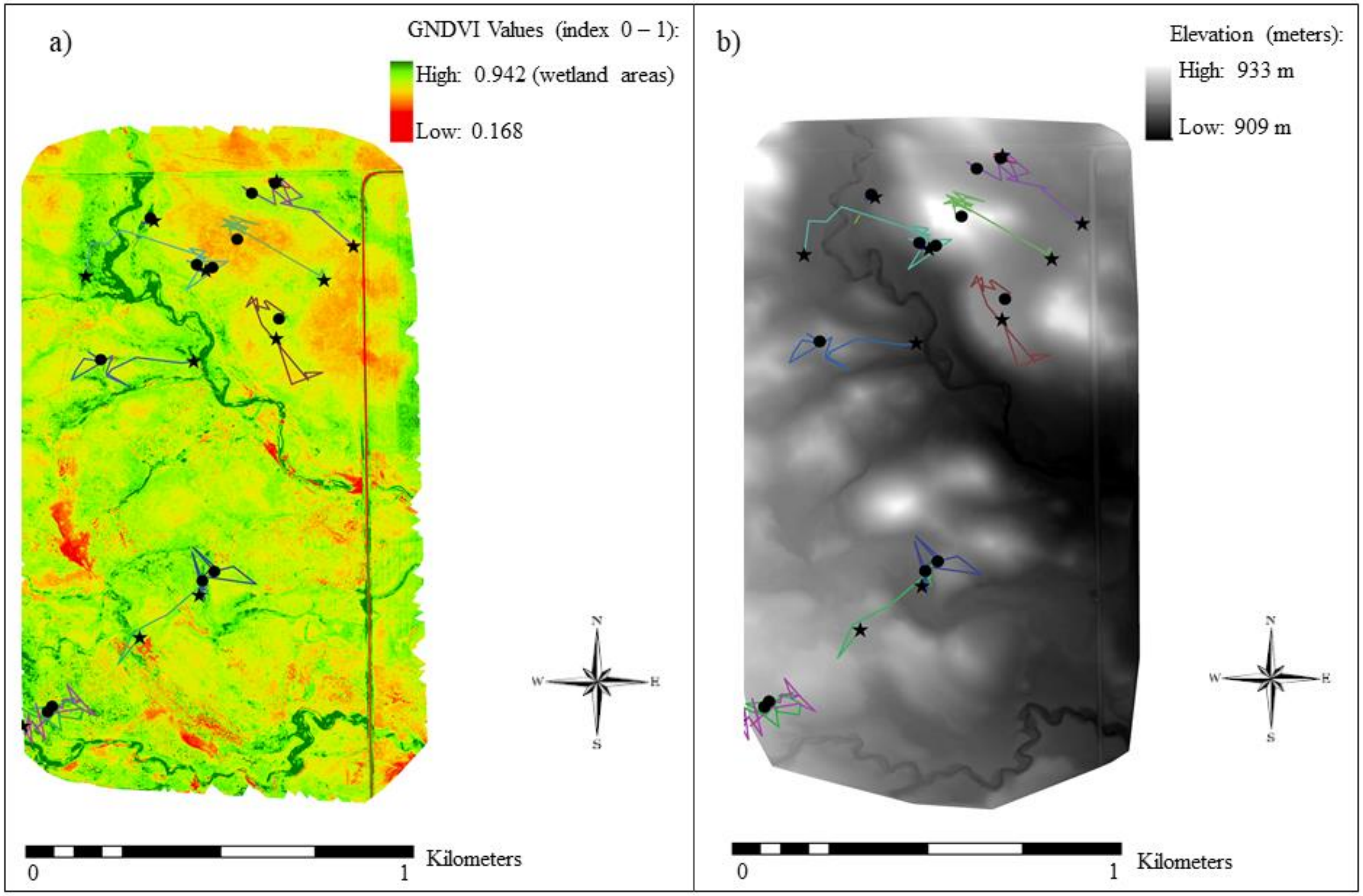

Figure B.4. Juvenile grasshopper sparrow movements in North Dakota, USA 2018. Black circles represent the first day juveniles left their nest, black starts represent the last day the sparrow was radio-tracked until. Each colored line represents an individual bird. Juvenile movement is displayed on top of a map that measures variation in greenness on the landscape using the Green Normalized Difference Vegetation Index (GNDVI; a) and a map that measures elevation (b).

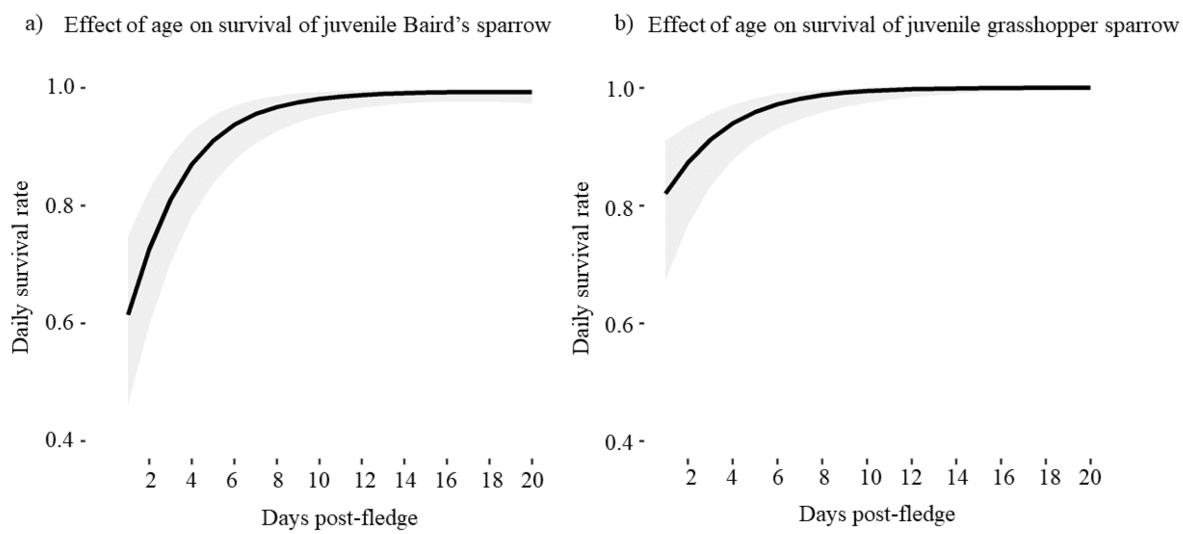

Figure B.5. Daily survival rate of juvenile sparrow movements in the Northern Great Plains, USA 2016 – 2018. Daily survival rates were measured for juvenile Baird's sparrows (a) and grasshopper sparrows (b) from the first day observed to have left the nest and for each consecutive day post-fledging.

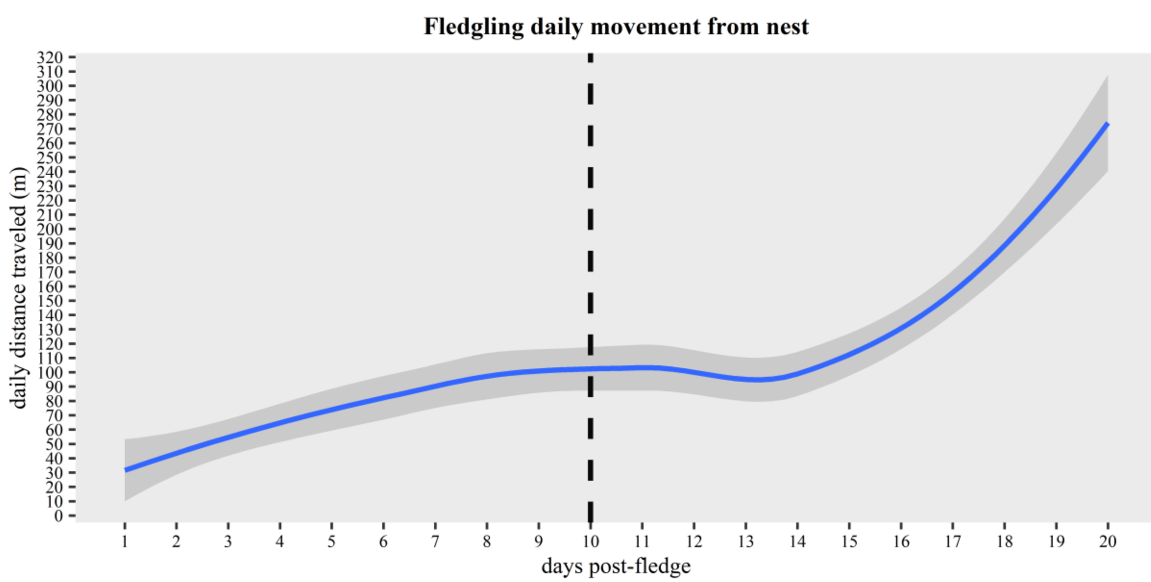

Figure B.6. Juvenile sparrow movement from nests in the Northern Great Plains, USA, 2016 – 2017. Values are based on the average daily movement for juvenile sparrows from their nest sites for each day after leaving the nest. The vertical dotted line divides the two age-dependent categories (days 1-10 out of the nest and days >11 out of the nest).

BIOGRAPHY OF THE AUTHOR

Nicole Guido was born and raised in Brooklyn, New York, where the most resilient ornithologists are spawned. She attended high school at St. John Villa Academy on the notoriously well-trafficked Staten Island. After graduating with a high school diploma in 2008, she ventured to the distant state of New Jersey to earn a B.S. from Rutgers University. Immediately upon graduating with her degree in 2012, she moved to Panama to learn permaculture farming which unbeknownst at the time was the beginning of a six-year string of chasing birds around the globe, fortunately for compensation. Her work travels provided opportunities to work with birds and many other taxa in the Catskill Mountains, Costa Rica, Quebec, Hawaii, Belize, Florida, Borneo, the Rocky Mountains, and the Great Plains. To keep the bird dream alive, Nicole was employed during the off seasons as an apple picker and a nanny among other diverse positions. The pinnacle of Nicole's technician career unexpectedly landed her as a crew leader in the remote sea of grass known as the Northern Great Plains. There, she was detected by a charismatic Principal Investigator on the project, who upon discovering that Nicole was searching for a graduate program had pitched the perfect plan to pursue this endeavor. It was not long before she accepted a position as a graduate student at the University of Maine, co-advised by Mo Correll and Kate Ruskin, where she also continued her research in the Great Plains. In the meantime, she moved to Maine where discovered friendship, a little mouse, and a newfound love for winter in the incredibly small town of Orono. Nicole is a candidate for the Master of Science Degree in Ecology and Environmental Sciences from the University of Maine in May 2020.