FINAL REPORT

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Project Title: Response of Bachman's Sparrow (*Peucaea aestivalis*) to habitat management in a wiregrass-free ecosystem

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Summary: Through much of its range, Bachman's Sparrow (*Peucaea aestivalis*) uses the wiregrass (*Aristida spp.*) dominant understory typical of longleaf pine (*Pinus palustris*) forest. The central South Carolina Coastal Plain, however, lies within the "wiregrass gap" where longleaf pine understories are absent of wiregrass and instead are dominated by bluestem grasses (*Schizachyrium spp.* and *Andropogon spp.*), bracken fern (*Pteridium aquilinum*), and shrubs. Habitat use of Bachman's Sparrow in this region has yet to be studied and declining Bachman's Sparrow populations necessitate a better understanding of habitat selection processes and population dynamics across regional habitat types. The goal of this study was to describe breeding season habitat selection and breeding ecology of Bachman's Sparrow in the unique wiregrass-free longleaf pine ecosystem of Tom Yawkey Wildlife Center, Santee Coastal Reserve, and Washo Reserve, South Carolina to inform best management practices for Bachman's Sparrow. We conducted repeated visit point count surveys at 95 sites and used open *N*-mixture models to estimate the effects of habitat management and forest stand characteristics (e.g. prescribed burns, basal area, stem density, pine species, canopy closure) on Bachman's Sparrow abundance, apparent survival probability, and recruitment rates during the 2020 and 2021 breeding seasons. We also located nests to identify vegetation composition and structure characteristics that Bachman's Sparrows select for nest-sites. To determine if habitat selection in the study population was adaptive, we monitored nests and related nest-site selection to nest survival rates by comparing habitat characteristics related to selection with those related to survival. Across the nine primary sampling periods, we estimated the abundance of male Bachman's Sparrows within the study area to be between 23 and 49 individuals. Initial abundance and recruitment rate were strongly predicted by the proportion of longleaf pine to other pine species within the sample area, with abundance and recruitment rate increasing with longleaf pine dominance. Apparent survival probability decreased as the density of stems between 10 and 25 cm DBH increased. Nest-site selection in the study population was non-adaptive. Bachman's Sparrows selected nest-sites that had intermediate groundcover densities compared to available nest-sites; however, nest survival rates decreased at intermediate groundcover densities. The results of this study can be used to inform region-specific management plans and restoration of degraded habitats, which often lack typical understory species like wiregrass, to increase Bachman's Sparrow abundance and reproductive success.

Background: Longleaf pine (*Pinus palustris*) forest currently exists at less than 3% of its historic range in the Southeast United States due to a history of habitat degradation, land-use change, and fire suppression (Frost 1993, 2006, Outcalt and Sheffield 1996). The vast reduction in longleaf pine habitat has resulted in the decline of longleaf pine obligate species (Van Lear et al. 2005, Means 2006) and a renewed interest to conserve and restore this unique ecosystem (Landers et al. 1995, Noss et al. 1995, McIntyre 2018, ALRI 2019). Current management practices for longleaf pine forest are geared towards improving ecosystem functioning through prescribed burning, midstory removal, and restoration of understory vegetation (Brockway and Lewis 1997, Brockway et al. 2005, Walker and Silletti 2006, Johnston and Gjerstad 2006). Management for avian use has historically been focused on recovery of the federally endangered Red-cockaded Woodpecker (*Dryobates borealis*). Through intensive research on its habitat selection, population dynamics, and applied management, the Red-cockaded Woodpecker has become a conservation success story, as many populations are now stable or growing (USFWS 2003, 2019). However, much remains unknown about the unique habitat use of other longleaf pine avifauna, such as Bachman's Sparrow (*Peucaea aestivalis*), which are similarly of conservation concern due to habitat loss and degradation. While forest management for Red-cockaded Woodpecker generally improves habitat for Bachman's Sparrow (Plentovich et al. 1998, Conner et al. 2002), it may not encompass all of Bachman's Sparrow habitat needs (Liu et al. 1995, Plentovich et al. 1998, Krementz and Christie 1999). For example, prescribed burning and stand thinning often are not specifically implemented to optimize understory structure and composition for Bachman's Sparrow recruitment, survival, and reproductive success (Plentovich et al. 1998). The widespread decline of Bachman's Sparrow and other longleaf pine obligate species suggest the need to supplement holistic ecosystem management with specific management plans for the species at greatest risk (Van Lear et al. 2005, Goble et al. 2012).

Bachman's Sparrow is a small, secretive passerine that inhabits pine-grass woodlands, especially longleaf pine forest, and other open habitats in the Southeastern United States. The species currently occurs from North Carolina to Florida on its eastern extent and from southern Missouri to East Texas on its western extent (Dunning et al. 2018). Aside from some short-distance migratory populations at the northern range periphery (Eifrig 1915, Brooks 1938, Weston 1968), Bachman's Sparrows are year-round residents. They are ground nesters and foragers and thus rely on frequent fire or other disturbance to maintain appropriate understory conditions. In general, Bachman's Sparrow habitat is characterized by short, dense understory growth abundant in grasses, forbs, some small shrubs, and patches of bare ground (Dunning and Watts 1990, Haggerty 2000, Brooks and Stouffer 2010, Jones et al. 2013, Taillie et al. 2015, Winiarski et al. 2017a). Selected habitat characteristics are ephemeral and Bachman's Sparrows disperse when habitat conditions are no longer suitable (Cox and Jones 2007, Jones et al. 2014, Cerame et al. 2014).

Bachman's Sparrow received little research attention until the mid-1980's. The species experienced a range expansion in the early 1900s due to wide-scale agricultural abandonment and clearcutting (Eifrig 1915, Brooks 1938). However, Bachman's Sparrow populations have since declined and their range retracted after this early-successional habitat was lost (Sauer 2017). Conversion of mature longleaf forest into plantations of faster-growing pines further reduced habitat availability in the Southeast (Frost 2006), as plantation forestry practices often inhibit understory growth if groundcover maintenance is not a management objective (Noss 1989, Harrington and Edwards 1999, Harrington et al. 2003). To this day a departure from natural and historic disturbance regimes contributes to habitat loss. In 2000, it was estimated that only half of the remaining longleaf forest was burned on a frequent basis (i.e. five year burn rotation; Outcalt 2000). Over the past three centuries, the Southeast has drastically shifted from a landscape of vast, open longleaf pine forest to fire suppressed loblolly pine (*Pinus taeda*) stands (Frost 2006). Although the total amount of pine landcover has not been drastically reduced (Frost 2006), species that rely on frequently burned open pine forest, such as Bachman's Sparrow, have been limited to fragmented patches of remaining pine-grasslands (Simberloff 1993, Van Lear et al. 2005). Consequently, populations have declined and Bachman's Sparrow has been listed as a species of conservation concern in all states across its range. A growing interest in conserving this lesser-known longleaf pine specialist has motivated research on habitat relationships and sources of population declines in order to conserve the species on remaining managed lands.

Management techniques and resulting forest stand characteristics can impact habitat occupancy by Bachman's Sparrow. Burn frequency influences Bachman's Sparrow occupancy as frequent burns maintain suitable understory conditions (Engstrom et al. 1984, Tucker et al. 2004, Cox and Jones 2009). Bachman's Sparrow density peaks around two years post-burn and declines after three years since burn (Tucker et al. 2004). Bachman's Sparrows typically do not occupy stands that have not been burned in over five years (Engstrom et al. 1984). Preferred understory habitat rich in grasses and forbs can also be maintained by increasing light availability (Harrington and Edwards 1999, Platt et al. 2006). Thus, treatments such as midstory removal, stand thinning, and prescribed burning can be useful tools for managing Bachman's Sparrow habitat (Brockway and Lewis 1997, Harrington and Edwards 1999, Meyer 2006, USFWS n.d.). By identifying habitat treatments and measuring vegetation characteristics that Bachman's Sparrows select, best management practices for Bachman's Sparrow can be refined. Although habitat use by Bachman's Sparrow can be generalized across the species' range, there are regional differences (Dunning and Watts 1990, Haggerty 2000, Winiarski et al. 2017b). For example, Bachman's Sparrows in the North Carolina Sandhills select nest-sites with intermediate vertical grass density and greater pine basal area, while individuals in the Coastal Plain select nest-sites with lower vertical grass density and greater vertical shrub density (Winiarski et al. 2017b). Often, differences in resource use in a species with a wide geographic range, such as Bachman's Sparrow, occur because the geographic range of a resource is smaller than that of the species (Fox and Morrow 1981, Haggerty 2000). Resource use is driven by resource availability (Johnson 1980), and thus regional differences in availability lead to different patterns in selection as long as the species' basic requirements for survival and reproduction are met (Grinnell 1917, James et al. 1984, Haggerty 2000). Despite the variation in habitat composition over geographic space, wide-ranging species – even those, like Bachman's Sparrow, that are considered to be habitat specialists – occur across resource gradients (Fox and Morrow 1981, Lawton et al. 2012). Thus, range-wide, habitat selection is more likely to be dictated by broad structural characteristics rather than specific vegetation associations. In local populations, habitat selection patterns may be region specific and reflect resource availability.

Through much of Southeast, Bachman's Sparrow uses the dense wiregrass (*Aristida spp.*) understory typical of longleaf pine forest. However, central South Carolina lies between the ranges of *Aristida stricta* to the north and *Aristida beyrichiana* to the south (Figure 1, Peet 1993, 2006), resulting in understories absent of wiregrass and with greater shrub density. Habitat use of Bachman's Sparrow in this unique wiregrass-free longleaf pine ecosystem has not received much research attention. The South Carolina State Wildlife Action Plan (SCDNR 2015) lists Bachman's Sparrow as a species of highest priority for conservation, and thus there is interest in increasing statewide populations. Understanding the drivers of Bachman's Sparrow habitat selection and survival in the unique longleaf pine ecosystem of the central South Carolina Coastal Plain can inform the development of region-specific management plans for species persistence in the current habitat. In addition to improving existing habitat for Bachman's Sparrow, studying how the wiregrass gap population uses the unique ecosystem can guide restoration of degraded habitats, which often have unsuccessful or slow wiregrass regeneration, and ultimately encourage Bachman's Sparrow recruitment.

The goal of this study was to describe the drivers of Bachman's Sparrow habitat selection in the wiregrass gap in order to inform targeted management for the species. We determined how stand-scale habitat metrics and management treatments (i.e. prescribed burning, stand thinning, midstory removal) influence abundance of Bachman's Sparrow. We also described nest-site selection in Bachman's Sparrow, focusing on vegetation structure and composition. We quantified nest survival rates and related drivers of nest survival to nest-site selection to determine if selection is adaptive. This research expands the current understanding of Bachman's Sparrow habitat selection to a new region and has implications for restoration of longleaf pine ecosystems where wiregrass has not been established.

Objective 1: Identify habitat management practices that maintain the highest densities of Bachman's sparrow in a wiregrass-free ecosystem within the current management framework.

Accomplishments:

Study Area

The study sites, Tom Yawkey Wildlife Center Heritage Preserve (YWC), Georgetown County, South Carolina and Santee Coastal Reserve Wildlife Management Area (SCR), Charleston County, South Carolina, are coastal properties managed by South Carolina Department of Natural Resources (SCDNR) The Washo Reserve (WR), a property owned by the Nature Conservancy and co-managed with SCDNR, lies within SCR. Upland areas of WR were included in SCR sampling. Study areas were dominated by longleaf and loblolly pine as well as mixed pine and hardwood forest. The understory vegetation composition of YWC and SCR is unique because the sites fall between the *Aristida stricta* and *Aristida beyrichiana* ranges and thus are free of wiregrass. Instead, understories are composed of predominantly bluestem grasses, bracken fern (*Pteridium aquilinum*), and short-statured shrubs (e.g. *Ilex glabra*, *Gaylussacia dumosa*, *Gaylussacia frondosa*, *Vaccinium spp*., *Lyonia lucida*). Switchcane (*Arundinaria tecta*) was common in areas, particularly those bordering hardwood slough. Longleaf, mixed pine, and mixed pine and hardwood stands at both sites are managed through dormant season prescribed burning, primarily in January through early April. Stands at YWC and SCR are typically burned every one to five years (YWC: mean = 1.33, SD = 2.67; SCR: mean = 2.11, SD = 1.38).

Point Count Surveys

We completed four rounds of 8-minute point count surveys between April 16 and July 4, 2020 and five rounds of point count surveys between March 28 and July 6, 2021 at YWC and SCR. All survey points were located in longleaf pine, loblolly pine, mixed pine, or mixed pine and hardwood stands, were at least 500 m apart, and had a 200 m survey radius. The number of unique vocalizing male Bachman's Sparrows within the 200 m radius of the site was recorded during three sequential sampling periods during each visit. Additional data on time of day and weather, which could affect detection, were recorded. In 2020, we detected adult male Bachman's Sparrows at 10 of 47 point count locations at YWC and 12 of 48 point count locations at SCR. In 2021, we detected adult male Bachman's Sparrows at 6 of 47 point count locations at YWC and 13 of 48 point count locations at SCR. In total we detected singing males at 12 of 47 point count locations at YWC (Figure 2) and 15 of 48 point count locations at SCR (Figure 3).

Stand Characterization

Between March 1 and August 25, 2021, we quantified management treatments and resulting forest characteristics at each point count location. We randomly selected five points a minimum of 60 m apart within each site. At each point, we measured basal area of pine stems using a 10-factor prism and canopy closure using a spherical densiometer. To quantify small stem density, we counted the number of pine, nonpine, and dead stems with a diameter at breast height (DBH) ≥ 10 cm and < 25 cm within a 0.04 ha circular plot centered around the point. To quantify large stem density, we counted the number of pine, nonpine, and dead stems with a DBH ≥ 25 cm within the same 0.04 ha plot. We calculated the percent of all stems ≥ 10 cm DBH that were pine species. We also calculated the proportion of longleaf pine stems to all pine species stems. We averaged basal area, canopy closure, and percent pine stems, and proportion longleaf measurements for each point count location. We summed the stem counts of pines, hardwoods, and dead trees to calculate the total number of small (≥ 10 cm and < 25 cm DBH) and large (≥ 25 cm DBH) trees per hectare. In addition to the field measured variables, we used the 2016 National Landcover Database (Dewitz 2019) to quantify the percent of each site that is classified as evergreen. Sites often spanned across management units with different burn histories. Thus, the unit-scale habitat variable "years since burn" assigned to each point was the weighted average of all management units within each site.

Habitat Selection Analysis

We used open *N*-mixture models (Dail and Madsen 2011) under an information theoretic framework to estimate the effects of habitat management and forest characteristics on site-specific initial abundance, recruitment rate, apparent survival probability, and detection probability of adult male Bachman's Sparrows. *N*-mixture models are suitable for estimating abundance in unmarked populations because they simultaneously model the ecological processes affecting abundance while accounting for imperfect detection using spatially and temporally replicated count data (Royle 2004). Open *N*-mixture models are a generalized form of the Royle (2004) model that explicitly model population dynamic parameters (e.g. initial abundance, recruitment rate, and apparent survival probability under constant population dynamics) to account for migration, births, and deaths when estimating abundance. We used open *N*-mixture models with a short time interval robust design (Figure 4, Pollock 1982, Betts et al. 2008) because resighting of color-banded individuals suggested some males moved within the breeding season, violating the population closure assumption of *N*-mixture models (Royle 2004). All point count surveys were divided into three subsequent secondary periods over which we estimated detection probability.

Results

The top model indicated that the proportion of longleaf pine to all pine species within the site best explained initial abundance and recruitment rate, small stem density best explained apparent survival probability, and minutes elapsed since sunrise and the secondary period best explained detection probability (Table 1). According to the top model, detection probability decreased as time since sunrise progressed and increased with each subsequent secondary period (Figure 5, Table 2), initial abundance increased as the proportion of longleaf pine increased (Figure 6, Table 2), recruitment rate increased as the proportion of longleaf pine increased (Figure 7, Table 2), and apparent survival probability increased as the density of small stems decreased (Figure 8, Table 2).

Each population dynamic parameter was modeled by the combinations of covariates that were best supported in each separate step of our modeling procedure. We estimated each parameter using average covariate values (Table 3). Across the nine primary periods, estimated density of adult male Bachman's Sparrow at YWC and SCR ranged from 0.85 – 1.70 birds/km^2 (85% CI: 0.76 – 1.85 birds/km^2, Figure 9). Bachman's Sparrow density decreased in 2021 (85% CI: 0.76 – 1.30 birds/km^2) compared to 2020 estimates (85% CI: 1.30 – 1.85 birds/km^2, Figure 9). Over the 26.589 km^2 area of upland habitat that was sampled, estimated abundance of adult male Bachman's Sparrows was between 23 (Primary Period: 20 Jun – 10 Jul 2021) and 49 individuals (Primary Period: 07 – 27 May 2020).

While previous studies have described how habitat features impact Bachman's Sparrow occupancy on multiple spatial scales (e.g. Taillie et al. 2015), this study provides novel information on how the habitat selection process differs throughout the breeding season. In this study, different forest characteristics drove site selection and dispersal. We found that the proportion of longleaf pine to other pine species best predicted initial abundance and recruitment while small stem density best predicted apparent survival probability. These results suggest that initial site selection after a dispersal may be driven by overstory composition. On the contrary, once an individual is established at a site, the decision of whether to stay at a territory or disperse may be driven by structural habitat attributes, like small stem density, which impact nesting and foraging success.

See attached appendix (Thistle Thesis) for complete methods, results, and discussion.

Significant deviations: None.

Objective 2 & 3: Identify nest sites and associated habitat characteristics of Bachman's sparrows in a wiregrass-free ecosystem. Identify habitat and habitat management practices that result in the greatest Bachman's sparrow nest success in a wiregrass-free ecosystem within the current management framework.

Accomplishments:

Nest Searching and Nest Monitoring

We searched for Bachman's Sparrow nests at YWC and SCR between 10 April and 31 July during the 2020 and 2021 breeding seasons and found 47 nests (Figures 10-11). We revisited each active nest every two to four days (mean = 2.82, SD = 0.82) to monitor nest survival following Martin and Geupel (1993). At each visit, we recorded the nesting stage, i.e. building, incubating, nestling, fledgling, or failed (abandoned, depredated, hatch failure, or unknown). If there were nest contents, we recorded the number of eggs and/or the number and age of young. The incubation period lasts on average 13 days and nestlings on average fledge after nine days (Haggerty 1994), so survival rates for the whole nesting period were calculated based on a 22 day nesting period. Observations after 22 days were not included in analyses.

Vegetation Surveys

We measured nest-site vegetation characteristics between 06 May and 17 August 2020 and 15 May and 11 August 2021. We measured nest-site characteristics 30±3 days after nest initiation (from first day of incubation) and compared these measurements to available nest-site characteristics. Measuring nests after the nesting attempt is complete decreases the likelihood of nest abandonment or predation due to human presence (Götmark 1992, Martin and Geupel 1993). Measuring vegetation characteristics at a consistent time in the nesting period rather than at the inconsistent times of nest detection, failure, or fledging reduces bias in estimated effects of vegetation characteristics on nest-site selection and nest survival due to vegetation growth (McConnell et al. 2017).

To quantify habitat characteristics of available nesting locations within Bachman's Sparrow home ranges, we randomly selected a paired available nest-site for vegetation surveys from within the assumed home range of the individual. We considered each home range to be a circle, centered on the nest, with a radius of 160 m. This delineation is based on 95% fixed kernel home range estimates of Bachman's Sparrow from past studies (Brown 2012, Winiarski et al. 2017b) that produced estimates using radio telemetry. Following Taillie et al. (2015) and Winiarski et al. (2017a), we measured vegetation characteristics along two 10 m perpendicular transects centered at the nest site or available nest site. We measured vegetation characteristics along each transect at 1 m increments away from the nest, totaling 20 vegetation survey points plus the central nest location. The vegetation measurements taken at the 21 points were averaged for analysis (Table 4). We measured vegetation density using methods established by Wiens and Rotenberry (1981). We measured vertical density by quantifying the number of "hits" of each vegetation class along 0.1 m increments of a pole 1.5 m long and 6 mm in diameter. We quantified groundcover density as the number of "hits" of each vegetation class along the first 0.1 m of the pole. Using a 0.5 m x 0.5 m quadrat, we visually determined percent bare ground and percent composition of five vegetation classes (grass, switch cane, forb/fern, shrub, and dead) making up > 5% of the ground cover, excluding litter, within the quadrat. We measured the maximum height of each vegetation class using a measuring tape. We counted the number of perches at each survey point, defined as the number of alive or dead woody plants > 1 m that can support the weight of a sparrow. We measured canopy closure using a spherical densiometer and pine basal area at the nest-site using a 10-factor prism.

Weather

We used daily summary weather data from station WBAN:03728, McClellanville 7 NE, SC (33.1532°, -79.3637°, NOAA 2021) to determine maximum temperature and total precipitation over nesting intervals. This weather station was selected because it was the closest station (distance = 2.42 – 15.42 km) to YWC and SCR nests that had the most complete records.

Statistical Analyses

Nest-site Selection

We assessed the effects of the vegetation structure and composition on Bachman's Sparrow nest-site selection using conditional logistic regression models under an information theoretic framework (Hosmer and Lemeshow 1989, Compton et al. 2002, Duchesne et al. 2010; Table 5). We incorporated pine basal area at the nest, canopy closure, number of perches, groundcover density, vertical density, maximum vegetation height, percent bare ground, and percent cover of five vegetation types (grass, switch cane, forb/fern, shrub, and dead) as covariates in the nest-site selection models. We exponentiated the top fitted model to formulate a Resource Selection Function (RSF) that estimates relative probability of nest-site selection under the modeled habitat covariates (Manly et al. 2002).

Nest Survival

We used the logistic exposure method (Shaffer 2004) to model the daily survival rate (DSR) of Bachman's Sparrow nests across nest-site vegetation characteristics under an information theoretic framework (Table 6). The logistic exposure method uses logistic regression with a modified logit link which accounts for exposure days to fit logistic regression models with or without random effects to formulate estimates of daily nest survival rates when nest exposure time varies. Nests survived (1) the interval between each nest check if at least one viable egg or one live nestling remained in the nest, or if at least one nestlings was confirmed fledged. If no viable eggs or live nestlings or fledglings remained, the nest failed (0) during that interval. Nests were considered successful if at least one nestling fledged.

Models shared the same covariates as the nest-site selection model set in order to determine if the same characteristics that Bachman's Sparrow select at nest-sites increase survival, supporting adaptive nest-site selection. In addition, modeled the effect of years since burn, weather, nest age, and date on daily survival rate. We used the modified logit link on the fitted models to estimate daily survival rates under the modeled covariates. We exponentiated the estimated daily survival rate to the 22 day nesting period to estimate the nest survival rate over the whole nesting period, or the probability of fledging at least one young.

Results

Nest-site Selection

Nests were strongly associated with bluestem grasses, with 34 nests (72.3%) placed in predominantly bluestem sp. clumps. Ten nests (21.3%) were placed at the base of short statured shrubs including *Gaylussacia frondosa, Gaylussacia dumosa, Ilex glabra, Quercus sp.*, and *Morella cerifera,* two nests (4.3%) were placed in unknown grass species, and one nest (2.1%) was placed in primarily *Tephrosia virginiana*. Live and dead bracken fern (*Pteridium aquilinum*) was often incorporated as nesting substrate (n = 20), especially for cover.

The top conditional logistic regression model included the quadratic form for groundcover density (Table 7). This model carried 63% of the Akaike weight and was 5.7 times more likely to be the best predicting model than the second-best model which included the quadratic form for percent bare ground (Table 7). The relative probability of nest-site selection was highest at intermediate groundcover densities (Table 8). The quadratic form for percent bare ground was included in the second through fourth ranked models and was also an important predictor of nest-site selection (second ranked model: β_{BARE}= 0.708, 85% CI = 0.080 – 1.336; $\beta_{\mathrm{BARE}}{}^{2}$= -0.739, 85% CI = -1.119 – -0.358).

Our results demonstrated that Bachman's Sparrows selected nest-sites with intermediate groundcover density. Additionally, vegetation structure and density played a stronger role in selection at my study sites than understory composition. Likely, as proposed by Winiarski et al. (2017a), site selection is driven by both perceived predation risk and likelihood of female survival, as intermediate groundcover density provides sufficient nest cover while allowing escape paths from the nest.

Nest Survival

We monitored 47 nests of which 29 fledged and 18 failed. Groundcover density best predicted daily nest survival rates (Table 9). The quadratic groundcover density model was the top model in the candidate set but it only carried 25% of the Akaike weight (Table 9). The quadratic groundcover density model and the nesting stage model were the only two models to rank higher than the null model (Table 9). The quadratic groundcover density model was 2.1 times more likely to be the best predicting model than the second-best model which only included nest stage (incubating or nestling) as a predictor and was 3.6 times more likely to be the best predicting model than the null model. Daily survival rates of nests were lowest at intermediate groundcover densities (Table 10, Figure 12). Nesting stage was an important predictor of nest survival, with a lower DSR observed in the nestling stage than the incubation stage ($\beta_{\mathrm{STAGE:N}}$ = -1.332, 85% CI = -2.342 – -0.322). However, nesting stage was not included in models with vegetation covariates because of issues with model convergence due to small sample size.

Across the range of groundcover densities observed, the top-ranked model indicated that daily survival rates ranged from 0.947 (85% CI: 0.919 – 0.980) to 1.000 (85% CI: 0.998 – 1.000; Figure 12) and survival across the 22-day nesting period ranged from 0.301 (85% CI: 0.112 – 0.491) to 0.999 (85% CI: 0.995 – 1.000). Nest survival was lowest when nest sites had an average groundcover density of 0.262 vegetation hits in the first 10 cm. Using the second-ranked model which included a covariate for nesting stage, daily survival rates were estimated to be 0.990 (85% CI: 0.982 – 1.000) for the incubation stage and 0.962 (85% CI: 0.942– 0.999) for the nestling stage. Survival rate across the 13-day incubation period was estimated to be 0.875 (85% CI: 0.749 – 1.000), survival rate across the nine-day nestling period was estimated to be 0.709 (85% CI: 0.568 – 0.849), and survival rate across the whole 22-day nesting period was estimated to be 0.621 (85% CI: 0.441 – 0.800).

We found no evidence for adaptive nest-site selection in Bachman's Sparrow at the study sites. Given the opposite trends in selection and survival, selection may actually be maladaptive. However, daily nest survival rates at groundcover densities with the greatest probability of selection were fairly high when compared to nest survival estimates from other regions and likely do not suggest that low nest survival alone would be a source of population declines in Bachman's Sparrow at the study sites. We therefore suspect that within the studied Bachman's Sparrow population, fitness benefits may be gained at a life history stage that we did not observe. For example, the observed nest-site selection strategy may increase the long-term survival of the female and thus may increase her genetic output more than if she were to be predated earlier but had slightly higher nest survival rate during her shorter life.

See attached appendix (Thistle Thesis) for complete methods, results, and discussion.

Significant deviations: None.

Objective 4: Collect preliminary information on Bachman's Sparrow dispersal, survival, and retention through opportunistic banding of adult and nestling Bachman's Sparrows.

Accomplishments:

We opportunistically captured and banded adult Bachman's Sparrows following Jones and Cox (2007). We only attempted to capture males when we could confirm that there was no active nest on the territory or that the male was not provisioning young fledglings so that we would not influence reproductive success. We confirmed the sex of captured individuals through behavior (i.e. singing, aggressive response to playback) and presence of an enlarged cloacal protuberance as well as the age through plumage characteristics. Although we targeted males for capture, we unintentionally captured one adult female and four juveniles which we opportunistically banded. Each individual was fitted with one USGS aluminum leg band as well as a unique combination of three colored leg bands. We similarly banded nestlings at nests located for another study objective (Objective 3). Nestlings were banded when they were aged to be approximately five days old.

In 2021, we resighted individuals opportunistically and following all detections on point count surveys (Objective 1). Band combinations were recorded along with the approximate location of the resighted individual. We determined the minimum and maximum distances moved between 2020 and 2021 for each banded demographic. We also calculated distances moved by banded males between 28 March and 10 July 2021 to determine if within breeding season dispersal occurred.

Results

In 2020, we banded 16 adult males, one adult female, four juveniles, and 20 nestlings. In 2021, we banded an additional 17 males and 39 nestlings. We resighted 10 of 16 males, two of four juveniles, and four of 20 nestlings banded in 2020 (Table 11). Naïve apparent survival rates based on this raw resighting data were 62.5%, 50%, and 20%, for males, juveniles, and nestlings, respectively. Seven of the 16 males banded as adults and resighted in 2021 survived overwinter and remained in their 2020 territory. The maximum distance moved by a resighted banded male was approximately 2000 m (Table 11). The two resighted males banded as juveniles moved about 600 m from their initial capture location (Table 11). Resighted male nestlings moved between 1700 and 2700 m away from the natal site and the one resighted female nestling moved 700 m away from the natal site (Table 11). During the 2021 breeding season, eight of 27 males that were resighted at least twice moved a distance of over 400 m (Table 12).

Although the inference that can be made from this initial band-resighting effort is limited due to small sample size and only one year of resighting data, we can report that adult male survival from

2020-2021 was comparable or higher than estimates from other regions, some males showed site-fidelity, fledglings and juveniles from the previous year survived, dispersed, and bred on-site, and males moved during the breeding season. This is the first description of survival and movement within the South Carolina wiregrass gap to our knowledge. Additional information on Bachman's Sparrow survival and dispersal in the wiregrass gap would aid in the understanding of local population dynamics.

See attached appendix (Thistle Thesis) for complete methods, results, and discussion.

Significant deviations: None.

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<u>Estimated Federal Cost:</u> $53,739.03

<u>Recommendations:</u> Close the grant.

Figures and Tables:

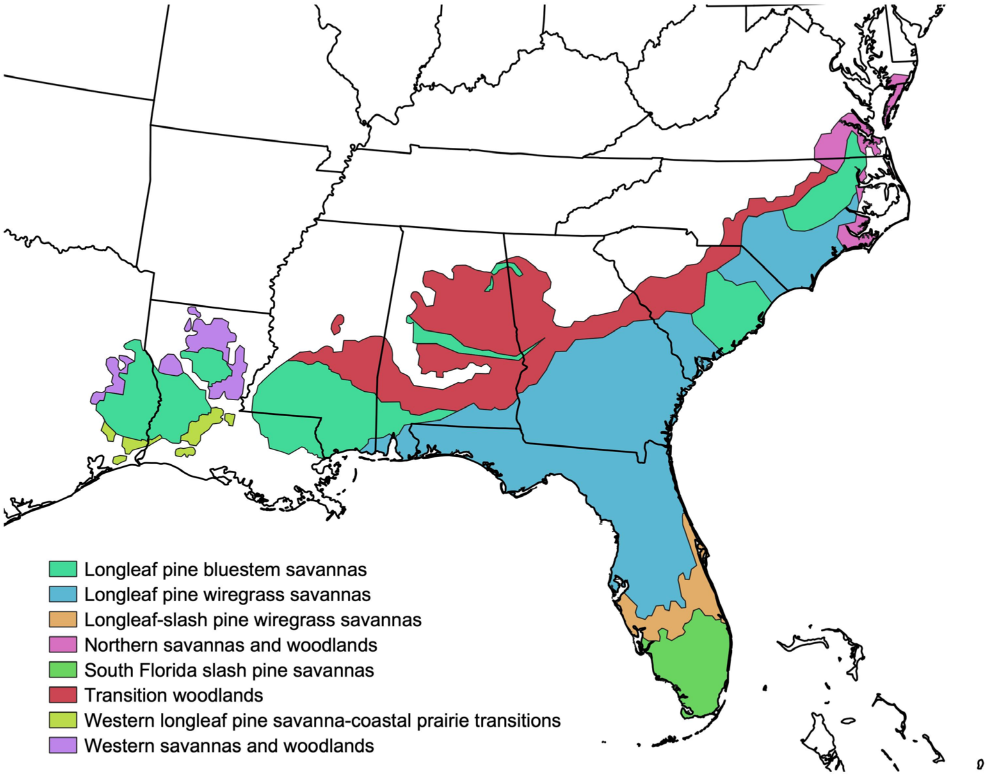

Figure 1. Pine-grass woodlands and savannas of the Southeast United States.
Data: Costanza et al. 2018, CC BY 4.0

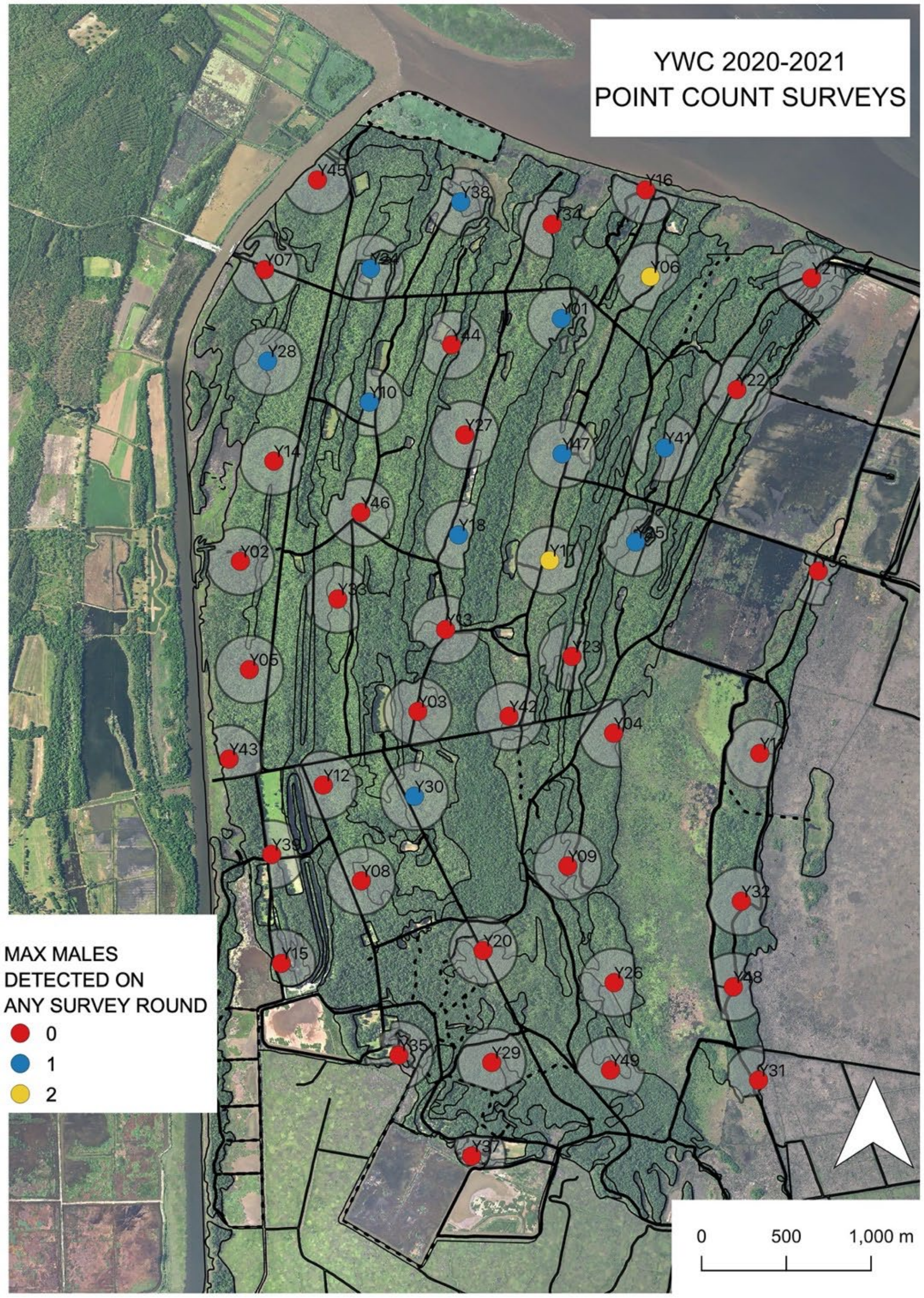

Figure 2. Point count sites with variable areas at Yawkey Wildlife Center. The maximum abundance (red = 0, blue = 1, yellow = 2) during any primary period is presented.

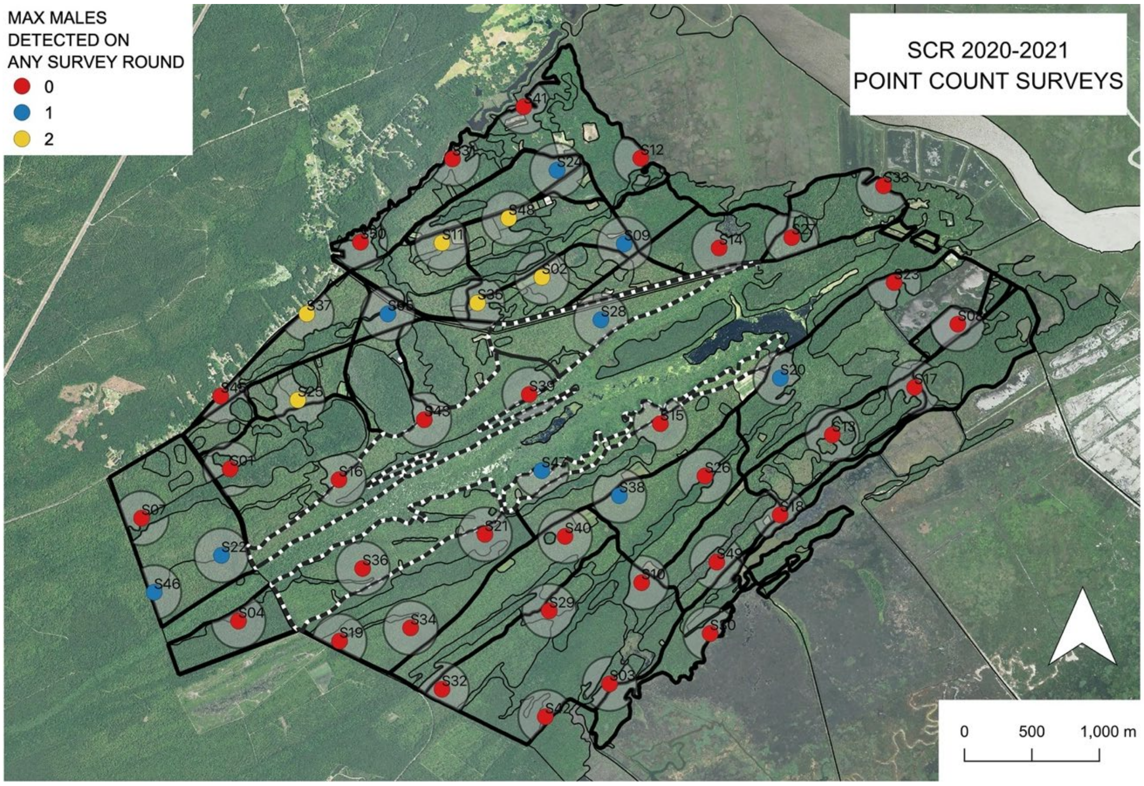

Figure 3. Point count sites with variable areas at Santee Coastal Reserve. The maximum abundance (red = 0, blue = 1, yellow = 2) during any primary period is presented.

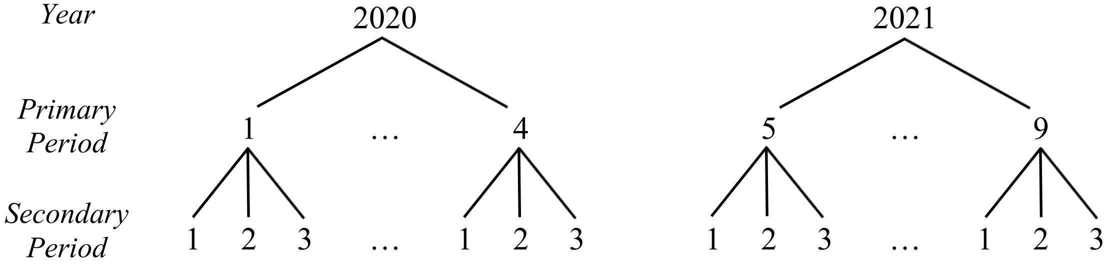

Figure 4. Short time interval robust sampling design in which each primary period is a sequential 3 week period during the breeding season and each secondary period is a sequential section of an 8 minute survey.

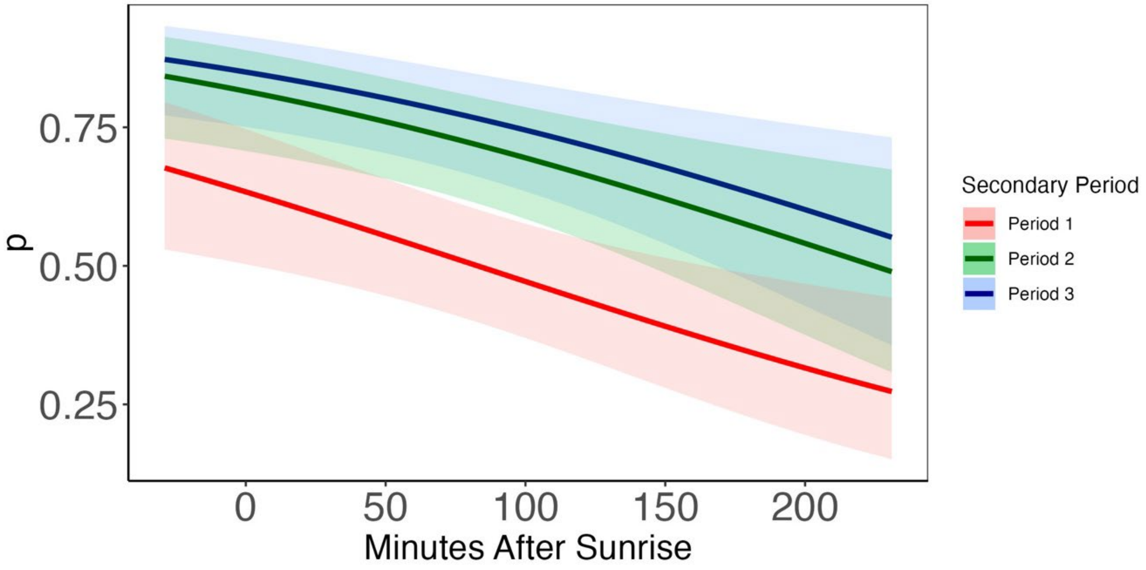

Figure 5. Detection probability (*p*) of adult male Bachman's Sparrows at survey sites as it relates to the minutes elapsed since sunrise and for each secondary period (red = Period 1, green = Period 2, blue = Period 3) during the 2020 and 2021 breeding seasons at YWC and SCR. Respective colored bands represents the 85% confidence intervals around the predictions.

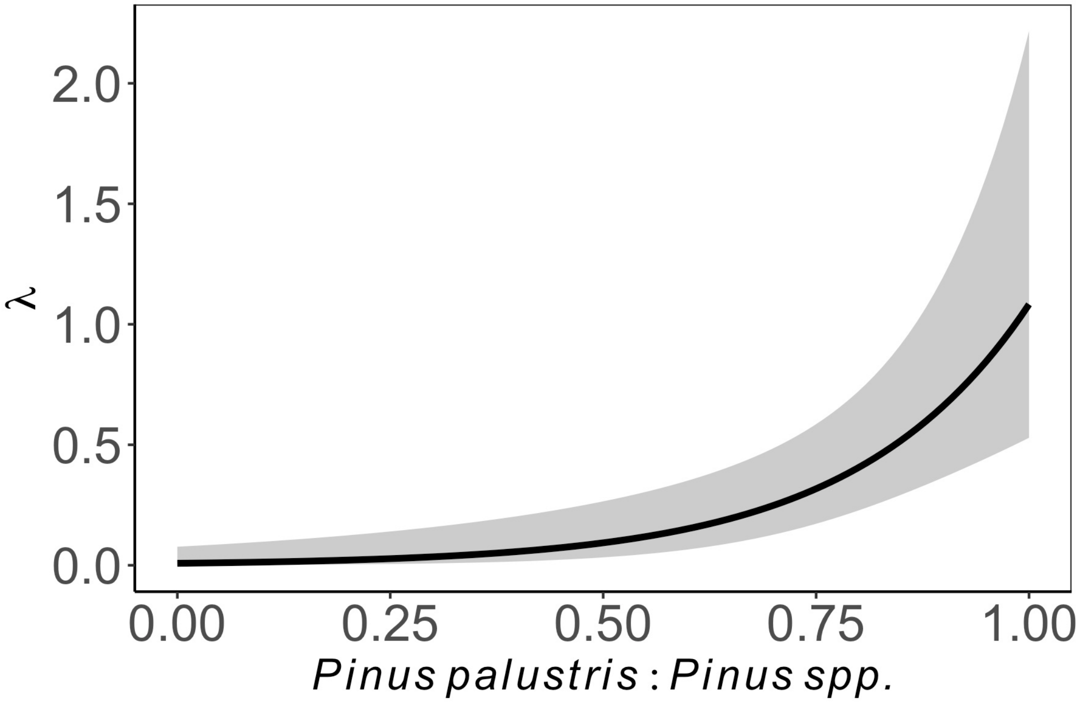

Figure 6. Predicted initial abundance (site-specific abundance during the first primary period, λ) of adult male Bachman's Sparrows at survey sites in response to the proportion of longleaf pine to other pine species during the 2020 breeding season at YWC and SCR. Gray band represents the 85% confidence interval around the prediction.

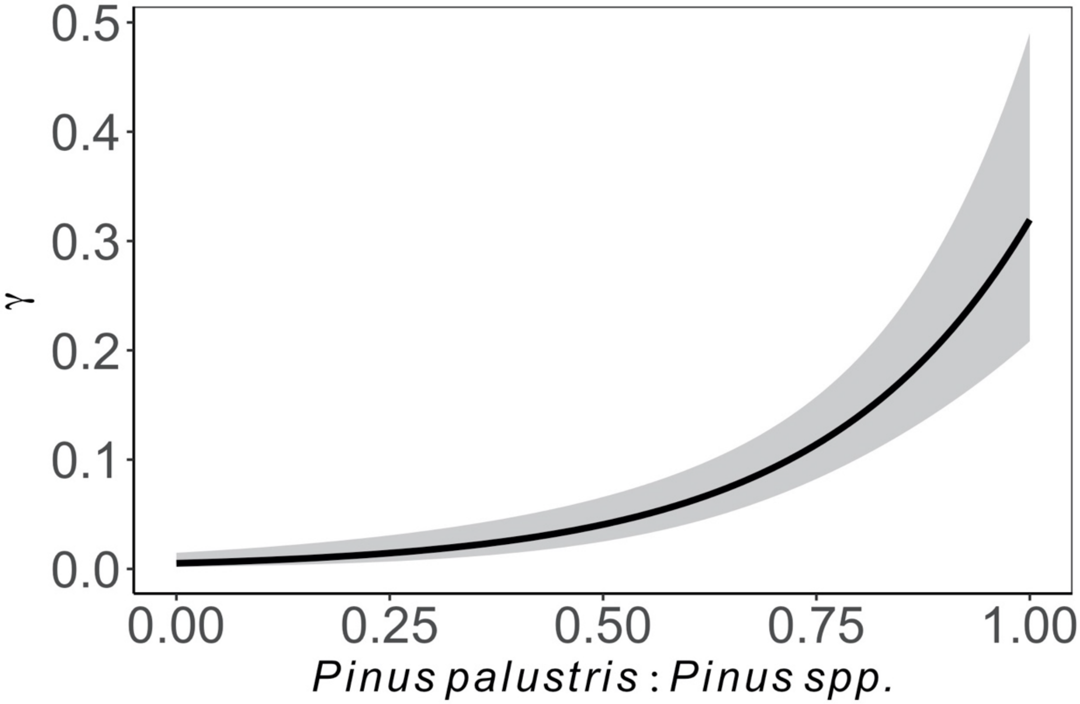

Figure 7. Predicted recruitment rate (gains due to birth or immigration between primary periods, γ) of adult male Bachman's Sparrows at survey sites in response to the proportion of longleaf pine to other pine species during the 2020 and 2021 breeding seasons at YWC and SCR. Gray band represents the 85% confidence interval around the prediction.

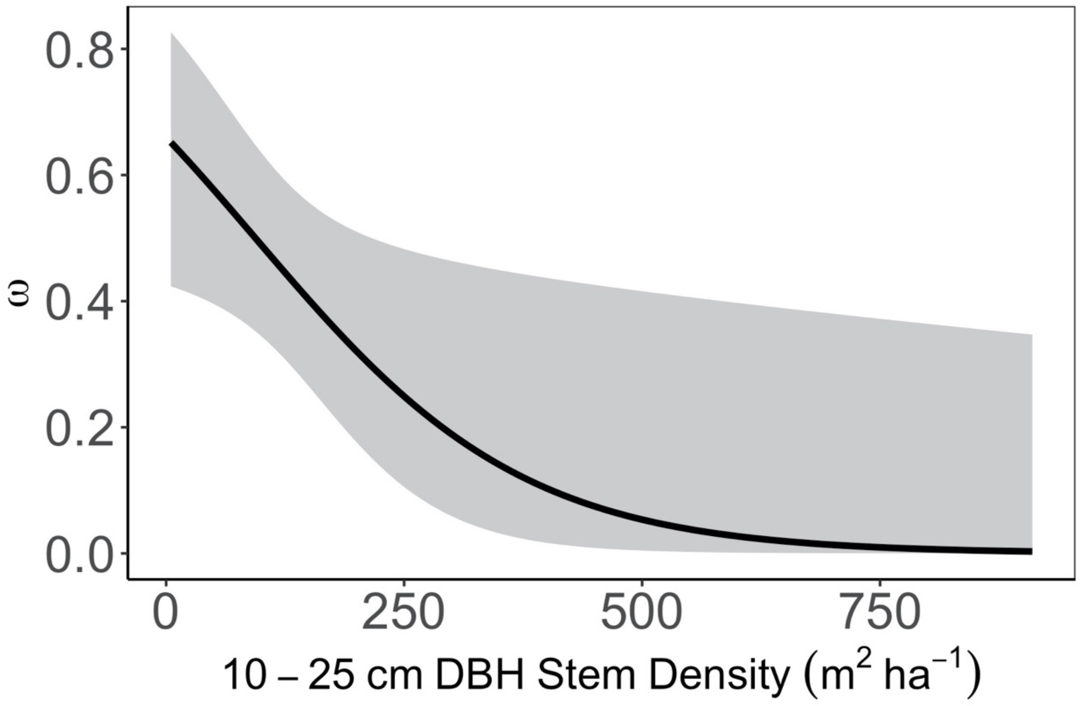

Figure 8. Predicted apparent survival probability (probability of survival or site-fidelity between primary periods, ω) of adult male Bachman's Sparrows at survey sites in response to small stem density (10-25 cm DBH stems per hectare) during the 2020 and 2021 breeding seasons at YWC and SCR. Gray band represents the 85% confidence interval around the prediction.

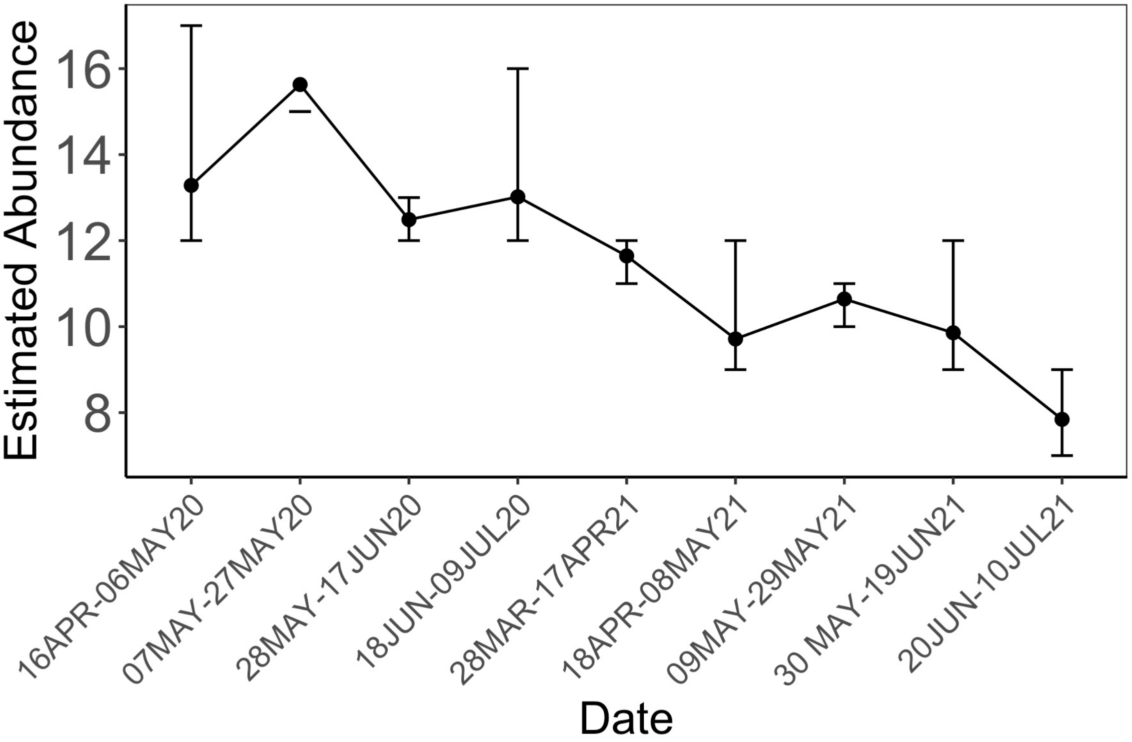

Figure 9. Bachman's Sparrow abundance at sites across the nine primary periods during the 2020 and 2021 breeding seasons at YWC and SCR. Error bars represent 85% confidence intervals around the predictions.

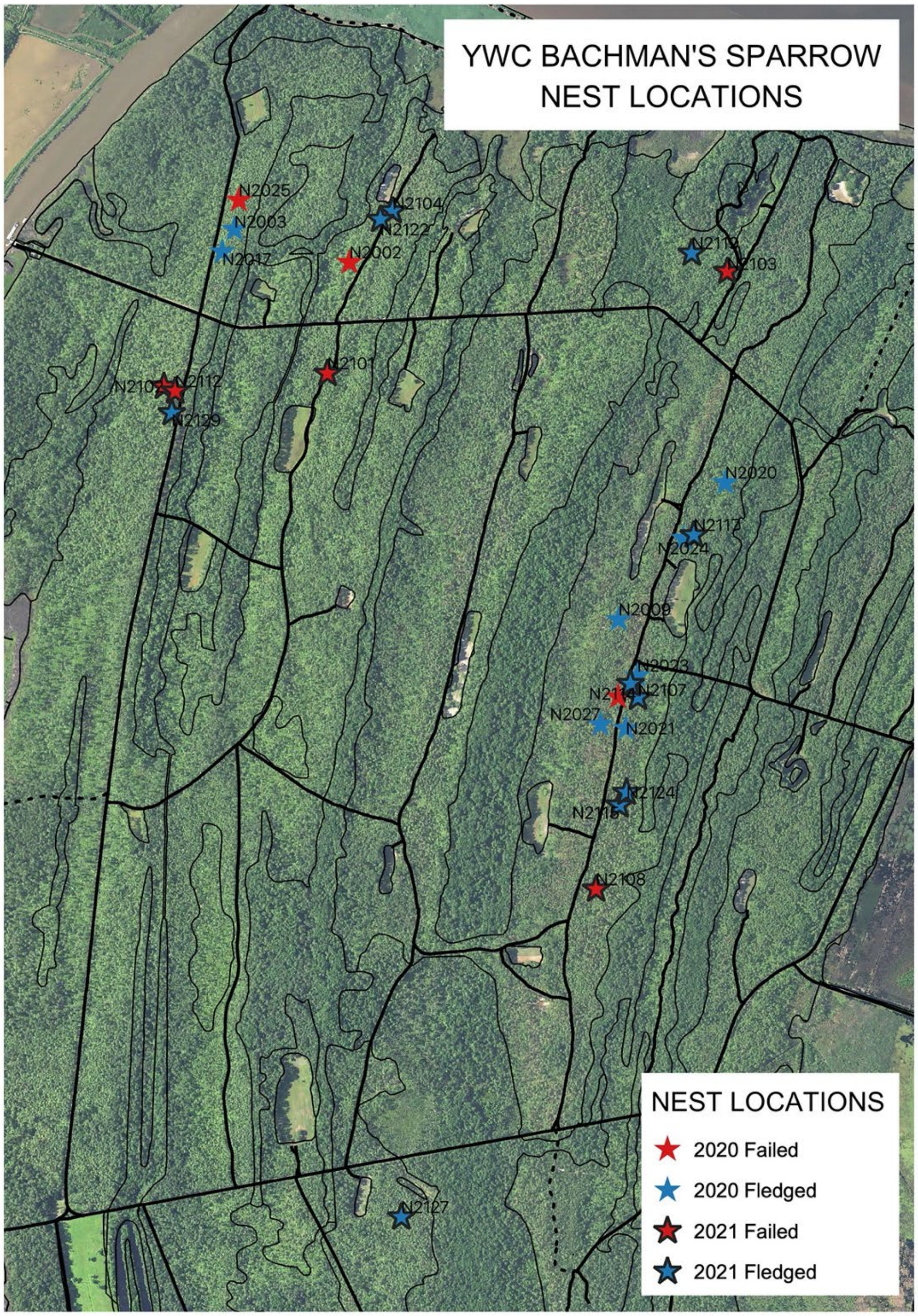

Figure 10. 2020 and 2021 nest locations and fates at Yawkey Wildlife Center.

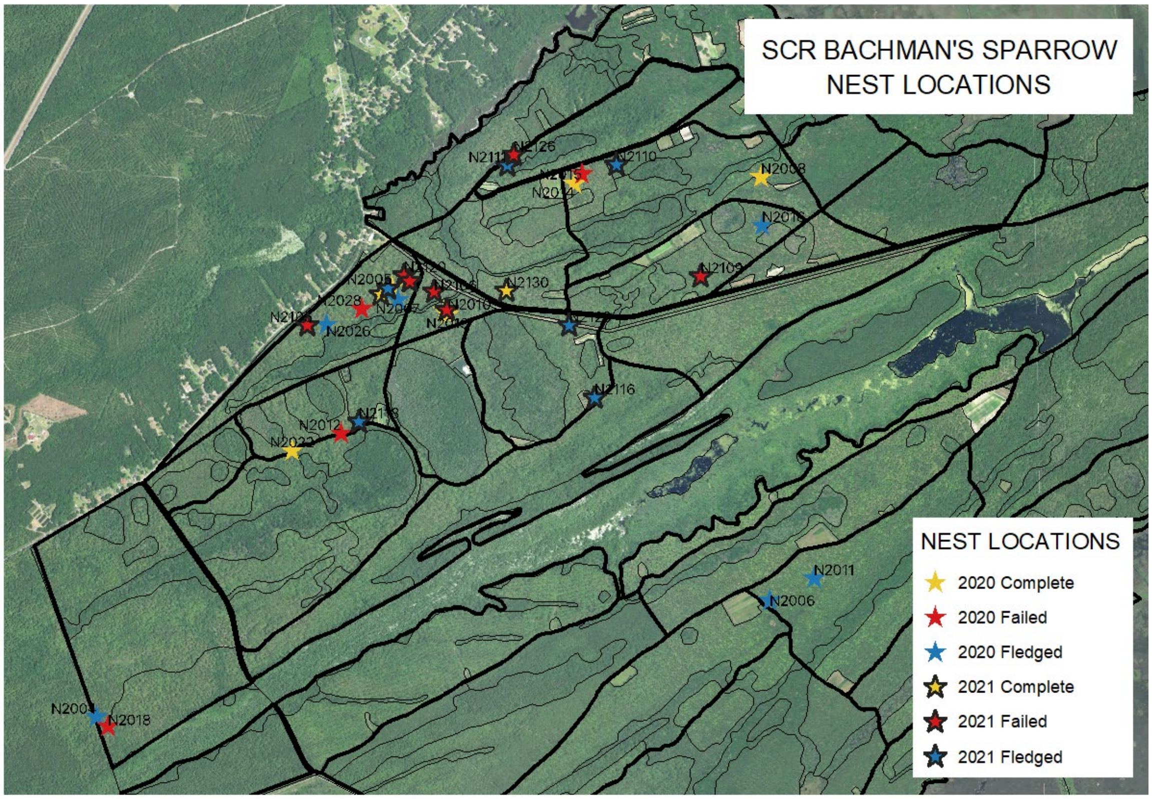

Figure 11. 2020 and 2021 nest locations and fates at Santee Coastal Reserve. Complete nests are nests that were found after fledging or failure and were not included in analyses.

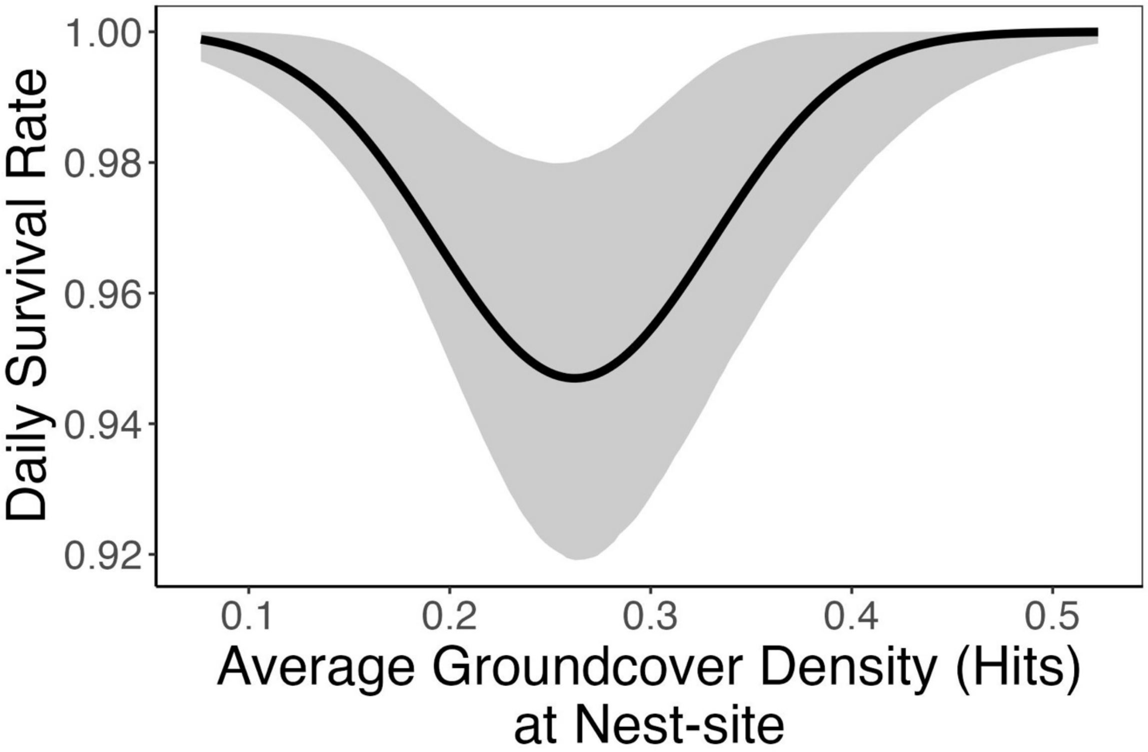

Figure 12. The predicted daily nest survival rate as is relates to groundcover density within the nest-site at YWC and SCR, South Carolina, 2020-2021. Gray band represents the bootstrapped 85% confidence interval around the prediction.

Table 1. Candidate set of *N*-mixture models estimating abundance of adult male Bachman's Sparrows during the 2020 and 2021 breeding seasons. Stepwise model selection schema is outlined along with model selection results. *K* = number of parameters, AIC = Akaike's Information, ΔAIC = the difference between the model AIC value and the top model AIC value, and w_i = Akaike weight.

	nPars	AIC	ΔAIC	w_i	$cum.w_\text{i}$
1. Distribution					
Zero-inflated Poisson $\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(.)$	5	857.59	0.00	0.59	0.59
Poisson $\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(.)$	4	858.31	0.72	0.41	1.00
2a. Detection Probability					
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(PER)$	6	845.83	0.00	1.00	1.00
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(.)$	4	858.31	12.48	0.00	1.00
2b. Detection Probability					
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	7	834.29	0.00	0.42	0.42
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(DAY + MIN + PER)$	8	834.50	0.21	0.37	0.79
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(TEM + I(TEM^2) + DAY + MIN + PER)$	10	835.79	1.50	0.20	0.99
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(OBS + PER)$	8	842.51	8.22	0.01	0.99
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(DAY + PER)$	7	845.00	10.71	0.00	1.00
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(PER)$	6	845.83	11.54	0.00	1.00
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(TEM + PER)$	7	846.66	12.37	0.00	1.00
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(TEM + I(TEM^2) + PER)$	7	846.66	12.37	0.00	1.00
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(WIN + PER)$	9	849.51	15.22	0.00	1.00
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(SKY + PER)$	9	849.97	15.68	0.00	1.00
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(TEM + I(TEM^2) + WIN + SKY + PER)$	14	855.25	20.96	0.00	1.00
3. Initial Abundance					
$\lambda(PPP)\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	8	826.49	0.00	0.99	0.99
$\lambda(CLO + I(CLO^2))\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	9	835.72	9.23	0.01	1.00
$\lambda(PBA + I(PBA^2) + YSB + I(YSB^2))\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	11	846.13	19.63	0.00	1.00
$\lambda(YSB + I(YSB^2))\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	9	848.92	22.42	0.00	1.00
$\lambda(PSD)\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	8	849.19	22.69	0.00	1.00
$\lambda(PBA + I(PBA^2))\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	9	850.26	23.77	0.00	1.00
$\lambda(EVR)\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	8	851.16	24.66	0.00	1.00
$\lambda(YSB)\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	8	852.16	25.67	0.00	1.00
$\lambda(SSD)\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	8	852.59	26.09	0.00	1.00
$\lambda(CLO)\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	8	852.65	26.15	0.00	1.00
$\lambda(PBA + YSB)\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	9	853.31	26.81	0.00	1.00
$\lambda(.)\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	7	853.46	26.96	0.00	1.00
$\lambda(PBA)\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	8	854.77	28.28	0.00	1.00
$\lambda(LSD)\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	8	855.17	28.68	0.00	1.00
4. Recruitment Rate					
$\lambda(PPP)\gamma(PPP)\omega(.)[\text{Const.}]p(MIN + PER)$	9	770.86	0.00	1.00	1.00
$\lambda(PPP)\gamma(PSD)\omega(.)[\text{Const.}]p(MIN + PER)$	9	804.31	33.46	0.00	1.00
$\lambda(PPP)\gamma(CLO + I(CLO^2))\omega(.)[\text{Const.}]p(MIN + PER)$	10	811.91	41.05	0.00	1.00
$\lambda(PPP)\gamma(PBA + I(PBA^2) + YSB + I(YSB^2))\omega(.)[\text{Const.}]p(MIN + PER)$	12	819.51	48.65	0.00	1.00
$\lambda(PPP)\gamma(YSB + I(YSB^2))\omega(.)[\text{Const.}]p(MIN + PER)$	10	821.30	50.45	0.00	1.00
$\lambda(PPP)\gamma(SSD)\omega(.)[\text{Const.}]p(MIN + PER)$	9	824.32	53.46	0.00	1.00
$\lambda(PPP)\gamma(CLO)\omega(.)[\text{Const.}]p(MIN + PER)$	9	824.59	53.73	0.00	1.00
$\lambda(PPP)\gamma(YSB)\omega(.)[\text{Const.}]p(MIN + PER)$	9	825.56	54.71	0.00	1.00
$\lambda(PPP)\gamma(PBA + I(PBA^2))\omega(.)[\text{Const.}]p(MIN + PER)$	10	825.63	54.77	0.00	1.00
$\lambda(PPP)\gamma(PBA + YSB)\omega(.)[\text{Const.}]p(MIN + PER)$	10	826.24	55.38	0.00	1.00
$\lambda(PPP)\gamma(EVR)\omega(.)[\text{Const.}]p(MIN + PER)$	9	826.28	55.42	0.00	1.00
$\lambda(PPP)\gamma(.)\omega(.)[\text{Const.}]p(MIN + PER)$	8	826.49	55.64	0.00	1.00
$\lambda(PPP)\gamma(LSD)\omega(.)[\text{Const.}]p(MIN + PER)$	9	827.19	56.33	0.00	1.00
$\lambda(PPP)\gamma(PBA)\omega(.)[\text{Const.}]p(MIN + PER)$	9	827.29	56.43	0.00	1.00

Table 1. (cont.)

	nPars	AIC	ΔAIC	w_i	$cum.w_i$
5. Apparent Survival Probability					
$\lambda(PPP)\gamma(PPP)\omega(SSD)[\text{Const.}]p(MIN+PER)$	10	766.19	0.00	0.55	0.55
$\lambda(PPP)\gamma(PPP)\omega(YSB)[\text{Const.}]p(MIN+PER)$	10	769.05	2.86	0.13	0.69
$\lambda(PPP)\gamma(PPP)\omega(.)[\text{Const.}]p(MIN+PER)$	9	770.86	4.67	0.05	0.74
$\lambda(PPP)\gamma(PPP)\omega\big(YSB+I(YSB^2)\big)[\text{Const.}]p(MIN+PER)$	11	770.94	4.76	0.05	0.79
$\lambda(PPP)\gamma(PPP)\omega(PBA+YSB)[\text{Const.}]p(MIN+PER)$	11	771.05	4.86	0.05	0.84
$\lambda(PPP)\gamma(PPP)\omega(EVR)[\text{Const.}]p(MIN+PER)$	10	772.55	6.37	0.02	0.86
$\lambda(PPP)\gamma(PPP)\omega(CLO)[\text{Const.}]p(MIN+PER)$	10	772.83	6.64	0.02	0.88
$\lambda(PPP)\gamma(PPP)\omega(PSD)[\text{Const.}]p(MIN+PER)$	10	772.84	6.65	0.02	0.90
$\lambda(PPP)\gamma(PPP)\omega(PBA)[\text{Const.}]p(MIN+PER)$	10	772.84	6.65	0.02	0.92
$\lambda(PPP)\gamma(PPP)\omega(PPP)[\text{Const.}]p(MIN+PER)$	10	772.85	6.67	0.02	0.94
$\lambda(PPP)\gamma(PPP)\omega(LSD)[\text{Const.}]p(MIN+PER)$	10	772.86	6.67	0.02	0.96
$\lambda(PPP)\gamma(PPP)\omega\big(PBA+I(PBA^2)+YSB+I(YSB^2)\big)[\text{Const.}]p(MIN+PER)$	13	772.99	6.81	0.02	0.98
$\lambda(PPP)\gamma(PPP)\omega\big(PBA+I(PBA^2)\big)[\text{Const.}]p(MIN+PER)$	11	773.78	7.59	0.01	0.99
$\lambda(PPP)\gamma(PPP)\omega\big(CLO+I(CLO^2)\big)[\text{Const.}]p(MIN+PER)$	11	774.56	8.38	0.01	1.00
6. Distribution					
Poisson $\lambda(PPP)\gamma(PPP)\omega(SSD)[\text{Const.}]p(MIN+PER)$	10	766.19	0.00	0.52	0.52
Zero-inflated Poisson $\lambda(PPP)\gamma(PPP)\omega(SSD)[\text{Const.}]p(MIN+PER)$	11	766.34	0.15	0.48	1.00

Table 2. Parameter estimates of the scaled predictors for the top *N*-mixture model with 85% confidence intervals. Covariates in the top model include minutes elapsed since sunrise (MIN), secondary period (PER), proportion of longleaf pine to all pine species (PPP), and 10-25 cm DBH stem density (SSD).

Predictor	**β**	**7.5%**	**92.5%**
Detection Probability (p)			
Intercept	-0.063	-0.367	0.242
MIN	-0.475	-0.696	-0.254
PER_2	0.936	0.503	1.369
PER_3	1.185	0.734	1.636
Initial Abundance (λ)			
Intercept	-2.975	-3.951	-2.000
PPP	1.734	1.053	2.414
Recruitment Rate (γ)			
Intercept	-3.708	-4.155	-3.261
PPP	1.457	1.124	1.789
Apparent Survival Probability (ω)			
Intercept	-0.936	-1.606	-0.265
SSD	-1.319	-2.202	-0.436

Table 3. Parameter estimates for the top *N*-mixture model using average covariate values with 85% confidence intervals. p_{PER1} = detection probability during secondary period 1, p_{PER2} = detection probability during secondary period 2, p_{PER3} = detection probability during secondary period 3, λ = initial abundance (males per site during the first primary period), γ = recruitment rate (additional males per site between primary periods), ω = apparent survival probability (probability of male survival or site-fidelity between primary periods).

Parameter	**Estimate**	**7.5%**	**92.5%**
p_{PER1}	0.484	0.408	0.560
p_{PER2}	0.705	0.632	0.779
p_{PER3}	0.754	0.684	0.825
λ	0.051	0.001	0.101
γ	0.025	0.014	0.035
ω	0.282	0.146	0.417

Table 4. Summary statistics (mean ± SD) for Bachman's Sparrow nest-site vegetation composition and structure variables at both YWC and SCR, South Carolina, 2020-2021.

		Nest Vegetation Plot	
Code	**Variable**	**Used**	**Available**
CLOS	Canopy Closure (%)	47.63±7.85	45.80±10.19
NBAP	Basal Area: Pine (m^2/ha)	22.76±6.77	19.54±6.73
YSB*	Years Since Last Burn	1.32±0.73	NA
TALL	# Shrub (Live or Dead) > 1 m	1.77±3.13	2.62±4.93
BARE	% Bare	46.09±10.22	44.88±16.29
GRAS	% Grass	7.55±5.02	7.46±7.50
SWIT	% Switch Cane	0.36±0.94	0.74±1.73
FOFE	% Forb/Fern	16.79±8.07	18.17±10.45
WOOD	% Shrub	25.87±8.87	25.35±11.13
DEAD	% Dead	3.34±3.31	3.40±3.72
MAXH	Max. Height: All Veg. Types	46.18±8.25	49.09±14.07
VDEN	Vertical Density: Total (hits 0 – 1.5 m)	0.77±0.25	0.79±0.41
GDEN	Groundcover Density: Total (hits < 0.1 m)	0.22±0.09	0.18±0.14

* Nest Survival Analysis Only

Table 5. Candidate set of 20 conditional logistic regression nest-site selection models based on the hypothesized effects of vegetation composition and structure on nest-site selection. Models are conditional on nest ID.

HYPOTHESIS	**COVARIATES**	**MODEL STRUCTURE**
BACS select nest sites based on nest-site structure.	Maximum Veg. Height	β_1 (MAXH)
BACS select nest sites based on nest-site structure.	Groundcover Density	β_1 (GDEN)
BACS select nest sites based on nest-site structure.	Groundcover Density^2	β_1 (GDEN) + β_2 (GDEN^2)
BACS select nest sites based on nest-site structure.	Vertical Density	β_1 (VDEN)
BACS select nest sites based on nest-site structure.	Vertical Density^2	β_1 (VDEN) + β_2 (VDEN^2)
BACS select nest sites based on availability of perches.	Number of Perches	β_1 (TALL)
BACS select nest sites based on nest-site floristics.	% Grass	β_1 (GRAS)
BACS select nest sites based on nest-site floristics.	% Grass^2	β_1 (GRAS) + β_2 (GRAS^2)
BACS select nest sites based on nest-site floristics.	% Switch Cane	β_1 (SWIT)
BACS select nest sites based on nest-site floristics.	% Woody	β_1 (WOOD)
BACS select nest sites based on nest-site floristics.	% Forb/Fern	β_1 (FOFE)
BACS select nest sites based on nest-site floristics.	% Dead	β_1 (DEAD)
Predator avoidance/foraging efficiency strategies impact nest-site selection.	% Bare Ground	β_1 (BARE)
Predator avoidance/foraging efficiency strategies impact nest-site selection.	% Bare Ground^2	β_1 (BARE) + β_2 (BARE^2)
Predator avoidance/foraging efficiency strategies impact nest-site selection	% Bare Ground^2 Groundcover Density	β_1 (BARE) + β_2 (BARE^2) + β_3 (GDEN)
Predator avoidance/foraging efficiency strategies impact nest-site selection	% Bare Ground^2 Tall	β_1 (BARE) + β_2 (BARE^2) + β_3 (TALL)
Stand thinning impacts nest-site selection.	Canopy Closure	β_1 (CLOS)
Stand thinning impacts nest-site selection.	Canopy Closure^2	β_1 (CLOS) + β_2 (CLOS^2)
Stand thinning impacts nest-site selection.	Pine Basal Area	β_1 (NBAP)
Stand thinning impacts nest-site selection.	Pine Basal Area^2	β_1 (NBAP) + β_2 (NBAP^2)

Table 6. Candidate set of 28 logistic exposure nest survival models based on the hypothesized effects of vegetation composition and structure, timing, and weather. Nest ID is included as a random effect in all models.

HYPOTHESIS	**COVARIATES**	**MODEL STRUCTURE**
VEGETATION MODELS		
No covariates impact daily survival rate (DSR).	Intercept Only	β_0
Nest-site structure impacts DSR.	Maximum Veg. Height	$\beta_0 + \beta_1$ (MAXH)
Nest-site structure impacts DSR.	Groundcover Density	$\beta_0 + \beta_1$ (GDEN)
Nest-site structure impacts DSR.	Groundcover Density^2	$\beta_0 + \beta_1$ (GDEN) + β_2 (GDEN^2)
Nest-site structure impacts DSR.	Vertical Density	$\beta_0 + \beta_1$ (VDEN)
Nest-site structure impacts DSR.	Vertical Density^2	$\beta_0 + \beta_1$ (VDEN) + β_2 (VDEN^2)
Number of perches impacts DSR.	Number of Perches	$\beta_0 + \beta_1$ (TALL)
Nest-site floristics impact DSR.	% Grass	$\beta_0 + \beta_1$ (GRAS)
Nest-site floristics impact DSR.	% Grass^2	$\beta_0 + \beta_1$ (GRAS) + β_2 (GRAS^2)
Nest-site floristics impact DSR.	% Switch Cane	$\beta_0 + \beta_1$ (SWIT)
Nest-site floristics impact DSR.	% Woody	$\beta_0 + \beta_1$ (WOOD)
Nest-site floristics impact DSR.	% Forb/Fern	$\beta_0 + \beta_1$ (FOFE)
Nest-site floristics impact DSR.	% Dead	$\beta_0 + \beta_1$ (DEAD)
Predator avoidance/foraging efficiency strategies impact DSR.	% Bare Ground	$\beta_0 + \beta_1$ (BARE)
Predator avoidance/foraging efficiency strategies impact DSR.	% Bare Ground^2	$\beta_0 + \beta_1$ (BARE) + β_2 (BARE^2)
Predator avoidance/foraging efficiency strategies impact DSR.	% Bare Ground^2 Groundcover Density	$\beta_0 + \beta_1$ (BARE) + β_2 (BARE^2) + β_3 (GDEN)
Predator avoidance/foraging efficiency strategies impact DSR.	% Bare Ground^2 Tall	$\beta_0 + \beta_1$ (BARE) + β_2 (BARE^2) + β_3 (TALL)
Stand thinning increases DSR.	Canopy Closure	$\beta_0 + \beta_1$ (CLOS)
Stand thinning increases DSR.	Canopy Closure^2	$\beta_0 + \beta_1$ (CLOS) + β_2 (CLOS^2)
Stand thinning increases DSR.	Pine Basal Area	$\beta_0 + \beta_1$ (NBAP)
Stand thinning increases DSR.	Pine Basal Area^2	$\beta_0 + \beta_1$ (NBAP) + β_2 (NBAP^2)
Prescribed burning increases DSR.	Years Since Burn	$\beta_0 + \beta_1$ (YSB)
Prescribed burning increases DSR.	Years Since Burn^2	$\beta_0 + \beta_1$ (YSB) + β_2 (YSB^2)
AGE/TIMING MODELS		
DSR changes with nest stage.	Stage	$\beta_0 + \beta_1$ (NEST)
DSR changes with time of year.	Julian Day	$\beta_0 + \beta_1$ (DAYS)
WEATHER MODELS		
DSR changes with temperature.	Maximum Temperature	$\beta_0 + \beta_1$ (MAXT)
DSR changes with precipitation.	Total Precipitation	$\beta_0 + \beta_1$ (PREC)
DSR changes weather.	Maximum Temperature Total Precipitation	$\beta_0 + \beta_1$ (MAXT) + β_2 (PREC)

Table 7. 95% confidence set of nest-site selection models for 47 nest-site and available nest-site pairs at YWC and SCR, South Carolina, 2020-2021. All models are stratified by nest ID. *K* = number of parameters, AIC_c = Akaike's Information Criterion corrected for small sample size, ΔAIC_c = the difference between the model AIC_c value and the top model AIC_c value, and w_i = Akaike weight.

MODEL	***K***	**Log-likelihood**	**AIC_c**	**ΔAIC_c**	**w_i**	***Cum.* w_i**
GDEN + $GDEN^2$	2	-24.10	52.33	0	0.63	0.63
BARE + $BARE^2$	2	-25.86	55.86	3.53	0.11	0.74
BARE + $BARE^2$ + GDEN	3	-24.80	55.87	3.54	0.11	0.85
BARE + $BARE^2$ + TALL	3	-25.64	57.54	5.21	0.05	0.89
VDEN + $VDEN^2$	2	-27.05	58.23	5.90	0.03	0.93
GRAS + $GRAS^2$	2	-27.33	58.80	6.47	0.02	0.95

Table 8. Parameter estimates of the scaled predictors for the top nest-site selection model with 85% confidence intervals. GDEN = groundcover density.

Predictor	**β**	**7.5%**	**92.5%**
GDEN	1.440	0.710	2.170
$GDEN^2$	-0.709	-1.073	-0.346

Table 9. 95% confidence set of nest survival models for 47 nests and 207 interval observations at YWC and SCR, South Carolina, 2020-2021. All models include nest ID as a random effect. *K* = number of parameters, AIC_c = Akaike's Information Criterion corrected for small sample size, ΔAIC_c = the difference between the model AIC_c value and the top model AIC_c value, and w_i = Akaike weight.

MODEL	***K***	**Log-likelihood**	**AIC_c**	**ΔAIC_c**	**w_i**	***Cum.* w_i**
GDEN + $GDEN^2$	4	-57.73	123.67	0.00	0.25	0.25
STAGE	3	-59.52	125.17	1.50	0.12	0.37
NULL	2	-61.12	126.30	2.63	0.07	0.43
PREC	3	-60.54	127.21	3.54	0.04	0.47
MAXT	3	-60.80	127.72	4.06	0.03	0.51
WOOD	3	-60.81	127.75	4.08	0.03	0.54
GDEN	3	-60.85	127.81	4.14	0.03	0.57
SWIT	3	-60.89	127.90	4.24	0.03	0.60
YSB	3	-60.89	127.91	4.24	0.03	0.63
GRAS	3	-60.90	127.91	4.24	0.03	0.66
VDEN	3	-60.90	127.92	4.25	0.03	0.69
GRAS + $GRAS^2$	4	-59.89	127.98	4.31	0.03	0.72
TALL	3	-60.93	127.99	4.32	0.03	0.75
DEAD	3	-61.00	128.13	4.46	0.03	0.77
NBAP	3	-61.02	128.16	4.49	0.03	0.80
DAYS	3	-61.06	128.23	4.56	0.03	0.82
CLOS	3	-61.07	128.25	4.58	0.03	0.85
BARE	3	-61.11	128.34	4.68	0.02	0.87
FOFE	3	-61.12	128.36	4.69	0.02	0.90
MAXH	3	-61.12	128.36	4.69	0.02	0.92
MAXT + PREC	4	-60.31	128.81	5.15	0.02	0.94
VDEN + $VDEN^2$	4	-60.71	129.62	5.96	0.01	0.95

Table 10. Parameter estimate of the scaled predictor for the top nest survival model with 85% confidence interval. GDEN = groundcover density.

Predictor	**β**	**7.5%**	**92.5%**
Intercept	3.131	2.625	3.636
GDEN	-0.883	-1.591	-0.175
$GDEN^2$	0.785	0.172	1.397

Table 11. Banding and resighting data with approximate distances moved for Bachman's Sparrows banded in 2020 at YWC and SCR. Individuals that moved < 160 m remained in their territory. AHY = After Hatch Year, J = Juvenile, L = Local (Nestling), M = Male,
F = Female, U = Unknown

AGE	SEX	NUMBER BANDED (2020)	NUMBER RESIGHTED (2021)	DISTANCE MOVED (MIN)	DISTANCE MOVED (MAX)
AHY	M	16	10	< 160 m	2000 m
	F	1	0	NA	NA
J	M	2	2	600 m	600 m
	F	0	0	NA	NA
	U	2	0	NA	NA
L	M	3	3	1700	2700 m
	F	1	1	700 m	700 m
	U	16	0	NA	NA

Table 12. Movement of banded males within the 2021 breeding season point count surveys period (28 Mar – 10 Jul 2021) at YWC and SCR. Approximate distance moved is only reported if > 400 m (diameter of point count survey area) away from initial resighting or 2021 banding location. AHY = After Hatch Year, J = Juvenile, L = Local (Nestling).

BAND NUM.	COLOR COMBO	DATE BANDED	AGE BANDED	SITE	DISTANCE MOVED (m)
2811-82502	WB-GS	5/31/20	AHY	YWC	< 400
2811-82507	OY-BS	6/11/20	L	YWC	< 400
2811-82513	RW-GS	6/25/20	AHY	SCR	< 400
2811-82517	OS-YB	7/14/20	L	YWC	2540
2811-82520	WW-WS	7/16/20	AHY	YWC	440
2811-82522	KG-RS	7/17/20	J	SCR	< 400
2811-82523	RR-BS	7/19/20	AHY	YWC	840
2811-82524	OK-WS	7/20/20	AHY	SCR	< 400
2811-82525	YG-WS	7/20/20	AHY	SCR	< 400
2811-82526	WR-OS	7/20/20	AHY	SCR	< 400
2811-82527	OK-YS	7/22/20	L	SCR	UNK
2811-82531	BW-BS	7/24/20	AHY	SCR	< 400
2811-82532	OW-GS	7/27/20	J	SCR	< 400
2811-82533	RW-KS	7/29/20	AHY	YWC	450
2811-82535	WW-OS	7/30/20	AHY	SCR	< 400
2811-82542	YO-WS	3/12/21	AHY	SCR	< 400
2811-82543	BR-OS	3/12/21	AHY	SCR	610
2811-82545	KW-WS	3/17/21	AHY	SCR	< 400
2811-82546	WR-BS	3/19/21	AHY	SCR	2160
2811-82547	OG-KS	3/22/21	AHY	YWC	< 400
2811-82548	BY-WS	3/25/21	AHY	SCR	< 400
2811-82549	BB-OS	3/25/21	AHY	SCR	< 400
2811-82551	GK-GS	3/28/21	AHY	YWC	460
2811-82552	YW-YS	3/30/21	AHY	SCR	UNK
2811-82553	RO-KS	3/31/21	AHY	YWC	800
2811-82554	YO-OS	4/2/21	AHY	SCR	< 400
2811-82555	RG-WS	4/9/21	AHY	WR	< 400
2811-82556	BK-YS	4/13/21	AHY	WR	< 400
2811-82557	RY-GS	4/15/21	AHY	WR	UNK
2811-82558	WO-RS	4/26/21	AHY	SCR	< 400

Attached:

Appendix. Habitat selection and breeding ecology of Bachman's Sparrow (*Peucaea aestivalis*) in a wiregrass-free ecosystem. M.S. Thesis, Mikayla Thistle