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Predictors of Bachman's Sparrow Occupancy at its Northern Range Limit

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Abstract - *Peucaea aestivalis* (Bachman's Sparrow), a songbird endemic to the southeastern US, has experienced long-term population declines and a northern range-boundary retraction. Habitat loss and degradation, largely related to fire suppression, are believed to be the major causes of population declines, but these relationships are less studied at the northern range-extent. Hence, we investigated habitat selection of Bachman's Sparrow on Fort Bragg Military Installation, where vegetation is characterized by extensive fire-maintained *Pinus palustris* (Longleaf Pine) uplands. We surveyed breeding male sparrows using repeat-visit point-counts. We visited 182 points 3 times from April to July during the 2014 and 2015 breeding seasons. We measured vegetation and distance to other habitat features (e.g., wildlife openings, streams) at each point. We recorded presence or absence of Bachman's Sparrows and fit encounter histories into a single-season occupancy model in program Unmarked, including a year effect on detection. Occupancy probability was 0.52 and increased with greater grass-cover and at intermediate distances from wildlife openings, and decreased with years-since-fire and with greater shrub height. Predictors of Bachman's Sparrow occupancy were similar to those reported for other portions of the range, supporting the importance of frequent prescribed fire to maintain herbaceous groundcover used by birds for nesting and foraging. However, our study indicated that other habitat features (e.g., canopy openings) provided critical cover within extensive upland Longleaf Pine-*Aristida stricta* (Wiregrass) forest.

Introduction

Peucaea aestivalis (Lichtenstein) (Bachman's Sparrow), an endemic songbird of the southeastern US, inhabits open *Pinus* spp. (Pine) woodlands managed with frequent prescribed fire. Bachman's Sparrows select areas burned in the previous 3 y (Dunning and Watts 1990, Plentovich et al. 1998, Tucker et al. 1998) and abandon sites greater than 5 y post fire (Engstrom et al. 1984, Tucker et al. 2004). Most Bachman's Sparrow populations are closely associated with *Pinus palustris* Mill. (Longleaf Pine) forests, but the species also occurs in the understory of other open pine or *Quercus* spp. (oak) forest types (Haggerty 1988, 2000) and less commonly in early successional communities (Krementz and Christie 1999).

In the early 20th century, Bachman's Sparrow had a much larger range, with breeding records in Indiana, Ohio, Pennsylvania, Virginia, and West Virginia

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(Brooks 1938). These northern populations were associated with agricultural fields, abandoned pastures, and regenerating forests that had been clearcut (Brooks 1938). However, Bachman's Sparrow populations on the northern-range edge have disappeared in recent decades, including some populations in North Carolina, which now represents the northern extent of eastern populations (CCB 2010). Bachman's Sparrows in North Carolina primarily occur in Longleaf Pine woodlands and are seldom encountered in other vegetation types (Taillie et al. 2015).

Habitat loss and fragmentation, largely from fire suppression and conversion of Longleaf Pine forests, are driving local population extinctions (Van Lear et al. 2005, Winiarski et al. 2017b). In southern portions of Bachman's Sparrow range, individuals primarily occupy open pine woodlands characterized by relatively low basal area, extensive native bunch-grass cover, and sparse shrub-cover maintained with frequent prescribed fire (Cox and Widener 2008; Dunning and Watts 1990, 1991; Haggerty 1998). Suppression of fire leads to taller and more extensive shrub-cover, which shades out herbaceous vegetation (Addington et al. 2015, Engstrom et al. 1984, Fill et al. 2012, Hmielowski et al. 2014, Nippert et al. 2013, Richardson and Williamson 1988). Without frequent fire, native bunch-grasses, including *Aristida stricta* Michx. (Wiregrass), become dense and restrict use by Bachman's Sparrows (Taillie et al. 2105, Winiarski et al. 2017a). Similarly, high basal area from dense tree-stocking decreases the amount of sunlight reaching the forest floor, thereby suppressing the growth of herbaceous groundcover required by sparrows (Darracq et al. 2016).

However, less is known about habitat associations at the northern extent of the Bachman's Sparrow range, where multi-scale factors are known to influence occupancy (Taillie et al. 2015, Winiarski et al. 2017b). Habitat conditions can vary across geographic gradients related to differences in soil chemistry, productivity, and saturation. Hence, habitat associations from other locations may not adequately predict habitat selection on the northern range extent. Accordingly, we investigated potential predictors of Bachman's Sparrow occupancy at its northern range extent in a landscape intensively managed with prescribed fire. We evaluated the importance of vegetation characteristics, fire history, and habitat features to identify specific mechanisms driving Bachman's Sparrow occupancy.

Field-site Description

Fort Bragg Military Installation (hereafter, Fort Bragg) is located in the Sandhills physiographic region of central North Carolina. Fort Bragg consists of ~621 km^2 situated within the Longleaf Pine–Wiregrass ecosystem. Fort Bragg contains one of the largest continuous tracts of intact Longleaf Pine forest in North Carolina (Sorrie et al. 2006). An extensive network of firebreaks that are oriented in an east–west direction and several streams more typically oriented on a north–south axis divided the study area into 34.0-ha (SE = 0.98) fire-management units. Longleaf Pine uplands on Fort Bragg were managed primarily with an early growing-season prescribed fire application once every 3 y (Cantrell et al. 1993). However, some sections of Fort Bragg were managed with dormant-season prescribed fire or had variable fire-return intervals from wildfires and fire suppression. This frequent-fire regime promotes an understory of Wiregrass and other herbaceous plants while reducing the prevalence of shrubs, small trees, and leaf litter (Harper et al. 1997, Shriver and Vickery 2001). Approximately 1280 wildlife openings were present across the installation; the plant communities in the openings varied because of past soil disturbance, fire history, and planting history. Most of the openings were fallow during the study.

Methods

Data collection

We conducted repeat-visit unlimited-distance point-counts at 182 survey locations within a 165-km^2 portion of Fort Bragg. Using ArcMAP (Environmental Systems Research Institute, Inc., Redlands, CA), we randomly generated survey points in mature Longleaf Pine stands, with a minimum distance of 250 m between points to maintain sampling independence (Ralph et al. 1993). To coincide with peak Bachman's Sparrow breeding activity, we visited each point-count location 3 times between 21 April and 29 June 2014 and 28 April and 15 July 2015. We visited point-count locations from 0.5 h before sunrise to 5 h after sunrise (Rimmer et al. 1996).

Point counts for Bachman's Sparrow consisted of an 8-min survey period with 4 min of passive observation followed by a 4-min playback period. We used an Eco Extreme (Grace Digital, San Diego, CA) waterproof speaker to broadcast playback recordings. The 4-min playback-period recording consisted of periodic Bachman's Sparrow singing, secondary calls, and chip notes. Bachman's Sparrows are considered highly secretive, so playback was used to increase detection probability (Rimmer et al. 1996, Taillie et al. 2015). We visited points approximately once every 3 weeks, with longer return-intervals when presence of military troops reduced accessibility.

We collected vegetation data immediately following point-count surveys. We recorded vegetation contacts (hereafter, hits) on each 10-cm interval of a 2.54-cm diameter and 2-m-tall Wiens pole (Wiens 1974). We classified vegetation as grass, shrub (perennial shrubs or regenerating trees), forb, or fern. During the first point-count, we measured vegetation at the point-count center and at every 1-m interval along two 10-m perpendicular transects centered on the point-count origin. We recorded groundcover as litter, bare ground, or vegetation immediately beneath each Wiens pole reading. At locations with >1 groundcover category present, we recorded the dominant category with ≥50% cover. We measured 2 additional vegetation plots located 50 m in a randomly selected direction from the point-count center during the 2 subsequent point-counts (Brooks and Stouffer 2010). We averaged the 3 vegetation plots to generate 1 estimate of vegetation characteristics for each point-count location.

We quantified 7 vegetation covariates to include in the a priori model set. We calculated percent grass, shrub, and forb cover at each plot by calculating the proportion of the 21 Wiens pole readings with ≥1 hits of each vegetation type. We estimated percent bare-ground cover by calculating the proportion of the Wiens pole readings that rested on bare substrate. We calculated shrub height by recording the tallest shrub hit to the nearest dm on each Wiens pole, and averaged across each survey plot. To determine vegetation heterogeneity, we calculated the coefficient of variation for vegetation height, using the highest grass, shrub, or forb contact on each Wiens pole, averaged across each survey plot. We calculated basal area using a 10-factor cruising prism from the center of the vegetation plot (Avery and Burkhart 2015). We included all vegetation covariates as linear terms in the models.

We calculated years-since-fire and distance to wildlife openings and streams for each point-count location using spatial landcover and fire-history data in ArcGIS. We calculated years-since-fire by back-calculating from the survey year (e.g., 2014 or 2015) to the most recent fire event (e.g., prescribed fire or wildfire) at the point-count center. We included distance covariates in the model because anecdotal observations by the field crew indicated birds chose locations in proximity to dense woody vegetation likely used as escape cover. Fire shadows within wildlife openings and along streams represented the most readily available escape cover on Fort Bragg. We included distance to wildlife openings and streams as both linear and quadratic terms and years-since-fire only as a linear term. We included ordinal date and survey-start time as detection covariates for each point-count survey, which can influence Bachman's Sparrow detection probability (Taillie et al. 2015). We included a year effect on detection, which additionally controlled for observer effects because a single observer was responsible for all point-count surveys each year. To ensure that the magnitude of the covariates was similar in the analysis, we scaled all covariates by subtracting the mean and dividing by the standard deviation.

We tested for collinearity among covariates using Pearson's correlation coefficient. We used a conservative threshold of $r < |0.6|$ (Vitz and Rodewald 2011, Winiarski 2017a) and identified only 2 correlated covariates (coefficient of variation for vegetation height and percent grass cover). We included percent grass-cover in models because previous work conducted by Dunning and Watts (1990) and Taillie et al. (2015) determined that grass-cover positively influenced occupancy (Table 1). We excluded the coefficient of variation for vegetation height from the analysis.

Statistical modeling

We fit single-species, single-season occupancy models, with a year effect, using the unmarked package in Program R (Fiske and Chandler 2011, MacKenzie et al. 2002, R Core Team 2016). To model detection probability, we fit 15 a priori models with ordinal date, survey start time, and year, holding the state-based side of the model constant. Using the Akaike information criterion corrected for small sample size (AIC_c) to rank model fit, we chose the model with the lowest AIC_c score as most parsimonious (Burnham and Anderson 2002). We considered models competitive if they differed by <2 AIC_c units for every additional 1 parameter of the top model; we ignored models with non-informative parameters (Arnold 2010). We then modeled occupancy by fitting 93 state-based a priori models including covariates from the best-supported detection model (Table 1). We did not include any interactions between covariates in the models.

If a survey point was burned between visits within the survey year, local Bachman's Sparrows abandoned their territories and dispersed to unburned vegetation. Occupancy modeling assumes a constantly occupied state. We considered this assumption to be violated at survey points exposed to prescribed fire (MacKenzie et al. 2002), and classified all post-burn as not estimable. Additionally, we conducted a goodness-of-fit test to assess the fit of the highest supported model (MacKenzie and Bailey 2004). Testing the fit of the top model ensures that the model fit the dataset and in extreme cases can indicate the need for additional explanatory covariates.

Results

We surveyed 182 points in both 2014 and 2015. We visited all point-count locations 3 times, but 44 point count locations—17 in 2014 and 27 in 2015—had at least 1 visitation affected by prescribed fire and the visitation was considered not estimable. We detected at least 1 Bachman's Sparrow at 66 sites in 2014 and at 80 sites in 2015, for a naïve occupancy estimate of 0.40.

Initially, we considered 4 detection models to be competitive (Table 2). Two of them had 1 additional parameter and were within 2 AIC_c units of the top model and

Table 1. List of covariates used in hierarchical occupancy modeling for detection (p) and occupancy (ψ), Fort Bragg Military Installation, NC (2014–2016).

ID	Covariate
p	
j.date	Julian date
time	Start time of point-count survey
year	Survey year
ψ	
ba.tot	Basal area
cv.mxht	Coefficient of variation max. height
dist.strm	Distance to nearest drainage
dist.wopn	Distance to nearest wildlife opening
mx.wd	Average maximum shrub height
per.frb	Percent cover forb
per.grs	Percent cover grass
per.wd	Percent cover shrub
pg.bare	Percent bare ground
sincefire	Year since fire

Table 2. Top 5 detection (p) models with number of parameters (K), AIC_c, ΔAIC_c, model weight (AIC_cwt) and negative Log likelihood (-LogLike) for Bachman's Sparrow surveys on Fort Bragg Military Installation, NC (2014–2015).

Model p ()	K	AIC_c	ΔAIC_c	AIC_cwt	-LogLike
j.date + year	4	1008.28	0.00	0.27	-500.08
j.date + time + year	5	1008.77	0.49	0.21	-499.30
j.date + j.date^2 + time	5	1009.63	1.35	0.14	-499.73
j.date + j.date^2 + time + year	6	1009.88	1.60	0.12	-498.82
j.date	3	1010.84	2.56	0.07	-502.39

1 had 2 additional parameters and was within 4 AIC_c units of the top model. The additional parameters in the competitive model set consisted of the same 2 parameters in various combinations to the top model (Table 2). The 3 competitive models below the top model included non-informative parameters with 95% confidence intervals overlapping zero. Thus, we proceeded with only the top model. Using the top model, the probability of detecting a male Bachman's Sparrow was 0.43. The top model suggested that detection declined with ordinal date and was greater in 2015 than in 2014 (Fig. 1). We used the top detection model to fit the state-based component of the occupancy model.

Of the initial 93 a priori state-based models, we considered 9 candidate models to be competitive (Table 3). The 8 models below the top model differed by a combination of non-significant parameters with 95% confidence intervals overlapping zero. The candidate models included combinations of 5 additional covariates: distance to stream, basal area, percent shrub-cover, percent forb-cover, and percent bare ground (Table 3). We rejected the 8 candidate models because they contained uninformative parameters; thus, we selected the top model as the best fit for occupancy. The top model estimated an occupancy rate of 0.52. The model included a positive linear relationship with percent grass-cover, negative linear relationship with year-since-fire, negative linear relationship with maximum height of shrubs, and a negative quadratic relationship with distance to wildlife opening (Fig. 2). On average, distance to wildlife opening was 17% closer for occupied sites than at unoccupied sites, shrub height was 23% lower at occupied sites than at unoccupied sites, and percent grass-cover was 27% greater at occupied sites than at unoccupied sites (Table 4). The goodness-of-fit test indicated that the top model was a good fit, returning a χ^2 statistic of 7.87 ($P = 0.59$). Hence, we failed to reject the null hypothesis and concluded the observed data set matched the expected observations.

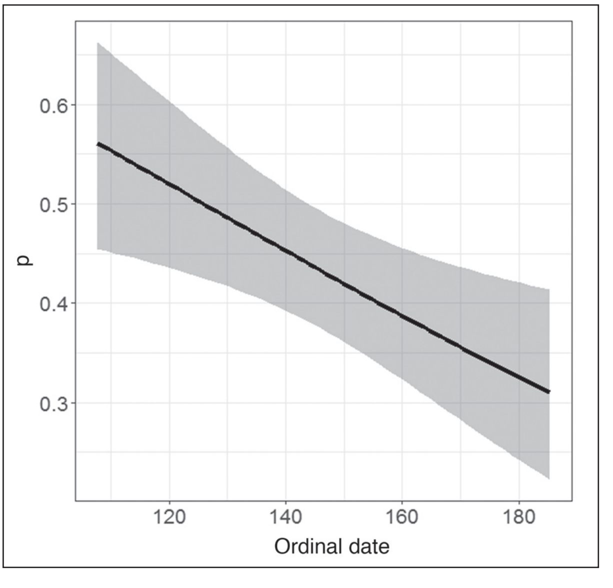

Figure 1. Predicted detection (p) and 95% confidence intervals for ordinal date, using the top detection model for Bachman's Sparrow at Fort Bragg Military Installation, NC (2014–2015).

Table 3. Top 10 occupancy (ψ) models with number or parameters (K), AIC_c, ΔAIC_c, model weight (AIC_cwt), and negative Log likelihood (-LogLike) for Bachman's Sparrow surveys on Fort Bragg Military Installation, North Carolina (2014–2015). Detection was modeled with ordinal date and year.

Model ψ()	K	AIC_c	ΔAIC_c	AIC_cwt	-LogLike
per.grs + mx.wd + sincefire + dist.wopn + dist.wopn^2	9	953.78	0.00	0.32	-467.63
per.grs + mx.wd + sincefire + dist.wopn + dist.wopn^2 + ba.tot	10	955.45	1.67	0.14	-467.41
per.grs + mx.wd + sincefire + dist.wopn + dist.wopn^2 + dist.strm + dist.strm^2	11	955.46	1.68	0.14	-466.36
per.grs + mx.wd + sincefire + dist.wopn + dist.wopn^2 + ba.tot + per.frb	11	956.36	2.58	0.09	-466.81
per.grs + mx.wd + sincefire + dist.wopn + dist.wopn^2 + dist.strm + dist.strm^2 + ba.tot	12	957.13	3.35	0.07	-465.98
per.grs + mx.wd + sincefire + dist.wopn + dist.wopn^2 + dist.strm + dist.strm^2 + per.wd	12	957.51	3.73	0.06	-466.12
per.grs + mx.wd + sincefire + dist.wopn + dist.wopn^2 + dist.strm + dist.strm^2 + pg.bare	12	957.60	3.82	0.05	-466.31
per.grs + mx.wd + sincefire + dist.wopn	8	957.96	4.18	0.04	-470.78
per.grs + mx.wd + sincefire + dist.wopn + dist.wopn^2 + dist.strm + dist.strm^2 + per.wd + per.frb	13	958.23	4.45	0.04	-465.34
per.grs + mx.wd + sincefire + dist.wopn + dist.wopn^2 + dist.strm + dist.strm^2 + per.wd + pg.bare	13	959.62	5.84	0.03	-465.60

Discussion

Similar to more southerly populations, Bachman's Sparrows on Fort Bragg selected recently burned areas dominated by native bunch-grasses. Grasses and other herbaceous vegetation provide high-quality cover (Cox and Jones 2009, Dunning and Watts 1990, Plentovich et al. 1998, Tucker et al. 2004) and food (Allaire and Fisher 1975), and these plants are essential for nest construction (Haggerty 1988, 1995; Jones et al. 2013). Frequent prescribed fire during the growing season promotes Wiregrass, which provides critical foraging and nesting cover for Bachman's Sparrows and bare ground between grass bunches to allow movement by sparrows (Taillie et al. 2015, Winiarski et al. 2017a).

Frequent prescribed fire is critical to prevent woody understory encroachment that shades and eliminates herbaceous grasses and forbs in uplands (Cox and

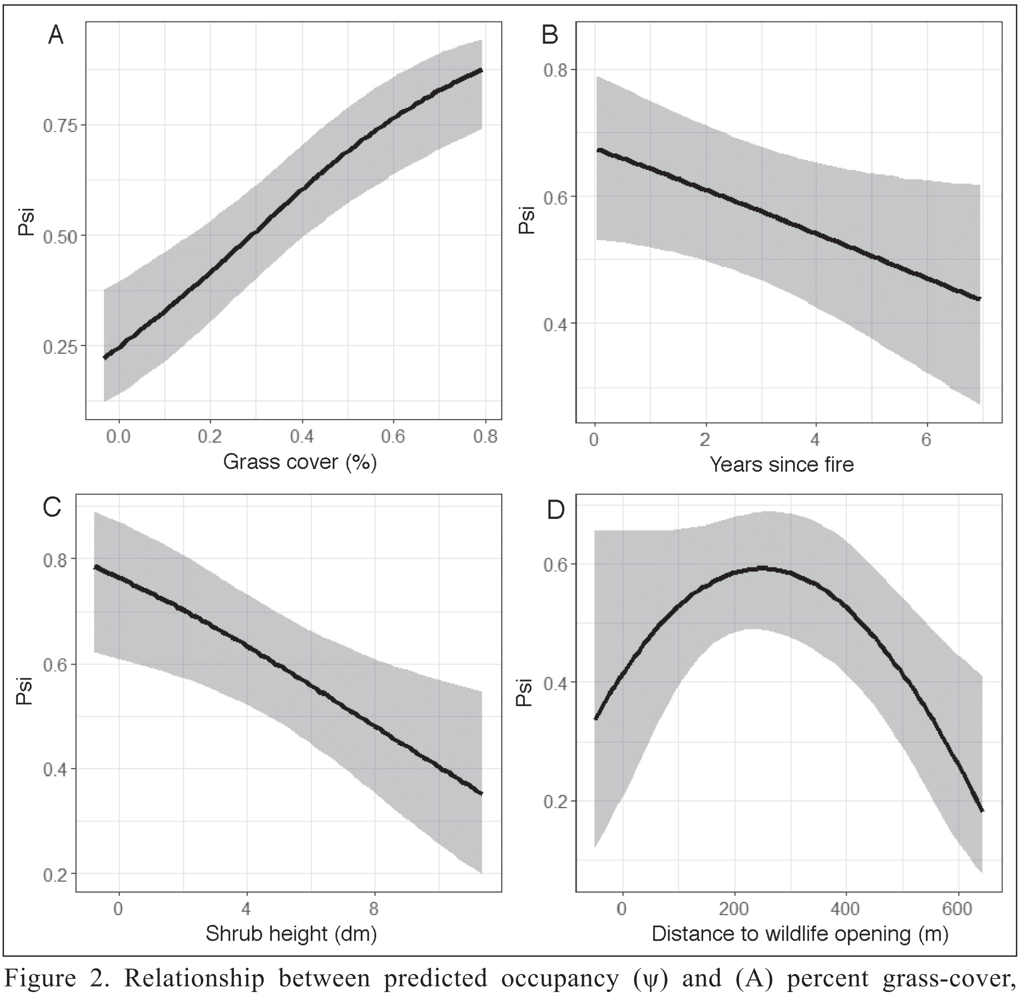

Figure 2. Relationship between predicted occupancy (ψ) and (A) percent grass-cover, (B) years-since-fire, (C) average shrub-height in decimeters, and (D) distance to wildlife opening using the top occupancy model for Bachman's Sparrow at Fort Bragg Military Installation, NC (2014–2015).

Jones 2009, Heuberger and Putz 2003, Myers and White 1987). Prescribed fire during the growing season top-kills shrubs, causing them to re-sprout from roots, and effectively reduces shrub height (Hmielowski et al. 2014). However, with frequent fire application, shrubs are unable to meet the energetic demands of re-sprouting and shrub cover decreases over time (Grady and Hoffman 2012). The low soil productivity of the Sandhills physiographic region further limits woody cover in Longleaf Pine woodlands (Lashley et al. 2015). Moreover, the systematic use of a 3-y fire regime has reduced the prevalence of oaks and other hardwood species in Fort Bragg uplands (Lashley et al. 2014).

Bachman's Sparrows selected for sites near wildlife openings, which is a habitat relationship not previously documented. Wildlife openings on Fort Bragg were relatively small (mean = 0.31 ha, SE = 0.02 ha, *n* = 717) and functionally mimicked naturally occurring canopy openings. Canopy openings foster a dense growth of understory shrubs and herbaceous vegetation because of increased sunlight penetration to the forest floor (Folkard et al. 2012, Jameson 1967). Wildlife openings on Fort Bragg were disced periodically to prepare a seedbed for planting annual food plants or to maintain early successional vegetation; however, they are commonly left fallow for several years following planting. Vegetation in these fallow openings was characterized by a mix of perennial and annual herbaceous plants, shrubs, and young trees (e.g., *Andropogon virginicus* L. [Broomsedge], *Rubus* spp. [blackberries], *Rhus* spp. [sumacs], *Lespedeza bicolor* Bunge [Shrub Lespedeza], *Liquidambar styraciflua* L. [Sweetgum], *Diospyros virginiana* L. [American Persimmon]). Hence, the mix of woody and herbaceous cover in the fallow wildlife openings provided a vegetation community that was structurally and compositionally unique within the matrix of frequently burned uplands. Vegetation along stream drainages on Fort Bragg may provide habitat conditions similar to wildlife openings, and occupied points were closer to streams than unoccupied points, although the relationship was not significant.

Table 4. The range of covariate values measured at Bachman's Sparrow point-count locations for occupied and unoccupied sites on Fort Bragg Military Installation, NC (2014–2015). The covariate units are [A]number of trees in a circular 11.3-m diameter plot, [B]meters, [C]decimeters, and [D]proportion of plot covered.

	Occupied			Unoccupied		
Covariate	Min	Max	Mean	Min	Max	Mean
ba.tot[A]	2.17	14.67	6.14	1.83	11.50	6.70
cv.mxht	0.25	3.35	1.28	0.30	3.82	1.55
dist.strm[B]	8.58	491.27	179.51	6.30	708.39	197.76
dist.wopn[B]	40.57	794.93	264.53	0.95	856.17	318.53
mx.wd[C]	0.00	13.78	4.48	0.00	19.00	5.83
per.frb[D]	0.00	0.22	0.04	0.00	0.22	0.03
per.grs[D]	0.06	0.95	0.45	0.00	0.81	0.33
per.wd[D]	0.00	0.57	0.18	0.00	0.79	0.22
pg.bare[D]	0.00	0.76	0.11	0.00	0.83	0.12

Bachman's Sparrows may have established territories near wildlife openings because of associated fitness benefits. Similarly, Brooks and Stouffer (2010) documented increased Bachman's Sparrow abundance near cover from downed tree crowns. Moreover, Lohr et al. (2002) showed that downed coarse woody debris provided important cover for songbirds in *Pinus taeda* L. (Loblolly Pine) woodlands. Although we were not able to document the specific benefits that the wildlife openings provided to Bachman's Sparrows, fledgling sparrows selected dense patches of woody vegetation, often including fallow wildlife openings (A.C. Fish, unpubl. data). The unique vegetation community in fallow openings may have provided perches for singing males, thermal refugia, or escape cover.

We consider the Bachman's Sparrow population at Fort Bragg to be stable, and males largely occupied sites with the same habitat features as elsewhere in the species' range, where populations are stable (Dunning and Watts 1990, Tucker et al. 2004). However, landscape-level habitat protection and restoration is required in addition to frequent application of prescribed fire to ensure Bachman's Sparrow populations persist. In eastern North Carolina, Taillie et al. (2015) showed that Bachman's Sparrows were less likely to occupy habitat patches with less surrounding habitat. Similarly, Winiarski et al. (2017b) reported that pairing success was lower when the amount of habitat in the surrounding landscape was reduced, but pairing success was not related to local habitat quality. Therefore, conservation of large, contiguous expanses of fire-maintained Longleaf Pine woodlands, like Fort Bragg, is critical to prevent extirpation of Bachman's Sparrow on their northern range extent.

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