ABSTRACT

FISH, ALEXANDER CHRISTOPHER. Effects of Ground-based Military Training on Bachman's Sparrow (*Peucaea aestivalis*) Breeding Ecology. (Under the direction of Christopher E. Moorman and Christopher S. DePerno).

Extent of the longleaf pine (*Pinus palustris*) ecosystem has declined by over 95%, primarily due to fire suppression and conversion to other forest or landcover types. Wildlife species associated with this ecosystem have undergone similar declines, and many species have been listed as threatened or of conservation concern. One example is the Bachman's sparrow (*Peucaea aestivalis*), which forages and nests in the rich herbaceous layer of fire-maintained longleaf pine forests and has experienced a continuous north to south range retraction and a population decline of 3% per year since the 1960s. Military installations across the southeastern United States harbor some of the highest quality longleaf pine communities, and therefore are critical to conservation of Bachman's sparrow. However, excessive military disturbance may cause individual birds to flush and relocate, abandon breeding sites, experience increased nest failure, or fledge fewer young. And, ground-based disturbances are of particular concern for ground-nesting birds such as Bachman's sparrow because of greater nest vulnerability. Our objectives were to: 1) determine the effect of ground-based military training on Bachman's sparrow breeding ecology; and 2) quantify micro-scale habitat selection of Bachman's sparrows on Fort Bragg Military Installation in the Sandhills region of North Carolina. Our results indicated that ground-based military training does not affect breeding biology of Bachman's sparrows (e.g., nest success, seasonal productivity metrics, or abundance). We documented one nest trampled by ground troop activity, but it was successful, and the majority (95%) of nest failure was caused by predation. Bachman's sparrows at Fort Bragg selected for habitat characteristics (e.g., areas

recently burned, with dense grass cover, and low woody shrubs) similar to other populations but also selected breeding sites with accessibility to fallow wildlife openings, characterized by denser woody cover used presumably for predator avoidance. Ground-based military training and conservation of Bachman's sparrow are not in conflict at the training intensities we studied on Fort Bragg. Moreover, the high fecundity we observed for the Fort Bragg Bachman's sparrow population should mitigate any minor nest loss from military training activities.

Effects of Ground-based Military Training on Bachman's Sparrow (*Peucaea aestivalis*) Breeding Ecology

by
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DEDICATION

To my grandmother, Audrey Kondrak, for fostering a love of science through thoughtful discussions and an inquisitive mind. I am indebted.

BIOGRAPHY

Born and raised in Minnesota, Alexander developed a deep seated love of the natural world early in his childhood. His parents kept the family busy with camping, hiking, canoeing, biking, hunting, and fishing trips. Alexander became infatuated with wildlife, whether watching PBS Nova, the backyard bird feeders, or walking trails in search of ruffed grouse. These experiences lead him to complete his Bachelors of Science degree in Fisheries, Wildlife, and Conservation Biology at the University of Minnesota in 2009. Afterword, Alexander spent three and one-half years traveling the United States, working as a wildlife research technician in Minnesota, Idaho, New Mexico, Tennessee, Kentucky, Arkansas and Alabama. In September 2013 he began his graduate studies in Fisheries, Wildlife, and Conservation Biology at North Carolina State University.

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CHAPTER 1

INFLUENCE OF MILITARY TRAINING ACTIVITY ON BREEDING ECOLOGY OF A GROUND-NESTING SPARROW

ABSTRACT

Anthropogenic disturbance may cause birds to flush and relocate, abandon breeding sites, experience increased nest failure, or fledge fewer young. Ground-based military activities are of particularly concern for ground-nesting birds, because of the increased risk of nest destruction and trampling of vegetation. Hence, we investigated how disturbance from ground-based military training affected reproductive ecology of Bachman's sparrow (*Peucaea aestivalis*) from 2014-2016, on Fort Bragg Military Installation, North Carolina. We designated two training intensity regimes and monitored sparrows at six observation areas, three in high intensity training areas and three in low intensity training areas. We compared seasonal productivity metrics and daily nest survival between training areas. Additionally, we compared male sparrow abundance and micro-habitat use between high and low intensity training areas. We monitored 60 male territories in each of the military training regimes and located 110 nests opportunistically and by tracking telemetered female sparrows. We used fixed-radius point counts to estimate relative abundance in each observation area, and measured vegetation composition and structure at a subset of 10 locations in each male territory. Daily nest survival, seasonal productivity metrics, relative abundance, and vegetation composition and structure at male locations did not differ between areas with high and low intensity military training activity. In 2015, one sparrow nest was trampled by military personnel, but at least one nestling force-fledged and the nest was considered successful. Our study showed that Bachman's sparrows appeared well-adapted to disturbance from military training, which indicates ground-based training on other military bases should have similarly limited effects on ground-nesting bird species.

KEYWORDS: Bachman's sparrow, ground disturbance, habitat selection, longleaf pine, nest survival, *Peucaea aestivalis,* prescribed fire

INTRODUCTION

Anthropogenic disturbance directly and indirectly affects birds, possibly reducing individual fitness. In areas with frequent pedestrian traffic, birds spend more time alert (Van de Voorde et al. 2015) and reduce time allocated to foraging (Bélanger and Bédard 1990), which can result in a net loss of energy (Bélanger and Bédard 1990). To conserve energy and prevent flushing, birds may shift activity centers away from disturbed areas (Thiel et al. 2008). However, shifting movement may not be feasible for birds with small home ranges or during the breeding season when nests or juvenile offspring restrict movement.

Ground-nesting birds are particularly vulnerable to ground-based disturbance. For example, nests may be trampled by pedestrians, off-road vehicles (Buick and Paton 1989), or cattle (32-98%: Pakanen et al. 2011, Perlut and Strong 2011, Sharp et al. 2015). In fact, increased levels of nest failure from trampling may be responsible for population declines of some ground-nesting birds (Rolek et al. 2016). Additionally, ground disturbance near nests can force incubating females to temporarily leave the nest (Sabine et al. 2006, Borneman et al. 2016). Predators key on incubating females as they flush from human disturbance, which leads to greater depredation rates (Hillman et al. 2015, Borneman et al. 2016, Stien and Ims 2016).

Military lands are managed primarily for training purposes, but conservation of natural resources is a critical objective. Balancing the needs of military training and biodiversity conservation may lead to conflicting management objectives. Birds that flush from low-flying aircraft expend excess energy (Conomy et al. 1998a, Conomy et al. 1998b). Additionally, birds may respond to aircraft by allocating greater proportion of time to alert behaviors (Goudie and Jones 2004). These alert or defensive behaviors have been shown to increase following artillery firing (Delaney et al. 2011) and ground-based training exercises (Barron et al. 2012). However, linking long-term effects of behavioral changes from military training to reproductive effects has received relatively little investigation.

The influence of military activity is of particular concern for a ground-nesting species like Bachman's sparrow (*Peucaea aestivalis*). Bachman's sparrow has experienced long-term population declines (Sauer et al. 2014), and the species is closely associated with the endangered fire-maintained longleaf pine (*Pinus palustris*) ecosystem (Dunning and Watts 1990, Plentovich et al. 1998, Tucker et al. 1998), common on military bases in the southeastern United States. Ground-based military training may destroy sparrow nests, reduce vegetation cover near nests, or cause breeding sparrows to disperse to avoid training exercises. Bachman's sparrows forage (Allaire and Fisher 1975) and nest (Haggerty 1995, Jones et al. 2013) in the dense herbaceous layer that develops immediately following prescribed fire, and ground-based military training commonly occurs in these same fire-maintained forests.

Our objective was to determine the effects of frequent ground-based disturbance, generated by military foot travel and off-road vehicle use, on Bachman's sparrow breeding ecology. We monitored sparrows at six observation areas, three in high intensity training areas (HIT) and three in low intensities training areas (LIT). Using marked sparrows, we were able to evaluate the effects of military training activity on: 1) pairing success, fledging success, and territory abandonment; 2) nest survival; 3) abundance of breeding males; and 4) habitat use of male Bachman's sparrows during the breeding season.

STUDY AREA

Fort Bragg Military Installation (Fort Bragg hereafter) is a 73,469-ha property owned and managed by the U.S. Department of Defense. Located in the Sandhills physiographic region of North Carolina, Fort Bragg lies in the longleaf pine ecosystem and is characterized by rolling hills with open canopy longleaf pine in the uplands interspersed with lowland drainages. Longleaf pine uplands on Fort Bragg primarily were managed with a growing-season prescribed fire application once every three years (Cantrell et al. 1993). However, some sections of Fort Bragg were managed with dormant-season prescribed fire due to logistical constraints. Lowland forests had saturated soils that suppressed prescribed fire, were densely vegetated, and were dominated by a mixed broadleaf-pine plant community (Just et al. 2015).

Fort Bragg employed approximately 56,000 army personnel who conducted year round training exercises, including tactical maneuvers, live-fire exercises, and paratrooper drops. We conducted our study in six observation areas (Figure 1), three in HIT areas ($\bar{x}$ = 770 ha, SE = 122 ha) and three in LIT areas ($\bar{x}$ = 776 ha, SE = 251 ha). HIT areas were characterized by presence of permanent upland orienteering training courses and received frequent foot traffic (once every 1-3 days) by ground troops. LIT areas had no permanent training feature to concentrate troop activities and were characterized by infrequent foot traffic (typically < 1 training event per month) in upland areas. Observation of troop activity supported our classification; we observed ground troops and off-road vehicles more often in HIT compared to LIT areas, and subsequently, vegetation was trampled in HIT areas more often than LIT areas. We primarily observed small groups (<10) or individual troops in the observation areas, but occasionally large (>30 troops) training activities were observed (A. Fish, North Carolina State University, personal communication). Troop activity was primarily during daylight hours but also occurred overnight. Management activities, including prescribed burning, were similar between HIT and LIT areas, with >97% of marked males occupying forest stands ≤2 years post burn.

METHODS

Data Collection

We captured Bachman's sparrows early in the breeding season (April 2014-2016), by target netting singing males and flushing birds into mist nests (Jones and Cox 2007). We determined sex by examination of the cloaca and presence of a brood patch (Pyle 1997). We attached a federal aluminum band and a unique set of three color bands to all captured birds. We were unable to capture some males and monitored them as unmarked individuals. Additionally, we attached a backpack style 0.55-g radio transmitter to a small number of females (Blackburn Custom Transmitters, Nacogdoches, Texas, U.S.A.). We attached transmitters using a thigh mounted figure-8 harness system (Rappole and Tipton 1991) or a modified weak-link harness system (Kesler et al. 2011).

We monitored male territories between one-half hour before sunrise and the first five hours of daylight from April-July. We observed each territory for one hour, recording sparrow activity and any behaviors associated with nesting (Vickery et al. 1992b). We collected three seasonal productivity metrics (e.g., paring success, fledging success, and territory abandonment) based on the Vickery Reproductive Index monitoring protocols (Vickery et al. 1992a, Vickery et al. 1992b, Tucker et al. 2006). We defined a male as paired if a female was present for greater than four weeks, a territory that fledged young by observing adults feeding young, and territory abandonment by failing to detect the territorial pair for greater than four weeks (Vickery et al. 1992a, Tucker et al. 2006). We recorded all male locations using a Global Position System.

We located nests opportunistically and using radio telemetry (Figure 2). We tracked females with radio transmitters two to four times per week throughout the breeding season (April-July). Using the homing method (Small et al. 2005), we visually confirmed incubation status of each female to locate nests. We flagged nests 10-30 meters away and monitored two to four times a week until success or failure (Martin and Geupel 1993). We classified nests as successful only when fledglings were detected near the nest, or when adults were observed feeding young.

We estimated breeding Bachman's sparrow male abundance in each of the observation areas. We randomly generated 10 point count locations in each observation area using ArcMAP (Environmental Systems Research Institute, Inc., Redlands, CA). All point count locations were in mature longleaf pine uplands and greater than 250 meters apart. We visited each point three times between 21 April and 4 July 2014-2016, using a single observer each year. We surveyed points between one-half hour before sunrise and the first five hours of daylight. Each survey was eight minutes long with four minutes of passive observation followed by four minutes of periodic playback (McNeil et al. 2014, Taillie et al. 2015). Only males detected within 100 meters of the point count center were recorded and included in the analysis.

We compared habitat use of breeding males between HIT and LIT areas to asses if male sparrows in HIT areas used sites with different vegetation characteristics than LIT males. We measured vegetation composition and structure at a subset of ≤10 locations for each marked male. We measured vegetation at every meter along two perpendicular 10-m transects centered on the male location. We recorded all grass and shrub contacts (hits hereafter) along a 2-m tall, 2.54-cm diameter Wiens pole (Wiens 1974). We classified all perennial woody stems as a shrub, including tree regeneration. We quantified three vegetation metrics (grass cover, shrub cover, and shrub height) for their influence on Bachman's sparrow habitat selection (Brooks and Stouffer 2010, Taillie et al. 2015, Winiarski 2016). We obtained grass and shrub percent cover estimates by calculating the proportion of Wiens poles with ≥1 grass or shrub hit at each male survey location. Shrub height was measured by recording the tallest shrub hit to the nearest dm on each Wiens pole, and averaged for each survey plot.

Statistical Analyses

We used seasonal productivity metrics gathered during territory monitoring to calculate the proportion of males that successfully paired, fledged young, or abandoned territories. We compared proportions between HIT and LIT training areas using a Chi-squared test.

We compared daily nest survival between HIT and LIT training areas using the Nesting Model (Dinsmore and Dinsmore 2007) in Program MARK (White and Burnham 1999), and the individual nest was the experimental unit. We created four *a priori* models to test the influence of training intensity and year as possible predictors of nest success.

Vegetation structure and composition do not influence Bachman's sparrow nest survival on Fort Bragg, so we did not include these factors in the analysis (Winiarski et al. in press). We used Akaike Information Criterion corrected for small sample size (AIC_c hereafter) to rank model fit, and chose the model with the lowest AIC_c score as most parsimonious (Burham and Anderson 2002). We considered models competitive if they differed by <2 AIC_c units for every additional one parameter of the top model, ignoring models with non-informative parameters (Arnold 2010).

We used N-mixture modeling in program Unmarked to generate Bachman's sparrow abundance estimates following a Poisson distribution, and included a year effect on detection (Fiske and Chandler 2011). We created a state covariate to account for HIT and LIT areas, which allowed for easy generation and comparison of abundance between HIT and LIT training areas.

We created generalized linear mixed effect models using the lme4 package (Bates et al. 2015) in Program R (R Version 3.2.2, www.r-project.org, accessed 29 January 2016) to compare micro-habitat use between HIT and LIT areas. We used 10 randomly selected locations for each male, but when an individual had been re-sighted less than 10 times we used fewer locations. We created a random effect in the model to account for variation among individual territories. We ran three models, each with a single response variable (grass cover, shrub cover, and shrub height), and compared parameter estimates between HIT and LIT areas. We set alpha at 0.05 for all analyses.

RESULTS

We captured and marked 46 males in HIT and 42 males in LIT areas from 2014-2016 (Table 1). We monitored an additional eight unmarked males in HIT and 10 in LIT sites. We captured and attached radio transmitters to 19 females in HIT and 18 in LIT areas.

We monitored and scored 52 territories in HIT and 54 territories in LIT areas (Table 2). We censored 14 males, as territories were burned during prescribed fire application and males were not located post burn (Table 2). We were unable to re-locate most males between breeding seasons but monitored 11 males for two breeding seasons and two males for three seasons.

Approximately 25% of male Bachman's sparrows abandoned territories during the study (Table 3). Abandonment rates were similar between HIT and LIT training areas ($\chi^2 < 0.001$, df = 1, p = 1.0; Table 3) and among years. Territory abandonment primarily occurred early in the breeding season (April-May; n = 20), but continued throughout the breeding season (June-August; n = 6), and even after successfully fledgling young (n = 4). In 2015, only one territory abandonment was linked with a military training event, during which a large portion of the understory vegetation was trampled. Males paired with females ($\chi^2 < 0.001$, df = 1, p = 1.0) and successfully fledged young ($\chi^2 < 0.001$, df = 1, p = 1.0) similarly between HIT and LIT areas (Table 3).

We located 60 nests in HIT and 50 nests in LIT areas, with 27 and 21 located with radio-telemetry, respectively. Daily nest survival rates were similar between LIT ($\bar{x} = 0.942$, SE = 0.011, n = 50) and HIT ($\bar{x} = 0.947$, SE = 0.009, n = 60) areas, but survival varied by year (Table 4). Nest failure (61) primarily was caused by depredation (58), but additional causes included prescribed fire (1), female depredation (1), and abandonment (1). During the

2015 breeding season, one nest was trampled by military personnel, but at least one nestling force-fledged. We considered the nest as successful, because we observed a juvenile with marked adults after nest destruction. Additionally in 2016, one nest was located within 5-10 m of a large military training event, with substantial vegetation trampling from Humvees and ground troops. The female continued to incubate the nest, which successfully hatched before being depredated in the nestling stage by an unknown predator.

Abundance of male sparrows was similar between HIT and LIT training areas ($p = 0.24$, $\beta = 0.11$). After back-transforming parameter estimates, we generated abundance estimates of 0.16 (95% CI: 0.15, 0.18) and 0.15 (95% CI: 0.13, 0.18) males per ha in HIT and LIT areas, respectively.

Male Bachman's sparrows used micro-habitat similarly in HIT and LIT areas. Grass cover ($p = 0.92$; $\beta = 0.30$), shrub cover ($p = 0.85$; $\beta = 0.70$), and shrub height ($p = 0.87$; $\beta = -0.04$) at male locations were similar between HIT and LIT areas.

DISCUSSION

Ground-based military training on Fort Bragg did not affect Bachman's sparrow reproductive ecology at current training intensities. In fact, a radio marked female successfully hatched a nest in 2016 after substantial vegetation trampling 5-10 m from the nest site, indicating tolerance to disturbance as long as the nest bowl is not disturbed. Similarly, other species of ground-nesting birds do not exhibit decreased nest survival in response to disturbance (Johnson et al. 2012, Bleho et al. 2014, and Lowe et al. 2014), and some ground-dwelling birds can tolerate low levels of human disturbance without incurring fitness costs (Gill et al. 2001). However, we documented one territory abandonment following a ground-based disturbance event in 2015 when ground vegetation was trampled in >50% of the territory. Although it certainly exceeds the training intensity we observed on Fort Bragg, a ground disturbance threshold likely exists beyond which breeding Bachman's sparrows are unable to successfully reproduce.

The drop zones and artillery firing points, where the majority of multi-day field camps and bivouac training sites were constructed on Fort Bragg, were characterized by bare ground and sparse understory vegetation that is not habitat for Bachman's sparrow. Hence, the most impactful training activities on Fort Bragg generally were situated away from breeding Bachman's sparrows. Bachman's sparrows are unambiguously associated with upland pine forest on Fort Bragg, using the dense herbaceous groundcover for nesting and foraging (Allaire and Fisher 1975, Haggerty 1995, Jones et al. 2013). Ground training in upland forested areas consisted of individual or small groups of troops (<10) traversing through Bachman's sparrow territories for short durations (<1 hour) and did not influence Bachman's sparrow habitat use.

Bachman's sparrows are adapted to frequent fire, which may make them better adapted to the low intensity training activities characteristic in the forests on Fort Bragg and other similar military installations. Growing-season prescribed fire application coincides with the peak of the Bachman's sparrow nesting season, yet few nests are destroyed by prescribed fire (Tucker et al. 2006, Winiarski et al. in press). On our study site, only one of 110 (<1%) nests was destroyed by fire and similarly only one (<1%) nest was trampled by ground troops, albeit still successful. Bachman's sparrows exhibit high rates of naturally occurring nest failure, yet individuals readily re-nest and produce multiple nesting attempts throughout the breeding season (Haggerty 1988, Stober and Kremnetz 2000). Moreover, Bachman's sparrows commonly produce multiple broods within a single breeding season (Haggerty 1988, Stober and Kremnetz 2000, Tucker et al. 2006), with as many as three possible under ideal conditions (Stober and Krementz 2000). Bachman's sparrow adaptation to high nest failure rates suggests sparrows could compensate for minimal military caused nest failure by readily re-nesting.

Our study builds on previous research that suggests military training activities have limited influence on the demography of breeding birds. Nest survival was not affected by military training for shrub-nesting northern cardinals (*Cardinalis cardinalis*; Barron et al. 2012) or cavity-nesting red-cockaded woodpeckers (*Picoides borealis*; Delany et al. 2011, Doresky et al. 2001). Similarly, white-eyed vireos (*Vireo griseus*) exposed to ground-based disturbance maintained normal breeding activities and resource provisioning to young (Bisson et al. 2009). However, if juvenile birds receive lower quality or quantity of food during the nestling life stage, carryover effects from diminished body condition or delayed wing development can increase post-fledging juvenile mortality (Jones et al. in press). We observed one case of nestlings force-fledging to avoid being trampled, and the post-fledging survival of those individuals remains unknown.

Future research needs to focus on a broader array of military installations and assemblage of species. The variability of training exercises among military bases, and the diversity of species occupying these bases, may limit the applicability of our study across all military bases and species, yet we expect a similar breeding bird response under similar ground-based training exercises. We recommend future investigation into whether there is a disturbance threshold where vegetation trampling from training activity causes territory abandonment for Bachman's sparrows and other bird species of concern.

MANAGEMENT IMPLICATIONS

Military installations provide critical habitat for Bachman's sparrows and other longleaf pine affiliated wildlife species. Although there is potential for biodiversity conservation and military training to conflict, breeding Bachman's sparrows do not experience fitness costs in response to ground-based training activity. Breeding sparrows may alter behavior (e.g., flushing from troops), but if these behavioral changes do not result in fitness costs, they are of limited conservation concern. However, other species of wildlife (e.g., gopher tortoise [*Gopherus polyphemus*]) and plants (e.g., Venus flytrap [*Dionaea muscipula*]) may be more susceptible to ground-based training, as they lack the mobility of Bachman's sparrows. Nevertheless, the sporadic and short-term nature of ground-based training activities likely limits prolonged exposure. And, under the levels of military activity we studied in the upland forests of Fort Bragg, ground-nesting birds are unlikely to be negatively affected by ground-based training.

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Table 1. Number of marked and unmarked Bachman's sparrow males monitored on Fort Bragg Military Installation, North Carolina (2014-2016) in High Intensity Training (HIT) and Low Intensity Training (LIT) areas.

		HIT	LIT
2014			
	Male - New Capture	20	19
	Male - Previous Capture	0	0
	Male - Unmarked	0	1
	Female - Radio Marked	7	5
	Total	**27**	**25**
2015			
	Male - New Capture	13	9
	Male - Previous Capture	3	7
	Male - Unmarked	4	4
	Female - Radio Marked	7	8
	Total	**27**	**28**
2016			
	Male - New Capture	13	14
	Male - Previous Capture	3	1
	Male - Unmarked	4	5
	Female - Radio Marked	5	5
	Total	**25**	**25**

Table 2. Number of male Bachman's sparrow breeding territories monitored and censored on Fort Bragg Military Installation, North Carolina (2014-2016) in High Intensity Training (HIT) and Low Intensity Training (LIT) areas. We censored territories from analysis when burned by prescribed fire and males were not re-located.

	Year	HIT	LIT
Males Monitored			
	2014	16	19
	2015	17	15
	2016	19	20
	Total	**52**	**54**
Males Censored			
	2014	4	1
	2015	3	5
	2016	1	0
	Total	**8**	**6**

Table 3. The proportion of male Bachman's sparrows that abandoned territories, paired with females, or fledged young in High Intensity Training (HIT) and Low Intensity Training (LIT) areas at Fort Bragg Military Installation, North Carolina (2014-2016).

		HIT (n)	LIT (n)	χ^2 Statistic	p-value
Abandonment	**2014**	0.25 (16)	0.32 (19)		
	2015	0.18 (17)	0.13 (15)		
	2016	0.42 (19)	0.35 (20)		
	TOTAL	**0.29 (52)**	**0.28 (54)**	<0.001	**1.00**
Pairing	**2014**	0.88 (16)	0.78 (19)		
	2015	0.82 (17)	0.80 (15)		
	2016	0.58 (19)	0.70 (20)		
	TOTAL	**0.75 (52)**	**0.76 (54)**	<0.001	**1.00**
Fledge Young	**2014**	0.44 (16)	0.53 (19)		
	2015	0.65 (17)	0.53 (15)		
	2016	0.47 (19)	0.55 (20)		
	TOTAL	**0.52 (52)**	**0.54 (54)**	<0.001	**1.00**

Table 4. Daily nest survival models for Bachman's sparrow at Fort Bragg Military Installation, North Carolina (2014-2016).

Model S()	**K**	**AIC$_c$**	**AIC$_c$**	**AIC$_c$ Weight**
year	3	337.06	0	0.61
null	1	338.84	1.78	0.25
training	2	340.68	3.62	0.1
year + training	6	342.63	5.57	0.04

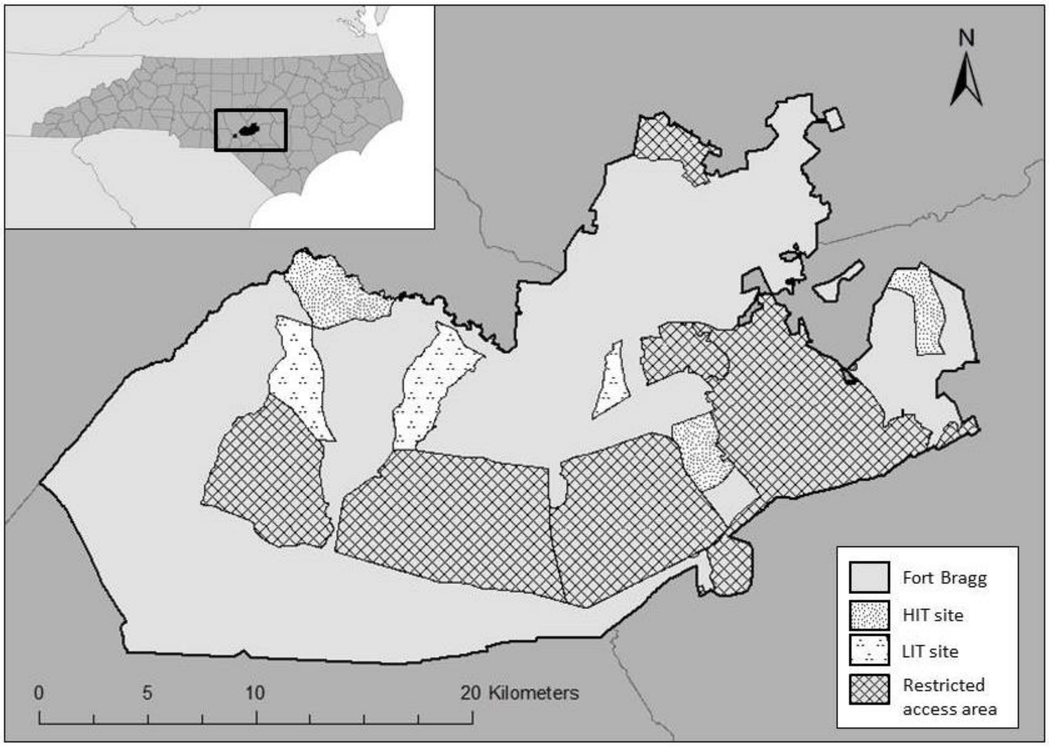

Figure 1. Location of Fort Bragg Military Installation in south central North Carolina. We conducted territory monitoring in 2014-2016 at three sites designated high-intensity training (HIT) and three designated low-intensity training (LIT).

Figure 2. Causes of Bachman's sparrow nest failure on Fort Bragg Military Installation, North Carolina (2014-2016). Intact nest (A), trampled nest (B), nest burned during prescribed fire (C), abandoned nest (D).

CHAPTER 2

MICRO-SCALE PREDICTORS OF BACHMAN'S SPARROW OCCUPANCY AT ITS NORTHERN RANGE LIMIT

ABSTRACT

Bachman's sparrow (*Peucaea aestivalis*), a songbird endemic to the southeastern United States, has experienced long term population declines and a northern range boundary retraction. Habitat loss and degradation 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, characterized by extensive fire-maintained longleaf pine (*Pinus palustris*) uplands. We surveyed breeding male sparrows using repeat visit point counts. We visited 182 points three times from April – July, during the 2014 and 2015 breeding seasons. We measured vegetation and distance to other habitat features (e.g., wildlife opening and stream) 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 woody shrub height. Predictors of Bachman's sparrow occupancy were similar to other portions of the range, supporting the importance of frequent prescribed fire to maintain herbaceous ground cover used by birds for nesting and foraging. However, our study more uniquely indicated that other habitat features (e.g., canopy openings) provide critical escape cover in areas of extensive upland longleaf pine forest.

KEYWORDS: Bachman's sparrow, hierarchical modeling, longleaf pine, North Carolina, *Peucaea aestivalis*, prescribed fire, wildlife opening, wiregrass

INTRODUCTION

Bachman's sparrow (*Peucaea aestivalis*), an endemic songbird of the southeastern United States, inhabits open pine (*Pinus* spp.) forests managed with frequent prescribed fire. Bachman's sparrows select areas burned in the previous three years (Dunning and Watts 1990, Plentovich et al 1998, Tucker et al. 1998) and abandon sites greater than five years post fire (Engstrom et al. 1984, Tucker et al. 2004). Most Bachman's sparrow populations are closely associated with longleaf pine (*Pinus palustris*) forests, but the species occurs in the understory of other pine forest types (Haggerty 1988) and less commonly in early successional communities (Krementz and Christie 1999).

The longleaf pine ecosystem has declined by 95-98% from its historic range and is considered one of the most endangered ecosystems in the world (Noss 1995, Outcalt and Sheffield 1996, Van Lear 2005). The significant loss of longleaf pine has caused concomitant and long-term Bachman's sparrow population decline (USGS 2013). Hence, Bachman's sparrow is listed as a species of concern across its range (Mitchell 1998).
In the early twentieth century, Bachman's sparrow had a much larger range, with breeding records in Indiana, Ohio, Pennsylvania, Virginia, and West Virginia (Brooks 1938). These northern populations were associated with agricultural fields, abandoned pastures, and regenerating clearcut forests (Brooks 1938). However, Bachman's sparrow populations on the northern range extent have disappeared in recent decades, including some populations in North Carolina, which now represents the northern extent of eastern populations (CCB 2010).

It is believed that loss and degradation of habitat is likely the primary driver of these local population extinctions. In southern portions of Bachman's sparrow range, individuals occupy open pine forests with extensive herbaceous cover, low basal area, and sparse woody shrubs maintained with frequent prescribed fire (Dunning and Watts 1990, Dunning and Watts 1991, Haggerty 1998, Cox and Widener 2008). Suppression of fire decreases herbaceous groundcover and increases the height and establishment of woody shrubs, leading to loss of herbaceous vegetation for Bachman's sparrow (Engstrom et al. 1984, Richardson and Williamson 1988, Fill et al. 2012, Nippert et al. 2013, Hmielowski et al. 2014, Addington et al. 2015). Similarly, high basal area from dense tree stocking decreases the amount of sunlight reaching the forest floor, thereby suppressing the growth of herbaceous ground cover required by sparrows (Darracq et al 2016).

However, less is known about habitat selection at the northern extent of the Bachman's sparrow range, where micro-habitat conditions alone may not predict occupancy (Taillie et al. 2015). 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 sparrow occupancy at its northern range extent in a landscape intensively managed with prescribed fire. Using an occupancy analysis, we evaluated the importance of vegetation characteristics, fire history, and habitat features to identify specific mechanisms driving Bachman's sparrow occupancy.

STUDY AREA

Fort Bragg Military Installation (hereafter Fort Bragg) is located in the Sandhills physiographic region of central North Carolina. Fort Bragg consists of approximately 621 km^2 contained within the longleaf pine-wiregrass (*Aristida stricta*) ecosystem. Fort Bragg is one of the largest continuous tracts of intact longleaf pine forest in North Carolina (Sorrie et al. 2006). Longleaf pine uplands on Fort Bragg primarily were managed with an early, growing-season prescribed fire application once every three years (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 woody shrubs, small trees, and leaf litter (Harper et al. 1997, Shriver and Vickery 2001).

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 meters between points to maintain sampling independence (Ralph et al. 1993). We visited each point count location three times between 21 April – 29 June 2014 and 28 April – 15 July 2015, to coincide with peak Bachman's sparrow breeding activity. We visited point count locations from one-half hour before sunrise to five hours after sunrise (Rimmer et al. 1996).

Point counts for Bachman's sparrow consisted of an 8-minute survey period with 4-minutes of passive observation followed by a 4-minute playback period. We used an Eco Extreme (Grace Digital, San Diego, CA, USA) waterproof speaker to broadcast playback recording. The 4-minute playback period recording consisted of periodic singing, secondary calls, and chip notes of Bachman's sparrow. 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 three weeks, with longer return intervals when presence of military troops reduced accessibility.

We collected vegetation data immediately following point counts surveys. We recorded vegetation contacts (hits hereafter) on each dm interval of a 2.54-cm diameter and 2-m tall Wiens pole (Wiens 1974). Vegetation was classified as grass, woody shrubs (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. Additionally, we recorded ground cover as litter, bare ground, or vegetation, immediately beneath each Wiens pole reading. At locations with greater than one ground cover category present, we recorded the dominant category with ≥50% cover. We measured two additional vegetation plots 50-m from the point count center along a random transect during the two subsequent point counts (Brooks and Stouffer 2010). We averaged the three vegetation plots to generate one estimate of vegetation characteristics for each point count location.

We quantified six 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 Wiens pole received bare ground classification. We calculated shrub height by recording the tallest shrub hit to the nearest dm on each Wiens pole, and averaged across each survey plot. Additionally, 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, as an indication of vegetation heterogeneity. 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 land cover 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 indicated birds chose locations in proximity to dense woody vegetation likely used as escape cover. Wildlife openings and streams represented the most readily available escape cover on Fort Bragg. We included distance to wildlife opening and streams as both linear and quadratic terms, and years-since-fire was only included as a linear term.

We collected the detection covariates ordinal date and survey start time 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, as a single observer was responsible for all point count surveys each year.

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 2016), and identified two correlated covariates (coefficient of variation for vegetation height and percent grass cover). We included percent grass cover in models, as previous work conducted by Dunning and Watts (1990) and Taillie et al. (2015) determined that grass cover positively influenced occupancy (Table 1). We removed the covariate coefficient of variation for vegetation height from analysis.

Statistical Modeling

We fit single-species, single-season occupancy models, with a year effect, using the unmarked package in Program R (R Version 3.2.2, www.r-project.org, accessed 29 January 2016; MacKenzie et al. 2002, Fiske and Chandler 2011). 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 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 (Burham and Anderson 2002). We considered models competitive if they differed by <2 AIC_c units for every additional one parameter of the top model, ignoring 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 in survey points exposed to prescribed fire (MacKenzie et al. 2002), and all visits post burn were considered not estimable.

We conducted a parametric bootstrapping goodness of fit test to access the fit of the highest supported model (MacKenzie and Bailey 2004). Testing the fit of the top model ensured 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. All point count locations were visited three times, but 44 point count locations, 17 in 2014 and 27 in 2015, had at least one visitation affected by prescribed fire and the visitation was considered not estimable. We detected at least one Bachman's sparrow at 66 sites in 2014 and at 80 sites in 2015, for a naïve occupancy estimate of 0.40.

Four detection models initially were considered competitive (Table 2). Two had one additional parameter and were within 2 AIC_c units, and one model had two 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 two parameters in various combinations to the top model (Table 2). All three competitive models included non-informative parameters with 95% confidence intervals overlapping zero. Thus, we proceeded with only the top model.

Using the top detection model, the probability of detecting a male Bachman's sparrow was 0.43. The top model suggested detection declined with ordinal date and was greater in 2015 than in 2014 (Figure 1). Using the top detection model, we fit the state based component of the occupancy model.

Of the initial 93 *a priori* models, we considered nine candidate models competitive (Table 3). The eight 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 five additional covariates - distance to stream, basal area, percent shrub cover, percent forb cover, and percent bare ground (Table 3). We rejected the eight candidate models and 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 woody shrubs, and a negative quadratic relationship with distance to wildlife opening (Figure 2).

The Goodness of Fit test indicated 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 and concluded the observed data set matched the expected observations.

DISCUSSION

Bachman's sparrows on Fort Bragg selected recently burned areas dominated by herbaceous groundcover, similar to southerly populations. Herbaceous vegetation provides high quality cover (Dunning and Watts 1990, Plentovich et al. 1998, Tucker et al. 2004, Cox and Jones 2009) and food (Allaire and Fisher 1975), and is essential for nest construction (Haggerty 1988, Haggerty 1995, Jones et al. 2013). Additionally, frequent prescribed fire is critical to prevent broad woody understory encroachment that shade and eliminate herbaceous grasses and forbs in uplands (Myers and White 1987, Heuberger and Putz 2003, Cox and Jones 2009).

Contrary to most studies elsewhere, Bachman's sparrows selected for sites with woody cover nearby. We commonly observed Bachman's sparrows flushing into isolated patches of woody cover during capture attempts, presumably to escape from perceived predation threat (e.g., research team). And, increased availability of escape cover has been shown to increase Bachman's sparrow abundance in upland sites (Brooks and Stouffer 2010). On Fort Bragg, escape cover was most common in fallow wildlife openings and along stream drainages. Wildlife openings were relatively small ($\bar{x}$ = 0.31 ha, SE = 0.02 ha, n = 717) and functionally mimicked naturally occurring canopy openings, which allow increased amounts of sunlight to reach the forest floor and foster denser understory of shrubs and herbaceous vegetation.

Patches of woody escape cover on Fort Bragg may be especially important because upland longleaf pine forests on Fort Bragg contain seven times less woody understory cover than sites occupied by Bachman's sparrows in southeastern North Carolina (Winiarski et al. in press). Low soil productivity of the deep sandy soils in the sandhills physiographic region often limits woody cover to sparse oak regeneration (*Quercus spp*.; Lashley et al. 2015), but woody understory plants are abundant in the more productive soils along stream drainages (Sorrie et al. 2006). Moreover, the systematic use of a 3-year fire regime has reduced the prevalence of oaks and other woody plants in Fort Bragg uplands (Lashley et al. 2014). The wildlife openings on Fort Bragg that are planted with agricultural crops to provide food for white-tailed deer (*Odocoileus virginianus*) or wild turkey (*Meleagris gallopavo*) are not used by Bachman's sparrow, but other openings left fallow were used by the Bachman's sparrows we monitored. We were not able to distinguish between planted and fallow openings in the analysis, so the predicted occupancy near wildlife openings had large confidence intervals.

Bachman's sparrows may have established territories nearby wildlife openings because of the associated fitness benefits (e.g., predator avoidance). Similarly, Brooks and Stouffer (2010) documented increased Bachman's sparrow abundance near downed crowns from storm-damaged trees. However the importance of this relationship to sparrow vital rates (e.g., survival and reproduction) is unknown. Our anecdotal observations suggest that sparrows flushed into wildlife openings and drainages to aid in predator avoidance, but a quantifiable effect on survival is needed. Additionally, we documented selection of fallow wildlife openings and drainages by juvenile Bachman's sparrows monitored with radio-telemetry (A. Fish, North Carolina State University, unpublished data). Juveniles of other passerines species have been shown to seek out dense woody cover to aid in predator avoidance throughout the post-fledgling period (Vitz and Rodewald 2011, Streby and Andersen 2012). Hence, patches of woody cover embedded in the extensive matrix of upland longleaf pine forest on Fort Bragg likely provide critically important escape cover to both adult and juvenile Bachman's sparrows.

The Bachman's sparrow population on Fort Bragg is stable and individuals largely selected the same habitat features as elsewhere in the species' range, where populations are stable (Dunning and Watts 1990, Tucker et al. 2004). Additionally, daily nest survival on Fort Bragg was 0.945 (A. Fish, North Carolina State University, unpublished data), which is similar to other studies in the core of the Bachman's sparrow range (Stober and Krementz 2000, Perkins et al. 2003, Jones et al. 2013). Conversely, Taillie et al. (2015) showed that

Bachman's sparrows were less likely to occupy habitat patches with less surrounding habitat in eastern North Carolina. The male sparrows in isolated patches were less likely to attract females during the breeding season and rarely produced offspring (Winiarski 2016). Therefore, conservation of large, contiguous expanses of fire-maintained longleaf forests are critical to prevent extirpation of Bachman's sparrow on their northern range extent.

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

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

Table 2. Top 5 detection (p) 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).

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

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

Model ψ()	**K**	**AIC_c**	**ΔAIC_c**	**$AIC_c wt$**	**-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 + $dist.strm^2$ + cv.mxht	12	956.85	3.07	0.07	-465.98
per.grs + mx.wd + sincefire + dist.wopn + $dist.wopn^2$ + dist.strm + $dist.strm^2$ + ba.tot	12	957.13	3.35	0.06	-466.12
per.grs + mx.wd + sincefire + dist.wopn + $dist.wopn^2$ + dist.strm + $dist.strm^2$ + per.wd	12	957.51	3.73	0.05	-466.31
per.grs + mx.wd + sincefire + dist.wopn + $dist.wopn^2$ + dist.strm + $dist.strm^2$ + per.wd + cv.mxht	13	957.72	3.94	0.04	-465.34
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	0.03	-465.60

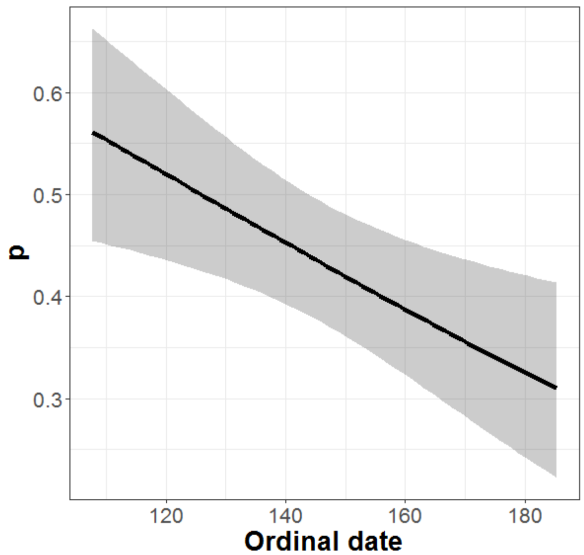

Figure 1. Predicted detection (p) and 95% confidence intervals for ordinal date, using top detection model for Bachman's sparrow at Fort Bragg Military Installation, North Carolina (2014-2015).

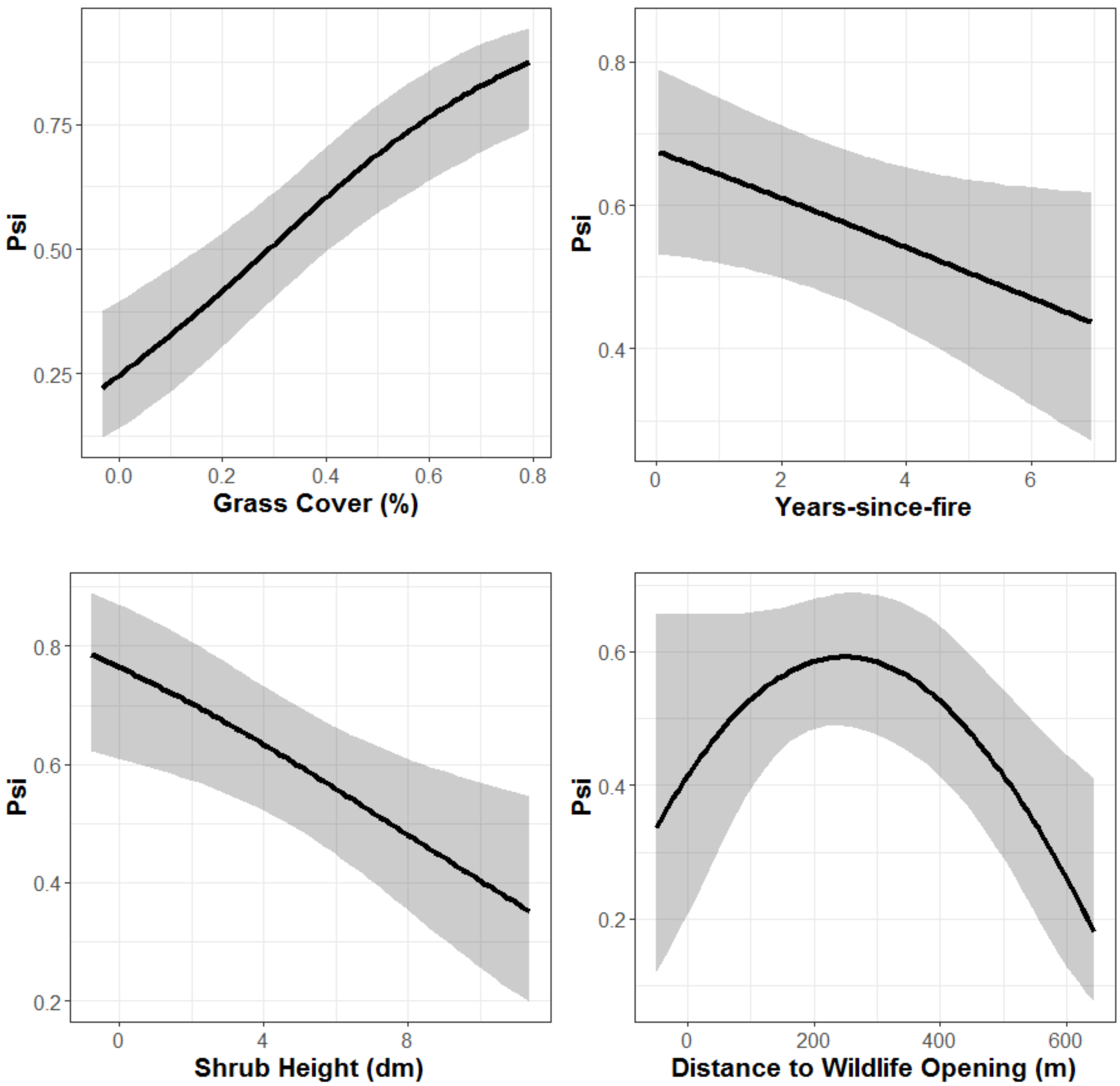

Figure 2. Relationship between predicted occupancy (ψ) and percent grass cover, year-since-fire, average woody shrub height in decimeters, and distance to wildlife opening using the top occupancy model for Bachman's sparrow at Fort Bragg Military Installation, North Carolina (2014-2015).