The Distribution, Persistence, and Habitat Associations of Bachman's Sparrow (*Peucaea aestivalis*) in North Carolina

Paul J. Taillie[1,2], Jeffrey F. Marcus[3], John P. Carpenter[2], and Scott K. Anderson[2]

[1]Corresponding author

[2]North Carolina Wildlife Resources Commission, Raleigh, NC 27699

[3]The Nature Conservancy, Southern Pines, NC 28388

Abstract

The primary objective for this study was to develop a comprehensive, high-resolution map of the distribution of Bachman's Sparrow (*Peucaea aestivalis*) in North Carolina. We reviewed aerial photography within the species' range to identify potential habitat and selected 1,511 locations to survey for sparrows. In addition, we compiled all historical records (prior to 2007) available and resampled these locations (n=80) to determine sparrow persistence. Finally, we added an additional 252 locations where suitable habitat was identified in the field for a total of 1,843 potential survey locations. We were able to visit 1,503 of these locations in the field, but only 929 of them (62%) were determined to have habitat suitable to support sparrows. At these 929 points we conducted 8-minute point-count surveys during the breeding seasons of 2012-2014, with and without Bachman's Sparrow song playback. We detected Bachman's Sparrows at 196 of the 929 (21%) surveyed points. Our results indicate this species is largely restricted to several large, fire-maintained pine woodlands in the Sandhills and southern Coastal Plain. We did encounter some birds at sites far from these core areas and in sub-optimal habitat (e.g., young pine stands, fire suppressed stands), but these instances were rare. We detected sparrows at only 9 of the historic locations (11%), strongly suggesting this species' range has continued to contract in recent decades, and it is now absent from the eastern Piedmont outside of the Sandhills. As expected, we observed Bachman's Sparrows presence to be strongly correlated with both recent fire, and moderate to high herbaceous groundcover. However, unlike in other parts of their range, sparrow use of powerline corridors, recent clearcuts, and abandoned fields appears to be rare, despite apparently suitable vegetation conditions. Future restoration and management of Bachman's Sparrow habitat should be focused on augmenting extant populations by creating and maintaining open-canopy conditions in pine-dominated forests and promoting herbaceous cover through the use of prescribed fire.

Introduction

Bachman's Sparrow (*Peucaea aestivalis*), a ground-dwelling sparrow

Bachman's Sparrow, 28 April 2016. Photo by John Carpenter.

endemic to the southeastern United States (Dunning 2006), is closely associated with the dense, herbaceous groundcover typically found in fire-maintained longleaf pine (*Pinus palustris*) forest, as well as pine savannah and other early successional habitats (Dunning and Watts 1990, Jones et al. 2013). Because of these habitat associations, Bachman's Sparrow often serves as a focal species for studies evaluating management and restoration of longleaf pine ecosystems, along with the endangered Red-cockaded Woodpecker (*Picoides borealis*; Rutledge and Conner 2002, Tucker et al. 2004)

Like many other species associated with fire-maintained herbaceous cover, Bachman's Sparrows have consistently declined over the past several decades across their range, largely in response to habitat loss and degradation in the absence of fire (Dunning 2006). According to the United States Geological Survey Breeding Bird Survey, this species has experienced a range-wide annual decline of 3.1% (95%CI: -4.1, -2.1) since 1966 (Sauer et al. 2012). However, the species' status is classified as "category 2" under the Endangered Species Act, meaning federal protection may be warranted, but insufficient evidence exists for formal designation. Following the extirpation of this species from the state of Virginia in recent decades (Watts pers. comm.), North Carolina harbors the northernmost breeding population. As such, our state currently marks the front lines of the effort to reverse the continued decline and range contraction.

Bachman's Sparrows still can be readily found in North Carolina on large blocks of frequently burned longleaf pine forests such as those on Sandhills Game Lands, Fort Bragg Military Installation, Holly Shelter Game Land, Camp LeJeune Marine Corps Base, and Croatan National Forest (LeGrand 2013), but the species has been observed infrequently away from conservation lands in recent decades (pers. obs.). Virtually all research on this species has

focused on public lands, whereas the distribution on private lands is largely undocumented, (but see Taillie et al. 2015). Previous studies outside North Carolina describe the use of treeless dry prairie (Shriver et al. 1999), clearcuts (Haggerty 1988, Dunning et al. 1995, Watts et al. 1998, Cox pers. comm.), young pine plantations (Haggerty 1998, Watts et al. 1998, Cox pers. comm.), and utility rights-of-way (Dunning et al. 1995) by Bachman's Sparrows; however, but use of these habitats (hereafter referred to as "secondary habitats") in North Carolina have been rare in recent years (pers. obs.). Though Bachman's Sparrows have been observed using several of these secondary habitats in the past in North Carolina, including two singing males in a young longleaf pine clearcut and one singing male in the treeless Rhine-Luzon Drop Zone of Fort Bragg Military Installation (McNair, unpubl. data), the extent to which these habitats are used today remains unclear. In light of the continued conservation concern of longleaf pine forest (Oswalt et al. 2012), as well as a recent proposal to elevate the state-level conservation status of Bachman's Sparrow from "special concern species," to "threatened" (Gerwin et al. 2011), a more comprehensive understanding of this species' distribution and use of secondary habitats on private lands will complement current research on public lands and serve to guide management and restoration of longleaf pine ecosystems state-wide.

Currently, the North Carolina Gap Analysis Project (NCGAP) Vertebrate Predicted Distribution Map is the only source for a comprehensive state-wide distribution of Bachman's Sparrows at a resolution finer than the county level (http://www.basic.ncsu.edu/ncgap/sppreport/abpbx91050.html). Though this map incorporates observations of Bachman's Sparrows to inform the model of predicted occurrence, these observations are both geographically limited and temporally variable (see Methods). This study attempts to refine the NCGAP predicted distribution of Bachman's Sparrows by conducting on-the-ground surveys of sparrows throughout the known range with a focus on privately owned and otherwise under-surveyed lands. Our objectives were to 1) develop a current map of Bachman's Sparrow breeding distribution in NC, 2) assess persistence of the species at sites where they were historically observed, 3) document habitat use, including use of secondary habitats, and 4) model the temporal variation in sparrow detection. To achieve these objectives, we systematically identified and surveyed Bachman's Sparrow habitat across its known range in NC. Our results greatly improve the ability to monitor and manage for Bachman's Sparrows in the future and will aid in the development of a state-wide conservation plan to mitigate, and ultimately reverse, its continued decline.

Field Site Description

We limited our study to the known range of Bachman's Sparrows in North

Carolina as approximated by the NCGAP Vertebrate Predicted Distribution Map. This range included southeastern North Carolina east of the Uwharrie Mountains and parts of northeastern North Carolina in the eastern Piedmont and inner Coastal Plain (Fig. 1). The forested areas of the Sandhills and the southern Coastal Plain are largely comprised of pine-dominated forest, whereas Northern Fall Line forests include pine, hardwood, and mixed-canopy forests. Outside of forested areas, these regions are largely comprised of varying levels of urban development and row crop agriculture.

Methods

We followed a systematic process to generate the most current and comprehensive breeding distribution map of Bachman's Sparrow in NC by 1) resampling historic records to evaluate site persistence, 2) evaluating aerial photography throughout its range to identify potential breeding habitat, and 3) conducting on-the-ground field observations to verify conditions at potential habitat sites and presence of Bachman's Sparrows.

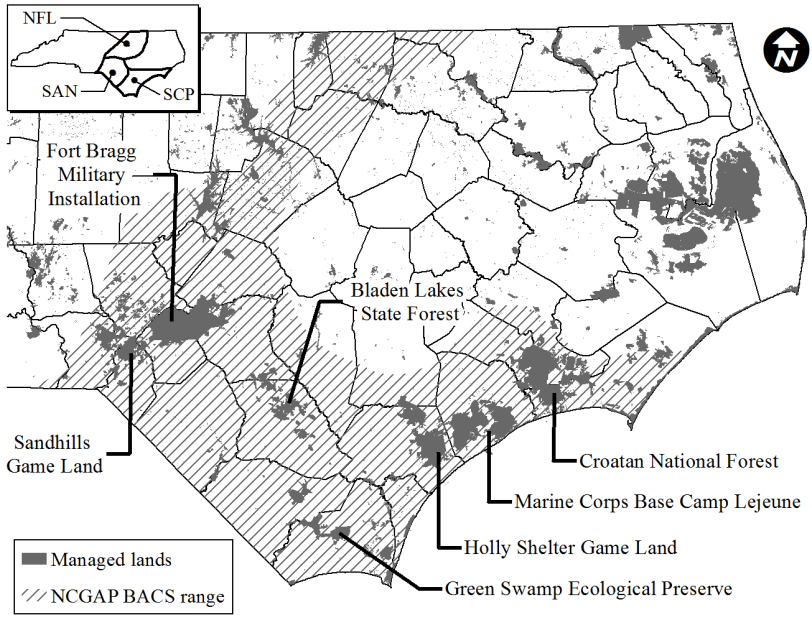

Figure 1. The North Carolina Gap Analysis (NCGAP) Project's estimate Bachman's Sparrow range is shown with the distribution of public lands across the region. The inset map shows the extent of the Northern Fall-line (NFL), Sandhills (SAN), and Southern Coastal Plain (SCP) sub-regions.

Site Selection

As a reference of historical distribution and to evaluate site persistence, we used all available existing breeding season (April – July) records of Bachman's Sparrows from the North Carolina Natural Heritage Program, North Carolina Wildlife Resources Commission, North Carolina Museum of Natural Sciences, US Forest Service, US Fish and Wildlife Service, and eBird (Sullivan et al. 2009). We resurveyed all observations (n = 80) collected prior to the 2007 breeding season, and hereafter refer to these as historical observations.

Because historical observations were limited and derived from localized bird surveys conducted primarily on public lands, we interpreted recent aerial photography and placed additional sampling locations in suitable habitat with an emphasis on private lands. We first divided the known range into a grid of 1,050 USGS quarter quadrangles (hereafter: "quarter-quads"), each with an area of 3,952 ha using ArcGIS™ v.10 (Environmental Systems Research Institute, Redlands, California, USA). At a scale of 1:10,000 to 1:16,000, we examined every quarter-quad in the Sandhills and Southern Coastal Plain regions (excluding Marine Corps Base Camp Lejeune and portions of Holly Shelter, Sandhills Game Lands, and Croatan National Forest, which were concurrently surveyed as part of other research projects; Fig. 1). We randomly selected 25% of the total quarter quads in the Northern Fall Line region to review because the likelihood of encountering a sparrow in this region is currently low (LeGrand 2013). For the purposes of this study, we focused our effort largely on identifying open pine woodlands; however, we did evaluate clearcuts and abandoned fields >50 acres, and powerline habitats >50 m wide if present within a matrix of apparent open pine habitat to determine if Bachman's Sparrows were also using these habitat types in NC. We placed a maximum of 16 points per quarter-quad while ensuring a minimum distance of 500 m between points. To facilitate access, 27% of the total selected points were situated <50 m from a paved road. Using this approach, we generated a total of 1,511 points: 1,250 in open pine habitat, 202 in clearcuts/abandoned fields, and 59 in powerline corridors.

We obtained permission to survey all points on public lands and properties owned by private conservation organizations (e.g. The Nature Conservancy). Permission to access survey locations on private property was solicited from 298 landowners using a combination of letter requests, phone calls, and emails. We received permission from 146 landowners (49%), were denied permission by 30 landowners (10%), and received no response from 122 landowners (41%). We were unable to survey 28 points on private land for which we were granted permission (19%) because of logistical constraints.

We ground-truthed each of the 1,511 points to verify the existence of suitable Bachman's Sparrow habitat, and to also locate additional habitat not identified

during investigation of aerial imagery. While conducting field surveys, we added survey points in the field if we encountered suitable Bachman's Sparrow habitat >500 m away from any existing survey point. We defined suitable as occurring within a minimum 2-ha patch of contiguous habitat comprised of >20% cover of native herbaceous vegetation (i.e. bunch grasses, forbs, etc.) with a sparse midstory. Points failing to meet these criteria were not surveyed for sparrows, and the reason for rejection was recorded, including closed canopy, dense midstory, conversion to other land use, or recent disturbance (e.g., controlled burn within the past 1-3 months). In summary, we generated a total of 1,843 survey points to potentially survey for Bachman's Sparrows: 1,511 via aerial imagery, 252 while in the field, and 80 based on historical observations.

Sparrow Surveys

Points were surveyed for sparrows using an infinite-radius point-count protocol during the months of April and May in 2012-2014, within 4.5 hr of sunrise on mornings without precipitation or excessive wind. At points that met the criteria for suitable habitat, the observer conducted a "passive" 4-min point-count survey, recording the estimated distance and direction to all detected Bachman's Sparrows, as well as the habitat type in which they were found: open longleaf pine forest, open forest of other pine species (*Pinus spp.*), fallow field, powerline corridor, clearcut and young (<10 years) pine plantations, or other. Immediately following the passive survey period, an additional 4-minute point-count (hereafter referred to as the "active survey period") was conducted while concurrently broadcasting a recorded Bachman's Sparrow vocalization. This recording consisted of short segments of a vocalizing sparrow interspersed by periods of silence to facilitate listening, and vocalizations included the traditional breeding song, aggressive chip notes, and a more excited song.

Distribution Mapping

For distribution mapping purposes, we included all available breeding season observations of Bachman's Sparrows not classified as historic (i.e., from 2007 and later; see Site Selection above), all sparrows detected during point counts, as well as all sparrows detected outside of the formal 8-min point-count period. Additionally, we included observations from concurrent investigations of Bachman's Sparrows on public lands, including parts of the Onslow Bight region (Walters 2009, Taillie et al. 2015), and portions of Holly Shelter and Sandhills Game Lands (NCWRC, unpublished data). To categorize our results according to ownership, we used the "managed areas" layer from the North Carolina Natural Heritage Program (http://www.ncnhp.

org/web/nhp/managed-areas), which includes properties owned by federal, state, and local governments, as well as private lands managed by conservation organizations (e.g., The Nature Conservancy) and properties associated with easements and other conservation programs, such as Safe Harbor. All points outside of the "managed areas" are privately owned and not associated with long-term conservation programs.

Detection Modeling

To investigate temporal variation in the detection of Bachman's Sparrows, we modeled detection using only data collected during our point-count surveys in an occupancy model framework using the "Unmarked" package in R (Fiske and Chandler 2011, R Development Core Team 2014). Because we surveyed the vast majority of sites only once, we treated the entire 3-yr period as a closed "season." We acknowledge that this method likely violates the closure assumption for single-season models, particularly for species associated with ephemeral vegetation conditions. However, given the effort required to survey such a large number of points and coordinate with hundreds of landowners, surveying all sites in one season was not possible. Nonetheless, we believe our results are informative at large spatial scales.

We treated the passive and active survey periods as 2 independent survey periods in order to estimate detection probability. Thus, we only included points that were surveyed for sparrows, and not those that were rejected due to insufficient habitat. We then added both linear and quadratic effects of date and time of survey as covariates on detection. Lastly, we included a binary categorical variable to distinguish between the active and passive survey periods.

Results

We investigated a total of 714 quarter-quads in the Sandhills and Southern Coastal Plain and 89 in the Northern Fall Line and visited 1,503 of the 1,843 (82%) total survey points. At the points we visited, we conducted point-counts at the 929 points that met our minimum suitability criteria (Fig. 2) and rejected the 574 points that did not. Of the points that were rejected for insufficient habitat, 28% had closed canopy, 59% had dense midstory, 6% had recent ground disturbance (e.g. tilling, recent fire), and 5% were converted to another land use.

Detection

According to our modeling results, a linear effect of date, a quadratic effect of time of survey, and the use of playback were significant predictors

of Bachman's Sparrow detection ($p<0.05$; Table 1). In early to mid-April, when the majority of our surveys were conducted, the estimated probability of detecting a sparrow was close to 1 for both passive and active sampling periods. However, as the breeding season progressed, the probability of detecting a sparrow decreased in both sampling periods, though it decreased less during the active period (Fig. 3). As for time of day, we observed peak detection rates around 0800-0900 with detection decreasing towards the early and late morning; however, the window of peak detection was wider (0700-1000) during the active sampling period. Overall, an estimated detection probability of <0.2 was observed later in the season and later in the morning for passive sampling, but detection was never <0.4 for active sampling.

Distribution

Bachman's sparrows were detected at 196 of the 929 (21%) points we surveyed, or 196 of the 1,503 (13%) of the total number of points we visited.

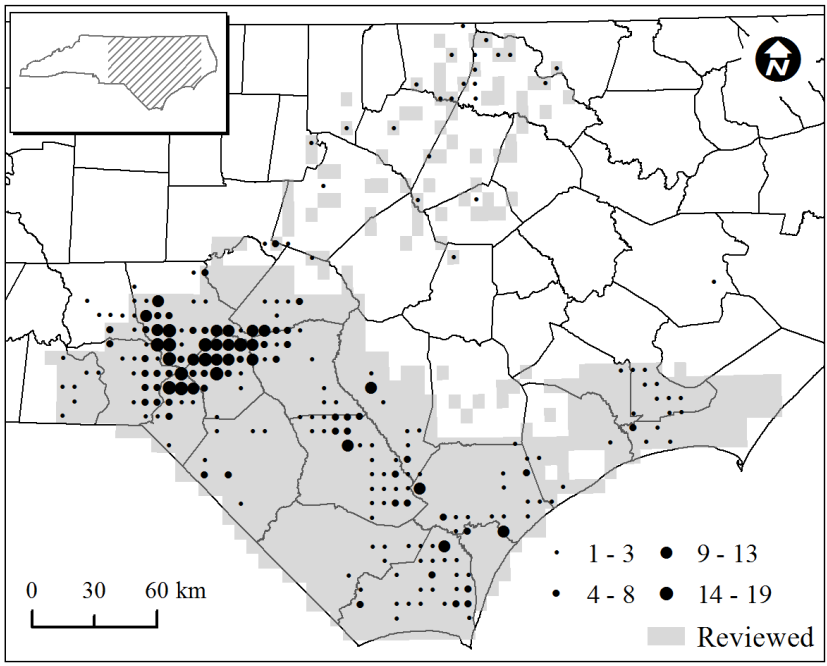

Figure 2. The shaded areas show the USGS quarter-quads for which the most recent aerial imagery was reviewed for potential habitat. If potential habitat was identified in the quarter-quad, a circle is shown in the middle of the quarter-quad to represent the number of points selected in that quarter-quad to survey for Bachman's Sparrows.

However, this naïve occupancy rate was adjusted to an estimated occupancy of 23% after accounting for imperfect detection using our model (Table 1). Only 36 of the 196 (18%) points where sparrows were detected were on private lands. Sparrows were detected mostly on and adjacent to publicly owned properties in the Sandhills and the Southern Coastal Plain that are managed for longleaf pine (Fig. 3). These two regions are separated by the Bladen Lakes area where fewer sparrows were detected despite the presence of small to moderate-sized patches of apparently suitable habitat. No sparrows were detected in the eastern Piedmont region north of the Fort Bragg Military Installation. We detected sparrows at only 9 of the 80 sites (11%) selected based on historic records. Of the 71 historic sites where sparrows were not detected, at least 24 (34%) no longer had suitable habitat (Fig. 4). At 27 of the 71 historic points, we detected a sparrow within 3 km of the historic record, but at the remaining 44 points (55%), no sparrows were detected within the estimated dispersal distance for Bachman's Sparrow (3 km; Cox and Jones 2007, Taillie et al. 2015).

Habitat

The great majority of the sparrows we detected were found in stands of open-canopy pine forest with evidence of recent fire on publicly owned properties.

Model	Variable Name	Variable Type	Mean	SE	P-value
Detection					
	Intercept		-0.41	0.31	0.18
	Date[a]	continuous	-0.85	0.18	<0.001
	Date[b]	continuous	0.16	0.17	0.33
	Time[b]	continuous	0.03	0.16	0.86
	Time^2	continuous	-0.34	0.15	0.02
	Type[c]	categorical	1.84	0.31	<0.001
Occupancy					
	Intercept		-1.18	.124	<0.001

Table 1. Parameter estimates (on logit scale), standard errors, and p-values for covariates included in our occupancy model.

[a]Date of survey
[b]Time of day
[c]Indicator variable for passive vs. active survey (passive is reference level)

Of the 293 Bachman's Sparrow observations, 278 (95%) were in mature longleaf pine woodland, 12 (4%) were found in open canopy stands of other pine species, one was detected on the edge between a clearcut and a mature longleaf stand, and two were in recently burned, young pine plantations. No sparrows were observed in fallow agricultural fields or utility rights-of-way.

At 88% of the sites we surveyed where at least one Bachman's Sparrow was detected, we observed evidence that the site was recently burned, i.e. trees were scorched, shrubs were dead, or wiregrass was flowering. The exceptions included sparrows detected in recently thinned pine woodlands, including "residential thinnings" conducted in woodlands in preparation for new home construction. An additional 11 points with sparrows had evidence of fire but it was not considered to be recent (i.e. in the last 4 years or less). Finally, over 80% of the sites where sparrows were detected were found on properties identified by the NCNHP as managed for some degree of conservation of biodiversity and ecosystem function.

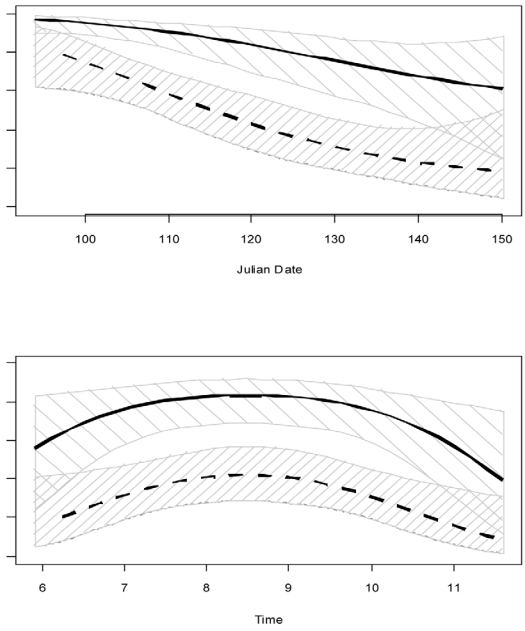

Figure 3. The predicted probability of detecting Bachman's Sparrow in North Carolina (2012-2014), shown as a function of date (a) and time of day (b), both before (dashed line) and after playback (solid line), with associated 95% CI (shaded regions)

Discussion

Bachman's Sparrows have a much narrower distribution than that suggested by the NCGAP predicted distribution, and more closely reflects the general pattern of many sensitive species associated with the longleaf pine community (Humphries and Sisson 2012, Beane et al. 2014). The Sandhills region contains the most contiguous habitat, specifically the frequently burned, open-canopy longleaf forests of Fort Bragg and Sandhills Game Land, and virtually all suitable habitat on and adjacent to these public properties was found to support sparrows. In addition, sparrows were found throughout the Southern Coastal Plain but were primarily concentrated on or near large, frequently burned properties such as Croatan National Forest, Marine Corps Base Camp Lejeune, Holly Shelter Game Land, and the Green Swamp Preserve. In these "core areas" continued efforts to maintain fire return intervals <4 yr, promote herbaceous ground cover, and restore fire-suppressed forests will help to maintain and expand extant Bachman's Sparrow populations. Similarly, more widespread use of prescribed fire as a forest management tool on

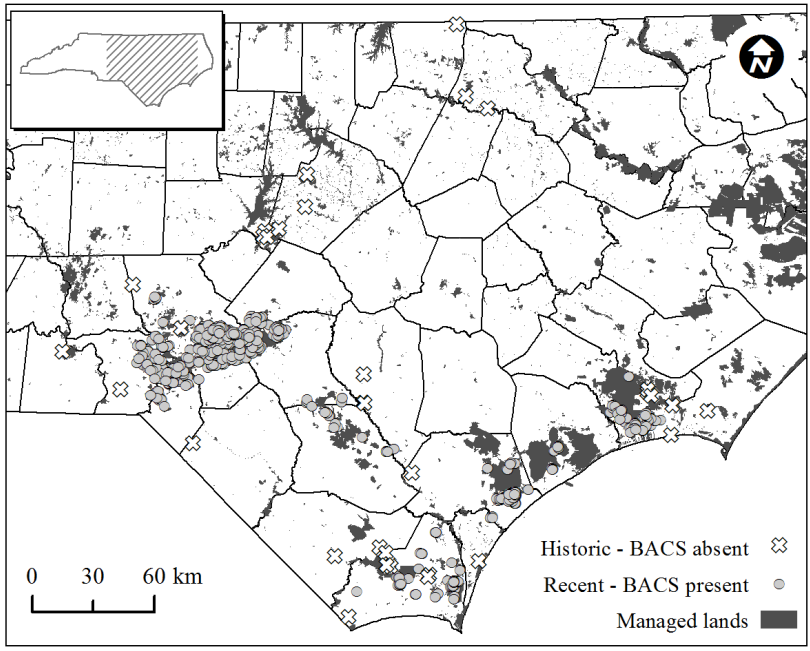

Figure 4. The distribution of recent Bachman's Sparrow observations from this study, Walters et al. (2009) and Taillie et al. (2015) as well as historical observations (prior to 2007) where sparrows were not found to persist.

adjacent private lands would likely benefit Bachman's Sparrow populations. Unfortunately, the logistics associated with burning continue to limit the extent of prescribed burning on private lands, despite various incentive programs that promote longleaf pine restoration (Alavalapti et al. 2002, Moorman et al. 2004).

Unlike in other parts of their range further south, use of secondary habitats such as clearcuts, fallow fields, and powerline rights-of-way is North Carolina. At this northeastern edge of their current range, Bachman's Sparrow productivity and survival may be more limited than at the core of their range farther south. North Carolina populations may therefore be at or below carrying capacity and without a surplus of individuals who are forced into less ideal, secondary habitats. Alternatively, timber management practices, such as site preparation, herbicide use, or tree spacing in NC may be affecting vegetation conditions in clearcuts and re-growing pine plantations. A more thorough quantification of regional differences in the vegetation conditions of clearcuts and re-growing pine plantations and their relationship to Bachman's Sparrow habitat use is needed in order to determine the mechanism behind this pattern. Though many of the recent clearcuts and fallow fields we surveyed had substantial herbaceous cover, both plant and bird species composition in these secondary habitats were different from the fire-maintained longleaf pine stands where Bachman's Sparrows were found, possibly resulting from management practices that disturb the soil such as disking and roller-chopping (Rutledge and Conner 2002). Finally, the duration of suitability of clearcuts and young pine plantations may be too short to support long-term persistence of sparrows (Watts et al. 1998). Given the extensive area of industrial timber operations across the study area, clearcuts and young pine plantations have tremendous potential to support populations of sparrows, if they are regularly thinned and managed with fire to promote abundant and diverse herbaceous vegetation (Tucker et al. 2004, Stober and Krementz 2006). Consideration of the mechanisms behind why these secondary habitats go unused is requisite to developing state-specific management goals for this species, and ultimately mitigating their decline.

The scarcity of sparrows outside the "core areas," despite the availability of apparently suitable habitat, suggests additional factors may be contributing to the decline of Bachman's Sparrows. For example, Bladen Lakes State Forest and surrounding areas supported fewer sparrows than expected, perhaps because the habitat patches in this area appear to be smaller, fragmented, and more isolated from each other relative to the "core areas." In addition to the historical sites we visited, a more recent study of Bachman's Sparrows using repeated visits confirmed our finding that few sparrows persist in the Bladen Lakes area (J. M. Winiarski, pers. comm.). Taillie et al. (2015) observed that the probability of sparrow occupancy decreased markedly when the amount of potential habitat within 3 km was less than ~500 ha. Thus, the landscape scale

distribution of habitat is likely a contributing factor to the observed patterns in habitat use.

In order to identify the mechanisms driving the observed patterns of habitat use by Bachman's Sparrows, future monitoring efforts should focus on investigating the temporal dynamics of sparrow populations in these occasionally-used, isolated sites. Ideally, these survey efforts would track individuals and occur over several consecutive years. However, for less intensive surveys, i.e. those not accounting for variable detection probability, focusing effort in the early breeding season (April – May), during the early to mid-morning, and incorporating the use of playback without a passive listening period will help to maximize detection of sparrows.

The private landowners involved with this study whose property supported Bachman's Sparrows had varying land management objectives, but many had an interest in managing their land for Northern Bobwhite (*Colinus virginianus*). As such, partnering with quail restoration efforts could be an effective strategy to promote Bachman's Sparrow habitat on private lands. Many of the private properties supporting Bachman's Sparrows in the Sandhills region are enrolled in the Safe Harbor program for Red-cockaded Woodpecker, suggesting that this program provides benefits for multiples species associated with longleaf pine. Future longleaf pine restoration efforts on private lands will need to find ways to incorporate prescribed fire while considering the management objectives and financial concerns of private landowners and industrial timber operations if functioning longleaf pine ecosystems are to be conserved outside of public lands.

Acknowledgments

This study would not have been possible without volunteers, field technicians, and individuals who helped secure permission to access survey points and collect data, including B. Beck, R. Bollinger, K. Brust, G. Coll, K. Cook, R. Elting, L. Fogo, J. Goodson, E. Gruber, N. Handle, K. Johnson, A. Lawrence, B. Massa, S. Miller, M. Nicossia, J. Schillaci, M. Sisson, N. Shepherd, B. Strope, and M. Wallgren. In addition, we would like to thank The Nature Conservancy, Fort Bragg Military Installation, and the many private landowners that granted us permission to conduct surveys on their land, A. Fish and J. Winiarski from North Carolina State University for providing supplementary observation data of Bachman's Sparrows, and J. A. Cox and D. B. McNair for providing additional expertise and historical context. Finally, we thank D. B. McNair for several reviews of the manuscript. This study was initiated and coordinated by the NC Wildlife Resources Commission and funding was provided by State Wildlife Grants, Federal Aid in Wildlife Restoration, and the North Carolina Non-Game and Endangered Species fund.

Literature Cited

Alavalapati, J. R. R., G. A. Stainback, and D. R. Carter. 2002. Restoration of the longleaf pine ecosystem on private lands in the US South: an ecological economic analysis. Ecological Economics 40:411–419.

Beane, J. C., S. P. Graham, T. J. Thorp, and L. T. Pusser. 2014. Natural history of the Southern Hognose Snake (*Heterodon simus*) in North Carolina, USA. Copeia 1:168–175.

Dunning, J. B. 2006. Bachman's Sparrow (*Peucaea aestivalis*). Birds of North America Online. (A. Poole, Ed.) Ithaca: Cornell Laboratory of Ornithology; Retrieved from The Birds of North America Online database: http://bna.birds.cornell.edu/ [Online.] Available at http://bna.birds.cornell.edu/bna/species/038.

Dunning, J. B., R. Borgella, K. Clements, and G. K. Meffe. 1995. Patch isolation, corridor effects, and colonization by a resident sparrow in a managed pine woodland. Conservation Biology 9:542–550.

Dunning, J. B., and B. D. Watts. 1990. Regional differences in habitat occupancy by Bachman's Sparrow. Auk 107:463–472.

Fiske, I. J., and R. B. Chandler. 2011. Unmarked: An R Package for fitting hierarchical models of wildlife occurrence and abundance. Journal of Statistical Software 43:1–23.

Gerwin, J. A., D. H. Allen, W. Golder III, M. E. Johns, H. E. LeGrand Jr., T. R. Simmons, and C. Smalling. 2011. Reevaluation of status listings for jeopardized birds in North Carolina. Report of the Scientific Council on Birds. North Carolina Wildlife Resources Commission.

Haggerty, T. M. 1988. Aspects of the breeding biology and productivity of Bachman's Sparrow in central Arkansas. Wilson Bulletin 100:247–255.

Haggerty, T. M. 1998. Vegetation structure of Bachman's Sparrow breeding habitat and its relationship to home range. Journal of Field Ornithology 69:45–50.

Humphries, W. J., and M. A. Sisson. 2012. Long distance migrations, landscape use, and vulnerability to prescribed fire of the Gopher Frog (*Lithobates capito*). Journal of Herpetology 46:665–670.

Jones, C. D., J. A. Cox, E. Toriani-Moura, and R. J. Cooper. 2013. Nest-site characteristics of Bachman's Sparrows and their relationship to plant succession following prescribed burns. Wilson Journal of Ornithology 125:293–300.

LeGrand, H. E. Jr. 2013. Bachman's Sparrow. [Online] Available at https://www.carolinabirdclub.org/ncbirds/accounts.php

Oswalt, C. M., J. A. Cooper, D. G. Brockway, H. W. Brooks, J. L. Walker, K. F. Connor, S. N. Oswalt, and R. C. Connor. 2012. History and current condition of longleaf pine in the southern United States. In USDA Forest Service GTR-SRS-166. Asheville, NC.

R Development Core Team. 2014. R: A Language and Environment for Statistical Computing. [Online.] Available at http://www.r-project.org.

Rutledge, B. T., and L. M. Conner. 2002. Potential effects of groundcover restoration on breeding bird communities in longleaf pine stands. Wildlife Society Bulletin 30:354–360.

Sauer, J. R., J. E. Hines, J. Fallon, K. L. Pardieck, D. J. Ziolkowski, and W. A. Link. 2012. The North American Breeding Bird Survey, results and analysis 1966 - 2011.

Shriver, W. G., P. D. Vickery, and D. W. Perkins. 1999. The effects of summer burns on breeding Florida Grasshopper and Bachman's Sparrows. Studies in Avian Biology 19:144–148.

Stober, J. M., and D. G. Krementz. 2006. Variation in Bachman's Sparrow home-range size at the Savannah River Site , South Carolina. The Wilson Journal of Ornithology 118:138–144.

Sullivan, B. L., C. L. Wood, M. J. Iliff, R. E. Bonney, D. Fink, S. Kelling. 2009. eBird: A citizen-based bird observation network in the biological sciences. Biological Conservation 142:2282-2292.

Taillie, P. J., C. E. Moorman, and M. N. Peterson. 2015. The relative importance of multi-scale factors on the distribution of Bachman's Sparrow and the implications for ecosystem conservation. Condor: Ornithological Applications.

Tucker, J. W., D. W. Robinson, and J. B. Grand. 2004. Influence of fire on Bachman's Sparrow, an endemic North American songbird. Journal of Wildlife Management 68:1114–1123.

Walters, J. 2009. Point Count Data. Defense Coastal/Estuarine Research Program: Monitoring and Research Data Information System [Database]. Jacksonville, NC. https://dcerp.rti.org/

Watts, B. D., M. D. Wilson, D. S. Bradshaw, and A. S. Allen. 1998. A survey of the Bachman's Sparrow in southeastern Virginia. The Raven 69(1):9-14