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Habitat Use of Wintering Henslow's Sparrows (Centronyx henslowii) in Power Line Right-of-Ways

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HABITAT USE OF WINTERING HENSLOW'S SPARROWS (*CENTRONYX HENSLOWII*)

IN POWER LINE RIGHT-OF-WAYS

by

ABIGAIL W. DWIRE

(Under the Direction of Elizabeth A. Hunter)

ABSTRACT

Habitat loss and degradation are the leading causes of grassland bird declines worldwide. The Henslow's Sparrow (*Centronyx henslowii;* hereafter HESP) is a grassland bird species of conservation concern that has historically relied on the herbaceous ground-layer of longleaf pine savannas and similar habitats in the southeastern U.S. for food and shelter in the winter. However, due to human development, alterations of habitat, and fire suppression, only fragments of these habitats remain. Over the last decade, surveys have annually documented HESPs using power line right-of-ways (hereafter, ROWs) at several sites in the coastal plain of Georgia as alternative habitat for overwintering. These ROWs share similar vegetative characteristics to pine savannas because they are managed to have low tree cover and because they have a graminoid-dominated ground-layer. However, which micro-habitat characteristics HESPs select, and how much space they use within ROWs has not yet been studied. During the winters of 2019 to 2021, I captured HESPs at three Wildlife Management Areas and attached radio-transmitters to track their habitat selection and evaluate space use within ROWs. I conducted vegetation surveys in used and available habitat in the ROWs to assess which vegetation characteristics (e.g., height, density, composition) HESPs select. I used principal component analysis to reduce the number of vegetation variables and look for correlations among variables. I then used conditional logistic regression and model selection to identify top predictors of HESP habitat use. Statistical analyses showed that HESPs select areas within a ROW with a greater number of forb species, a small percentage of woody vegetation for escape refugia, and high vegetation density at the ground level. HESPs used less space (using 0.14 ha on average) than in longleaf pine savanna habitats, based on comparison with the literature. Based on these findings, I recommend habitat management practices that promote forb diversity, increase food resources, and maintain habitat structure. This study shows that ROWs can be important areas for conservation of overwintering HESPs. With continued management, ROWs can support overwintering grassland birds and could potentially act as corridors between longleaf pine restoration sites.

INDEX WORDS: Grassland birds, Habitat management, Habitat selection, Habitat use, Henslow’s Sparrow, Power line right-of-way

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CHAPTER 1

INTRODUCTION

Bird populations in North America are declining, with a net loss of 2.9 billion birds since 1970 across almost all biomes (Rosenberg et al. 2019). In particular, grassland birds in North America have experienced a steep decline in numbers: a 20.8% loss on average between 1966 and 2013 (Stanton et al. 2018). These cumulative losses can be largely attributed to alterations in grassland bird habitat due to agricultural intensification, development, and fire suppression (Vickery et al. 2000; Askins et al. 2007). These anthropogenic changes have caused a decrease in suitable habitat space, a decrease in native food sources, and an influx of toxins from pesticides and herbicides (Herkert et al. 2003; Stanton et al. 2018). Though grassland birds have undergone immense habitat loss, some human-influenced landscapes, such as agricultural field margins and power line right-of-ways, have the potential to replace some lost habitat (King and Byers 2002; Blank 2013).

Grassland bird habitats in eastern North America have historically required ecological disturbances, such as fire, grazing, and beaver activity, for creation and to maintain their integrity (Askins et al. 2007). The longleaf pine savanna ecosystem in the American Southeast, for instance, requires burning to provide a competitive advantage to fire-resistant plants, such as longleaf pine (*Pinus palustris*) and wiregrass (*Aristida stricta*), over plants susceptible to fire such as hardwood trees and shrubs (Landers et al. 1995). Historically, lightning and Native Americans initiated this disturbance (Lear et al. 2005). If not burned for one to three years, shrub encroachment can completely alter the habitat by creating a fire-intolerant, woody mid-story (Engstrom et al. 2001), which negatively impacts the many plants and animals that are adapted to the longleaf pine savanna (Outcalt 2000).

The longleaf pine savanna ecosystem once extended over 24.3 million hectares across the Southeast (Outcalt 2000); however, the extent has decreased by an estimated 97% due to historical logging, fire suppression, and conversion to agriculture and timber production (Van Lear et al. 2005), and only small fragments of longleaf pine savannas remain (Frost 1993). Restored longleaf pine savannas today are dependent on active management using prescribed fire and the selective removal of woody vegetation which allows sunlight to penetrate to the ground-layer, supporting diverse herbaceous cover (McGuire et al. 2001; Platt et al. 2006). This ground-layer provides food (e.g., seeds) and cover from predators for wildlife, including many grassland bird species (Engstrom 1993; Hunter et al. 2001).

Since the vast majority of pine savanna habitat has disappeared, investigating how human-altered landscapes can provide grassland bird habitat is critical to the long-term persistence of grassland-dependent species. One potentially undervalued land resource that could be utilized to address habitat loss is power line right-of-ways (hereafter, ROWs). ROWs present an opportunity for grassland bird conservation because they must be managed to have minimal tree cover to prevent interference with the power lines. This management can create an open savanna habitat that mimics the ground-layer of a typical southeastern pine savanna, benefitting grassland bird species. When ROWs share similar characteristics to native grasslands, they may hold substantial conservation value (Gardiner et al. 2018). The area of ROWs is unlikely to decrease substantially in the near future (Gardiner et al. 2018) because of increasing energy demands. Although longleaf pine habitat area continues to fluctuate over time based on changing conservation goals and land ownership (Outcalt and Sheffield 1996; McIntyre et al. 2018), ROWs could act as long-term or permanent substitution habitat for grassland birds and are therefore a reliable resource. ROWs can support the habitat requirements of some breeding bird species (King and Byers 2002; Yahner 2004) and other wildlife (Johnson et al. 1979; Wagner et al. 2014; Russo et al. 2021). Confer and Pascoe (2003) found that ROWs with early-successional shrubland habitat supported high nesting success for many avian species of conservation concern in the northeastern US; however, the use of ROW habitat by grassland and Southeast wintering birds has not been sufficiently studied.

The Henslow's Sparrow (HESP) is one grassland bird species that has historically relied largely on various southeastern grassland habitats, particularly longleaf pine savannas, for overwintering. Its wintering range extends across the Southeast coastal plain from eastern North Carolina, south to southern Florida, and west to eastern Texas (Hyde 1939; Herkert et al. 2020). Along with pine savannas, HESPs also overwinter in silviculture lands (Plentovich et al. 1999), prairies (Korosy et al. 2013), and pitcher plant bogs (Tucker and Robinson 2003). In the winter, HESPs are predominantly ground dwelling birds that prefer to hide from predators under dense vegetative cover that is open at the ground level to allow them to walk and forage for food (Johnson et al. 2011). These behaviors, coupled with their decreased vocalizations during the winter, make observations of habitat use difficult. Due to their secretive nature in the winter, much more information exists on HESP habitat use on their breeding grounds than wintering grounds; however, there have been several wintering habitat use studies in the past two decades. Some studies found that, in longleaf pine ecosystems, HESPs tend to select for areas that were burned during the previous growing season (Carrie et al. 2002; Bechtoldt and Stouffer 2005; Johnson et al. 2009); however, different sites and ecosystems appear to lose openings at the ground level at different rates, dependent on the rate of vegetation litter fall and frequency of burning (Korosy et al. 2013). Longleaf pine duff tends to accumulate quickly, therefore wintering HESPs in these ecosystems typically benefit from annual burning (Bechtoldt and

Stouffer 2005), whereas sites without longleaf may benefit from less frequent burn regimes (e.g. every ~2 years), implying that management regimes should be site specific (Palasz et al. 2010).

Further highlighting the need for site specific research and management, Johnson et al. (2011) found that the structural characteristics (i.e. height and density) of vegetation in HESPs wintering habitat were more important to HESPs than the composition or abundance of seeds in restored longleaf pine savannas, but Tucker and Robinson (2003) found that the presence of grass seeds and forb density best explained HESP presence in pitcher plant bogs (though they did not examine structural characteristics). HESPs are omnivorous, eating both seeds and insects, and are generalist feeders in the winter (Fuller 2004; Johnson et al. 2011). Common seeds found in fecal and crop samples of HESPs diet included *Rhynchospora*, *Scleria*, *Andropogon*, and *Panicum* grass species, and common invertebrates included *Coleoptera* (beetles) and *Arachnida* (spiders, ticks, etc.) species (Fuller 2004; Johnson et al. 2011).

Very few studies have attempted tracking HESPs during the winter to observe their movements over time and estimate their home-range (e.g., Bechtoldt and Stouffer 2005). Estimates of home-range size are important to better understand the species' ecology and to serve as an indicator of resource availability, with smaller home ranges potentially indicating which habitats have greater resource availability (Harestad and Bunnell 1979). Home-range sizes can also be used as a proxy to compare the resource availability of natural vs. substitution habitats (Godet et al. 2018).

Since the 1960s, HESP populations have experienced one of the fastest declines of disturbance-dependent bird species (-1.93%/year from 1966-2019), but more recent survey results suggest that populations may be increasing (+2.2%/year from 1993 to 2019) (Sauer et al. 2020). However, HESP numbers are still well below population estimates from the first half of the 20th century. The overarching reason for the decline of the HESP parallels all grassland bird declines: habitat loss and degradation (Herkert et al. 2016). In Georgia, the State Wildlife Action Plan lists the HESP as a high priority for conservation because of its decrease in population size after continued reduction in pine savannas in the state (Schneider and Keyes 2015).

HESPs have been found using ROWs as replacement habitat in the Southeast (Champlin et al. 2015). In the Georgia coastal plain, bird surveys in selected ROWs have documented HESP presence over the past decade (personal communication, T. Schneider). Investigating how HESPs are using ROW habitat provides site-specific information to add to our understanding of this species' life history and conservation. The overall objective of this study was to determine how HESPs are using ROWs: a human-altered and managed ecosystem that will be available to HESPs for many decades into the future. For this purpose, I (i) measured vegetation characteristics that HESPs select in ROWs and compared them to what vegetation characteristics are available in ROWs, and (ii) tracked HESPs using radio-telemetry and estimated their space-use area over time. I predicted that HESPs are using ROW habitat that has low vegetative density near the ground and high density higher up from the ground (such habitat allows for ground-level movement while also providing cover from predators). I also hypothesized that HESP presence will be positively correlated with plant species richness and the number of inflorescent stems (an indicator of seed availability, a primary winter food source). In addition, I predicted that HESPs will use a similar amount of space as in longleaf pine ecosystems (by comparing results with Thatcher 2003 and Bechtoldt and Stouffer 2005).

CHAPTER 2

METHODOLOGY

Study Sites

I collected data on HESP habitat use at three Wildlife Management Areas (WMAs) in the coastal plain of Georgia: Moody Forest WMA, Townsend WMA, and Paulks Pasture WMA. All sites contain a ROW with characteristics similar to the graminoid-dominated ground-layer of a pine savanna. Georgia DNR selected these WMAs in 2010 for long-term monitoring of the HESP populations within ROWs and they have been monitored every year since then.

All sites are in close proximity to the Altamaha River (Figure 1). Moody Forest WMA (hereafter, Moody Forest) lies in Georgia's upper coastal plain and is a pine savanna restoration site, with a pine-wiregrass ecosystem surrounding both sides of the ROW. Moody Forest is a sandhill ecosystem and is drier than the other two sites. The ROW's predominant grasses are *Andropogon virginicus*, *Dichanthelium* spp., and *Aristida* spp., and the predominant forb species is *Rhexia* spp. Moody Forest is typically burned in the spring on a 2-year rotation. For the duration of this study (2019-2021), the ROW was burned biennially in alternating burned and unburned areas.

Townsend WMA (hereafter, Townsend) and Paulks Pasture WMA (hereafter, Paulks Pasture) lie in the lower coastal plain, and their ROWs are predominantly surrounded by densely stocked timber, primarily slash *(Pinus elliottii)* and loblolly pine *(Pinus taeda).* Some timber stands contain an understory of smaller trees, shrubs, and brambles, and occasionally a herbaceous ground-layer; whereas other stands have no understory or ground-layer plants, only pine straw. Townsend's and Paulks Pasture's ROWs are mowed by Georgia Power contractors on approximately a six-year rotation, with some variability depending on growth, to prevent trees from becoming large and interfering with power lines. Selective herbicide treatments and hand cutting are also used as needed to control trees and shrubs in areas inaccessible to mowing (e.g., too wet) or for other reasons. Townsend's ROW is predominantly composed of *Andropogon virginicus*, *Sporobolus* spp., *Dichanthelium* spp., and *Panicum* spp. grasses. Paulks Pasture's ROW is predominantly *Andropogon virginicus*, *Aristida* spp., *Xyris* spp. and *Dichanthelium* spp. grasses, and *Rhexia* spp. forbs.

I investigated HESP habitat use during the winters of 2019-2021 by surveying transects that were established by Georgia DNR in 2010. DNR biologists chose the transects based on vegetation attributes consistent with typical HESP habitat—dense herbaceous cover with limited woody vegetation (Carrie et al. 2002; Bechtoldt and Stouffer 2005). Transects were delineated (for the most part) using power poles as start and end points. The arrangement of power poles varied at each site, and transect lengths ranged from 100 m to 600 m long (Table 1).

Bird Capture and Tracking

I surveyed HESPs to determine which habitat characteristics HESPs select in the power line ROWs. Surveys for HESPs took place from early January through mid-March. I began surveying when dew had dried from the vegetation, approximately two hours after sunrise, and ended when the survey was complete, or at sunset. I did not re-survey a given transect for at least two weeks. The number of people (observers) conducting a given survey varied from two to seven. HESPs were flushed from the ground by dragging a 23 m (75-foot) weighted rope between two people along transects. Anyone not dragging the rope spread out equidistantly ~5-7 m behind the rope and followed at that distance as the rope was dragged. This was done to increase the chances of flushing any birds that had evaded the rope and of observing flushed birds. When dragged, the “U” shaped bow of the rope covered approximately 18 m (60 feet) of space. The two people pulling the rope added about an additional meter of effective flushing distance to each end of the rope, making the effective transect width about 20 meters. When a HESP flushed, I recorded the flush location, even if it was not captured. Observers visually tracked the bird noting the point where it landed. A 12m x 2.5m x 30mm mesh nylon mist net was then strategically placed near where the bird landed and the observers flushed the bird into the net. Once captured, I attached a uniquely numbered USGS aluminum leg band to one of the legs. I fitted a subset of birds with a transmitter (Model BD-2X, Holohil Systems Ltd., Carp, Ontario, Canada) to the flattest part of the lower back close to the tail feathers, but above the uropygial gland to leave it accessible to the bird (see Appendix A for photo of attachment location). I deployed up to two transmitters per transect; thus additional birds captured in a transect did not receive a transmitter. Using a maximum of two transmitters per transect allowed me to sample more areas of the ROWs as well as reduced the chances of inadvertently affecting movement patterns during tracking. Transmitters weighed 0.35 grams (<3% of HESP body weight) and the expected battery life was 21 days.

To attach a transmitter, I first trimmed feathers at the attachment site, then applied Cyanoacrylate (CA) gel glue to the corners and one long edge of a piece of cotton cloth slightly larger than a transmitter, and then used tweezers to place the cloth onto the bird’s skin and trimmed feather shafts. I pressed the cloth down carefully with the blunt end of the tweezers. I then applied CA gel glue to the transmitter, placed the transmitter onto the cloth, and held it in place until the glue was dry (about one minute). Using gel glue instead of thinner glues was imperative for effective adhesion and to maintain control over where the glue was placed. This method, adapted from Johnson et al. (1991) and Diemer et al. (2014), proved to be the most reliable in attachment longevity, compared to using VetBond glue and other fabric types. Leaving a few feathers untrimmed in addition to the trimmed feathers may have also allowed the transmitter to remain attached for longer. I then released the bird at the flush point site and waited until the following day to begin tracking to allow it to re-acclimate and resume normal movement patterns and habitat use. I triangulated bird locations up to 4 times daily until the transmitter fell off, the transmitter battery died, or the bird was depredated.

Habitat Surveys

I conducted vegetation surveys within habitat used by HESPs and within habitat available to HESPs in the ROWs for comparison and assessment of HESP habitat selection. In winters 2019 and 2020, I sampled vegetation at HESP flush point locations which represented habitat used by HESPs, and at systematically placed points which represented habitat available to HESPs. In the winter of 2021, I collected vegetation data inside of HESP use areas defined during telemetry tracking to sample used habitat, and outside of these use areas to sample available habitat.

I adapted vegetation survey methods from Bechtoldt and Stouffer (2005). I used a 10 m radius circular plot to collect various vegetation parameters. Data was collected at the center of each plot and at 5 increments (every 2 m) in four directions from the center parallel and perpendicular to the power lines (Figure 2). Data collected within the plots included five components:

1. *Vegetation height* was estimated as the height of the tallest plant within a 30 cm radius of the base of a 19 mm (0.75 inch) diameter wooden rod. Height was recorded at the plot center and at every 2 m increment away from the center.

2. *Vegetation density* was measured at the plot center point and at every 6 m and 10 m point from the center. I used the same 19 mm diameter rod which had increments marked at 5 cm from the bottom, 10 cm from the bottom, and every 10 cm after that to count the number of vegetative contacts (and therefore provide an index of vegetation density) at each height increment. Increments with more than 10 vegetative contacts were defined as greater than 10, instead of the actual number of vegetative contacts.

3. *Percent cover of vegetation* was estimated visually from the plot center and included classifying habitat into five categories: grasses, forbs, woody vegetation, open water, and bare ground. Woody vegetation included palmettos, shrubs, and trees.

4. *Inflorescent stems (stems with seeds)* were counted and identified to genus, or species when possible, within two 1 m^2 quadrats placed in random directions (degrees) and at random distances from the plot center.

5. *Water depth* was recorded when water was present at the plot center and at every 6 m and 10 m point from the center using the same rod used for measuring vegetation density.

In winters 2019 and 2020, I assigned locations in which HESPs flushed from the ground during surveys as a habitat “use” location, and I placed the center of a vegetation survey plot at a random subset of these flush points (Figure 3). I intended to survey a sample of flush points that was proportional to the number of HESPs flushed at each site; however, due to logistical constraints, the number of flush points actually surveyed was approximately equal across all sites

(Table 2). To evaluate available habitat, I combined the length of all transects for each site and placed a vegetation survey plot systematically every 200 m as if there was no space between separated transects. Therefore, the number of systematic plots at a field site was dependent on the combined length of transects (Table 2). If a bird flushed from the ground inside the area of a systematic plot, I reassigned the plot to be a flush point plot. I collected vegetation data from early January to early April, with the subset of flush point survey plots collected at the end of the season.

In winter of 2021, I revised the study design by defining use areas as individuals' activity areas based on telemetry locations (see below), while retaining the same vegetation plot survey methods as the previous two years. Area outside of the use areas represented habitat that was available. This approach was advantageous over the previous approach as I was able to observe bird movement over a longer period of time, rather than only using a bird's flush coordinates for spatial use data.

I carried out use and available vegetation surveys within one week from the time a bird's transmitters died or fell off. I determined where to place the vegetation survey plots by first estimating bird locations from field triangulations using a maximum likelihood estimator in LOAS software (Ecological Software Solutions, LLC, Version 4.0.3.8). I removed locations with ellipse errors greater than 314 m^2, thereby eliminating locations with uncertainty greater than the size of a vegetation survey plot. I used biangulations when triangulations were impractical because a bird was not stationary, or when LOAS detected that a 3^{rd} bearing was not intersecting with two other bearings due to user or GPS error (biangulations represented <10% of retained locations). I then used package AdehabitatHR (Calenge 2006) in program R (R core team 2020) to create 100% minimum convex polygons (MCPs) for every tracked bird that had at least 9 locations. MCPs represented the area that the birds used ("use areas") and these terms will be used interchangeably throughout.

To collect vegetation data from inside MCPs (use areas), I randomly placed survey plots inside of the MCPs while keeping the plots at least 10 m away from the MCP boundary. If the MCP was less than 314 m^2, I generated a center point for placement of the survey plot. I randomly placed one survey plot inside use areas <1600 m^2, two survey plots when use areas were 1600-2400 m^2, and three survey plots when use areas were >2,400 m^2. During the study, three different birds had use areas that included two clusters of locations that were separated by a significant distance (Figure 4). These clusters consisted of at least four telemetry locations and distance between clusters was at least 200 m. In these instances, I placed vegetation survey plots at each of the clusters in accordance with their separate MCP sizes. All locations for each bird were then used to create a single MCP before calculating the average use area size of all birds.

In order to assess available habitat, I projected vegetation plots outside of the MCPs. The number of inside (used habitat) survey plots for a bird was equivalent to the number of outside (available habitat) survey plots for that bird. I calculated the square root of each MCP area to find the relative maximum distance in which to place the outside survey plots for each bird. For very small MCPs, in which the square root of the MCP was less than 10, I set the maximum distance to 20 m from the MCP. I restricted all habitat availability survey plots to the ROW (Figure 5). In total, I performed 36 vegetation surveys inside use areas and 36 vegetation surveys outside use areas, for a total of 72 surveys.

In order to calculate the average amount of space that HESPs used in ROWs, I first excluded outliers (n = 3), which included birds whose use areas comprised a vast amount of unused space between two smaller areas of heavy use, causing the use area to be deceptively large. I then calculated the average size of all use areas obtained over the three study seasons that had at least 9 telemetry locations. I also calculated average use area size for locations collected over 5 days (these had a minimum of 9 locations as well) to see if a longer duration of data collection resulted in larger estimated use area size. Last, I determined average use area sizes for each of the three sites for comparison between sites.

Statistical Analyses

In order to determine what habitat characteristics HESPs used in the ROWs, I compared vegetation data at used and available areas by first reducing the number of variables using principal component analyses (PCAs) and then using conditional logistic regression. Similar analyses were performed on the 2019/2020 data and the 2021 data, with the main difference occurring in available and used habitat assignments: available habitat data were derived from systematic plots in 2019/2020 and plots outside of the use areas in 2021, and "use" data were derived from flush point plots in 2019/2020 and plots inside of the use areas in 2021.

To prepare for the analyses, I averaged data within each survey plot so that only one data point per variable would describe a plot. To account for the difference in the number of vegetation survey plots per bird in winter 2021, I assigned a strata so that use and availability data is only compared for each bird. Assigning individual stratum for animals with limited mobility (e.g., HESP habitat restricted to narrow strips of ROW) also allows for more realistic paired logistic regression modeling of habitat selection choices that each bird is making (Compton et al. 2002). In winter 2021, there were two observers conducting vegetation surveys, potentially resulting in observer bias given that some measures are subjective. I compared five repeated surveys between these observers to determine any significant differences that occurred during data collection. By performing paired t-tests, I found that observers differed significantly only in vegetation density estimation, with one observer consistently counting more vegetative contacts than the other observer, and I used the averaged difference to correct for this incongruity.

In order to reduce the number of variables that went into the logistic regression models, I performed a PCA using all vegetation variables in program R (R core team 2020), using varimax rotation in package Psych (Revelle 2019). Not all vegetation variables were aligned with PCA axes, so I reduced the number of variables by looking at the correlation coefficients among all variables and the top 3 principal components from the PCA (Table 3). I considered variables with a correlation coefficient lower than 0.6 as uncorrelated. The variables that correlated with the top 3 principal components were removed from further analysis, as the principal components already represented those variables. This process resulted in 9 and 11 variables (including principal components 1-3) that were included in habitat selection models for 2019/2020 and 2021 analyses respectively. I assigned a 0 for vegetation surveys in available habitat and a 1 for surveys in used habitat to prepare for the logistic regression. I created conditional logistic regression models with all possible linear combinations of the 9 and 11 uncorrelated variables, with each model including the strata for each bird (n = 512 and 2,048 models for 2019/2020 and 2021 analyses respectively). I compared models using Akaike Information Criterion corrected for small sample size (AICc). I used model averaging of top models (ΔAICc < 4) in order to interpret the effect of each variable on HESP habitat selection. To determine how strong the effects of the top model variables are on HESP habitat selection, I calculated 95% confidence intervals around each model averaged parameter. Variables whose confidence intervals did not overlap with zero had a strong effect on HESP habitat selection.

Table 1. The number, total length, and total area of right-of-way transects used to study Henslow's Sparrow wintering population fluctuations and habitat use at Moody Forest, Paulks Pasture, and Townsend Wildlife Management Areas (WMAs).

WMA	Number of transects	Length of transects (m)	Area of transects (m^2)
Moody Forest	6	1,880	37,600
Paulks Pasture	4	2,070	41,400
Townsend	20	4,185	83,700
Totals	30	8,135	162,700

Table 2. The number of vegetation survey plots sampled per study site in winters 2019 and 2020 for studying Henslow's Sparrow habitat use in power line right-of-ways in the coastal plain of Georgia.

			2019		**2020**	
WMA	**Length (m)**	**Area (m^2)**	**Systematic**	**Flush***	**Systematic**	**Flush***
Paulks Pasture	2070	41,400	11	5	11	15
Townsend	4185	83,700	21	5	21	13**
Moody Forest	1880	37,600	10	5	10	11
Totals	8135	162,700	42	15	42	39

*Includes systematic plots that contained flush points.
**Flooding prevented the intended 20 flush point survey plots at Townsend WMA for 2020.

Table 3. Henslow's Sparrow habitat variables used in principal component analyses from winters 2019 - 2021. I averaged each data point collected within a plot (second column in table) into a single variable to represent that plot for use in analysis. Variables with an [a] and [b] were neither correlated with principal components 1 through 3 nor other variables and therefore included in logistic regression for 2019/2020 and 2021 analysis, respectively.

Categories of vegetation data collection	Variables used in PCA
Density: number of contacts hitting increments along 19 mm rod)	0 - 5 cm
	5 - 10 cm
	10 - 20 cm
	20 - 30 cm
	30 - 40 cm
	40 - 50 cm[b]
	50 - 60 cm
	Total sum of contacts
Height: tallest plant within 30 cm of rod base	Maximum plant height
	Height mean[b]
	Height standard deviation[a]
Water: depth measured at rod	Maximum water depth[a]
	Mean water depth
Seed abundance and diversity: two 1-m^2 quadrats	Number of grass species
	Number of grass stems[b]
	Number of forb species[b]
	Number of forb stems[b]
	Number of total stems
	Evenness[a]
Percent cover: estimated out of 100%	Woody[ab]
	Grasses[b]
	Forbs[ab]
	Water
	Bare ground[a]*

*bare ground was removed from 2021 analysis due to it only occurring in one vegetation survey plot.

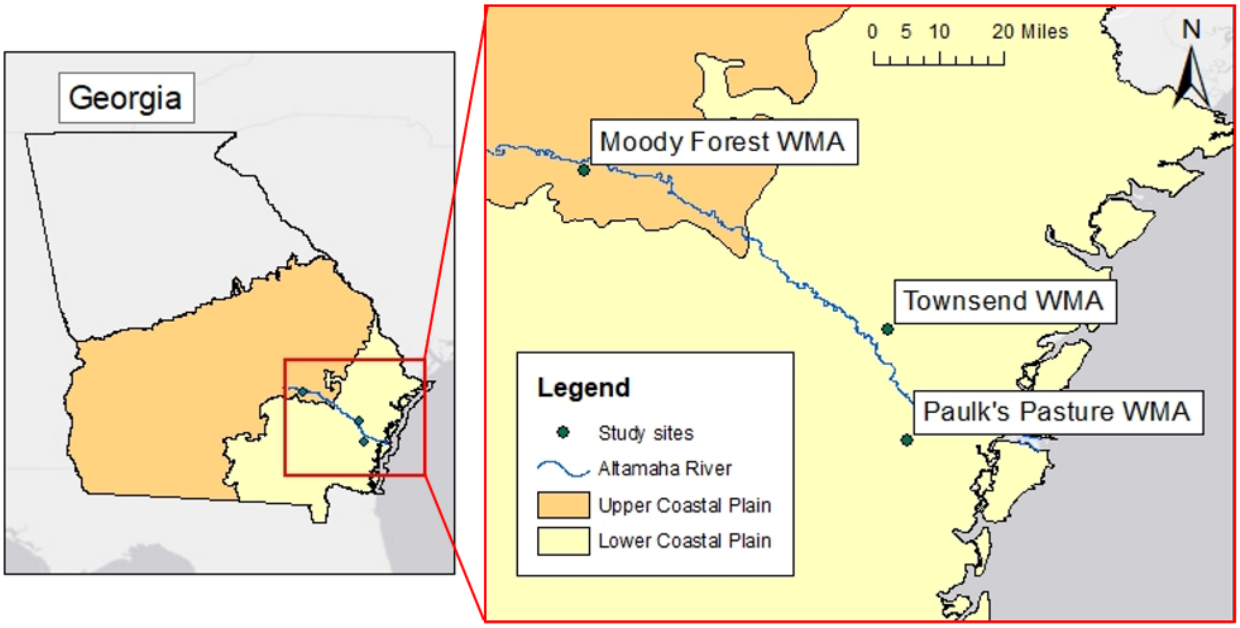

Figure 1. Map of Henslow's Sparrow wintering habitat selection study sites (2019-2021). Moody Forest Wildlife Management Area (WMA) is situated in Georgia's upper coastal plain and Townsend and Paulks Pasture WMAs lie in Georgia's lower coastal plain. All three sites are in close proximity to the Altamaha River.

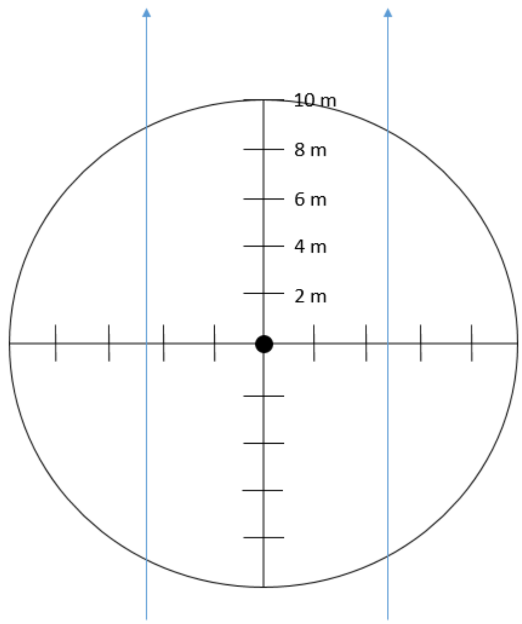

Figure 2. Diagram of a vegetation survey plot adapted from Bechtoldt and Stouffer (2005) used to survey power line habitat for Henslow's Sparrow habitat study in the coastal plain of Georgia in winters 2019 through 2021. Dashes represent the locations of data collection points and blue lines with arrows represent power lines. I collected data on vegetation height at the center point and at every 2 m increment from the center, and density and water depth at the center point and at every 6 m and 10 m increment from the center. I used the power lines as visual guides for collecting the data in four opposing directions parallel and perpendicular to the lines.

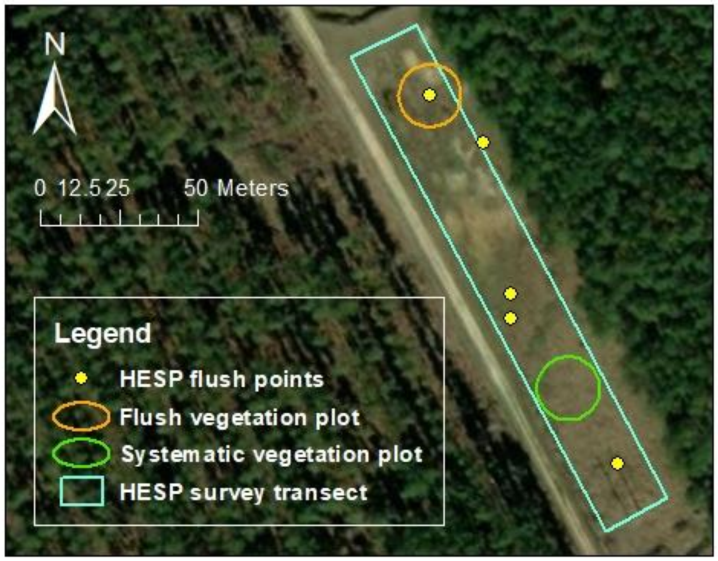

Figure 3. Map displaying a Henslow's Sparrow survey transect inside a power line right-of-way at Townsend Wildlife Management Area, Georgia, in winter 2020. Yellow points represent the location where a Henslow's Sparrow flushed from the ground during surveys. I collected vegetation data in flush point plots (representing used habitat) and in systematically placed plots (representing available habitat) to look for patterns in Henslow's Sparrow habitat selection. I placed systematic plots every 200 m within consecutive transects, and used a random subset of flush points for placing flush plots.

Figure 4. An example of a Henslow's Sparrow at Paulks Pasture Wildlife Management Area in winter 2021 that moved approximately 250 meters overnight, creating two widely separated clusters of locations before its transmitter eventually fell off. I separated this Henslow's Sparrow use area into two clusters in order to more accurately place vegetation plots and collect habitat use data. I then returned the use area back to its original, single use area form before using its use area size in analyses.

Figure 5. Map of a Henslow's Sparrow use area from winter 2021 field season at Paulks Pasture Wildlife Management Area. I collected 20 locations over six days to acquire this Henslow's Sparrow's use area, after which the transmitter fell off. Green circles represent vegetation plots. This use area is 2,033 m^2, therefore I placed two plots inside of the use area to measure vegetation in the "habitat use" area, and two plots outside of the use area to measure vegetation in the "habitat availability" area.

CHAPTER 3

RESULTS

Bird Capture

In winter 2019, I captured 46 HESP individuals (non-recaptures) out of a total of 59 HESP flush occurrences. Flush occurrences included HESPs that were captured and banded, HESPs that were recaptured, and HESPs that we were unable to capture. In winter 2020, I captured 41 HESP individuals out of 73 flush occurrences. In winter 2021, I captured 65 HESP individuals out of 107 flush occurrences. Over all study years, a total of 152 individuals were captured 168 times (Table 4). Other species detected during surveys included Bachman's Sparrow (*Peucaea aestivalis*), Swamp Sparrow (*Melospiza georgiana*), Grasshopper Sparrow (*Ammodramus savannarum*), Savannah Sparrow (*Passerculus sandwichensis*), and Sedge Wren (*Cistothorus stellaris*).

I collected flush points for thirty-two of the radio-tagged birds during bird surveys. Comparison of each bird's flush point with its use area revealed that half of the flush points were located outside of use areas (n = 16). The average distance between these flush points and use areas was 21.6 m (SD = 27.4 m, excluding one bird whose flush point was 294 m away).

Use Areas

Winter 2019 was a trial year for telemetry-tracking, and I only deployed four transmitters at one site, Paulks Pasture. One transmitter's battery failed soon after deploying so I was only able to estimate use areas for three birds. In winter 2020, transmitters frequently fell off birds before I acquired sufficient locations to estimate use areas, primarily due to using VetBond glue instead of CA gel glue. Winter 2020 was also the only year in which I observed suspected predations (four total) during tracking, three of which I found HESP carcasses with puncture wounds or feathers strewn about, and the other I found just the transmitter on top of an exposed mound a couple hours after tracking the transmitter high up in trees. Thus, in 2020, I attained one use area out of five transmitters deployed at Paulks Pasture, six use areas out of 16 transmitters deployed at Townsend, and one use area out of four transmitters deployed at Moody Forest. I had higher success in transmitter retention in winter 2021 using CA gel glue and following gluing techniques described in the methods. I attained six use areas out of six transmitters deployed at Paulks Pasture, 14 use areas out of 20 transmitters deployed at Townsend, and four use areas out of four transmitters deployed at Moody Forest. Over all years and sites, individual use area sizes varied, ranging from 327.7 m^2 to 10,440.1 m^2, with an overall average size of 1442.0 m^2 (SD = 655 m^2), excluding outliers (n = 30 birds; Table 5). The number of locations per use area ranged from 9 to 26 locations with an average of 14.1 locations (SD = 4.7 locations) and the average number of days tracked was 4.9 (SD = 1.7 days).

Two of the four birds released with transmitters at Moody Forest in 2021 only used the adjacent pine savanna habitat for the entire duration of tracking (after capture in the ROW) and therefore their use areas are excluded from use area averages. Moody Forest was the only site where I observed considerable use of non-ROW habitat. It was also the only site whose ROW was burned during the study; however, I did not detect any apparent selection inside or outside recently burned areas in the ROW (Appendix C).

Habitat Use

Principal component analysis (PCA) indicated large overlaps between flush point and systematic vegetation surveys (winters 2019 and 2020), but systematic surveys showed broader vegetation community characteristics than flush point surveys (Figure 6A). In addition, PCA indicated that Moody Forest has a narrower scope in vegetation characteristics but there are still large overlaps among sites (Figure 6B). Principal component one (PC1) explained 23.1% of variation in the data and was mostly represented by plant density at 20-60 cm from the ground and plant height. Principal component two (PC2) explained 14.3% of variation in the data and was mostly represented by plant density at 0-20 cm from the ground and the presence of standing water. From the logistic regression habitat use models for 2019 and 2020 that included the top three principal components and other uncorrelated variables (Table 3), I identified 29 models with a ΔAICc < 4, indicating substantial model uncertainty. The variables in the top model to describe Henslow's Sparrow habitat use included PC1, PC2, and the percent cover of woody vegetation (Table 6). PC1 had a negative relationship with HESP use, indicating that HESPs were more likely to use habitat with lower plant densities at 20-60 cm above the ground (Figure 7). PC2 and the percent cover of woody vegetation had a positive relationship with HESP use, indicating that HESPs were more likely to use habitat with higher plant densities at 0-20 cm from the ground and the presence of standing water (Figure 7). Model averaged results with 95% confidence intervals show that PC2 is the only variable in the top model whose confidence interval does not overlap with zero (Figure 8).

According to winter 2021 analyses, PCA indicated large overlaps between used and available habitat, but like previous years, available habitat had more variability in vegetation characteristics than used habitat (Figure 9A). PCA also indicated a large overlap in vegetation communities among sites, but Moody Forest had a much narrower range due to a small sample size (Figure 9B). Principal component one (PC1) explained 24% of variation in the data and was mostly represented by plant density at 0 to 20 cm from the ground and the presence of standing water. Principal component two (PC2) explained 15.5% of variation in the data and was mostly represented by plant density at 20 to 60 cm from the ground. From the logistic regression habitat use models for 2021 that included the top 3 principal components and other uncorrelated variables (Table 3), I identified 73 models with a $\Delta AICc < 4$, again indicating a large degree of model uncertainty. The variables in the top model to describe Henslow's Sparrow habitat use were mean plant height and the number of forb species (Table 7). Mean plant height had a negative relationship with HESP use, indicating that HESPs were more likely to use habitat with relatively shorter plants (Figure 10). The number of forb species had a positive relationship with HESP use, indicating that HESPs were more likely to use habitat with a relatively greater number of forb species (Figure 10). All three sites had four forb species in the top ten most frequently occurring plant species in quadrats (Table 8). Model averaged results with 95% confidence intervals show that all of the most frequent variables from top models (mean plant height, number of forb species, and number of forb stems) have confidence intervals that overlap with zero, and therefore may not have a strong effect on HESP use (Figure 11).

Table 4. Summary of Henslow's Sparrow surveys for winters 2019 through 2021 in power line right-of-ways in the coastal plain of Georgia. The three study sites are Paulks Pasture WMA (Paulks), Townsend WMA (Town), and Moody Forest WMA (Moody).

	2019				**2020**				**2021**			
	Paulks	**Town**	**Moody**	**Total**	**Paulks**	**Town**	**Moody**	**Total**	**Paulks**	**Town**	**Moody**	**Total**
# of flush events*	17	36	6	59	27	34	12	73	26	71	10	107
# of captured individuals	11	30	5	46	13	22	6	41	11	47	7	65
# of within-year recaptures	2	6	1	9	3	1	0	4	1	1	1	3
# of between-year recaptures	3	4	0	7	2	5	0	7	0	1	1	2
# of transmitters deployed	4	0	0	4	5	16	4	25	6	20	4	30

*Flush occurrences included HESPs that were captured and banded, HESPs that were recaptured, and HESPs that we were unable to capture.

Table 5. Average use area sizes acquired from radio-telemetry tracking of Henslow's Sparrows in power line right-of-ways at three study sites in the coastal plain of Georgia in winters 2019 through 2021.

Site	**Average Area (m^2)**	**# of birds (non-outliers)**	**Average # of locations**	**Average # of days tracked**
Moody Forest	1679.6	2	12.0	4.5
Townsend	1372.5	19	13.1	4.5
Paulks Pasture	1535.8	9	16.8	5.8
Overall results	1442.0	30	14.1	4.9

Table 6. Results of a conditional logistic regression analysis to assess Henslow's Sparrow habitat use versus availability in power line right-of-ways in the coastal plain of Georgia during winters 2019 and 2020. This table contains all models with a ΔAICc <2, although models with a ΔAICc <4 were used for model averaging (29 models total). Variables included in the global model included principal components 1, 2, and 3 from principal component analyses, max depth of water, plant height standard deviation, species evenness, percent cover of forbs, percent cover of bare ground, and percent cover of woody vegetation. Principal component 1 (PC1) is correlated with vegetation density at 20 to 60 cm from the ground and plant height, principal component 2 (PC2) is correlated with vegetation density at 0-20 cm from the ground and standing water, and principal component 3 (PC3) is correlated with the number of grass and forb inflorescences (number of species and abundance).

Model	**K**	**log-Likelihood**	**AICc**	**ΔAICc**	**Weight**
PC1 + PC2 + woody (% cover)	5	-55.92	118.40	0	0.11
PC1 + PC2 + PC3 + woody (% cover)	6	-54.77	118.50	0.10	0.10
PC2 + woody (% cover)	4	-57.66	119.60	1.20	0.06
PC2 + PC3 + woody (% cover)	5	-56.83	120.22	1.82	0.04
forb (% cover) + PC1 + PC2 + woody (% cover)	6	-55.71	120.38	1.99	0.04

Table 7. Results of a conditional logistic regression analysis to assess Henslow's Sparrow habitat use versus availability in power line right-of-ways in the coastal plain of Georgia during winter of 2021. This table contains all models with a ΔAIC <2, although models with a ΔAIC <4 were used for model averaging (73 models total). Variables included in the global model included principal components 1, 2, and 3 from principal component analyses, and all variables that did not correlate with the principal components including: density at increment 40-50 cm, mean plant height, number of grass stems, number of forb species, number of forb stems, percent cover of grasses, percent cover of forbs, and percent cover of woody vegetation.

Model	**K**	**log-Likelihood**	**AICc**	**ΔAICc**	**Weight**
mean height + number of forb species	4	-19.95	44.31	0	0.05
mean height + number of forb species + number of grass stems	5	-18.96	44.77	0.46	0.04
mean height + number of forb stems	4	-20.22	44.85	0.54	0.04
mean height + number of forb species + number of forb stems	5	-19.14	45.13	0.82	0.03
number of forb stems	3	-21.66	45.46	1.15	0.03
forb (% cover) + mean height + number of forb species	5	-19.43	45.72	1.41	0.02
forb (% cover) + mean height + number of forb stems	5	-19.54	45.94	1.63	0.02
forb (% cover) + number of forb stems	4	-20.78	45.97	1.66	0.02
forb (% cover) + mean height + number of forb species + number of forb stems	6	-18.30	46.08	1.76	0.02
grasses (% cover) + mean height + number of forb species	5	-19.63	46.12	1.81	0.02
grasses (% cover) + mean height + number of forb stems	5	-19.63	46.12	1.81	0.02
mean height + number of forb species + number of forb stems + number of grass stems	6	-18.32	46.13	1.82	0.02
mean height + number of forb species + woody (% cover)	5	-19.72	46.30	1.99	0.02

Table 8. Percent occurrence of the ten most frequently detected plant species found in quadrats within survey plots for years 2019 through 2021 at all three Henslow's Sparrows habitat use study power line right-of-way sites in the coastal plain of Georgia. When genera were not identifiable to species, but appeared morphologically distinct, they were assigned a number (not shown) to distinguish them from other species within the genus. For example, the *Hypericum* species listed under Paulks Pasture Wildlife Management Area (WMA) is not necessarily the same as the *Hypericum* species listed under Townsend WMA.

Paulks Pasture WMA	**Relative occurrence (%)**	**Townsend WMA**	**Relative occurrence (%)**	**Moody Forest WMA**	**Relative occurrence (%)**
Andropogon virginicus	62.5	*Aster,* unknown spp.	52.2	*Andropogon virginicus*	77.1
Panicum spp.	62.5	*Andropogon virginicus*	51.1	*Aristida* spp.	48.6
Xyris spp.	56.3	*Eragrostis* spp.	44.9	*Paspalum* spp.	34.3
Eragrostis spp.	32.1	*Panicum* spp.	43.8	*Eragrostis* spp.	32.9
Sporobolus spp.	30.4	Unknown forb	39.9	*Rhexia* spp.	30.0
Marshallia spp.	26.8	*Sporobolus* spp.	30.9	Unknown forb	28.6
Unknown forb	23.2	*Rhexia* spp.	19.1	Unknown forb	28.6
Aristida spp.	21.4	*Rhynchospora* spp.	18.0	*Dichanthelium* spp.	27.1
Hypericum spp.	21.4	*Xyris* spp.	18.0	Unknown forb	20.0
Linum spp.	20.5	*Hypericum* spp.	17.4	*Xyris* spp.	20.0

Table 9. Vegetation plot summary from winters 2019 through 2021 for all three Henslow's Sparrow power line right-of-way sites in the coastal plain of Georgia. Standard deviations are shown in parentheses.

Vegetation Variable	**Paulks Pasture WMA**	**Townsend WMA**	**Moody Forest WMA**
Mean grass % cover	69.1 (11.8)	73 (12.9)	72.3 (12.5)
Mean forb % cover	11.6 (7.5)	14.2 (8.5)	18.7 (10.9)
Mean woody % cover	12.4 (10.1)	7.7 (7.2)	4.9 (5.5)
Mean bare ground % cover	1.4 (3.3)	0.8 (2.1)	3.6 (6.9)
Mean water % cover	5.3 (8.4)	4.2 (6.4)	0.6 (2.0)
Mean litter % cover*	0 (0)	0.1 (0.8)	0 (0)
Mean height (cm)	92.3 (29.5)	91.5 (33.9)	85.5 (34.4)
Mean number of grass species with seeds in a quadrat	4.2 (1.8)	4.1 (1.9)	3.5 (1.6)
Mean number of grass stems with seeds in a quadrat	28.8 (25.1)	27.4 (24.1)	63 (44.7)
Mean number of forb species with seeds in a quadrat	3.5 (1.9)	3.4 (1.7)	2.4 (1.5)
Mean number of forb stems with seeds in a quadrat	20.2 (29.7)	13.5 (13.6)	18.6 (15.5)
Total number of plant species	86	91	54

*Mean is from winter 2021, the only year in which % litter was included in vegetation surveys. Percent cover of litter was not included in analyses due to its infrequent occurrence.

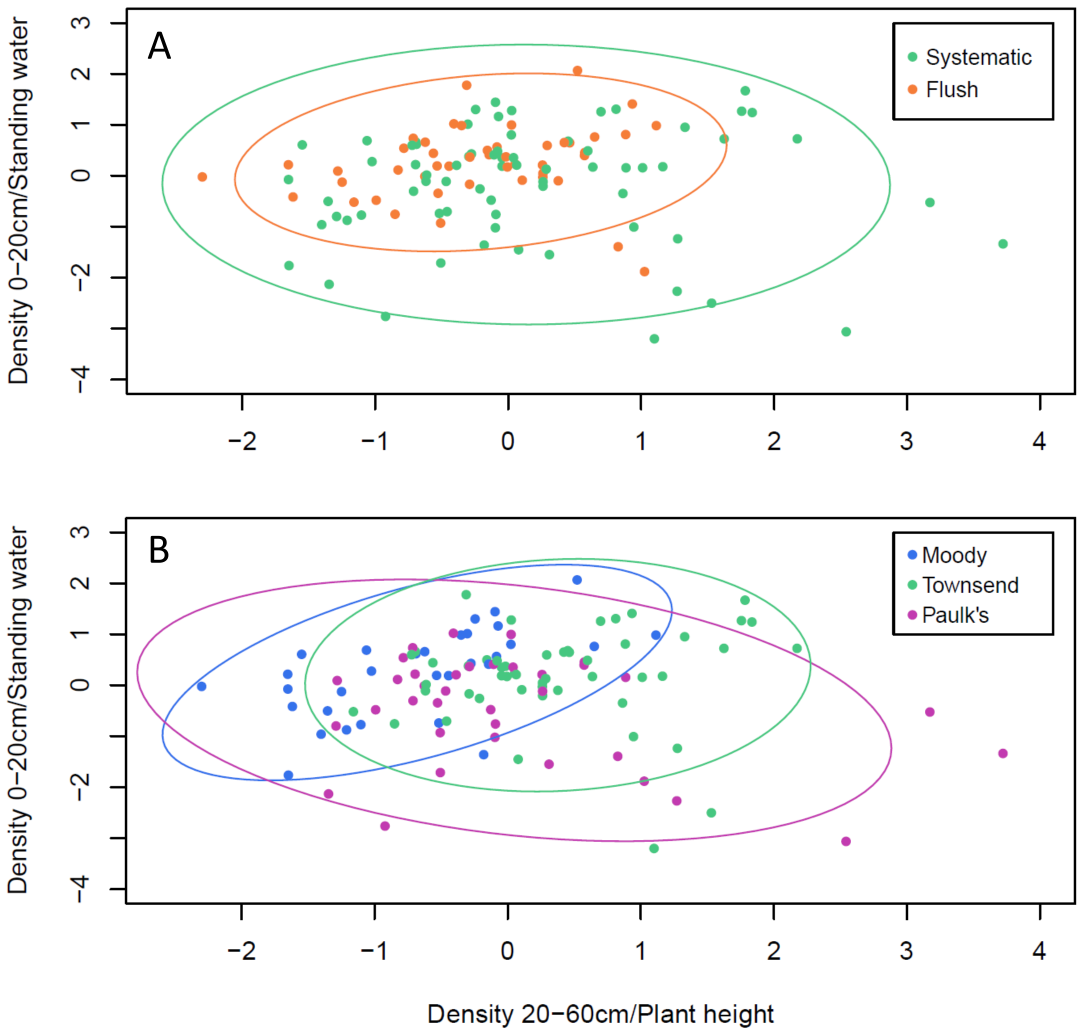

Figure 6. A. Principal Component Analysis (PCA) plot showing the overlap between habitat used by Henslow's Sparrows versus available habitat in power line right-of-ways in the coastal plain of Georgia from winters 2019 and 2020. The PCA shows the majority of survey plots overlapping between flush point vegetation plots in orange (representing used habitat) and systematic vegetation plots in green (representing available habitat), but with systematic plots having broader vegetation characteristics. For ease of interpretation, I renamed the axes, which are principal components 1 and 2, as the variables that correlated with the principal components. Principal component 1 (on the x axis) primarily represents vegetation density at 20 to 60 cm

above the ground and plant height, and describes 23.1% of variation in the data. Principal component 2 (on the y axis) primarily represents vegetation density at 0-20 cm above the ground and standing water, and describes 14.3% of the variation in the data. Ellipses comprise 95% of the survey plots. B. PCA plot using the same principal components as A., but showing the overlap among study sites. Moody Forest Wildlife Management Area (WMA) is shown in blue, Townsend WMA is shown in green, and Paulks Pasture WMA is shown in purple. The PCA shows that Moody Forest WMA has a narrower range in vegetation characteristics but most plots are overlapping among sites.

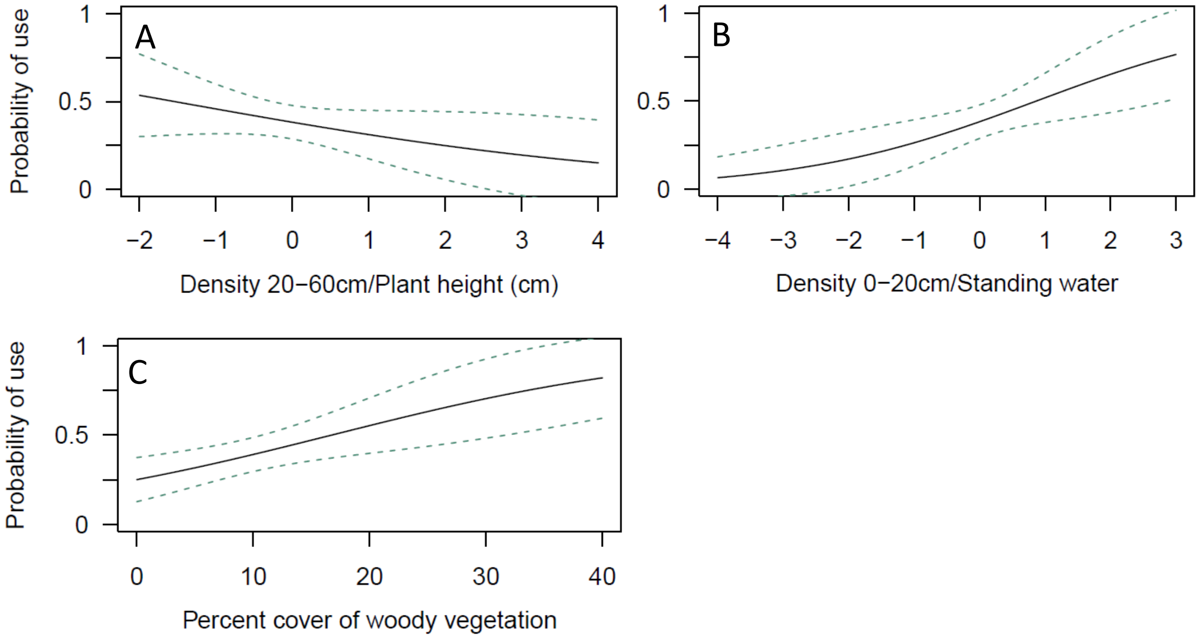

Figure 7. Logistic regression curves of the covariates in the top model for predicting Henslow's Sparrow (HESP) habitat use in power line right-of-ways in the coastal plain of Georgia, winters 2019 and 2020. Solid lines indicate the correlations between the probability of use and vegetation variables, and dashed lines indicate 95% upper and lower confidence intervals. The covariates in the top model are principal component 1 (PC1), shown in figure A, principal component 2 (PC2), shown in figure B, and percent cover of woody vegetation, shown in figure C. PC1 was mostly represented by vegetation density at 20-60 cm above the ground and plant height. PC2 was mostly represented by density at 0-20 cm above the ground and presence of standing water. On the Y-axes, 0 represents available habitat and 1 represents used habitat. The curves show that the probability of HESP use decreases with greater density at higher increments and taller plant height. In contrast, HESP use increases with higher density near the ground, the presence of standing water, and with higher percentage of woody cover.

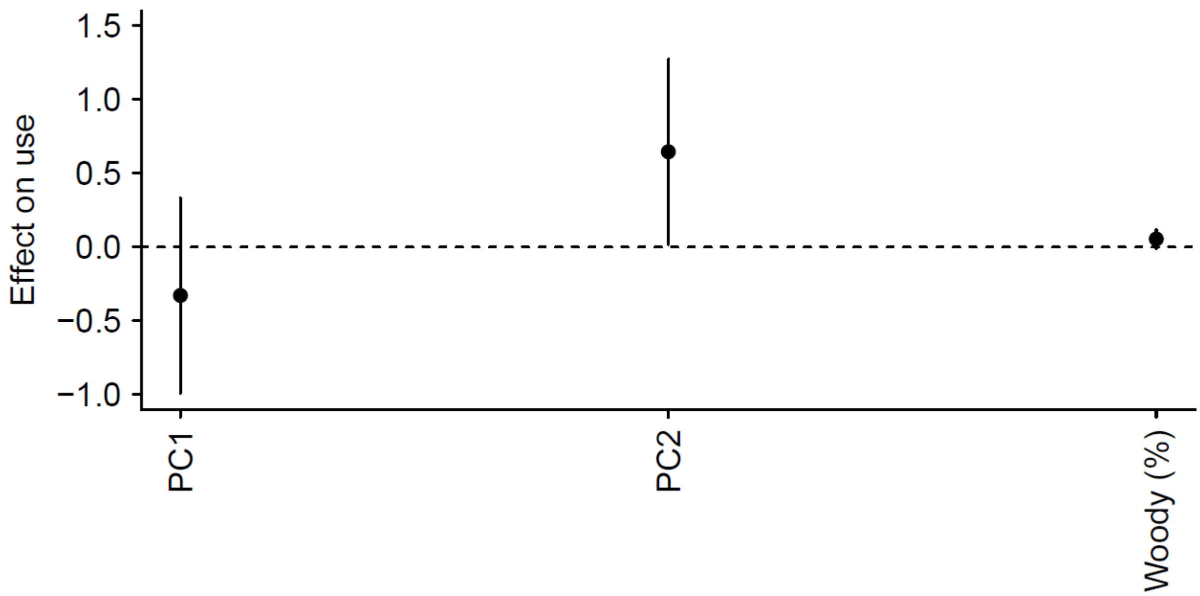

Figure 8. Effect size plot of vegetation variables on Henslow's Sparrow habitat selection in power line right-of-ways in the coastal plain of Georgia in winters 2019 and 2020. Points indicate the model averaged covariate effect and lines indicate 95% confidence intervals. The plot shows the most common covariates found in models with a delta AIC less than 4, including PC1 (principal component one), PC2 (principal component two), and percent cover of woody vegetation. PC1 was mostly represented by vegetation density at 20-60 cm above the ground and plant height. PC2 was mostly represented by density at 0-20 cm above the ground and presence of standing water. Zero on the Y-axis indicates a *no effect* result. PC2 is the only covariate that does not intersect with zero indicating that it has an effect on Henslow's Sparrow habitat selection.

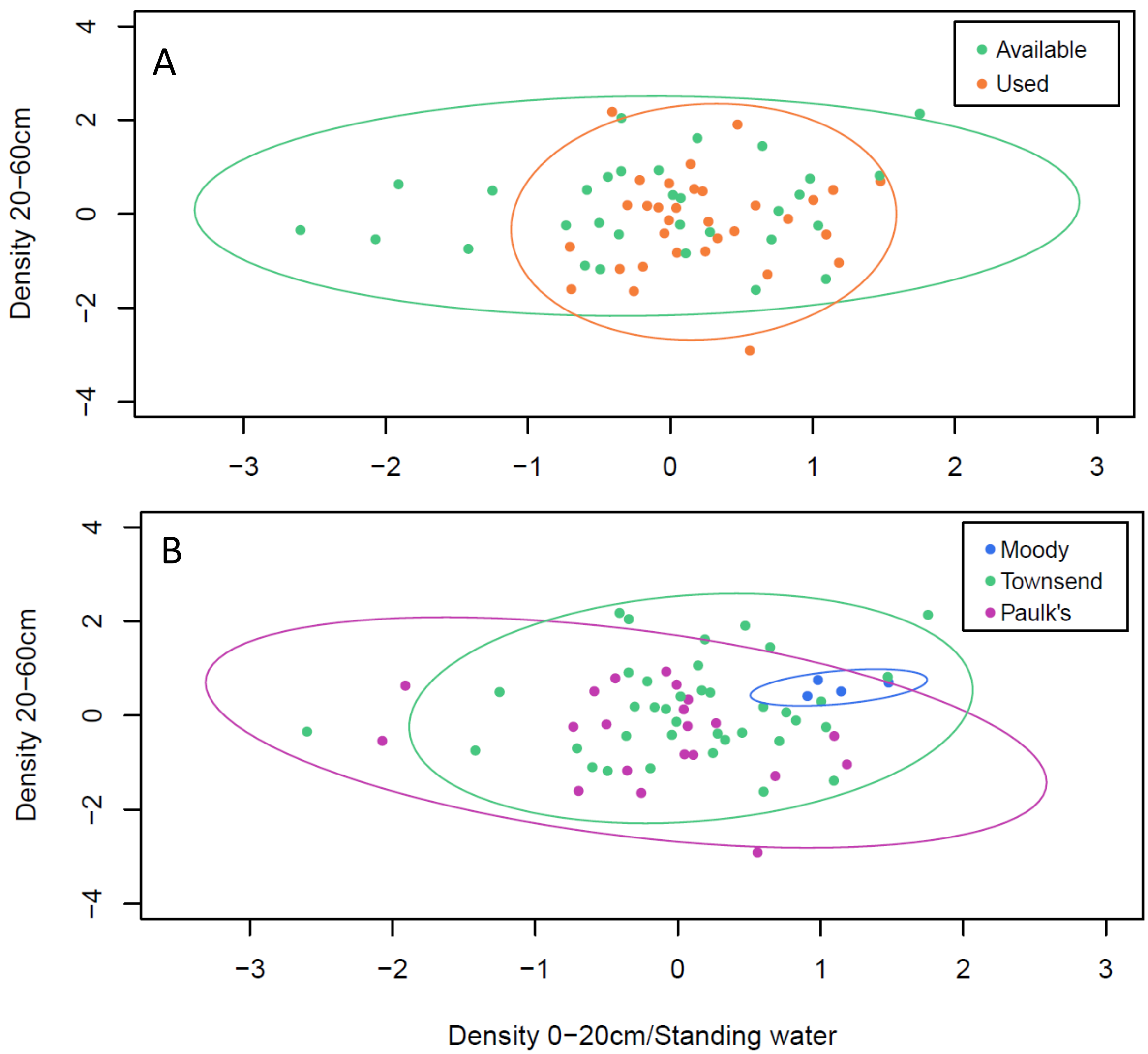

Figure 9. A. Principal Component Analysis (PCA) plot showing the overlap between habitat used by Henslow's Sparrows versus available habitat in power line right-of-ways in the coastal plain of Georgia from winter 2021. Used habitat data was collected inside Henslow's Sparrow radio-tracked areas, and available habitat data was collected outside of the radio-tracked areas. For ease of interpretation, I renamed the axes, which are principal components 1 and 2, as the variables that correlated with the principal components. Principal component 1 (PC1) on the X-axis mostly represents vegetation density at 0 to 20 cm above the ground and the presence of

standing water and describes 24.0% of variation in the data. Principal component 2 (PC2) on the Y-axis mostly represents vegetation density at 20-60 cm above the ground and describes 15.5% of the variation in the data. The PCA shows a majority of the “used” plots, in orange, are clustered in the center, with some “available” plots, in green, having more variation in vegetation characteristics. B. PCA plot using the same principal components as A., but showing the overlap among study sites. Moody Forest Wildlife Management Area (WMA) is shown in blue, Townsend WMA is shown in green, and Paulks Pasture WMA is shown in purple. The PCA shows only slight differences among study sites (Note: Moody Forest WMA had a small sample size).

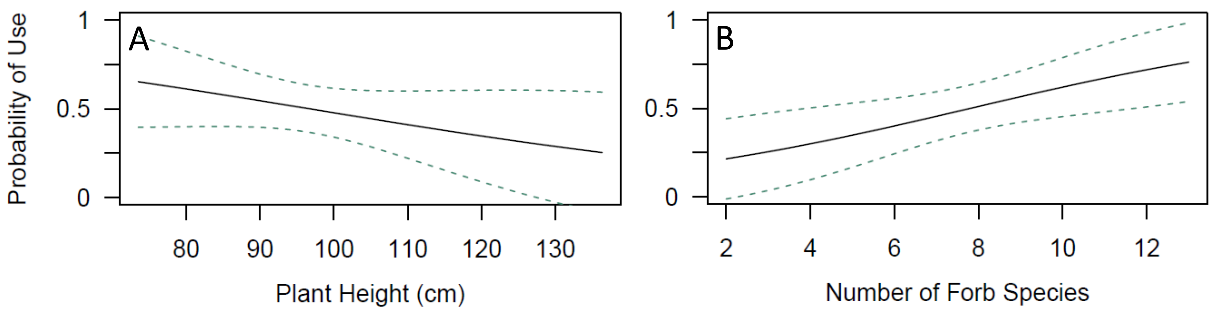

Figure 10. Logistic regression curves of the covariates in the top model for predicting Henslow's Sparrow (HESP) habitat use in power line right-of-ways in the coastal plain of Georgia, winter 2021. Solid lines indicate the correlations between the probability of use and vegetation variables, and dashed lines indicate 95% upper and lower confidence intervals. The mean height of the tallest plants and the number of forb species formed the top model for predicting habitat used by HESPs. On the Y-axis, 0 represents available habitat and 1 represents used habitat. The curves show that the probability of Henslow's Sparrow use decreases with increasing plant height (graph A) but increases with the number of forb species present (graph B).

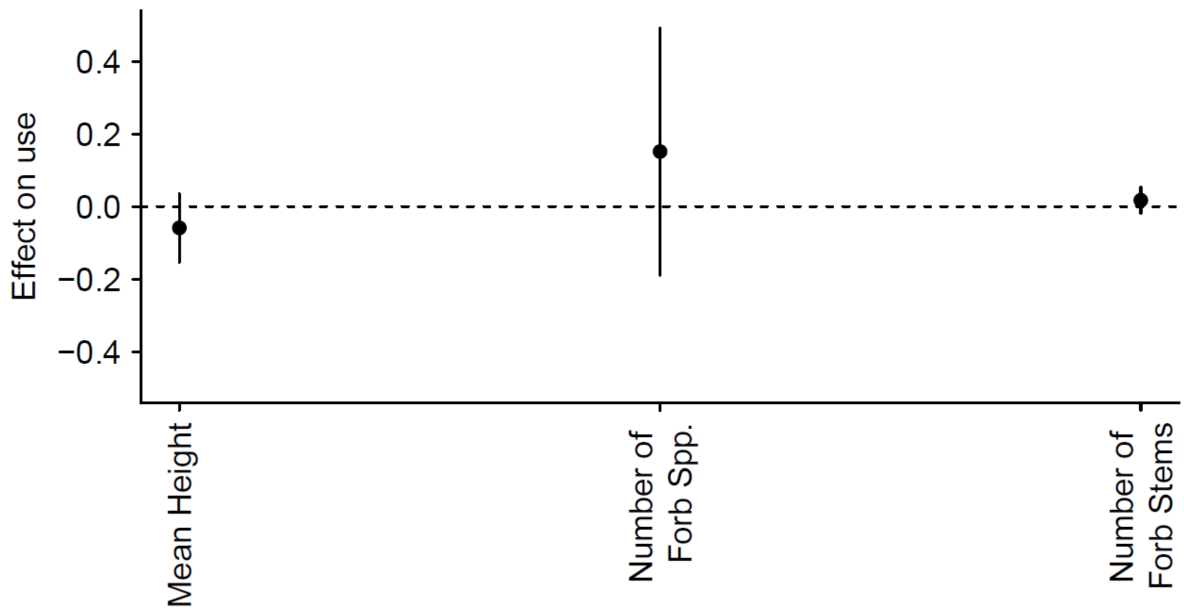

Figure 11. Effect size plot of vegetation variables on Henslow's Sparrow habitat selection in power line right-of-ways in the coastal plain of Georgia in winter 2021. Points indicate the model averaged covariate effect, and lines indicate 95% confidence intervals. The plot shows the most common covariates found in models with a delta AICc < 4, including mean plant height, number of forb species, and number of forb stems. Zero on the Y-axis indicates a *no effect* result. Confidence intervals for all three covariates intersect with zero and therefore appear to have no effect on Henslow's Sparrow habitat selection.

CHAPTER 4

DISCUSSION

Habitat Use

Henslow's Sparrows were found consistently wintering in ROWs over the timeline of this study. Overall, HESPs used habitat within ROWs that is similar to that of natural ecosystems used as wintering habitat, such as longleaf pine savannas, with features including a sparse tree canopy and dense herbaceous ground-layer (Carrie et al. 2002). However, HESPs appear to be using some microhabitat characteristics differently, such as dense vegetation at the ground level and a preference for some woody vegetation. Other studies have shown that ROWs can provide comparable and, at times, even better quality habitat for avian species than their "natural" habitat counterparts (Meunier et al. 2000; Tryjanowski et al. 2014). Tryjanowski et al. (2014) found that ROWs promoted bird abundance and diversity in an intensive agricultural landscape. These marginal habitats have the potential to represent rare examples in which human-altered habitats promote biodiversity and conservation of an at-risk species.

I used two different methods for estimating habitat use of HESPs in ROWs. Both methods compared vegetation characteristics of used ROW habitat with available ROW habitat. In winters 2019 and 2020, I used flush points (the location where HESPs flushed from the ground during rope-drag surveys) to represent used habitat, and systematically placed points every 200 m along transects to represent available habitat. In winter 2021, I refined these methods using radio-telemetry tracking of the birds to better estimate actual "use areas". Inside plots represented used habitat and outside plots represented available habitat. This second method is likely more indicative of actual habitat use because it represents bird locations over multiple days and not on the day of disturbance during the rope drag survey. Flush points could be biased because birds may run on the ground to escape the rope and observers before flushing. I found that only half of the flush points overlapped with the corresponding birds' use areas, providing evidence that use areas more accurately represent actual used habitat. Flush points were 21.6 m away from use areas on average (SD = 27.4 m); therefore, flush points may be used as a comparable alternative in a large-scale study; however, in smaller scale studies such as this one, use areas are superior representations of habitat use. For both of these methods, there was substantial model uncertainty (low model weights for top models, Tables 6 and 7) when comparing vegetation characteristics between used and available plots. This model uncertainty likely indicates that HESP habitat selection within ROWs was weak or highly variable among individuals. In other words, most of the habitat within ROWs was acceptable or usable habitat, and there was not strong or consistent selection for specific vegetative features. With this weak habitat selection in mind, the two methods produced different results in terms of which habitat features were selected; therefore, I will discuss the results of each method separately, starting with the results from winter 2021 because it is likely that these results are more indicative of actual winter habitat use due to (1) the improved methodology for placing vegetation surveys as mentioned above, and (2) the number of vegetation surveys at each site in 2021 was more proportional to each site's relative size than in 2019 and 2020 (Table 2).

According to the results from use areas estimated from radio-telemetry collected in winter 2021, HESPs used habitat with shorter plant height and habitat with a greater diversity of forb species (although both of these effects had 95% confidence intervals that overlapped with zero, Figure 11). The use of relatively shorter plant height at these sites contrasts previous study results showing HESPs preference for areas of taller vegetation height in longleaf pine savannas in Louisiana (Bechtoldt and Stouffer 2005; Johnson et al. 2011). These two studies found a tallest plant height average of 128 cm and 123 cm respectively, whereas my site averages ranged from 86 to 92 cm (Table 9). It is possible that max plant height is not as important as other habitat factors such as vegetation structure that provides cover from predators. In addition, areas where the plants were bowed over in the ROWs may have provided better cover from predators, but had shorter "tallest plant heights".

The use of areas with greater diversity of forb species suggests a preference for more heterogeneous areas, but it is unknown if this implies a more heterogeneous vegetation structure or diverse food source. Forbs have a greater variety of growth forms than grasses, and when forb diversity is high, there is likely greater structural diversity in terms of openings at various heights in the vegetation (Liira et al. 2002). In addition, a greater number of forb species may attract a greater diversity of arthropod prey items that HESPs eat (McMellen 2006). The low prevalence of forb species from previous HESP diet studies (Fuller 2004; Korosy 2013) suggests that forb diversity may be important for HESPs in Georgia to provide habitat structure, diverse invertebrate food resources, or possibly both, but this is not definitive without a corresponding comprehensive diet analysis for wintering HESPs in Georgia. Along with forb species diversity, forb density was also present in many of the top models, which is similar to a previous study that found that the likelihood of HESP presence increased with greater forb density in pitcher plant bogs (Tucker and Robinson 2003).

According to the results from the 2019-2020 flush point analysis data, HESPs used habitat areas with dense vegetation at the ground level and less dense vegetation higher above the ground, which is the opposite of what I predicted. These results are contrary to some studies that found that HESPs selected for habitat with low density at the ground and high density higher above the ground, providing room for movement and shelter from predators (Bechtoldt and Stouffer 2005; Johnson et al. 2011). However, this pattern was primarily seen in recently burned pine savanna habitats in gulf coast states, where these ecosystems are typically drier and contain different vegetation characteristics (such as longleaf pine duff accumulation on the ground, different plant species composition, etc.) than in the coastal plain of Georgia. Thus, the flush point analysis results can be explained by HESPs using habitat differently due to the different environment. That said, this result may provide evidence that HESPs are using whatever habitat is available in these ROWs (as observed in Palasz et al. 2010), regardless of what has traditionally been considered good quality habitat for HESPs. This is further supported by the overlap between habitat that was used versus what is available in the ROWs (Figure 6A). Because other studies have found that low density at the ground level is critical for HESPs to be able to move around, this begs the question: How are HESPs navigating in the ROWs that have not been recently burned and have dense vegetation at the ground level? One possible explanation is that HESPs are using above-ground rodent tunnels to navigate through the dense vegetation. At Townsend WMA, I recovered at least five transmitters from within tunnel-like structures in grasses and forbs at the ground surface (see Appendix B). If HESPs are primarily using tunnels and other fine-scale passageways for movement within habitat and cover from predators, it would be difficult for the density sampling methodology that I employed to detect these important habitat characteristics. Future studies may want to incorporate finer scale density measuring in order to quantify these passageways and to help improve the accuracy of results. One caveat to these results is the potential confounding factor between low vegetation density near the ground and standing water. For example, areas that had standing water prevented measuring vegetation density and therefore would be recorded as falsely having low vegetation density. To account for this, an interaction term between density and water could be added to logistic regression models.

According to the 2019 and 2020 flush point analysis, HESPs used habitat with relatively higher percent cover of woody vegetation. Contrastingly, in southern Arkansas HESPs were found to have a negative correlation with shrub cover (Holimon et al. 2008); however, not much woody vegetation occurs in the ROWs, with woody cover ranging from 4.9% to 12.4% on average, depending on the study site (Table 9). Therefore, this result must be interpreted relative to the habitat within ROWs (which is managed to have no trees and low woody plant cover overall). One likely explanation for this result is the need for some woody vegetation to provide escape refugia from predators (and observers during surveys). After flushing HESPs, I observed them return to the ground under saw palmettos (*Serenoa repens*), gallberry shrubs (*Ilex* spp.), pine saplings (*Pinus* spp.), and other woody vegetation in the ROW. Similarly, Dean and Vickery (2003) observed Bachman's Sparrows frequently using saw palmettos as escape refugia.

In order to account for the small sample size of telemetered locations per bird, MCPs represented "use areas" rather than "home-ranges". Home-ranges constitute the entire space that an animal uses in a given season, whereas use areas are a portion of that range and may only provide a snapshot of their space-use during that season. As the number of telemetry locations per bird increased, average use area size increased, suggesting that if I had monitored the birds for a longer period of time, their home-range would have been larger than the use area I estimated. Though I averaged approximately 14 locations per bird over 5 days of tracking (Table 5), a previous study showed that home-ranges do not stabilize until 21 locations per bird have been acquired (average of 16 days of tracking) (Thatcher 2003). However, my estimate of the average use area size (0.14 hectares; Table 5), which was based on 9 to 26 locations per bird, suggests that the amount of space that the HESPs used in ROWs is likely smaller than, and possibly as little as half the size of the average home-range in longleaf pine savanna areas in Louisiana ($\bar{x}$=0.3 hectares; Bechtoldt and Stouffer 2005). My use area estimation method was different from Bechtoldt and Stouffer (2005), who used a bootstrap of 11 random locations per bird to estimate home-ranges. If I had used this method the estimated size of use areas would have been even smaller. In longleaf pine savannas in coastal Mississippi, Thatcher (2003) found that HESPs used 0.45 hectares (estimated from a range of 22 – 98 locations per bird using 95% MCPs). The comparison of these home-ranges is important because smaller home-ranges can indicate greater quantities of resources in a smaller area, and therefore better habitat quality (Godet et al. 2018). The small areas used by HESPs in ROWs suggest that ROWs in the coastal plain of Georgia may have better habitat structure and more food resources than longleaf pine savanna habitat. However, this result should be interpreted cautiously as a small home-range could also indicate an ecological trap due to limited habitat availability and a densely packed habitat, and therefore limited resource availability (Anich et al. 2010). Henslow's Sparrow breeding populations have shown an overall increasing trend since the early 2000s (Sauer et al. 2020), which could mean that more HESPs are arriving in Georgia to overwinter but may be encountering the same amount of limited wintering space.

This research helps to fill a knowledge gap on how HESPs are using ROWs to overwinter; however, I acknowledge a few weaknesses that could be improved upon in future studies. Since we continued surveying the same transects that DNR biologists surveyed before this project started, transects were not selected based on a randomized study design. These transects were originally chosen because they had habitat that looked suitable for HESPs: habitat with a graminoid-dominated ground-layer and little woody vegetation. We used these same

ROW transects in order to continue the mark-recapture project to study survivorship and maintain a long-term dataset at the same sites. Long-term datasets are essential to monitoring changes that communities sustain over time and to gauge how environmental changes will affect communities in the future (Magurran et al. 2010). However, because these transects were selected for their observed high densities of HESP, it is possible that this study was conducted in the highest quality habitat within ROWs, which could have contributed to the weak habitat selection that I observed. Expanding this study's scale to include areas that appeared unsuitable for HESPs would have likely produced results of stronger habitat selection, as the scale of a study can influence its results (Wiens 1989). Weak habitat selection may be expected in the winter, though, as habitat requirements in the winter (i.e., food and cover) are more general than they are in the breeding season when nesting requirements may make habitat selection stronger (Igl and Ballard 1999).

A significant challenge faced in this project included the unreliability of transmitter attachment, though using Cyanoacrylate gel glue in winter 2021 rather than VetBond glue as used in the previous years, improved results. Leg loops, used in other studies (Thatcher et al. 2006), may help alleviate this problem and allow for a longer tracking duration; however, we chose not to use this method because we were concerned that the high vegetation density at the unburned sites could lead to entanglement in the leg loops and injuries or mortalities (Hill and Elphick 2011). Secondly, because birds had such small use areas during telemetry-tracking, it was often difficult to determine if a bird had moved since previous locations were taken, making it difficult to tell if and when its transmitter had fallen off. In response to this, I sometimes flushed birds so that I could see whether the transmitter was still attached; however, to avoid this biasing subsequent telemetry triangulations, I would wait until the end of a tracking day.

Next Steps and Conservation Implications

Moving forward, it will be important to assess if any particular plant species are important food resources to HESPs in these ROWs, or if they are selecting for specific vegetation structures rather than specific plant species. Johnson et al. 2011 observed HESPs selecting for tall vegetation and reduced ground-level vegetation density over plant species composition or density of seeds. Fecal-diet analysis would help determine dietary preferences and would help land managers to focus on managing for specific plant species. Concurrent survivorship investigation on the long-term mark-recapture data set will also help elucidate the overwintering ecology of HESPs in these ROWs.

Though my results indicate that HESPs are using unburned sites (Paulks Pasture and Townsend WMAs) and high vegetation density at the ground level, burning these sites in the future may prevent vegetation from becoming too dense, which could cause the sparrows to only use rodent tunnels or the ROWs to become unusable over time. Experimental burning would allow for monitoring of how the vegetation structure and composition, and HESP use, responds over time. Burns should try to mimic natural lightning strike fires that historically occurred during the growing season. Growing season burns have been found to promote forb species richness (Fynn et al. 2004), which appeared in many top models describing HESP use in ROWs (Table 7). Patchy burns (like those often generated by lightning strike fires) would leave some untouched areas for HESPs and promote vegetation diversity (Keeley et al. 2009). Future experimentation on burning regimes would elucidate the optimal timing and frequency of burning.

Post-management monitoring is important as it will allow biologists to watch for sudden declines in use, potentially because the habitat has stopped being suitable for the sparrows, and to watch for signs of an ecological trap (such as high predation rates). ROWs may pose a high risk of avian predation due to an abundance of optimal perching locations on the power poles, lines, and adjacent trees (Meunier et al. 2000). In addition, ROWs have very little core area and are mostly edge habitat, therefore likely have an even higher risk of predation (Ellison et al. 2013). The predations that I observed in winter 2020 were consistent with bird of prey attacks, including large beak or talon piercings, or piles of plucked feathers. Frequent predators that I observed using ROW perches included American Kestrels (*Falco sparverius*) and Northern Harriers (*Circus hudsonius*).

My results support the idea that ROWs can provide comparable wintering habitat to longleaf pine savannas, and support site-faithful HESPs throughout the winter months. As grassland birds nationwide continue to decline, ongoing monitoring of the HESP populations using ROWs is critical. In the future, more partnerships with power companies should be encouraged to allow biologists and land managers access and the ability to monitor and manage habitat within the ROWs. This will expand suitable HESP habitat and can benefit both parties, due to the shared desire for minimal tree growth. Managing more ROWs for the conservation of HESPs will increase suitable habitat space, increase movement capabilities, and support the continued persistence and increase of wintering HESP populations. ROWs managed for HESPs can also promote landscape connectivity by providing corridors between fragments of remaining longleaf pine savanna habitat. If managed and monitored properly, ROWs throughout the southeastern United States may become a conservation resource that can help support many native species of flora and fauna.

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APPENDIX A

PHOTO OF TRANSMITTER ATTACHMENT

Cotton cloth and transmitter glued to the lower back of a Henslow's Sparrow using cyanoacrylate gel glue.

APPENDIX B

PHOTO OF ABOVE-GROUND TUNNEL IN VEGETATION

Tunnel at Townsend WMA in which I recovered a VHF transmitter that was used to track movements by a Henslow's Sparrow in the winter of 2020.

APPENDIX C

MAP OF HENSLOW'S SPARROW DISTRIBUTION AT MOODY FOREST

Map showing the distribution of Henslow's Sparrow flush points and use areas in the power line right-of-way at Moody Forest WMA, Georgia, in relation to recent prescribed fire. Burning was done within alternate areas ("burn units") of the right-of-way in early March of 2019 and 2020. Map "A" shows winter 2020 flush points and use area (only one use area was acquired) with 2019 burn units. Map "B" shows winter 2021 flush points and use areas with 2020 burn units. Map "C" shows winter 2021 flush points and use areas with 2019 burn units. No apparent selection for or avoidance of burn units was observed for any burn unit ages.


Henslow's Sparrow Distribution in Relation to Burning:
Power Line Right-of-Way at Moody Forest WMA, Georgia
N
0
200
400
800 Meters
Legend
2020 Flush points
2021 Flush points
2020 Use area
2021 Use areas
2020 Use area locations
2021 Use area locations
2019 Burn units
2020 Burn units
A
B
C