J. Field Ornithol. 88(3):250–261, 2017 DOI: 10.1111/jofo.12215

Bachman's Sparrows at the northern periphery of their range: home range size and microhabitat selection

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Received 16 September 2016; accepted 14 August 2017

ABSTRACT. Populations of Bachman's Sparrows (*Peucaea aestivalis*) have declined range-wide since the late 1960s. Populations at the periphery of their range have exhibited some of the steepest declines, and these sparrows are now rare or extirpated over much of the northern extent of their historical range. To better understand the spatial ecology of Bachman's Sparrows in this region of decline, we examined microhabitat selection and determined the home range sizes of radio-tagged male Bachman's Sparrows ($N = 37$) in the Coastal Plain of North Carolina in 2014 and 2015. From April to July, we located males 1–2 times daily for 5–6 d per week. We measured vegetation structure in home ranges using 5-m-radius plots centered on a subset of 10 randomly selected telemetry locations as well as in available unused locations 50 m and in a random direction from each telemetry location. Mean size of home ranges (7.9 ha) was larger than estimates reported in most previous studies, with differences among studies possibly due, at least in part, to differences in the characteristics of habitats where studies were conducted. The home ranges of Bachman's Sparrows in our study had greater densities of woody and dead vegetation than unused areas. Although generally considered detrimental to the presence of Bachman's Sparrows, the presence of some woody vegetation in frequently burned (i.e., $\leq$ 3-yr return interval) longleaf pine (*Pinus palustris*) communities like those in our study may be important in providing song perches for males and cover from attacking predators. Bachman's Sparrows in our study showed clear selection for several vegetation characteristics linked to frequent fire. Management strategies that approximate historical fire regimes in longleaf pine ecosystems should continue to be promoted as essential tools for the conservation of Bachman's Sparrows.

RESUMEN. ***Peuceaea aestivalis* en la periferia norte de su rango de distribución: tamaño del rango de hogar y selección de micro hábitat.**
Las poblaciones de *Peucaea aestivalis* han disminuido a lo largo de su rango de distribución desde finales de 1960s. Las poblaciones en la periferia han mostrado las disminuciones más drásticas hasta el punto en que la especie es rara o ha sido extirpada de gran parte del límite norte de su rango histórico. Con el fin de comprender mejor la ecología espacial de *Peucaea aestivalis* en esta región, donde la especie ha disminuido su población, utilizando radio transmisores, examinamos la selección de micro hábitat y determinamos el tamaño del rango de hogar de machos de *Peucaea aestivalis* ($N = 37$) en las planicies costeras de Carolina del Norte en 2014 y 2015. Desde abril hasta julio, ubicamos los machos 1–2 veces al día y 5–6 veces por semana. De los puntos registrados usando telemetría, seleccionamos 10 al azar en los cuales ubicamos una parcela de 5-m de radio en la cual medimos la estructura de la vegetación. Posteriormente, medimos la estructura de la vegetación del hábitat disponible pero no usado por la especie mediante una parcela similar, ubicada a 50 metros en dirección aleatoria de la ubicación seleccionada para medir la vegetación en uso. El tamaño promedio del rango de hogar (7.9 ha) fue mayor al estimado reportado en la mayoría de estudios previos. Las diferencias entre los estudios se deben probablemente, al menos en parte, a las diferencias en las características de los hábitats donde se realizaron los estudios. Los rangos de hogar de *Peucaea aestivalis* en nuestro estudio tuvieron una mayor densidad de vegetación leñosa y vegetación muerta que áreas no usadas. A pesar de ser considerada como perjudicial para la presencia de *Peucaea aestivalis*, la presencia de vegetación leñosa en comunidades de *Pinus palustris* (longleaf pine) quemadas con una alta frecuencia (i.e., intervalos $\leq$ 3 años), como la observada en nuestro estudio, puede ser importante para proveer perchas de canto para los machos y protección del ataque por depredadores. *Peucaea aestivalis* en nuestro estudio mostro una clara selección por varias características de la vegetación asociadas con quemas frecuentes. Las estrategias de manejo que aproximen los regímenes históricos de fuegos en los ecosistemas dominados por *Pinus palustris*, deben continuar siendo promovidos como una herramienta esencial para la conservación de *Peucaea aestivalis.*

Key words: kernel density estimators, longleaf pine, minimum convex polygon, radio-telemetry

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Bachman's Sparrows (*Peucaea aestivalis*) nest and forage on the ground, and require a diverse understory of grasses, forbs, and low shrubs maintained either by frequent prescribed fire or mechanical disturbances (Dunning and Watts 1990, Haggerty 1998, Tucker et al. 2004, 2006). In fact, habitat conditions are often so ephemeral that Bachman's Sparrows may abandon sites in as few as 3 or 4 yr without ground cover maintenance (Tucker et al. 2004, 2006). Bachman's Sparrows have historically been associated with fire-dependent longleaf pine (*Pinus palustris*) woodlands (Dunning and Watts 1990, Dunning 2006) and dry prairie ecosystems (Shriver et al. 1999, Shriver and Vickery 2001, Dean and Vickery 2003). In addition, these sparrows have been reported to use a variety of early successional plant communities where similar ground cover conditions exist, including powerline corridors, abandoned agricultural lands, and recent clearcuts (Brooks 1938, Krementz and Christie 1999, Dunning 2006, Stober and Krementz 2006).

At the start of the twentieth century, Bachman's Sparrows expanded their range northward into West Virginia, Pennsylvania, Ohio, Indiana, and Illinois (Brooks 1938, Dunning and Watts 1990, Fig. 1) following widespread abandonment of agricultural fields and extensive clearing of mature pine savannas (Dunning 2006). Since the 1930s, range expansion in these areas has reversed, and Bachman's Sparrows are now largely restricted to the current distribution of the endangered longleaf pine ecosystem (Fig. 1; Dunning 2006). In response to fire suppression and loss of longleaf pine communities (~97% loss; Frost 2006), populations of Bachman's Sparrows have been steadily declining (−3% per year; Sauer et al. 2017) and the species has been classified as a species of conservation concern across its entire range (Cox and Widener 2008). Along the periphery of their range, declines in population have been particularly severe (Sauer et al. 2017). For example, Bachman's Sparrows have been extirpated from their original northern range limit in Virginia (Wilson and Watts 2012), and populations in North Carolina have declined by 5.75% per year since 1966 (Sauer et al. 2017), coinciding with a range contraction throughout the eastern Piedmont region in recent decades (Taillie et al. 2016).

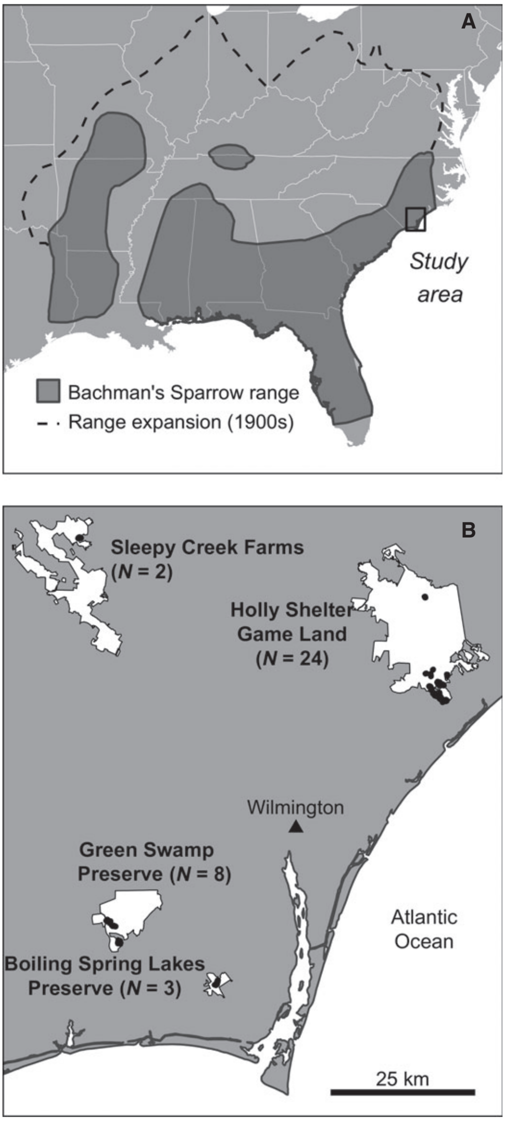

Fig. 1. (A) Location of our study area near the northern limit of the range of Bachman's Sparrows and in the context of their range expansion during the early twentieth century. Bachman's Sparrows are now extirpated from Virginia and the Piedmont region of North Carolina. (B) We determined the size of home ranges (*N* = 37; black polygons) and examined habitat selection by male Bachman's Sparrows at four sites in the Coastal Plain region of North Carolina, 2014–2015.

Northern populations of Bachman's Sparrows are important to the persistence of the species, and provide a unique opportunity for examining possible geographic variation in aspects of their natural history such as space use. Elsewhere, Bachman's Sparrows have home ranges averaging 3–5 ha, with sizes varying with habitat type, method of collecting location data (i.e., spot-mapping or radio-telemetry), and use of different home range estimators (i.e., kernel density or minimum convex polygon estimators; McKitrick 1979, Meanley 1990, Haggerty 1998, Dean and Vickery 2003, Stober and Krementz 2006, Cox and Jones 2007, Jones 2008). For example, Brown (2012) used radio-telemetry and kernel density estimators and reported that the home ranges of Bachman's Sparrows in Florida were ~1 to 5 times larger than most previous estimates. Thus, a better understanding of the home range requirements of Bachman's Sparrows and the factors influencing variation in home range size are needed.

Bachman's Sparrows have a greater probability of occurring in areas with recent fire, open longleaf pine canopy, short woody vegetation (i.e., ≤ 1-m tall), high forb cover, and high grass density (Dunning and Watts 1990, Haggerty 1998, Plentovich et al. 1998, Pickens et al. 2017), although two recent studies have revealed a threshold above which grass density can be detrimental to the occurrence of Bachman's Sparrows (Brooks and Stouffer 2010, Taillie et al. 2015). Although the basic habitat requirements of Bachman's Sparrows have been examined at broad spatial scales, finer scale microhabitat selection (i.e., third-order habitat selection within home ranges) has not. Because microhabitat features may influence fitness components such as survival and reproductive performance, a better understanding of microhabitat requirements could be useful in designing more effective management strategies (Barg et al. 2006, Anich et al. 2010, 2012).

Given the higher rates of population decline and potential differences in habitat quality and land use changes at the northern limit of their range (Dunning and Watts 1990), we examined home range sizes and microhabitat selection by Bachman's Sparrows in North Carolina. Our objectives were to: (i) use radio-telemetry to estimate the size of the home ranges of Bachman's Sparrows, (ii) examine variables that potentially influence home range size, and (iii) quantify microhabitat selection within home ranges.

METHODS

Study area. Our study was conducted at four locations in the Middle Atlantic Coastal Plain (hereafter, Coastal Plain) physiographic region of southeastern North Carolina during 2014 and 2015 (Fig. 1). The climate in this region is subtropical, and annual precipitation ranged from 152 cm in 2014 to 187 cm in 2015 (mean = 160 cm; Southeast Regional Climate Center 2016). Because Bachman's Sparrows are uncommon across most of the region, we chose study sites based on previous occurrence records (North Carolina Wildlife Resources Commission [NCWRC], unpubl. data) and accessibility. Sites differed in area (range = 904–25,695 ha) and proportion of longleaf pine woodlands (range = ~4 to 22%), and were on lands managed by the NCWRC, the North Carolina Plant Conservation Program, The Nature Conservancy, and private industry. Study sites were surrounded by a mosaic of urban and suburban development, row-crop agriculture, and loblolly pine (*Pinus taeda*) plantations.

Bachman's Sparrow habitat in our study sites consisted primarily of mesic longleaf pine woodlands bordered by pocosin wetlands. Mesic longleaf pine woodlands were characterized by seasonally saturated soils, an open canopy of longleaf pine (ranging from recent clearcuts to ~50-yr-old stands), and a diverse ground cover layer dominated by wiregrass (*Aristida stricta*), cinnamon fern (*Osmunda cinnamomea*), bracken fern (*Pteridium aquilinum*), gallberry (*Ilex glabra*), huckleberry (*Gaylussacia frondosa*), blueberry (*Vaccinium* spp.), swamp redbay (*Persea palustris*), sweet pepperbush (*Clethra alnifolia*), switchcane (*Arundinaria tecta*), and insectivorous plants, depending on soil moisture. Longleaf pine woodlands were typically managed on a ≤ 3-yr return interval with prescribed fire (during the growing and non-growing seasons), but time since fire exceeded 4 yr at one privately owned site.

Data collection. We limited our study to tracking adult (i.e., classified as after-hatch-year only; Pyle 1997) male Bachman's Sparrows because females are cryptic and difficult to capture (Dunning 2006, Tucker et al. 2006). Males were captured by playing recordings of conspecific vocalizations near mist-nets. Upon capture, we measured wing length and mass, and banded Bachman's Sparrows with a U.S. Geological Survey aluminum leg band and a unique combination of colored-plastic leg bands. Finally, we fit each male with a radio-transmitter (~0.64 g, Blackburn Transmitters, Nacogdoches, TX) using an elastic leg-loop harness (Rappole and Tipton 1991, Streby et al. 2015). Transmitter weight represented ~3.5% of the body mass of adult male sparrows (mean body mass = 18.8 ± 0.6 [SD] g).

We collected home range and microhabitat data from April to July 2014–2015. We located each sparrow 1–2 times daily for 5–6 d per week to obtain ≥ 30 locations over the lifetime of the transmitter, which is recommended as the minimum sample size for kernel-based home range analyses (Seaman et al. 1999). To ensure biologically independent telemetry locations, we tracked individuals at intervals ≥ 2 h apart. Radio-tagged birds could easily travel across their home ranges during this time period, which exceeded intervals considered independent in other passerine home range studies (Mazerolle and Hobson 2004, Barg et al. 2006, Anich et al. 2009). We located sparrows by homing and typically confirmed their locations either visually or aurally. For birds that did not sing or were obscured by ground cover, we estimated locations (i.e., within 5 m) based on the strength and direction of telemetry signals. Once a sparrow was located, we recorded the location (Universal Transverse Mercator Zone 17N or 18N) using a handheld GPS unit (± 5 m accuracy) and marked the point with a labeled flag for future vegetation sampling.

To determine the effect of reproductive status on home range size, we collected behavioral data on radio-tagged sparrows using a protocol modified from Vickery et al. (1992) and Tucker et al. (2006). Once per week, observers spent 60 min in male territories recording behaviors that indicated successful pairing (e.g., a male near a female, copulation, or nest building), nesting (e.g., parents carrying food/fecal sacs to or away from nests or finding active nests), and fledging of offspring (e.g., adults carrying food to fledglings or visual confirmation of fledglings; Vickery et al. 1992). Nests were typically located via tracking and during visits to determine breeding status, and we determined nest fates using established protocols (Martin and Geupel 1993). After completion of radio-tracking, males were assigned a reproductive score based on evidence gathered during territory visits and nest fates (Table 1).

We measured vegetation structure in home ranges using 5-m-radius plots centered on a subset of 10 randomly selected telemetry locations prior to the conclusion of each season (mean = 24 ± 16 [SD] d after completion of radio-tracking). Vegetation categories were modified from Taillie et al. (2015), and included grass, forb-fern (hereafter, forbs), woody vine-shrub (hereafter, woody vegetation), switchcane, and dead vegetation. We quantified vegetation structure using indices of density by recording the presence of each vegetation category (i.e., "hits" or vegetation contacts) on 0.1-m sections of a 1.5-m vertical pole. Vertical density included vegetation hits along the entire length of the pole, whereas ground cover density was calculated as the number of hits on the first 0.1-m section of the pole (Wiens and Rotenberry 1981). Maximum vegetation height was obtained by recording the tallest hit on the pole and rounding to the nearest 0.1-m section (Wiens and Rotenberry 1981, Moorman and Guynn 2001, Taillie et al. 2015). Measurements were taken at every meter along

Table 1. Reproductive index scores used as an index of Bachman's Sparrow reproductive success (modified from Vickery et al. 1992 and Tucker et al. 2006).

Score	Description
1	Male was on territory for ≥ 4 weeks, but showed no indication of pairing.
2	Male paired with female, but no evidence of nesting.
3	Indication of nesting, such as female carrying nest material, adults delivering food to nestlings, or locating a nest.
4	Direct observation of fledglings or young known to have fledged.

four 5-m transects in each cardinal direction. At the same 1-m increments along each transect, we estimated canopy closure by recording the presence or absence of live canopy using an ocular sighting tube. We used a 10-factor prism from the plot center to determine the basal area (m^2/ha) of pines surrounding each used location.

To estimate availability of vegetation types and structure, we repeated these same measurements in available unused locations 50 m from each telemetry location in a random direction. We chose this distance to eliminate overlap between used and available points, and to constrain reference locations within a bird's home range (i.e., third-order habitat selection). Because we sometimes measured microhabitat features while simultaneously tracking birds, we did not first generate home range polygons and randomly sample points within territories.

Statistical analyses. All statistical analyses were performed in R 3.3.0 (R Development Core Team 2016). We estimated home range size for each sparrow using the 95% fixed kernel utilization distribution (Worton 1989) with the ks package (Duong 2007). We used the 'plug-in' bandwidth estimator (Millspaugh et al. 2006), which generally outperforms other bandwidth selection approaches (e.g., reference and least-square cross validation; Gitzen et al. 2006) and has been increasingly used in avian home range studies (e.g., Rota et al. 2014, Stanton et al. 2014, Lorenz et al. 2015, Goldenberg et al. 2016). We also calculated 95% minimum convex polygon (MCP) home range sizes using the adehabitat package (Calenge 2006) to facilitate comparisons with previous studies.

Variation in 95% fixed kernel home range size was investigated using linear models, and home range size was log-transformed to achieve normality prior to analysis. We considered variables informed by our own observations and studies of space use by other species of birds (e.g., Mazerolle and Hobson 2004, Anich et al. 2010, Lorenz et al. 2015), including time since fire, site, year, mean tracking date, number of telemetry locations, body size (i.e., wing length), and reproductive status (i.e., reproductive score). Following Brown (2012), we calculated time since fire for each sparrow by averaging the number of days since the previous burn across all telemetry locations within a home range. Due to a limited sample size, we examined variation in home range size using univariate models.

Microhabitat selection was analyzed with the lme4 package (Bates et al. 2015) and generalized linear mixed effects models specifying a logit link function and binomial response (where 1 = used location and 0 = reference location). Prior to analysis, we tested for highly correlated ($r > |0.60|$) variables, and retained the variable with the lowest value of Akaike's information criterion for small sample sizes (AIC_c; Burnham and Anderson 2002, Table 2). We also included a quadratic effect of vertical grass density because dense grass may restrict movement on the ground in the absence of frequent fire (Brooks and Stouffer 2010, Taillie et al. 2015). For all models, we included bird identity (BirdID) as a random effect to account for repeated measures of each individual and potential variation between individual sparrows. We examined models with BirdID nested within a random site effect, but determined that models with BirdID alone performed better. We used a manual forward-selection approach (Burnham and Anderson 2002) to build microhabitat selection models, starting with univariate models separately. We then built more complex models by adding variables that lowered the AIC_c value.

Home range variation and microhabitat selection models were ranked using AIC_c with the MuMIn package (Bartoń 2016). We considered models with $\Delta AIC_c < 2$ to have substantial support (Burnham and Anderson 2002). A parameter was then considered informative if the 95% CI did not include zero, and was considered to have no relationship with the response variable if the 95% CI included zero. We report means ± 1 SD unless otherwise noted.

RESULTS

Home range size. We captured and attached radio-transmitters to 10 sparrows in 2014 and 27 sparrows in 2015 (Fig. 1). Birds were tracked over an average of 43 ± 12 d (range = 10–61 d), and we collected a total of 1199 locations. We obtained a sufficient number of telemetry locations ($N \geq 30$) to estimate home range size for 27 birds, and

Table 2. Summary statistics (mean ± SD) for vegetation variables in the home ranges of male Bachman's Sparrows ($N = 37$) and randomly selected unused areas in the Coastal Plain physiographic region in North Carolina, USA, 2014–2015.

Variable	Used	Unused
Canopy cover (%)	35.8 ± 25.4	35.9 ± 25.5
Pine basal area (m^2/ha)	11.1 ± 6.6	10.9 ± 7.0
Woody vertical density (hits)	1.4 ± 0.8	1.1 ± 0.7
Grass vertical density (hits)	2.1 ± 1.2	2.4 ± 1.3
Forb vertical density (hits)	0.3 ± 0.4	0.3 ± 0.4
Switchcane vertical density (hits)	0.02 ± 0.1	0.02 ± 0.1
Dead vertical density (hits)	0.1 ± 0.2	0.1 ± 0.1
Woody ground cover density (hits)	0.5 ± 0.2	0.4 ± 0.2
Grass ground cover density (hits)	0.5 ± 0.3	0.6 ± 0.3
Forb ground cover density (hits)	0.1 ± 0.1	0.1 ± 0.1
Switchcane ground cover density (hits)	0.0 ± 0.01	0.0 ± 0.01
Dead ground cover density (hits)	0.01 ± 0.03	0.01 ± 0.03
Woody maximum height (m)	0.2 ± 0.1	0.2 ± 0.1
Grass maximum height (m)	0.3 ± 0.2	0.3 ± 0.2
Forb maximum height (m)	0.1 ± 0.1	0.1 ± 0.1
Switchcane maximum height (m)	0.01 ± 0.03	0.01 ± 0.03
Dead maximum height (m)	0.04 ± 0.1	0.02 ± 0.04

the average number of GPS points for these individuals was 36 ± 5 (range = 30–46). Mean 95% kernel home range size was 7.9 ± 4.1 ha (range = 2.6–18.2 ha) across all years and study sites; 95% MCPs provided smaller estimates of mean home range size (3.5 ± 1.9 ha; range = 1.0–8.6 ha).

Of 27 radio-tagged males with ≥ 30 telemetry locations, nine (33%) remained unpaired, two (7%) were paired, but showed no signs of nesting, two (7%) nested, but did not fledge young, and 14 (52%) fledged young. Time since fire averaged 596 ± 516 d (range = 124–2333 d). Reproductive status and time since fire were not influential in predicting home range sizes of male Bachman's Sparrows (Table 3). Likewise, univariate models that included study site, year, mean tracking date, number of telemetry locations, and body size all ranked lower than the null model (Table 3).

Microhabitat selection. We collected vegetation data at used and unused locations in the home ranges of each radio-tracked male (Table 2). The top microhabitat selection model ($\Delta AIC_c \leq 2$) included a positive effect of woody vertical density, a quadratic effect of grass vertical density, and a positive effect of dead vegetation vertical density on microhabitat selection in home ranges (Table 4). Woody vertical density had the strongest relationship with microhabitat selection based on the mean value of the covariate, and with greater dead vegetation vertical density increasing the probability of relative use by male Bachman's Sparrows. Probability of

Table 3. Linear models examining variation in the size of home ranges of male Bachman's Sparrows in the Coastal Plain region of North Carolina, USA, 2014–2015. Model sets tested habitat and nonhabitat predictors. Models were compared using Akaike's information criterion corrected for small sample size (AIC_c).

Model	K	Loglik	AIC_c	ΔAIC_c	w_i
Null	2	−20.59	45.68	0.00	0.29
Telemetry locations	3	−19.63	46.30	0.62	0.21
Time since fire	3	−19.83	46.71	1.03	0.18
Year	3	−20.35	47.75	2.07	0.10
Mean tracking date	3	−20.48	48.01	2.33	0.09
Body size	3	−20.49	48.02	2.34	0.09
Site	4	−20.58	50.98	5.30	0.02
Reproductive score	5	−19.87	52.60	6.92	0.01

Table 4. Mixed-effects logistic regression models of microhabitat selection by male Bachman's Sparrows in the Coastal Plain region of North Carolina, 2014–2015. BirdID was used as a random effect in all models. Models were compared using Akaike's information criterion corrected for small sample size (AIC_c).

Model	K	Loglik	AIC_c	ΔAIC_c	w_i
VerWD[a] + VerGR[b] + $VerGR^{2}$[c] + VerDD[d]	6	−485.27	982.65	0.00	0.74
VerWD + VerGR + $VerGR^2$	5	−487.91	985.90	3.26	0.15
VerWD + VerDD	4	−489.46	986.97	4.33	0.09
VerWD	3	−491.57	989.18	6.53	0.03
VerDD	3	−503.06	1012.14	29.50	< 0.01
VerGR + $VerGR^2$	4	−503.89	1015.83	33.18	< 0.01
HorWD[e]	3	−505.89	1017.81	35.17	< 0.01
VerFB[f]	3	−509.01	1024.05	41.40	< 0.01
Null	2	−510.15	1024.32	41.68	< 0.01

[a] Woody vertical density
[b] Grass vertical density
[c] Grass vertical density (quadratic)
[d] Dead vertical density
[e] Woody ground cover density
[f] Forb vertical density

relative use also increased with increasing grass density, but with a threshold beyond which relative use began to decline (Fig. 2). However, we found weak statistical support for this trend (the 95% CI for the linear grass vertical density parameter overlapped zero; Table 5).

DISCUSSION

Fixed kernel home ranges of Bachman's Sparrows in our study were larger than most previously reported estimates from elsewhere in their range, but none of the variables we examined influenced home range size. In addition, we identified a suite of vegetation characteristics important for microhabitat selection in the home ranges of male Bachman's Sparrows, including intermediate grass density and a higher density of woody and dead vegetation. Overall, our results reinforce the need for frequent prescribed fire to create and maintain habitat for Bachman's Sparrows, including important vegetation features at the home range level.

Comparison with previous studies. The mean size of home ranges in our study was larger than most previous estimates (McKitrick 1979, Haggerty 1998, Dean and Vickery 2003, Stober and Krementz 2006, Cox and Jones 2007, Fig. 3). Differences in methods used to estimate home range sizes, time of year, and the sex of birds tracked may help explain differences among studies in estimates of home range size. When comparing only studies where investigators used fixed kernel and MCP home range estimates, home range sizes in our study averaged ~1.8 and ~1.2 times larger, respectively (Fig. 3). The mean home range size of male Bachman's Sparrows in our study was within the range of estimates reported in the only other study that combined radio-telemetry with fixed kernel density estimators (Brown 2012). Prior to the recent miniaturization of tracking devices, spot-mapping of color-banded male Bachman's Sparrows was commonly employed and was used in four of the seven published studies (Fig. 3). This may explain the smaller home ranges reported in some previous studies because home range sizes estimated using spot-mapped locations can average ~30 to 70% smaller than those based on radio-tagged birds (Anich et al. 2009, Streby et al. 2012). Other researchers have either combined home range estimates of paired males and females (Stober and Krementz 2006) or examined home range size during the non-breeding season (Dean and Vickery 2003). Thus, studies where investigators use both radio-telemetry and kernel-based methods are needed to clearly determine if there is geographic variation in the size of the home ranges of male Bachman's Sparrows.

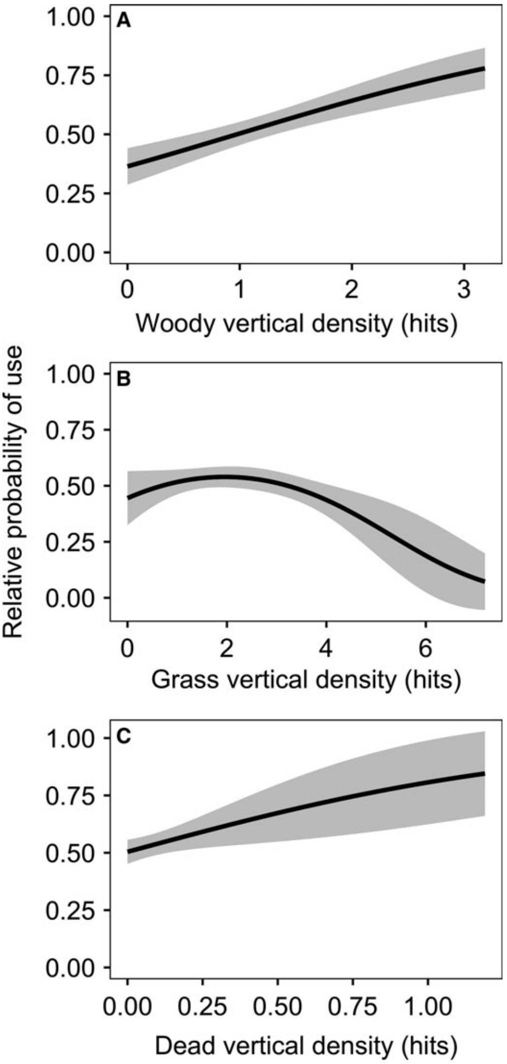

Fig. 2. Predicted probability of microhabitat use by male Bachman's Sparrows in the Coastal Plain physiographic region, North Carolina, USA, 2014–2015, based on (A) woody vertical density, (B) grass vertical density, and (C) dead vegetation vertical density. Shaded regions indicate 95% confidence intervals.

Table 5. Parameter estimates for the top microhabitat selection model ($\Delta AIC_c \leq 2$) for male Bachman's Sparrows ($N = 37$) in the Coastal Plain region of North Carolina, 2014–2015.

		Confidence limits	
Parameter[a]	Estimate	2.5%	97.5%
(Intercept)	0.15	−0.04	0.35
Woody vertical density	0.41	0.25	0.58
Grass vertical density	−0.07	−0.23	0.10
Grass vertical density (quadratic)	−0.15	−0.28	−0.03
Dead vertical density	0.20	0.03	0.38

[a]Parameter estimates and 95% CIs were derived from standardized variables.

Environmental factors could also contribute to differences in our estimates of home range size and those reported in previous studies. For example, Brown (2012) studied Bachman's Sparrows during two breeding seasons and found that estimates of home range size were ~2.5 times larger during the season that coincided with a severe drought and two birds made long-distance movements of ~2 to 4 km. Weather conditions were similar during both years of our study, and we observed no long-distance movements by radio-tagged sparrows. Differences among studies in the estimated size of the home ranges of Bachman's Sparrows may also be due to differences in the characteristics of habitats where studies were conducted, e.g., dry prairie (Dean and Vickery 2003), plantation forests (Haggerty 1998, Stober and Krementz 2006), sandhills longleaf pine (Brown 2012), and old-growth longleaf (Cox and Jones 2007).

Variation in home range size. Home range size was not influenced by any of the predictor variables that we examined, including time since the last fire. However, home ranges of most males (25 of 27) in our study were in stands burned ≤ 3 yr prior to our study, which is considered an optimal fire-return interval for Bachman's Sparrows (Tucker et al. 2004, 2006). Time since fire was > 6 yr for only two males in our study, and their home ranges were larger than average (9.04 and 9.24 ha, respectively).

We also found no effect of differences in male reproductive status on home range size. In contrast, Jones (2008) found that paired males had larger home ranges than unpaired male Bachman's Sparrows, and suggested that

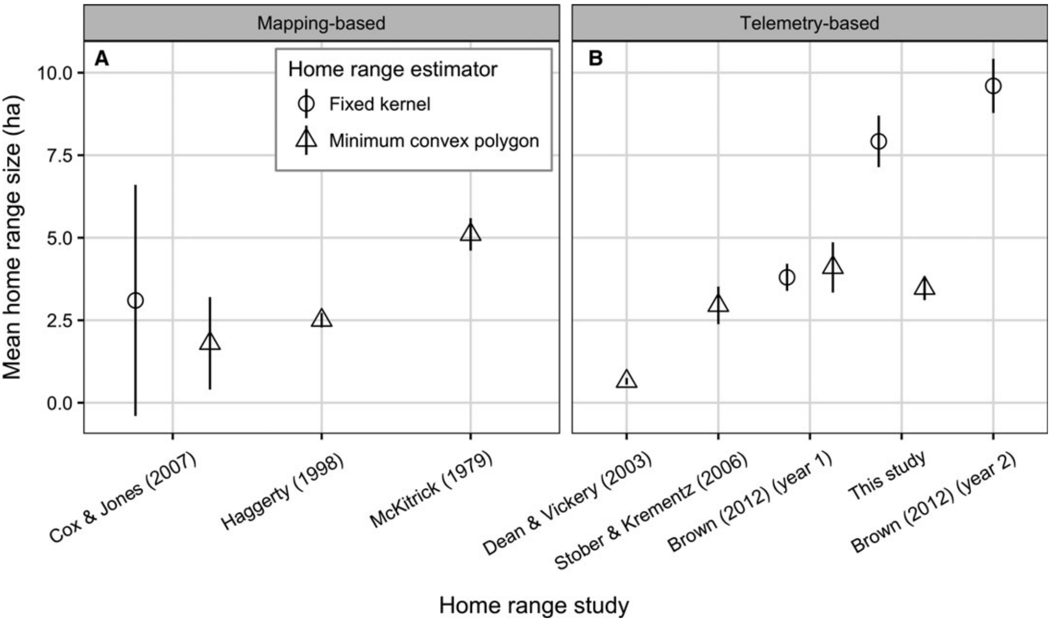

Fig. 3. Summary of the results of studies where home ranges sizes of Bachman's Sparrows were estimated using (A) spot-mapping and (B) radio-telemetry. Symbols and error bars indicate mean home range size ± SE. The minimum convex polygon estimate from the second year of Brown's (2012) study (33.0 ± 10.2 [SE] ha) was omitted from the figure to ease interpretation. All studies were conducted during the breeding season except Dean and Vickery (2003).

paired males made longer movements to acquire food for nestlings and fledglings and, therefore, had larger home ranges. However, Brown (2012) also found no relationship between reproductive status (i.e., paired vs. unpaired) and the size of Bachman's Sparrow home ranges. One possible explanation for these differing results is, as noted previously, a difference in methods used to estimate home range sizes, i.e., radio-telemetry (Brown 2012, our study) versus spot-mapping (Jones 2008).

Microhabitat selection. Although dense grass has often been emphasized as a key component of ground cover for Bachman's Sparrows (Dunning and Watts 1990, Plentovich et al. 1998), our results build upon recent studies documenting threshold responses to grass density (Brooks and Stouffer 2010, Jones et al. 2013, Taillie et al. 2015). Consistent with a broad-scale occupancy study conducted at one of our sites (Holly Shelter Game Land) and others in the adjacent Onslow Bight region of North Carolina (Taillie et al. 2015), we documented a decreasing probability of use in areas where grass density was greater than ~2 hits per the lowest 0.1-m section of a vertical pole. Bachman's Sparrows may require areas with relatively sparse grass because dense grass can impede movement (Haggerty 1998, Brooks and Stouffer 2010, Taillie et al. 2015), and we regularly observed radio-tagged Bachman's Sparrows running on the ground instead of flushing as we approached. Less grass also may allow for easier provisioning of nestlings by adults that typically land on the ground and approach nests from several meters away (Haggerty 1998, Jones et al. 2013).

Surprisingly, greater densities of woody and dead vegetation also increased the probability of use by male Bachman's Sparrows in our study. Woody vegetation is generally considered detrimental to the presence (Brooks and Stouffer 2010, Taillie et al. 2015) and reproductive success of Bachman's Sparrows (Tucker et al. 2004). Indeed, as time since fire increases, fire-intolerant woody species can become too tall (i.e., ≥ 1 m high) and outcompete herbaceous vegetation (Engstrom et al. 1984, Glitzenstein et al. 2003), causing Bachman's Sparrows to abandon sites.

However, in frequently burned (i.e., ≤ 3-yr return interval) longleaf pine communities like those in our study, woody vegetation likely provides several important benefits. For example, several investigators have documented the importance of song perches for male Bachman's Sparrows (Dunning and Watts 1990, Haggerty 2000, Brooks and Stouffer 2010, Jones et al. 2013), and we did observe males singing from the branches of living and dead shrubs. Shrubs also may provide escape cover from attacking predators (Pulliam and Mills 1977, Dunning 2006). Like sparse grass, a higher density of woody vegetation is considered an important feature for nest-site selection by Bachman's Sparrows, and may create a favorable microclimate (i.e., shade and protection from rain events) for nestlings (Jones et al. 2013, Winiarski et al. 2017) and fledglings.

Management implications. Our estimates of the home range sizes of male Bachman's Sparrows at the northeast limit of their range should be useful for managers needing estimates of abundance and carrying capacity across landscapes (e.g., Tingley et al. 2016). Additionally, Bachman's Sparrows in our study showed clear selection for several vegetation characteristics linked to frequent fire in their home ranges. Management strategies that approximate historical fire regimes in longleaf pine ecosystems (especially growing season fire; Jones et al. 2014) should continue to be promoted as essential tools for the conservation of Bachman's Sparrows. Prescribed fire can be used to ensure the presence of important microhabitat characteristics within home ranges, including low shrubs, dead vegetation, and sparse grasses (Glitzenstein et al. 2003, Thaxton and Platt 2006).

ACKNOWLEDGMENTS

Partial funding for this project was acquired through the Wildlife Restoration Act. The North Carolina Wildlife Resources Commission and North Carolina State University Fisheries, Wildlife, and Conservation Biology Program provided additional support. We thank A. Bartelt, D. Bernasconi, A. Bledsoe, S. Masecar, M. McAlister, T. Root, M. Seamster, and M. Wallgren for assistance in the field. A. Carl, R. Hudson, and L. Starke granted site access and provided valuable fire information and logistical support. We appreciate comments by the editor and three anonymous reviewers that substantially improved the manuscript. Bird handling was conducted in accordance with Institutional Animal Care and Use Committee guidelines (North Carolina State University Protocol #14-015-O).

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