MOVEMENTS, HOME RANGE AND HABITAT SELECTION OF BACHMAN'S SPARROWS (*PEUCAEA AESTIVALIS*) ON A LONGLEAF SANDHILL FOREST—IMPLICATIONS FOR FIRE MANAGEMENT

by

SARAH KATHERINE BROWN

(Under the Direction of Robert J. Cooper)

ABSTRACT

Frequent prescribed burning of longleaf pine sandhill is necessary for maintaining Bachman's sparrow (*Peucaea aestivalis*) habitat. Late-breeding season burns (after June) and fire size are thought to influence survival and site fidelity of Bachman's sparrows. To assess habitat selection and effects of breeding season fire size (139-204 ha) on movements and survival of Bachman's sparrows, I radio-tagged 31 Bachman's sparrows in northern Florida during 2010-2011. Survival rate was 0.966±0.037. Mature open longleaf pine stands were selected for home ranges above other habitat types, including sapling stands, regeneration areas, and oak hammocks. Fire size did not appear to negatively affect movements of Bachman's sparrows vacating burned areas except when suitable habitat was not available near their home range. Post-burn Bachman's sparrows were located in saw timber stands 90% of the time. Managers should consider fire size in relation to availability of suitable habitat and maintain frequent burning of old growth forests.

INDEX WORDS: Apalachicola National Forest, Bachman's sparrow, *Peucaea aestivalis*, movements, habitat selection, home range, longleaf pine, prescribed fire, radio telemetry, sandhill

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION, LITERATURE REVIEW, OBJECTIVES, AND HYPOTHESES

INTRODUCTION

Once dominating the southeastern landscape of North America, longleaf pine (*Pinus palustris*) forests became one of the fastest declining ecosystems in the world (Landers et al. 1995). Historically, this ecosystem was maintained by natural and anthropogenic fires that swept the landscape and created a fire-dependent habitat upon which many declining fire-adapted species have become dependent (Bartram 1791). Due to a suppression of wildfires, these southeastern habitats now rely on prescribed fire for maintenance. Current fire regimes in southeastern pine habitats compared to natural and pre-settlement fire regimes show an increase in time between fires (hereafter burn interval) and often a suppression of fire altogether (Engstrom et al. 2005). High burn frequencies (<3 years) are normally necessary to sustain the ecological integrity of longleaf pine forests and support declining fire-dependent species, such as Bachman's sparrow (*Peucaea aestivalis*) (Brennan et al. 1998, Glitzenstein et al. 2003, Tucker et al. 2006).

Previous studies suggest that timing of prescribed burns within the breeding season and the size of individual fires relative to surrounding habitat may affect survival, productivity, and movements of Bachman's sparrows (Cox and Jones 2009, Seamen and Krementz 2000, Tucker et al. 2006). Therefore, using radio-telemetry, my objective was to determine how fire size, in relation to pre-burn home range placement, affected movements and survival of Bachman's sparrows. The way in which previous fire management and availability of habitat surrounding burns influences post-burn behaviors of Bachman's sparrows is important for management of this species.

To date, there has not been a habitat use study using selection analysis of radio-marked Bachman's sparrows. Because Bachman's sparrows are associated with various age classes of pine forests (Dunning 2006), I was interested if habitat selection of various pine forest age classes may be different on sites that are frequently burned. I was specifically interested in if high fire frequency of different age class pine stands improved their suitability as habitat for Bachman's sparrows.

LITERATURE REVIEW

Longleaf Sandhill Forests

Longleaf pine grows in a variety of habitats, including woodlands, savannas, and sandhill forests, stretching from Virginia southward into eastern Texas (Stout and Marion 1993, Boyer 1990). A significant portion of remnant intact longleaf pine ecosystems occur on sandhill increasing its conservation value (Frost 1993). Sandhill ecosystems occur across the Southeastern U.S. and are considered a conservation priority in central and north Florida where approximately 300,000 ha remain (Florida Fish and Wildlife Conservation Commission 2005). Longleaf sandhill habitats are characterized as xeric, sandy soiled forests with widely spaced pine trees, a grassy ground cover and a fire-stunted understory of deciduous oaks and as such are important habitat for Bachman's sparrows (Myers 1990, Frost 1993, Rodgers and Provencher 1999).

Frost (1993) reported sandhill habitats were historically burned on a 1 to 3 year fire frequency. In pine ecosystems fire frequency drives community structure and composition (Glitzenstein et al 2003, Glitzenstein et al. 2012). Frequent fire promotes herbaceous ground cover, while fire suppression permits the development of shrub-hardwood communities. The ecological condition of sandhill ecosystems are often threatened by a lack of fire and resulting turkey (*Quercus laevis*) and post oak (*Quercus stellata*) intrusion (Glitzenstein et al. 2003).

Species Account

The Bachman's sparrow (*Peucaea aestivalis*) is a fire-adapted species that inhabits pine forest ecosystems, including longleaf sandhill forests of the southeastern United States (American Ornithologists' Union 1983). Life-history traits of Bachman's sparrows allow them to flourish within a fire-dependent ecosystem, including a lengthy breeding season and ability to produce multiple broods per season (Haggerty 1998, Dunning 2006, Cox and Jones 2009). Bachman's sparrows are known to abandon areas where the burn interval exceeds 3 years (Engstrom et al. 1984). Likely due to fire suppression and a reduction of suitable habitat, Bachman's sparrows are declining (Sauer et al. 2011) and have been classified as near threatened (Dunning and Watts 1990, Haggerty 1988, IUCN 2008).

As a ground-nesting and foraging species they require a medley of grasses and forbs that frequent fires create in the understory (Haggerty 1998, Tucker et al. 2006, Glitzenstein et al. 2003, Plentovich et al. 1998). More specifically, Bachman's sparrow habitat has been described as relatively thick herbaceous groundstory with hardwood shrub community < 1 m in height with less vegetation in the above 1 m (Haggerty 1998).

Bachman’s sparrows appear to be sensitive to development of vegetation above 2 m and avoid sapling stages of pine regeneration (Dunning and Watts 1990, Haggerty 1998). In longleaf wiregrass communities, habitat is provided by relatively open pine stands frequently burned (Stoddard 1978). Regeneration areas (e.g., clear cuts) provide habitat until 5-7 years post-planting when pine regeneration becomes too thick for sparrows (Dunning and Watts 1990; Stober and Krementz 2006).

Bachman’s sparrow home range size is thought to be related to suitability of habitat, with smaller home ranges in areas with higher habitat quality. Haggerty (1998) found smaller home ranges in areas with higher forb and grass cover and low shrub and tree density. Previous studies on Bachman’s sparrow home ranges have largely been conducted using spot-mapping techniques with unmarked sparrows (McKitrick 1979, Meanley 1990) and color-banded males (Haggerty 1998, Cox and Jones 2007). However, re-sighting estimates of movements and home range size may be biased towards low values because large distance movements of birds are frequently undetected. Only one study of Bachman’s sparrows (Stober and Krementz 2006) has utilized radio-telemetry to determine home range size, and it found sizes similar to resighting estimates.

Prescribed Fire

Several studies on prescribed burns and Bachman’s sparrows have focused on dormant season (winter) burns (Gobris 1992, Haggerty 1986). Increasingly prescribed burns are being conducted during the breeding season (April-August). Studies suggest that timing of burns may influence Bachman’s sparrow reproduction, survival and site abandonment (Seamen and Krementz 2000, Tucker et al. 2006, Liu et al. 1995). Seamen and Krementz (2000) suggest that burning during the breeding season reduces sparrow survival and reproduction. Shriver and Perkins (1999) found lower Bachman's sparrow densities on sites burned after June. Tucker et al. (2006) commented that fires during the breeding season do not influence reproductive success of Bachman's sparrows, but more research is needed on the effects of burn timing within the breeding season.

Few studies have addressed how fire size (the size of individual fires) impacts the movements and survival of Bachman's sparrows. While large fires were part of the natural fire regime for uplands in Florida, recent evidence suggests that natural fire regimes were characterized by significant temporal and spatial variation in fire size (Holmes et al. 2004, Duncan et al. 2010). Dispersal distance and patch heterogeneity are important considerations in developing burn plans (Dunning and Watts 1990, Fitzpatrick et al 1991, Liu et al. 1995). Cox and Jones (2009) found no effect of fire size on Bachman's sparrows, but burn sizes were small (2 - 100 ha). To meet burn goals, land management agencies often depend on aerial ignition to burn large areas (400-4,000 ha) at one time. The small size of home ranges relative to large fires suggests that Bachman's sparrows may be sensitive to fire size.

OBJECTIVES

The four chapters in this thesis are divided by subjects relating to my objectives and relative hypotheses. This first chapter provides an overall introduction and literature review to explain my motivation for the study and support the chapters that follow. Chapter 2 treats the primary objective of this project, which is to assess how movements and home range of Bachman's sparrows are influenced by prescribed fire size and season. Chapter 3 analyzes habitat selection of Bachman's sparrows in a sandhill habitat. And finally, Chapter 4 summarizes my findings regarding my hypotheses and provides management recommendations.

Specific Project Objectives

1. Estimate home range size, movements, and survival of Bachman's sparrows using radio-telemetry (Chapter 2).
2. Assess how fire size relative to available habitat increases movements and/or reduces survival of Bachman's sparrows (Chapter 2).
3. Assess if timing of prescribed burns conducted during the breeding season increases movements and/or reduces survival of Bachman's sparrows (Chapter 2).
4. Assess habitat selection of Bachman's sparrows both pre and post-burn on frequently-burned sandhill (Chapter 3).

HYPOTHESES

1. Home range size on sandhill habitat will be larger than reported for other habitats (Chapter 2).
2. Telemetry-based home range estimates will be larger than those previously estimated using band-resighting methods (Chapter 2).
3. As distance from Bachman's sparrows' home ranges to the burn edge increases Bachman's sparrows will make larger movements to find suitable habitat (Chapter 2).
4. Burns conducted later in the breeding season will cause Bachman's sparrows to abandon their home ranges (Chapter 2).
5. Increased movements of Bachman's sparrows will cause lower survival rates (Chapter 2).

6. Frequently burned mature forest stands and regeneration areas will be selected for home range and habitat use of Bachman's sparrows (Chapter 3).
7. Bachman's sparrows forced from home ranges by fire will use a broader range of habitats than selected habitat types (Chapter 3).

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CHAPTER 2

EFFECTS OF PRESCRIBED FIRE ON HOME RANGE, SURVIVAL, AND MOVEMENTS OF BACHMAN'S SPARROW (*PEUCAEA AESTIVALIS*) ON A LONGLEAF SANDHILL FOREST[1]

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[1] Brown, S.K., W.E. Palmer, and R.J. Cooper. To be submitted to the Journal of Wildlife Management.

ABSTRACT

Frequent prescribed burning is necessary for maintaining Bachman's sparrow (*Peucaea aestivalis*) habitat. Late-breeding season burns (after June) and fire size are thought to influence survival and site fidelity of Bachman's sparrows. To access effects of breeding season fire size (139-204 ha) on movements and survival of Bachman's sparrows, I radio-tagged 31 Bachman's sparrows in northern Florida, 2010-2011. Bachman's sparrow 95FK home range estimates were (±SE) 3.8 ha±0.41 ($n = 8$) in 2010 and 9.6 ha±0.82 ($n = 23$) in 2011 (during a severe drought). In 2010, sparrows returned to their home ranges quickly post-burn (median = 24 days); sparrows in 2011 set up new home ranges or abandoned the study area. Survival rate was 0.966±0.037. Fire size did not appear to negatively affect movements of Bachman's sparrows except when suitable habitat was not available near their home range. Managers should consider fire size in relation to availability of suitable habitat.

INTRODUCTION

The Bachman's sparrow (*Peucaea aestivalis*) inhabits fire-dependent pine forest ecosystems, including longleaf sandhill forests of the southeastern United States (American Ornithologists' Union 1983). As a ground-nesting and foraging species they require a medley of grasses and forbs that frequent fires create in the understory (Haggerty 1998, Plentovich et al. 1998, Glitzenstein et al. 2003, Tucker et al. 2006). Bachman's sparrows are known to abandon areas where the burn interval exceeds 3 years (Engstrom et al. 1984). Likely due to fire suppression and a reduction of suitable habitat, Bachman’s sparrow populations are declining (Sauer et al. 2011) and have been classified as near threatened (Dunning and Watts 1990, Haggerty 1988, IUCN 2008).

Sandhill ecosystems occur across the Southeastern U.S. and are considered a conservation priority in central and north Florida where approximately 300,000 ha remain (Florida Fish and Wildlife Conservation Commission 2005). Sandhill longleaf forests were historically maintained by natural and anthropogenic fires that swept the landscape creating a fire-dependent ecosystem upon which many declining fire-adapted species have become dependent (Bartram 1791). Due to a suppression of wildfires, these southeastern habitats now rely on prescribed fire for maintenance. Current fire regimes in southeastern pine habitats compared to natural and presettlement fire regimes show an increase in time between fires (hereafter burn interval) and often a suppression of fire altogether (Englestrom 2005). High burn frequencies (<3 years) are normally necessary to sustain the ecological integrity of longleaf pine forests and support declining fire-dependent species, such as Bachman’s sparrow (Brennan et al. 1998, Glitzenstein et al. 2003, Tucker et al. 2006).

Several studies on prescribed burns and Bachman’s sparrows have focused on dormant season (winter) burns (Gobris 1992, Haggerty 1986). Increasingly prescribed burns are being conducted during the breeding season (April-August). Studies suggest that timing of burns may influence reproduction, survival and site abandonment of Bachman’s sparrows (Seamen and Krementz 2000, Tucker et al. 2006, Liu et al. 1995). Seamen and Krementz (2000) suggested that burning during the breeding season reduces Bachman’s sparrow survival and reproduction. Shriver and Perkins (1999) found lower Bachman’s sparrow densities on sites burned after June. Tucker et al. (2006) commented that fires during the breeding season do not influence reproductive success of Bachman's sparrows, but more research was needed on effects of timing of burn during the breeding season.

Spatial heterogeneity in habitat structure is thought to be important to many wildlife species in fire-maintained ecosystems because it provides escape and breeding habitats while burned vegetation recovers. Few studies have addressed how fire size (the size of individual fires) impacts the movements and survival of Bachman's sparrows. While large fires were part of the natural fire regime for uplands in Florida, recent evidence suggests that natural fire regimes were characterized by significant temporal and spatial variation in fire size (Holmes et al. 2004, Duncan et al. 2010). The small size of home ranges relative to large fires suggests that Bachman's sparrows may be sensitive to fire size. Dispersal distance and patch heterogeneity are important considerations in developing burn plans (Dunning and Watts 1990, Fitzpatrick et al 1991, Liu et al. 1995). Cox and Jones (2009) examined fire size with Bachman's sparrows, but burn sizes were small (2 - 100 ha). Land management agencies often depend on aerial ignition to burn large areas (400-4,000 ha) at one time to meet prescribed burning acreage goals.

Understanding how Bachman's sparrow home range, habitat use, movements and survival are affected by burning during the breeding season is important for guiding management on sandhill habitats. Therefore, I assessed how fire size, in relation to pre-burn home range placement, affected movements and survival of Bachman's sparrows using radio-telemetry. I also assessed how previous fire management and habitat condition of habitats surrounding burns influenced Bachman's sparrow post-burn behaviors. I also report on home range size of Bachman's sparrows on frequently burned sandhill ecosystems.

METHODS

Study site

The study site (~1,657 ha) is located in the Apalachicola National Forest in Leon County, Florida, on the Munson Sand Hill Burn unit between Crawfordville Highway (U.S. 319) and Woodville Highway, south to L. L. Wallace road (Figure 2.1). The northern, north western, and southern boundaries of the study site were bordered by developed areas. The area was treated and established in 2006 as part of Tall Timbers Research Station's Upland Ecosystem Restoration Project (UERP), and has been burned at intervals of less than two years at a fire size of 100 to 250 ha.

Four different burns (hereafter referred to as burn units 220, 255, 257, 258) were used in this study (Figure 2.2). These units were chosen because they were targeted for burning by the USFS during the summer of 2010 and 2011. Burn unit 257 (179 ha) was burned on July 23, 2010 and was the only burn conducted in 2010. Burn unit 258 (139 ha) was burned on July 21, 2011, burn unit 255 (204 ha) was burned on August 5, 2011, and burn unit 220 (142 ha) was burned on August 10, 2011.

Radio-tagging and Telemetry

Male Bachman's sparrows were captured using target netting techniques where recorded aggressive calls are played near mist nets (Jones and Cox 2007). Only male Bachman's sparrows were captured as females are less aggressive and consistently successful female Bachman's sparrow capture techniques have yet to be developed. I did not attempt to catch sparrows when ambient temperature exceeded 26^{o} C to avoid causing harm (Jones and Cox 2007). Males were fitted with a uniquely numbered U.S. Fish and Wildlife leg band along with three color-bands. I attached model NBQT-3-2 nano-tags radio-transmitters (Lotek Company, Ontario, Canada) with a 12 hr active cycle. Nano-tags weigh 0.64 g (~3% of Bachman's sparrow body weight) and have a battery life of approximately 4.5 months. I custom-modified the tags using a method similar to that used in Stober and Krementz (2006) and attached them around the thigh using a method by Rappole and Tipton (1991). Despite recent concerns about biased data from radio-tagging, it can provide unbiased estimates of movement, reproduction and survival if properly and carefully utilized (Stober and Krementz 2006, Folk et al. 2007, Palmer and Wellendorf 2007). With proper attachment and by using tags that are light relative to body weight, these biases can be avoided.

Radio-tagged Bachman's sparrows were located at least four times per week. I used the homing method (White and Garrott 1990) using a handheld 3-element Yagi antenna and a Lotek digital receiver (Model SRX400A; 164-168mz range). Bachman's sparrow locations were recorded using a handheld Trimble (Geo XT) GPS and later transferred to ArcMap (ESRI 1998) using a Universal Transverse Mercator projection (zone 16, North American datum 1983).

Often Bachman's sparrows were located visually, but I also frequently took a GPS point when I was confident the sparrow was within 5m of the observer (judged by signal strength). I saw no evidence that tracking Bachman's sparrows or even flushing them disturbed normal behaviors such as continued foraging, flushing to a tree, or perching and singing. Bachman's sparrows were located immediately or hours prior to ignition of prescribed burns. Bachman's sparrows were tracked during the prescribed burn, then frequently thereafter unless they disappeared from the study site, in which case I searched other areas of suitable habitat outside of the study site in an attempt to relocate them.

Breeding Status

Although I was unable to fully assess reproductive parameters, such as nesting rate, nesting success, and fledgling survival, I used a modified reproductive index based on behavioral observations developed by Vickery et al. (1992) and modified by Tucker et al. (2006) in response to the difficultly of locating sparrow nests. During telemetry, I monitored Bachman's sparrows for pair behavior, nest building, provisioning of young, and fledgling presence to help determine the productivity of radio-tagged males. In addition to daily telemetry, in 2011, I also conducted 10 min breeding behavior surveys to assess breeding status of each radio-tagged male.

Home Range Estimation

Home range estimations were conducted using three different methods (100% minimum convex polygons (MCP), 95% fixed kernel (95FK), and 95% a-LoCoH) in order to compare my results with previous studies estimating Bachman's sparrow home range size. Only telemetry locations recorded prior to prescribed burns were used in these home range calculations. Juvenile home ranges were excluded from all analyses and were reported separately using MCP estimates. All MCP and FK95 estimates were created using ArcView (ESRI 1998) and Hawth's Analysis Tools (Beyer 2004). The likelihood cross validation (CVh) smoothing parameter was used when calculating 95FK as it provides a better estimate for sample sizes <50 (Horne and Garton 2006). All LoCoH data analyses were conducted in R (R Development Core Team 2011) with the home range estimation packages AdehabitatHR and AdehabitatLT (Calenge 2006). LoCoH is a non-parametric convex hull method called local convex hull and has been successfully applied to other home range projects (Getz and Wilmer 2004, Peters and Nibbelink 2011, Ryan et al 2006). I used a modified version of Getz and Wilmer's (2004) fixed k LoCoH method called the adaptive, or a-LoCoH method.

I determined the number of telemetry locations needed to estimate home range size by plotting 95FK home ranges against the number of telemetry locations in the sample, and judged that home range size was consistent if 15 or more locations were used to determine home ranges. Therefore, I included Bachman's sparrows with 15 or more locations in home range analyses. There was no correlation between number of telemetry locations and home range size ($r = 0.22$, $P > 0.24$) when using these criteria. I tracked Bachman's sparrows in 2010 and 2011 over different time frames (June through mid-November in 2010 and mid-March through August in 2011). Therefore, to examine differences in home range size and movements by year during the same months, I used locations taken June through August (pre-burn) both years.

Breeding Status and Home Range Size

I investigated differences in home range size for paired versus unpaired male Bachman's sparrows as well as differences in home range size for Bachman's sparrows seen with fledglings and those not seen with fledglings. To do so, I conducted an analysis of variance in STATISTICA 6.0 (StatSoft, Inc., Tulsa OK) with paired status (or fledgling status) and year to control for variation among years. In all home range and movement analyses, I checked for heteroscedasticity and when present I log-transformed the dependent variable in an attempt to equalize the variances.

Burn Interval Effects on Home Range Size and Movements

Bachman’s sparrows are known to be sensitive to fire frequency (Engstrom et al. 1984; Dunning 2006). Therefore, I investigated if the burn interval of habitats used by radio-tagged sparrows may have affected home range size. To do so, for each Bachman’s sparrow I averaged the number of days since burn of the habitat assigned to each telemetry location within its home range. I then assessed if the average number of days since burn was correlated with the size of MCP home ranges. I used MCP rather than 95FK or a-LoCoH because it is more inclusive of all sparrow locations.

Each burn unit in the study site had a different burn interval ranging from 756 to 1070 days. These burn intervals are longer than the ~2 year fire frequency usually maintained for this site. This is due to a delay of prescribed burns by the USFS for collection of adequate pre-burn data for this study (in 2010) as well as unsuitable burning conditions (in 2011) caused by the drought. I assumed that the longer the burn interval the more likely Bachman’s sparrows would leave the burn unit. Therefore I calculated the proportion of sparrows that vacated the burn unit prior to burning and compared this to the burn interval of the burn unit. For each burn, I also determined if there was a relationship between burn interval of surrounding habitats and post-burn movements.

Survival Rates

Survival rates were estimated using the known fates model in program MARK (White and Burnham 1999) and the Kaplan-Meier staggered-entry design (Pollock et al. 1989). Survival was estimated by using bi-weekly periods from 1 June–November 15 2010 and 1 April–15 September 2011. This included Bachman’s sparrows that were located within the burn units and monitored after prescribed burns. A classification of survived, censored, or died was assigned to each sparrow at the end of each monitoring period. Survival was assigned to Bachman's sparrows when a transmitter failed due to battery expiration determined by weakening signals or for Bachman's sparrows with radio-transmitters that continued until the end of the study. Mortality was assigned when remains were found or when a recovered transmitter harness showed signs of predation. Censored was assigned to Bachman's sparrows that were thought to abandon the study site, and Bachman's sparrows that dropped transmitters with no signs of predation. I am confident that dropped transmitters were not mortalities as several times I relocated a banded Bachman's sparrow that had dropped its transmitter and once was able to recapture and re-fit the same Bachman's sparrow with another transmitter.

The following 5 Bachman's sparrows were excluded from this analysis: two Bachman's sparrows' transmitters fell off one to three days after attachment (2010, 2011), one Bachman's sparrow predated by a hawk 2 days after attachment (2011), and two Bachman's sparrows went into gopher tortoise burrows after 4-6 days and never came out (2010, 2011). These observations were excluded, because they occurred <6 days after radio-tagging and I attribute the cause to transmitter-attachment (Pollock et al. 1989). Due to few mortalities (only one), survival rates by treatment (burned versus unburned) or juveniles were not separated nor did I test for significant differences between years. Survival rates for each year are reported separately because they were tracked during different time frames.

Movements Pre and Post-Burn

To assess the effects of prescribed burns on Bachman's sparrow movements I found the arithmetic center (centroid) of both pre and post-burn MCP's for each

Bachman's sparrow. The centroid of each MCP was found in order to calculate the average distance from the centroid to each telemetry location within the MCP (Stober and Krementz 2006, Cox and Jones 2007). I also determined the displacement distance of pre- and post-burn home ranges by calculating the distance between pre- and post-burn centroids. To investigate a possible correlation between pre-burn distance to edge and displacement distance post-burn, I measured the distance from the pre-burn centroid to the nearest available edge not targeted for burning and compared this to the displacement distance. I assessed if there was a correlation between proportion of Bachman's sparrows that abandoned the study site post-burn and proportion of suitable habitat bordering the burn unit perimeter (suitable habitat was determined by habitat selection (Chapter 3)). To do so, the proportion of the perimeter of the burn unit bordered by suitable habitat was compared to the proportion of Bachman's sparrows in each burn unit that abandoned the study site post-burn.

RESULTS

Radio-tagging and Telemetry

A total of 10 adult male Bachman's sparrows and two juveniles were radio-tagged in June of 2010. Two of the 10 radio-tagged adult Bachman's sparrows failed, which left a sample of 8 adult and two juvenile Bachman's sparrows in 2010. Radio-tag failures included one sparrow whose transmitter (fully intact with no signs of predation) fell off 2 days after attachment, and the second failure occurred when a sparrow went into a gopher tortoise burrow after 6 days and never came out. Of these, 7 adult males and two juveniles were in burn unit 257 which was burned in July of 2010, and one sparrow was in burn unit 255 which was not burned in 2010.

A total of 28 male Bachman's sparrows was radio-tagged in March to mid-April 2011 in burn units 220, 255, and 258. Out of these 28 sparrows, 4 were considered failures: one sparrow was killed by a hawk after 2 days, one transmitter fell off a few days after attachment, and 2 sparrows went into gopher tortoise burrows (1 after 4 active days and the other after ~ 30 days) and never came out. For both years combined (excluding failures), I had a sample of 32 adult and 2 juvenile radio-tagged sparrows.

Average transmitter life was 146.6 days (SD = 4.7). This average was calculated using only the transmitters in which battery failure was known due to weakening signals. This average, however, is likely a slight underestimation considering a few transmitters not used in the calculation lasted >150 days before I stopped tracking them due to logistical constraints.

Bachman's sparrows (*n* = 32) were located an average of 35.9 times (Range = 15 to 81) prior to prescribed burns. I tracked a total of 16 Bachman's sparrows just prior to and during prescribed burns. Of these, 14 Bachman's sparrows were located post-burn an average of 25.7 times (Range = 1 to 65). Two Bachman's sparrows left the study site immediately post-burn and were not located again. There was a difference in timing of transmitter failure between 2010 and 2011 that resulted in a larger number of post-burn locations in 2010 (= 46.3) than 2011 (= 5.1).

Home Range Size

Average home range size for Bachman's sparrows (±SE) in 2010 was 4.1 ha±0.76 (*n* = 8) using MCP, 3.8 ha±0.41 (*n* = 8) using 95FK, and 2.9 ha ± 0.43 (*n* = 7) using 95 a-LoCoH. Average home range size for Bachman's sparrows in 2011 was 33.0 ha±10.2 (*n* = 23) using MCP, 9.6 ha±0.82 (*n* = 23) using 95FK, and 5.2 ha±0.68 (*n* = 22) using 95 a-LoCoH in 2011. Home range size of two juvenile Bachman's sparrows using MCP was 16.2 ha and 38.9 ha. Home ranges (95FK) were significantly larger in 2011 than in 2010 (t_{29} = -5.29, P <0.001) (Figure 2.3). Using locations collected during the same months in 2010 and 2011, home ranges were larger in 2011 (t_{15} = -6.60, P <0.000): average home range size was 4.6 ha ±0.26 in 2010 and 8.2 ha±0.68 in 2011.

Breeding Status and Home Range Size

I observed 21% (5 of 24) of radio-tagged males in 2011 as unpaired and 25% (2 of 8) in 2010. I observed 46% (11 of 24) of radio-tagged males with fledglings in 2011 and 63% (5of 8) in 2010. Controlling for differences in home range size by year, paired males had similar home range size (= 6.7 ha) to unpaired males (= 6.8) ($F_{1, 28}$ = 0.006, P <0.94). Similarly, there was no difference in home range size for males seen with fledglings (= 6.3 ha) versus those not seen with fledglings (= 7.2 ha) $F_{1,28}$ = 0.43, P <0.51).

Burn Interval Effects on Home Range Size and Movements

I calculated the average days since burn for each telemetry location for each radio-tagged sparrow (*n* = 28). Average days since burn averaged 710 days ±28.3 and ranged from 363 to 1001 days. However, for most Bachman's sparrows (*n* = 22) the average days since burn for their locations ranged from 600-800 days. In a linear regression of home range size on year and average days since burn, there was no significant relationship between days since burn of the habitat and home range size (β = -0.085±0.133, P =0.53). Sparrows did not appear to choose new habitat post-burn based on days since last burn (Figures 2.4, 2.5, 2.6), rather they selected saw timber habitats (Chapter 3).

In 2011, 11 Bachman's sparrows left their burn unit prior to burning. I examined if the rate at which sparrows vacated a burn unit was dependent on the length of time since the last prescribed fire. Burn unit 255 was last burned 842 days prior and 54% (6 of 11) of sparrows left prior to burning. Burn Unit 220 was last burned 756 days prior and 50% (3 of 6) of sparrows left prior to the burn. Burn unit 258 had the longest burn rough and was previously burned 1070 days prior and 33% (2 of 6) sparrows left prior to the burn. In 2010 no sparrows (0 of 7) left burn unit 257 prior to the burn which was last burned 768 days prior.

Pre-Burn Movements among Years

Prior to burns, 67% (16 of 24) of Bachman's sparrows in 2011 made large (>400m) movements. Of these 16 Bachman's sparrows, 2 moved multiple times, 8 disappeared from the study site, and 6 created a new home range outside of the burn unit they were captured in. One Bachman's sparrow simultaneously maintained 2 distinct home ranges 3.6 km apart, and had the longest distance recorded between two consecutive days (3.9 km). This sparrow was seen with a female in both home ranges. Another Bachman's sparrow was located in his original home range and then located two hours later 2,880 m away; 10 days later this sparrow moved 3,590m and set up a new home range. No Bachman's sparrows (*n* = 8) in 2010 showed these behaviors but remained in their home ranges until burning forced them to emigrate. In 2010, I also radio-tagged one sparrow in a burn unit (255) that was not targeted for burning in 2010.

This sparrow did not exhibit large distance movements and remained in the study site until its transmitter died after 132 days.

Log-transformation of average pre-burn movements in 2010 versus 2011 removed heteroscedasticity (P <0.09). Excluding sparrows that left their home range before a burn unit was burned, the average pre-burn movements of sparrows (±SE; 386.0±108.8 m, *n* = 6) were larger in 2011 than in 2010 (88.8±3.13 m, *n* = 7) (*t* = -1.7, P =0.06).

Post-burn Movements among Years

I log-transformed post-burn movements of sparrows, which removed heteroscedasticity (P <0.91), and compared post-burn movements among years. Average post-burn movement (±SE) of sparrows from their home range centroid was 151.8±57.4 m in 2010 (*n*=7) and was significantly larger for sparrows in 2011 (779.6±224.8 m, *n* = 6) (t_{11}= -2.77, P <0.02).

Pre-burn movements versus Post-burn Movements

Post-burn movements were significantly larger than pre-burn movements ($t_{12} = -3.42$, P <0.005). Bachman's sparrows' movements from their home range centroids averaged 225.9±124.6 m pre-burn versus 485.3±129.6 m post-burn.

Distance to Edge and Post-Burn Movements

Average displacement distance (shifts in home range centroids after burning) in 2010 was 228.8 m (SD = 187.0, *n* = 7) and 733.4 m (SD = 466.2, *n* = 7) in 2011. I assessed the effect of year and distance to nearest edge from the centroid of each bird's home range on displacement distance using stepwise regression. I excluded 2 birds with 1 location post-burn because there were too few locations to create a centroid from post-burn movements. The resulting model was significant ($F_{1,10} = 12.28$, P <0.006; R^2 =

0.55) and included distance from home range centroid to edge of the burn but not year (P <0.169) (Figure 2.7). The proportion of sparrows that abandoned the study site post-burn was negatively related to the proportion of suitable habitat bordering the burn unit however, this was confounded with burn date (Figure 2.8).

Five of seven (71%) adult Bachman's sparrows in 2010 eventually returned to their original home ranges post-fire (Table 2.1). Sparrows returned to their home range within an average of 43.8±9.7 days with one extreme observation of 102 days. The median time to return to their home range was 24 days, which better represented most of the sparrows in my sample. One of the juvenile sparrows returned to their original home range after 39 days.

Bachman's sparrows that returned to their home ranges in 2010 were originally closer to the edge of the burn unit prior to the burn. These sparrows did not abandon the study site, but either set up temporary home range outside the burn unit or moved in an unsystematic pattern until returning to their original home range. The remaining Bachman's sparrows in 2010 set up a new home range within the study site. In contrast, post-burn Bachman's sparrows in 2011 either set up a new home range outside the burned area (36%) or left the study site (64%). None of the sparrows returned to their original home ranges in 2011 (Table 2.1).

Survival Rates

Survival rate for the period 1 June–November 15 2010 was 1.0 based on 10 radio-tagged male Bachman's sparrows (Table2.2). Survival rate for the period 1 April—15 September 2011 was 0.951±0.048 (SE) based on 25 radio-tagged Bachman's sparrows including two juveniles. One Bachman's sparrow moved ~465m from its home range and located in a gopher tortoise burrow 30 days after it was radio-tagged. This sparrow never emerged and was the only confirmed mortality during my study. The overall survival rate for both years was 0.966±0.037 based on a total of 35 radio-tagged Bachman's sparrows. None of the radio-tagged Bachman's sparrows died as a result of the prescribed burn.

DISCUSSION

Home Range and Pre-Burn movements

I assessed home range size and movements of Bachman's sparrows prior to prescribed burning. Researchers often consider home range size a surrogate measure for habitat quality, with smaller home ranges indicating better habitat (Stober and Krementz 2006, Haggerty 1998). However, home range size is a function of many variables that can confound this potential relationship. Weather conditions among years may influence movements necessary to find food resources, reproductive strategies and success vary among individual birds, and presence of competition all may impact measures of home range size. Therefore, although there is much support for the general inverse relationship between habitat quality and home range size, assessing habitat quality among sites using home range size alone should be viewed with caution.

Pre-burn movements and home range size were larger in 2011 than in 2010. This difference is likely due to discrepancies in tracking time frames between years (Jun – Nov, 2010 versus Mar – Aug, 2011) and the severe drought in 2011. I observed Bachman's sparrows making significant shifts in their home ranges prior to June in 2011; if similar movements occurred in 2010 they would have been unobservable. Similarly, in

2011, I observed Bachman's sparrows with fledglings shortly before relocating their home ranges. While timing of telemetry partially explained home range size differences, I believe the drought in 2011 had a significant impact on Bachman's sparrow movements and likely resulted in increased movements in search of available food sources, especially for successful pairs with fledglings. This idea is corroborated by the significant difference in home range size between 2010 and 2011 using only telemetry locations located during the same time frame. Dunning and Watts (1990) thought that Bachman's sparrows' patterns of habitat use were not affected by the drought that occurred during their study in 1988; however, differences in movements between pre- and post-burn, plus abandonment of home ranges, suggest the drought had a significant impact on Bachman's sparrow behavior relative to habitat use.

Previous studies on Bachman's sparrow home ranges have largely been conducted using spot-mapping techniques with unmarked sparrows (McKitrick 1979, Meanley 1990) and color-banded males (Haggerty 1998, Cox and Jones 2007). Haggerty (1998) reported home range size (±SE) of 2.5±0.22 ha (range= 0.7 - 4.5, *n* = 25) using MCP in Arkansas clear-cuts, whereas McKitrick (1979) found home ranges at 5.1ha (SD =1.2, range=4 - 6.7, *n*=6) in mature Florida pinewoods. Another study in an old growth forest with high Bachman's sparrow habitat quality measured a mean home range of 3.1±3.5 ha (*n*=46) using FK95 and 1.8±1.4 ha using MCP (Cox and Jones 2007). However, re-sighting estimates of movements and home range size may be biased towards low values because large distance movements of sparrows are frequently undetected. Only one study of Bachman's sparrows (Stober and Krementz 2006) has utilized radio-telemetry to determine home range size, and they reported 95% MCP method at 4.79±0.27 ha (*n*=4) in mature pine stands, 3.0±0.31 ha (*n*=3) in four-year-old stands, and 1.46±0.31 ha (*n*=3) in two-year-old stands, which were similar to previous studies.

Home range sizes and movements in this study were larger than previously reported for Bachman's sparrows, especially in 2011. Larger home range sizes may be due to differences in habitat suitability or monitoring methodology. This study occurred on sandhill habitat which may have lower primary productivity and food resources relative to other sites (Cox and Jones 2007). The fact that in 2010, home ranges were similar to previous studies in mature saw timber habitat (Stober and Krementz 2006, Cox and Jones 2007), suggests the drought in 2011 reduced habitat suitability on sandhill forcing sparrows to move more to meet daily resource needs. Sandhill habitats are water stressed by definition so it is reasonable to conclude that drought conditions would reduce habitat suitability. Other studies did not report significant shifts in home range size or habitat use associated with drought (Cox and Jones 2009, Dunning and Watts 1990), although Cox and Jones (2009) reported lower apparent survival rates during a drought period which they suggest could have been due to larger movements undetected during resighting of banded birds.

Methodological differences permitted measuring larger home ranges in my study and makes comparisons to other studies difficult. The battery life of radio-tags used in my study lasted considerably longer than those used in previous studies (Stober and Krementz 2006, Seamen and Krementz 2000) and enabled us to capture Bachman's sparrow movements with multiple broods throughout the breeding season. The large movements I observed, even within a single day, by radio-tagged sparrows suggests previous studies using visual resighting estimates may have underestimated sparrow movements and home range size. Seaman and Krementz (2000) reported that Bachman's sparrows moved approximately 100 m between daily locations. Stober and Krementz (2006) had similar daily distances (87±7 m) with the largest distance of 824m (Stober and Krementz 2006). I observed sparrows making over 2000 m linear distances within hours. I believe that if I had aerial tracking capabilities (e.g., helicopter) movement measurements and home range sizes would have been even larger.

Breeding Status and Home Range

Differences in home range size among Bachman's sparrows have been explained by behaviors associated with paired status or attending fledglings. Jones (2008) found that mean home range size was significantly larger for paired Bachman's sparrows than for unpaired Bachman's sparrows. Whitaker et al. (2006) found that sparrows with greater reproductive success had larger home ranges due to increase travel for food for fledglings. I found no effect of paired status or fledgling status on home range size of Bachman's sparrows. The lack of significant difference in home range size of paired versus unpaired males in my study could be attributed to large distance movements made by unpaired males (moved their home range) in search of a mate. Two males were observed in their home range without a mate, then moved large distances to another territory and were later seen with a mate in their new territory. Another Bachman's sparrow acted as a "floater" (i.e., unpaired) and was seen being aggressive with other males in multiple territories. Long distance movements made by male Bachman's sparrows to find females have been observed in other studies (Cox and Jones 2009, Tucker et al. 2006).

While I found no significant correlation between home range size and fledgling success I did observe Bachman's sparrows in neighboring territories attending fledglings. These post-fledgling large distance movements have been documented in other Bachman's sparrow studies and have been reported with other passerines as well (Cox and Jones 2007, Jones 2008, Vega Rivera et al. 2003). Cox and Jones (2007) reported a male Bachman's sparrow moved with his fledglings >500m.

Burn Interval Effects

Several studies have noted that home range size of Bachman's sparrows declines as habitat quality increases (Stober and Krementz 2006, Haggerty 1998). Haggerty (1998) found smaller home ranges in areas with higher forb and grass cover and low shrub and tree density. In mature pine forests, the interval between prescribed burns effects the composition of ground cover (Glitzenstein et al. 2003) and therefore may influence home range size. For example, Jones (2008) found that Bachman's sparrow home range size increased with increasing burn interval. He reported slightly smaller home ranges for Bachman's sparrows in areas that were burned within the past 12 months versus >12 months. Perkins et al. (2009) found that time since burn affected Bachman's sparrow more than seasonality of fire.

I did not find a relationship between burn interval and home range size on my sandhill study site. The majority of my Bachman's sparrows however were located in areas with >12 months burn interval, ranging from 207 to 1,001 days. Post-burn sparrows did not appear to select for areas with less burn interval, but for saw timber stands (the selected habitat type) instead (Figure 2.4, 2.5, 2.6; Chapter 3). Bachman's sparrows are sensitive to the density of vegetation at the ground level and habitat suitability increases as vegetation density increases, to a point, then suitability declines as vegetation and plant litter becomes too thick. The infertile xeric soils on my sandhill study site may permit a longer burn interval than more fertile sites because vegetation and at the ground level does not become as rank as quickly as on more fertile sites (Jones 2008). Over a longer time span, however, if sandhills are not burned on a two-year interval then the woody vegetation will ultimately dominate (Glitzenstein et al. 2003, 2012). Therefore, while Bachman's sparrows may find older burns suitable on sandhill habitat, it is still important to maintain higher burn frequencies for long-term habitat suitability.

Burn interval affected reproductive status of Bachman's sparrows in longleaf forests in Alabama (Tucker et al. 2006). They found that 28% of territorial male Bachman's sparrows in stands that were ≤3 burn intervals were unpaired compared 50% unpaired in stands with a 4-year burn interval. The entire study site had a burn interval less than 3 years and my results of paired percentages were similar to Tucker et al. (2006) percentages for stands that were ≤3 burn intervals. Tucker also reported 52% of Bachman's sparrows had fledglings in stands with ≤3 year burn intervals versus only 20% in stands with a 4 year burn interval, I found similar results. These results suggest that Bachman's sparrows on frequently burned sandhill have similar reproductive success to other habitats, despite larger home ranges in some years.

Survival Rates

Survival rates were higher than previous estimates of male Bachman's sparrows using mark-recapture/re-sight methods (Krementz and Christie 1999, Cox and Jones 2007), but similar to other studies using radio-tagged Bachman's sparrows (Stober and

Krementz 2000, Seamen and Krementz 2000). Stober and Krementz (2000) reported survival rates of 0.905 (95% CI = 0.779–1.02) for 2 May–9 August 1995 and 0.882 (95% CI = 0.729–1.04) for 10 May–25 July 1996. Stober and Krementz's (2000) estimates, however, included radio-tagged females and 3 out of 4 mortalities in their study were female. Similarly, Seamen and Krementz (2000) estimated a survival rate of 0.80±0.11 from 20 April–26 July 1997 and all three mortalities were again female. Because only female Bachman's sparrows incubate eggs, they are thought to have lower survival rates (Dunning 1993). My survival rate estimates do not include females and therefore only represent estimated survival rates of territorial males. The survival rates of adult and juvenile Bachman's sparrows outside the breeding season are unknown. Most Bachman's sparrow adult mortality is thought to occur after the breeding season (Pulliam et al. 1992). However, my 2010 survival rates extend through mid-November and include no mortalities on male adult or juvenile Bachman's sparrows.

No known mortalities were caused by the prescribed burns. Bachman's sparrows remained in the burn unit for the duration of the burn (sparrows escaped the flames by going high into the trees or perhaps into gopher tortoise burrows). Immediately following the burn, many sparrows were observed resuming normal activities in their home range (singing and defending territories); this further illustrates that Bachman's sparrows are well adapted to fire dependent ecosystems.

Using a simulation model, Liu el al (1995) found that sparrow population dynamics were sensitive to juvenile survival. They assume that juvenile dispersal involves extra mortality risks, therefore breeding season burns may cause more juvenile mortality. I observed no negative effects of breeding season burns on fledgling or juvenile Bachman's sparrows. It appears my radio-tagged juveniles (of unknown development level) were relatively un-phased by the prescribed burns. The two juveniles radio-tagged in 2010 survived the burn and were seen in groups with other juveniles post-burn. Both juveniles remained in the burn unit for 7 days post-burn (Table 2.1). One juvenile later moved to an unburned area and the second juvenile eventually returned to its original capture area after 39 days. Pre-burn MCPs of juvenile movements were larger than post-burn MCPs indicating that breeding season burns may not drastically affect movements by juvenile Bachman's sparrows as long as suitable habitat is accessible. Furthermore, some adult radio-tagged Bachman's sparrows were seen with fledglings hours before the burn and were seen again with their fledglings for several days post-burn.

Burn Month Effects

Burning during the lightning season (May-August) is a subject of concern for management of Bachman's sparrows due to potential impacts on site abandonment, breeding productivity, and survival (Cox and Jones 2007, Tucker et al. 2006, Seamen and Krementz 2000). Perkins et al. (2009) found that burns conducted after July 28 were more detrimental for Florida grasshopper sparrows (*Ammodramus savannarum floridanus*), but that Bachman's sparrow densities increased in areas with summer burns conducted before June 20. Shriver and Perkins (1999) found Bachman's sparrow densities increased in densities after June fires but not after July fires.

Another study found that Bachman's sparrows abandoned sites after breeding season burns conducted in early May and mid-late June (Seaman and Krementz 2000). Overall, Cox and Jones (2007) found that breeding season burns were not as detrimental as reported and suggest the burns are helpful to maintain habitat. Cox and Jones (2009) did however report that burns conducted after mid-June seemed to be more disruptive to Bachman's Sparrows and suggest the need for further study.

I saw no evidence that the burn conducted on July 23, 2010 negatively impacted radio-tagged male Bachman's sparrows or would have inhibited their ability to produce another brood. In fact, most Bachman's sparrows returned to their original home range or set up new territories in ample time, considering that Haggerty (1988) found egg laying for Bachman's sparrows to occur as late as August 26 in Arkansas. The high percentage of sparrows that returned to their home ranges in 2010 in my study was consistent with Cox and Jones (2007) findings that 75% of banded males monitored remained in their home ranges after breeding season burns. It is unclear if my radio-tagged sparrows that relocated within the study site in 2011 (post-burn) would have eventually returned to their home ranges after the vegetation recovered. These sparrows were tracked from 26, 13, 5, and 28 days post burn until transmitter failure and sparrows in 2010 took a median of 24 days to return post-burn. Additionally, the drought in 2011 likely would have slowed recovery time of vegetation post-burn and may have postponed return.

After a burn conducted on July 21, 2011, 1 out of 4 Bachman's sparrows abandoned the study site after 2 days. This includes a Bachman's sparrow that maintained two simultaneous home ranges in two different burn units. This Bachman's sparrow's home range was burned on July 21, 2011 at which point the sparrow moved to the second home range until abandoning the study site after the burn conducted on August 5, 2011. In the August 5, 2011 burn, 3 out of 5 abandoned the study site after 0, 12 and 5 days. However, my latest burn conducted on August 10, 2011 may have had a negative effect as all three sparrows abandoned the study site after 0-1 days. This however, could also be attributed to a larger distance from an unburned edge (Figure 2.1) (Table 2.1).

I am confident that post-burn abandonment of the study site was not a function of transmitter failure as these transmitters had an average of 26.4 days until reaching average battery life of 146.6 days SD = 4.7. Also, it is unlikely that the transmitters would have coincidently failed the day after the burns were conducted.

It is possible that burns conducted in mid-August would cause site abandonment and potentially cut the breeding season short, but it is likely that the majority of sparrows would have completed clutches by mid-August; Haggerty (1998) found that 85% of clutches were started in May, June, and July. It should be noted however, that my small sample size for Bachman's sparrow in August burns (*n*=7) is likely inadequate to fully assess the effects of August burns (Table 2.1). Moreover, I suspect that these results are more likely a function of available habitat surrounding the perimeter of the burn than the date of the burn. Unfortunately, the burns conducted later in the breeding season were also associated with larger distances to suitable habitat (Figure 2.8).

Post-burn Movements among Years

The difference in post-burn return times of Bachman's sparrows observed between my study and others (Cox and Jones 2009, Seamen and Krementz 2000) implies that Bachman's sparrows may be sensitive to not only the fire size but also the recovery times of vegetation immediately post-burn. Seamen and Krementz (2000) stipulate that burning decreases the potential for Bachman's sparrow reproduction on burned stands, because sparrows did not return to the burn area until 50-100 days post-burn. Cox and Jones (2007, 2009) however, found that Bachman’s sparrows returned to their home ranges quickly post-burn, but their study was conducted on sites with diverse native ground-cover and relatively fertile soils managed with frequent fires (1-2 years). While my study site was also managed with frequent fires (~2 years), post-burn vegetation recovers more slowly on my sandhill site due to its lower fertility xeric soils. Three of the Bachman’s sparrows in 2010 in my study returned to original home ranges after ≤25 days and one sparrow never left his home range post-burn. It is unknown if my radio-tagged sparrows that relocated within the study site in 2011 (post-burn) would have eventually returned to their home ranges after the vegetation recovered; these sparrows were tracked from 26, 13, 5, and 28 days post burn until transmitter failure. Additionally, the drought in 2011 likely would have slowed recovery time of vegetation post-burn and may have postponed return. Cox and Jones (2009) found that Bachman’s sparrows had a lower survival rate post-burn in 2007 during a severe drought, but they say that this could be due to decreased detection probability in that the drought could have affected sparrow’s post-burn use of their study sites. Perhaps the lower density of sparrows in burned stands documented by Stober and Krementz (2000) could be attributed to the longer burn interval (3-5 years) present on their study site versus the shorter burn interval (< 2 years) in my study and Cox and Jones (2007, 2009). Vegetation in pine forests with burn intervals > 2 years results in hardwood dominance of the groundstory (Glitzenstein et al. 2003, Glitzenstein et al. 2012) Hardwood dominance competes with grasses and forbs preferred by Bachman’s sparrows (Haggerty 1998). This suggests that post-burn recolonization of pine forests burned infrequently, as found by Stober and Krementz

(2000), may be a function of both vegetation composition at the time of the burn and its relation to the time needed for suitable habitat to recover. My data, and that of Cox and Jones (2009), suggests that if frequent fire is applied Bachman's sparrows recolonize habitats in a matter of weeks and sometimes days. My data further supports the need for frequent fire to maintain Bachman's sparrow habitat. (Tucker et al. 2006)

Scale of Burn

While several studies have examined effects of fire frequency and season on Bachman's sparrows, the effects of fire size on Bachman's sparrows remains relatively unknown. I used distance to edge of a burn as a surrogate for burn size. Bachman's sparrows were sensitive to distance to suitable habitat. Individuals with home ranges near or overlapping the edge of the burn moved less and were more likely to return to their home range after the burn. I suspect that fire size is important but the threshold at which Bachman's sparrows are negatively affected remains unknown. Cox and Jones (2009) found that Bachman's sparrows were well-adapted to relatively small-scale fires (<100 ha). In my study, the largest burns were closer to 200 ha, but bordering compartments burned in the same week totaled 346 ha.

The spatial pattern of a landscape is thought to dictate the dispersal distance for colonizing organisms (Turner et al. 1997). In my study, Bachman's sparrows with limited access to suitable habitat left the study site (Figures 2.4, 2.5, 2.6). Seamen and Krementz (2000) also found that availability of suitable habitat around the burned stand affected the distance of post-burn movements. While this suggests that fire size impacts Bachman's sparrows dispersal movements, it is unknown if larger movements have negative impacts on their survival or reproduction. Other studies have speculated that larger, more frequent movements by Bachman's sparrows are associated with higher mortality (Seamen and Krementz 2000, Liu et al. 1995, Pulliam et al. 1992), but (to my knowledge) this has yet to be shown conclusively. Several of my radio-tagged Bachman's sparrows made large distance movements before any burns were applied; these sparrows not only survived, but most were also eventually reproductively successful (later observed with fledglings).

I expect that Bachman's sparrows are making even larger movements than reported here as some disappeared from the study site prior to the prescribed burns. Haggerty (1988) found that only 20% of males showed site fidelity and Cox and Jones (2009) observed many sparrows making long distance movements to newly burned areas. This suggests that long distance movements to adjust to shifting habitat suitability are common at least in some habitats. More studies on survival and reproductive success post-burn are needed to determine if fire size negatively effects Bachman's sparrows' population.

Determining the "right" burn extent for managing Bachman's sparrows is a complex matter and may be dependent upon a myriad of factors including distance to nearest suitable habitat, conspecific density of nearest suitable habitat, burn month, previous burn management, and drought conditions that affect post-burn vegetation growth. Although studies conducted at larger fire sizes (>200 ha) are needed, I currently recommend that land managers diversify both season of fires and juxtaposition of habitat if they want to provide Bachman's sparrows with suitable habitat within their management area. Burning at various seasons will allow managers to maintain larger scale burns and fire frequency while providing Bachman's sparrows forced to leave areas that are burned during the breeding season access to suitable habitat. Winter burns will provide habitat during summer for sparrows forced out of home ranges with breeding season fires (Gobris 1992, Dunning 1993). Bachman's sparrow densities on management areas may be increased by maintaining greater amounts of breeding season habitat. Consideration of the distribution of suitable habitats when planning burning would help guide the scale of burn. For instance, on my sandhill study site, a few burn units contained a significant portion of the selected habitat (older sawtimber longleaf stands). Burning these burn units significantly reduces suitable habitat. By adjusting burn unit boundaries to increase the heterogeneity of burned versus unburned suitable habitats would provide Bachman's sparrows with habitat options post-burn.

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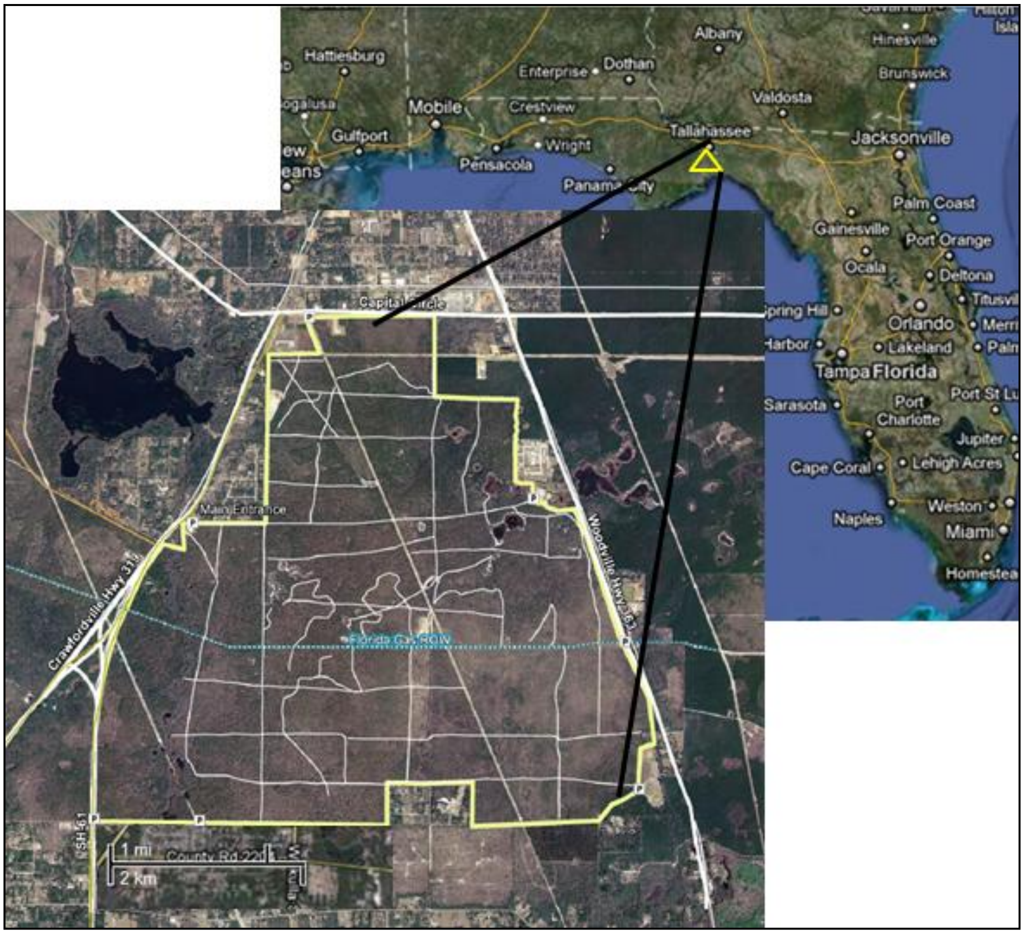


Figure 2.1. Study area (outlined in yellow) on Munson Unit, Apalachicola National Forest.

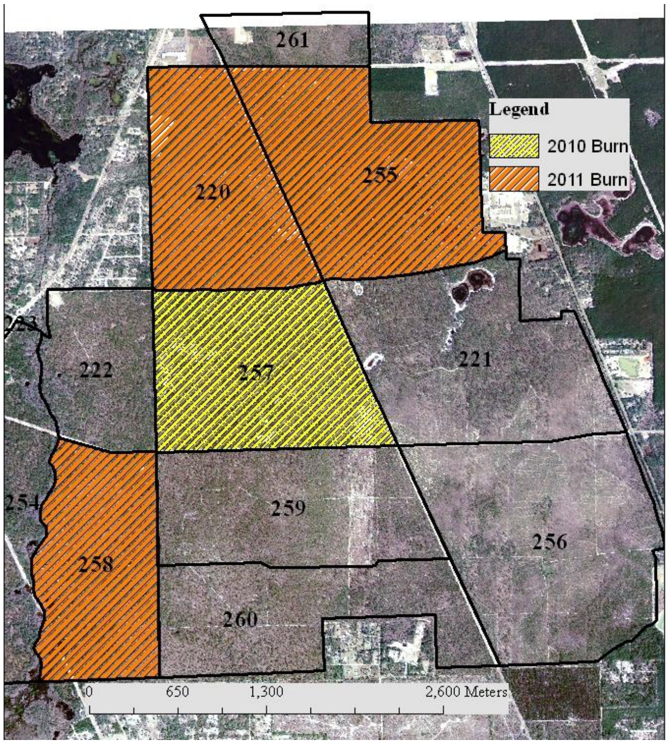


Figure 2.2. Burn unit 257 (179 ha) was burned on July 23, 2010, burn unit 258 (139 ha) was burned on July 21, 2011, burn unit 255 (204 ha) was burned on August 5, 2011 and burn unit 220 (142 ha) was burned on August 10, 2011, Apalachicola National Forest.

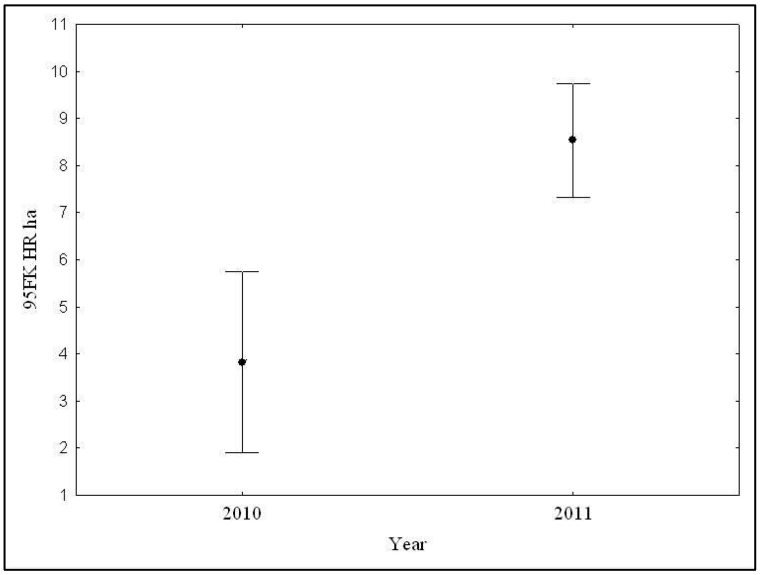
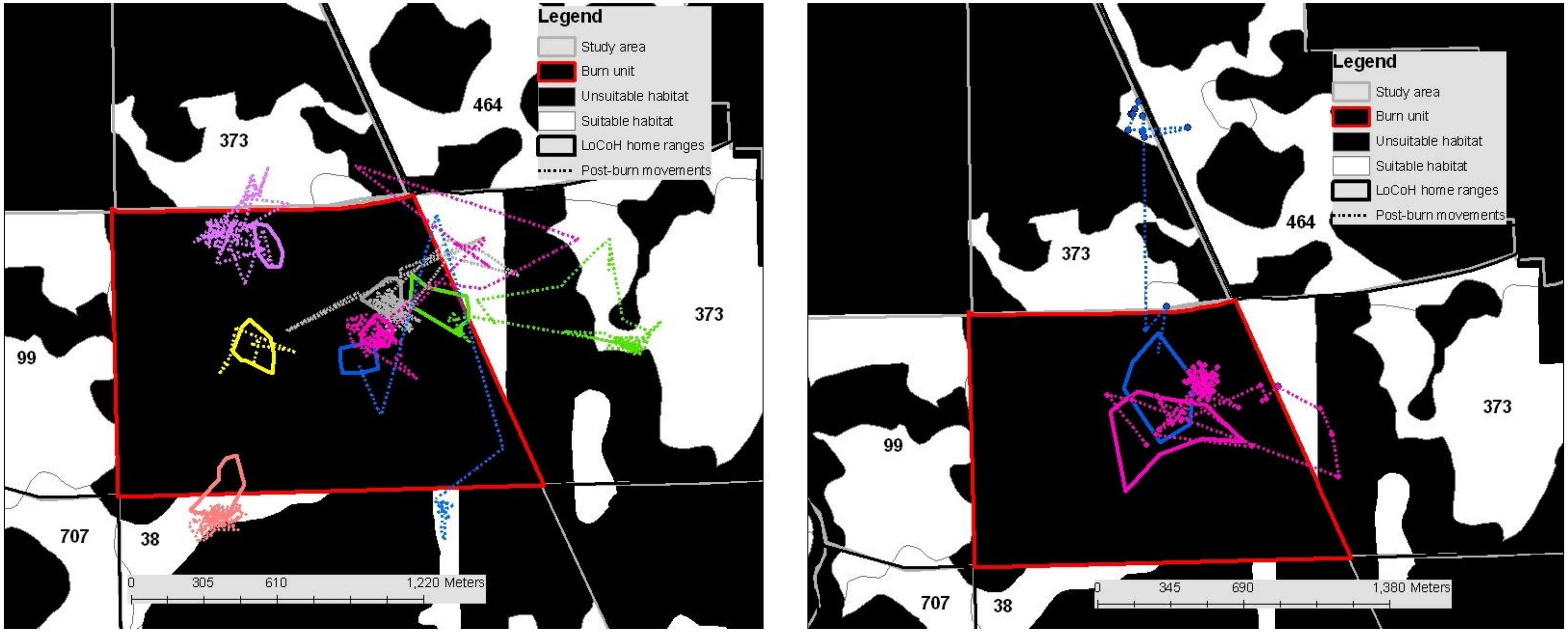


Figure 2.3. Home range size and associated 95% CI of male Bachman's sparrows using 95% fixed kernels, 2010-2011, Apalachicola National Forest, Florida.



A

B

Figure 2.4. Bachman's sparrows adult (A) and juvenile (B) pre-burn 95% a-LoCoH home ranges and post-burn movements for burn unit 257 burned on July 23, 2010. Numbers surrounding burn unit indicate days since last burn of habitat. White areas represent saw timber stands (suitable habitat) and black areas represent forest types that were not suitable.

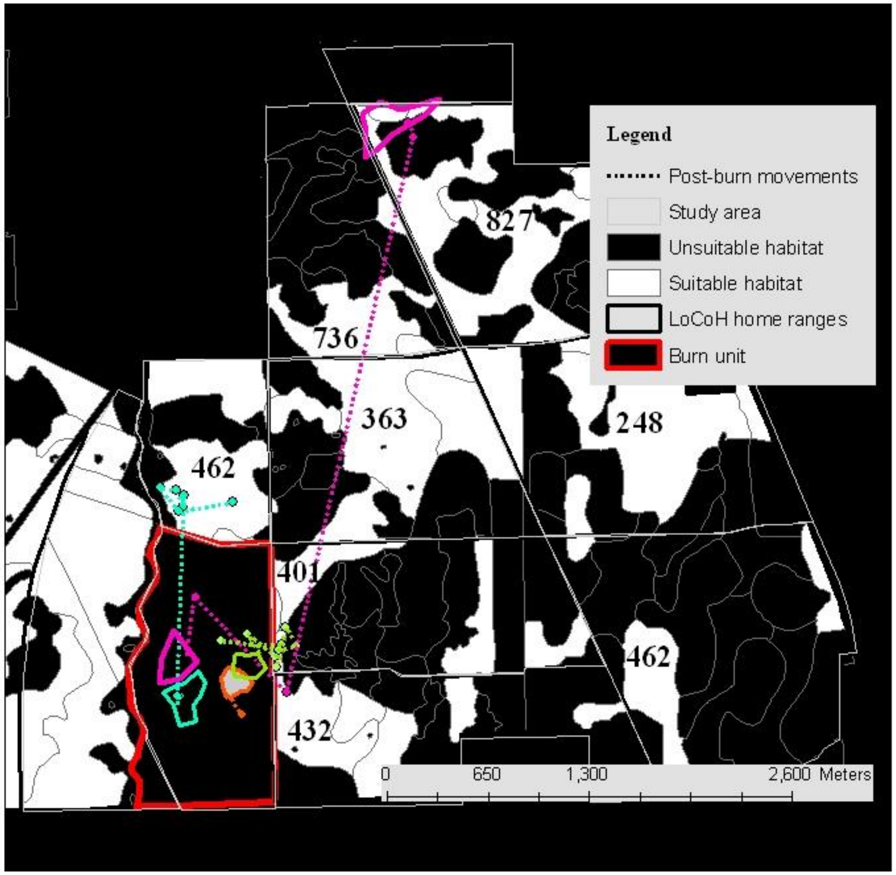
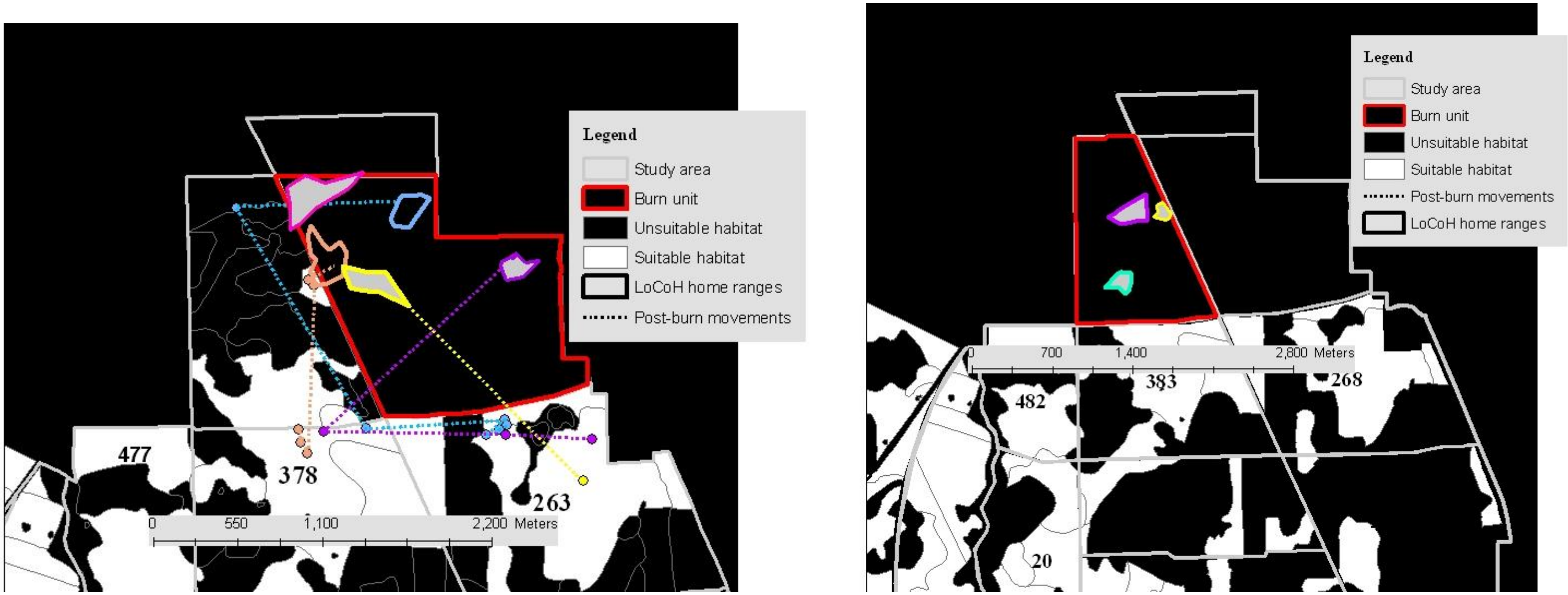


Figure 2.5. Bachman's sparrow pre-burn 95% a-LoCoH home ranges and post-burn movements for burn unit 258 burned on July 21, 2011. Numbers surrounding burn unit indicate days since last burn of habitat. White areas represent saw timber stands (suitable habitat) and black areas represent forest types that were not suitable. Grayed-in home ranges represent Bachman's sparrows that abandoned the study area post-burn.



A

B

Figure 2.6. Bachman’s sparrows pre-burn 95% a-LoCoH home ranges and post-burn movements for burn unit 220 burned on August 5, 2011 (A) and burn unit 255 burned on August 10, 2011 (B). Numbers surrounding burn unit indicate days since last burn of habitat. White areas represent saw timber stands (suitable habitat) and black areas represent forest types that were not suitable. Grayed-in home ranges represent Bachman’s sparrows that abandoned the study area post-burn.

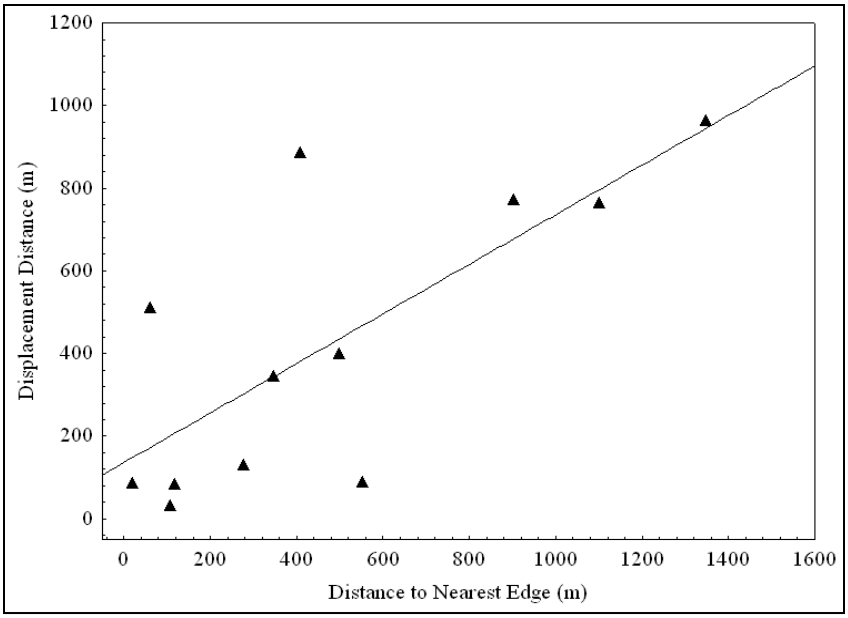


Figure 2.7. Relationship of Bachman's sparrows' centroid distance to nearest edge of burn and post-burn displacement distance.

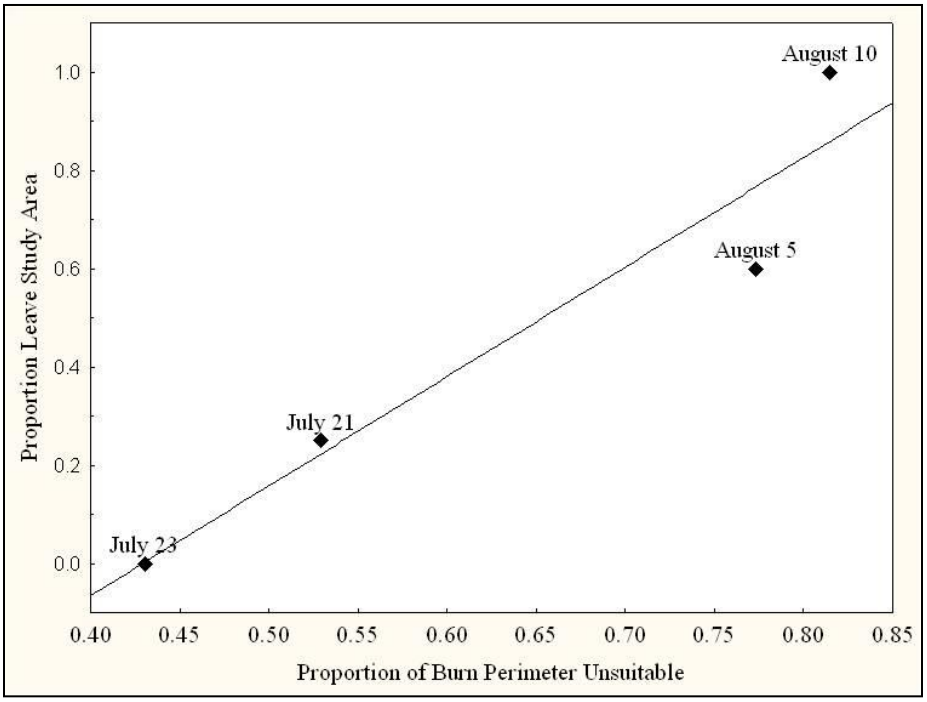


Figure 2.8. Proportion of Bachman's sparrows that abandoned the study area post-burn for each burn date versus the proportion of unsuitable habitat surrounding the burn unit perimeter.

Table 2.1. Post-burn movements of male and juvenile Bachman's sparrows. Juveniles are indicated as JV in Bird ID. Numbers in parentheses indicate order in which post-burn movements occurred. Shaded areas indicate different burns.

Bird ID	Days before movement	Returned to original HR	Days until returned to original HR	New HR outside burn	Erratic movements	Left study area	Days until left study area	Days active transmitter	Burn unit	Burn date
11A	4	Yes (2)	24		Yes (1)			136[d]	257	7/23/2010
18A	0			Yes				141[d]	257	7/23/2010
22A	0	Yes	24					135[d]	257	7/23/2010
25A	0	Yes (2)	102	Yes (1)				151[d]	257	7/23/2010
26A	0			Yes (2)	Yes (1)			112[d]	257	7/23/2010
28A	N/A	Stayed	0					76[a]	257	7/23/2010
29A	0	Yes (2)	25		Yes (1)			149[c]	257	7/23/2010
JV_12A	7	Yes (2)	38		Yes (1)			134[d]	257	7/23/2010
JV_20A	7			Yes (1)		Yes (2)	39	51	257	7/23/2010
47A	1			Yes				152[c]	258	7/21/2011
49A	1			Yes				149[c]	258	7/21/2011
52A	1					Yes	2	128	258	7/21/2011
43A[b]	0				Yes (1)			121	258	7/21/2011
43A[b]	1					Yes (2)	0	121	255	8/5/2011
36A	1				Yes (1)	Yes (2)	12	125	255	8/5/2011
38A	0				Yes (1)	Yes (2)	5	118	255	8/5/2011
48A	1			Yes (2)	Yes (1)			148[c]	255	8/5/2011
50A	1			Yes				153[c]	255	8/5/2011
54A	0					Yes	1	126	220	8/10/2011
44A	0					Yes	0	128	220	8/10/2011
16B	0					Yes	0	136	220	8/10/2011

[a]Dropped transmitter after 76 days [b]Had two home ranges in two different burns [c]transmitter died [d]stopped tracking

Table 2.2. Fate of Radio-tagged male Bachman's sparrows and two juveniles in a longleaf sandhill forest (Munson Unit, Apalachicola National Forest) 1 June–November 15 2010 and 1 April–15 September 2011.

Year	Treatment	Survived	Censored	Mortality	Exposure days
2010	Burned	7	2	0	1136
2010	Not burned	1	0	0	144
2011	Burned	4	7	0	1486
2011	Not burned	4	9	1	1307
Total		16	18	1	4073

CHAPTER 3

HABITAT SELECTION OF BACHMAN'S SPARROW (*PEUCAEA AESTIVALIS*) ON A SANDHILL LONGLEAF PINE FOREST[2]

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[2] Brown, S.K., W.E. Palmer, and R.J. Cooper. To be submitted to TheCondor.

ABSTRACT

Sandhill longleaf pine ecosystems are important habitat for Bachman's sparrows (*Peucaea aestivalis*). Studies of Bachman's sparrows on sandhill are limited to areas with longer burn intervals. To assess habitat selection on a sandhill forest managed with frequent fire, I radio-tagged 31 male Bachman's sparrows in northern Florida during 2010-2011. Mature, open longleaf pine stands were selected for home ranges above other habitat types: sapling stands, regeneration areas, and oak hammocks. Within home ranges, saw timber stands were selected above other habitats. Post-burn sparrows were located in saw timber stands 90% of the time. Regeneration areas and older sapling stands were used infrequently by sparrows despite frequent fire and similar ground cover, possibly due to greater tree-stem density. Without thinning of sapling stands it may take 6 decades before habitat is suitable for this species. Frequent burning of old growth forests is critical to sustain Bachman's sparrows on sandhill.

INTRODUCTION

Bachman's sparrow is a resident of pinelands in the Southeastern U. S. traditionally associated with mature frequently-burned longleaf pine forests (Stoddard 1978). Since the 1930's Bachman's sparrows have experienced a range contraction as northern populations disappeared (Dunning and Watts 1990). Further, populations in the southeastern core of its range have declined (Sauer et al. 2011) and have been classified as near threatened (Dunning and Watts 1990, Haggerty 1988, IUCN 2008). Population declines are likely a result of habitat loss due to a widespread decline in early successional habitats (Brennan et al. 1998). Further, extensive changes to forest structure from fire suppression and a shift to short-rotation pine silviculture has resulted in a loss of open pine and oak savannas (Brennan et al. 1998).

Bachman's sparrow habitat has been described as relatively thick herbaceous groundstory with a hardwood shrub community < 1 m in height and less vegetation above 1 m from the ground. Bachman's sparrows appear to be sensitive to development of vegetation above 2 m and avoid sapling stages of pine regeneration (Dunning and Watts 1990, Haggerty 1998). In longleaf wiregrass communities, habitat is provided by relatively open pine stands that are frequently burned (Stoddard 1978). Regeneration areas (e.g., clear cuts) provide habitat until 5-7 years post-planting, when pine regeneration becomes too thick for sparrows (Dunning and Watts 1990, Stober and Krementz 2006).

Sandhill ecosystems occur across the Southeastern U.S. and are considered a conservation priority in central and north Florida where approximately 300,000 ha remain (Florida Fish and Wildlife Conservation Commission 2005). A significant portion of remnant intact longleaf pine ecosystems occurs on sandhills, increasing their conservation value. These xeric sites are characterized by widely-spaced longleaf pine and a diverse ground cover and as such are important habitat for Bachman's sparrows. Frost (1993) reported sandhill habitats were historically burned on a 1 to 3 year fire frequency. In pine ecosystems fire frequency drives community structure and composition (Glitzenstein et al 2003, Glitzenstein et al. 2012). Frequent fire promotes herbaceous ground cover, while fire suppression permits the development of shrub-hardwood communities. The ecological condition of sandhill ecosystems is often threatened by a lack of fire due to turkey (*Quercus laevis*) and post oak (*Quercus stellata*.) intrusion (Glitzenstein et al. 2003).

Studies of Bachman's sparrow habitat use in sandhill ecosystems have occurred in western and north eastern South Carolina (Dunning and Watts 1990, Seamen and Krementz 2000, Stober and Krementz 2006). At the time of these studies fire frequency in mature pine stands was relatively long (3 to 5 year return interval) except in areas managed for red-cockaded woodpeckers (*Picoides borealis*), which were burned during the summer on a 3 to 4 year fire rotation (Stober and Krementz 2006). Studies of Bachman's sparrows in areas of higher fire frequency (1 – 3 years) have occurred on the Wade Tract in Georgia (Cox and Jones 2007), which is part of a contiguous old growth longleaf site without the regeneration areas often found on public lands. Bachman's sparrows are associated with various age classes of pine forests (Dunning 2006). Therefore habitat selection of various pine forest age classes may be different on sites that are frequently burned. To date there has not been a habitat use study of Bachman's sparrow on a true sandhill site with high fire frequency.

Therefore I studied habitat selection of radio-marked Bachman sparrows on a sandhill site in northern Florida. The Munson unit of the Apalachicola National Forest is a longleaf sandhill habitat that has been burned on a 2 year basis since 2005, and prior to that on a 3 to 4 year fire frequency. This is the only study to my knowledge that has assessed habitat use using selection analyses of radio-marked sparrows. I was specifically interested in assessing if high fire frequency of different age class pine stands improved their suitability as habitat for sparrows.

METHODS

Study site

The study site was located in the Apalachicola National Forest in Leon County, Florida, on the Munson Sand Hill Burn unit between Crawfordville Highway (U.S. 319) and Woodville Highway, south to L. L. Wallace road (Figure 2.1). The northern, north western, and southern boundaries of the study site were bordered by developed areas. The area was treated and established in 2006 as part of Tall Timbers Research Station's Upland Ecosystem Restoration Project (UERP), and has been burned at intervals of less than two years with a fire size of 100 to 250 ha.

I classified habitats on the study site using USDA Forest Service stand attributes including forest type (species), stand condition (e.g., size, quality and density), and date the stand was planted (Figure 3.1). Forest stand types included mature longleaf saw timber planted between 1908 to 1943, longleaf pole timber planted between 1953 to1962, longleaf sapling planted prior to 1980, longleaf sapling stands planted after 1980, regeneration (clear cuts and shelterwood cuts), and oak hammock. Longleaf saw timber stands were relatively open and had intact wiregrass (*Aristida stricta*) native ground cover typical of sandhill habitats (Myers 1990). Saplings planted before 1980 were 45 years old. Saplings planted after 1980 ranged from 20 to 29 years of age. Clear cuts were previously 40-year-old, slash pine (*Pinus elliottii*) plantations replanted to longleaf and were primarily located in burn units 259 and 256 (Figure 3.1). Regeneration also occurred in open shelterwood cuts and were scattered among the longleaf saw timber stands. Longleaf pole timber stands were not thinned and had significant hardwood in the understory and midstory. Pole timber stands occurred in two burn units and were not well distributed across the study site. Oak hammock ranged from true hammock to isolated pockets of hardwood hammock embedded in the longleaf uplands. All habitats were burned on a 2-year rotation, mostly during May through August, with occasional winter burns in October through January.

Vegetation Sampling

I randomly established 7 500-m radius sampling areas (79 ha) in 2011 to assess vegetation conditions on the study site. These sampling areas covered ~20% of the study area. A total of 150 plots was systematically-placed along parallel transects bisecting the sampling areas. Data was collected at sampling points, which served as plot centers, approximately every 48 m along the parallel transects (Figure 3.2). At each plot, ground cover vegetation was measured using a modified Daubenmire method by vegetation form (% shrub, grass, vine, forbs, etc.) as well as maximum height of shrub or hardwood (Herrick et al. 2005). Categories included grasses and grass-like species, forbs, vines and shrubs, palmetto, and legumes. A meter stick was used to estimate percent bare ground and litter. Also basal area (m^2/ha) of hardwoods and pine was measured at every 3rd point. Each sampling point was assigned a habitat type and days since burn in ArcMap (ESRI 1998). Vegetation conditions were summarized by habitat type and days since burn to help explain habitat selection results.

Radio-tagging and Telemetry

Male Bachman’s sparrows were captured using target netting techniques where recorded aggressive calls are played near mist nets (Jones and Cox 2007). Only male Bachman’s sparrows were captured as females are less aggressive and consistently successful female Bachman’s sparrow capture techniques have yet to be developed. I did not attempt to catch sparrows when ambient temperature exceeded 26 C to avoid causing harm (Jones and Cox 2007). Males were fitted with a uniquely numbered U.S. Fish and Wildlife leg band along with three color-bands. I attached model NBQT-3-2 nano-tags radio-transmitters (Lotek Company, Ontario, Canada) with a 12 hr active cycle. Nano-tags weigh 0.64 g (~3% of Bachman's sparrow body weight) and have a battery life of approximately 4.5 months. I custom-modified the tags using a method similar to that used by Stober and Krementz (2006) and attached them around the thigh using a method by Rappole and Tipton (1991).

Radio-tagged Bachman's sparrows were located at least four times per week. I used the homing method (White and Garrott 1990) using a handheld 3-element Yagi antenna and a Lotek digital receiver (Model SRX400A; 164-168mz range). Sparrow locations were recorded using a Trimble (Geo XT) GPS and later transferred to ArcMap (ESRI 1998) using a Universal Transverse Mercator projection (zone 16, North American datum 1983).

Often the sparrows were located visually, but I frequently obtained a GPS point when I was confident the sparrow was within 5m (judged by signal strength). I saw no evidence that tracking Bachman's sparrows or even flushing disturbed normal behaviors.

Habitat Selection

I assessed habitat selection using compositional analyses (Aebischer et al. 1993) and Resource Selection software (Leban 1999). Habitats included those described in the study site section. I compared habitat selection at two levels. Habitats available to each sparrow within their pre-burn 95FK home ranges (Chapter 2) was compared to that available on the entire study area, or 2nd order selection (Johnson 1980). I used the overall study site as available rather than an MCP composed of all sparrow locations because based on movements (Chapter 2) all habitats on my study site were theoretically available to sparrows at all times. I also compared habitat use within each Bachman's sparrow's home range to what was available in their home range, or third order selection (Johnson 1980). For 3rd order selection, I did not include the habitat type pole timber because it was only used by 2 sparrows, which was insufficient use to judge selection at this level (Aebischer et al. 1993). In these cases proportions of use were recalculated without the pole timber habitat type.

To estimate home range sizes I determined the number of telemetry locations needed by plotting 95FK home range sizes by the sample of telemetry locations. Home range size remained consistent if 15 or more locations were used to determine home ranges. Therefore, I included Bachman's sparrows with 15 or more locations in home range analyses. There was no correlation between number of telemetry locations and home range size ($r = 0.22$, P <0.24) when using these criteria.

Habitat use selection analyses assess evidence for habitat selection for sparrows which have already selected a home range. Prescribed burning provided an opportunity to assess habitat selection of sparrows after forced to select a new home range due to a temporary loss of cover. If habitats used post-burn were selected in similar proportion to those prior to the burn it would provide support for selection results. If habitats were used at random after sparrows were forced to leave their home ranges, then that would cast doubt on the habitat selection analyses. Therefore, I determined habitats used post-burn and compared them to proportions available on the study site. The entire study site was used as sparrows post-burn often made large movements before selecting a new home range or returning to their prior home range (Chapter 2).

Point count surveys were conducted on 56 GPS point count locations within the study site (pre-established in 2010 for the UERP project) (Figure 3.3). Each point count was visited a total of 5 times: 4 visits from April 4 through June 7, 2010 and 1 visit from May 17 through May 20, 2011. Surveys began at sunrise and were completed no later than 4 hours after sunrise according to standard point count protocol (Bibby et al. 1992). The number of Bachman's sparrows seen or heard within a 100 m radius for a 5 minute duration was recorded. Surveys were performed in all weather conditions except when rain and thunderstorms occurred. Weather variables at the time of the survey were recorded including barometric pressure, wind speed, and cloud cover.

I calculated the proportion of each forest stand type included in each 100 m radius point count circle and compared this to the total number of Bachman's sparrows recorded for each point count circle.

RESULTS

I monitored 8 radio-tagged adult Bachman's sparrows in 2010 during June - November and 24 Bachman's sparrows during March - August 2011 (Chapter 2). Bachman's sparrows (*n* = 31) were located an average of 36.4 times (Range = 15 to 81) prior to burning the stand. I monitored 18 sparrows post-burn an average of 20.0 locations (SE = 6.2). Three sparrows disappeared from the study site post-burn and two sparrows were located a total of 1 time each before leaving the study site.

Habitat Selection

Habitats were not used at random at 2nd order (X^2 = 86.3, df = 5, P < 0.001) or 3rd order (X^2 = 18.6, df = 4, P < 0.001). For 2nd order selection longleaf saw timber stands were selected > sapling (pre-1980) > regeneration > oak hammock > pole timber > sapling (post-1980). Longleaf saw timber stands were selected for home ranges more than all other habitat types (Table 3.1). Sapling stands (pre-1980) were selected more than sapling (post-1980), pole timber stands, and oak hammock.

Longleaf saw timber stands were selected more than other habitat types by Bachman's sparrows within their home ranges and > Oak Hammock > sapling (post-1980) > sapling (pre-1980) > regeneration. Longleaf saw timber stands were used more than all other habitat types (Table 3.2).

Bachman's sparrow post-burn locations were ranked longleaf saw timber > regeneration > pole timber > saplings pre-1980 > oak hammock > sapling stands post-1980. Bachman's sparrow post-burn locations were in longleaf saw timber stands 90% of the time. This habitat type made up 45.3% of the study site (X^2 = 292.8, 5 df, P <0.001). Use to availability ratios were 2 for longleaf saw timber, but less than one for the remaining habitats: 0.35 for regeneration stands, 0.25 for pole timber stands, 0.17 for sapling planted before 1980, 0.11 for oak hammocks and 0.06 for sapling planted after 1980.

Point count data in relation to habitat types supported my habitat selection analyses. I assumed there was no difference in detection probabilities across habitat types within the 100-m radius point counts. Number of Bachman's sparrows heard per point was correlated with the percent of selected habitats for home ranges (longleaf saw timber and saplings pre-1980) within the 100-m radius surrounding the point count. I counted nearly 3- fold more Bachman’s sparrows in areas composed of more than 75% selected habitats, than those with < 0.75% (Figure 3.4). As the percent of the top two selected habitats increased, so did the number of Bachman’s sparrows heard per point ($r = 0.28$, $P < 0.04$). Similarly, as the percent of the 3 least selected habitats increased the number of Bachman’s sparrows counted declined ($r = -0.26$, $P < 0.06$).

Vegetation Conditions

The ground story vegetation on my study site was relatively consistent among habitat groups but with important although subtle differences. Ground cover was composed of grasses, primarily wiregrass, and hardwood shrubs and vines including oak resprouts, runner oak (*Quercus elliotii*), and sparkleberry (*Vaccinium* spp.). Other common species included bracken fern (*Pteridium aquilinum*). Forbs were relatively sparse in all habitat types. Sparkleberries were most prevalent in open saw timber stands and regeneration areas and rarely found in sapling stands.

Among groups, ground cover was densest in longleaf saw timber stands and regeneration areas and sparsest in sapling stands and oak hammocks. Litter accumulation was also greater in oak hammocks and sapling stands (Table 3.3). Regeneration areas, along with saw timber stands, had the highest amount of woody vegetation. Also, percent standing dead woody vegetation was greater in regeneration areas (1.1%) versus longleaf saw timber stands (0.4%), saplings stands (0.0-0.05%) and oak hammocks (0.1%).

Vegetation conditions were dependent on the particular burn unit, as well as habitat type, because the Forest Service manages on a burn unit basis. Pine basal area was similar in open saw timber stands, on average, compared to shelter wood regeneration areas, and oak hammock. Sapling stands had the greatest amount of pine basal area (Table 3.4) which was consistent among burn units. Hardwood basal area was greater in regeneration areas followed by saw timber stands. The high amount of hardwood in longleaf saw timber was mostly due to higher amounts of hardwood burn units (255 and 258 versus 257, 220 and 255).

DISCUSSION

Frequently burned saw timber stands were selected for Bachman's sparrow home ranges. This result was strengthened by observing selection of saw timber stands by Bachman's sparrows forced out of their home ranges post-burn. Further, my point count data collected over 2 years also substantiated higher abundance of sparrows in this habitat type than other habitats available on the study site. Raw point count data was used because previous studies have shown that detection probability is 100% within 100m. However singing rates of Bachman's sparrows may be lower in areas with fewer nearby conspecific males (Brown et al. unpublished manuscript). Longleaf saw timber stands had intact native ground cover with a significant shrub component which produced soft mast during the summer months (e.g., blueberries). Frequent use of prescribed fire combined with the open pine canopy created text book habitat conditions for Bachman's sparrows (Dunning 2006, Haggerty 1998, Stoddard 1978) including a relatively dense groundstory and a sparse but present understory > 1 m in height.

Habitat use results were mixed for younger stands of longleaf. Longleaf planted prior to 1980 (45 years of age) were the second highest ranked habitat type for home ranges, but were ranked next to last at the 3rd order. The older sapling stands were included in home ranges of Bachman's sparrows as the ground cover conditions in these stands were beginning to improve as stands aged but apparently did not provide suitable habitat within their home ranges as they were used infrequently overall. Longleaf in these stands had greater stem density than in saw timber or seed tree cut areas and were apparently less suitable for Bachman’s sparrows than the more open mature longleaf saw timber stands. Sapling stands planted after 1980 were relatively dense with relatively high plant litter and sparse ground cover. This habitat type was ranked last at the 2nd order of selection and next to last at the 3rd order. Stober (1996) reported that Bachman’s sparrows rarely used stands 20 to 35 year old middle-aged pine stands. Post-burn locations by Bachman’s sparrows showed little use of these stands and point count data indicated that sparrow abundance was overall lower in these stands relative to saw timber stands. Basal area of these stands (= 36 m^2/ha) was high relative to the more open saw timber stands, but not so dense as to prohibit understory development. Haggerty (1998) reported unoccupied pine stands had higher stem density than occupied sites, higher litter cover, greater shrubs and higher wood vegetation height. Dunning and Watts (1990) reported that Bachman’s sparrows selected younger stands only if the understory habitat conditions mimicked that of old growth frequently burned habitats. These conditions were found in regeneration areas until 4 to 7 years of age and mature stands that had been thinned and burned. In my study, sparkleberry, a food source for Bachman’s sparrows, was much reduced in the sapling stands. Collectively, the higher amounts of litter, sparser ground cover vegetation, and denser mid-story of young pines, reduced the suitability of these stands for Bachman’s sparrows. Thinning of these sapling stands would likely increase the suitability of these sites for Bachman’s sparrows.

Regeneration areas were ranked 3rd at the 2nd order and ranked last at the 3rd order of selection. Similar to older sapling stands regenerations areas were tolerated within the home range of Bachman's sparrows but they were not selected for habitat use within their home range. Other studies have found that regeneration areas are a suitable habitat for Bachman's sparrows (Dunning and Watts 1990, Stober and Krementz 2006). Dunning and Watts (1990) found that Bachman's sparrows used regeneration areas until ~6 years post-planting after which development of the understory pines and hardwoods became too thick for sparrows. Stober (1996) reported similar use of regeneration areas. Regeneration areas on my study site were mostly seed tree or shelterwood cuts with young longleaf beginning to fill the gaps in the canopy. Ground cover conditions in these areas were similar to saw timber stands and appeared to be suitable habitat for Bachman's sparrow. Apparently the developing pine above 2 m in height reduced the suitability of these stands for Bachman's sparrows. Haggerty (1998) found that unoccupied sites were those that had higher litter cover and taller woody vegetation. Jones (2008) found sparrows had larger home ranges with increasing shrubs > 1 m. Lower habitat use of regeneration areas in my study were likely a function of higher amounts pine and hardwoods > 1 m in height than a lack of groundstory vegetation.

Oak hammock was the second ranked habitat at the 3rd order of selection, but the 4th ranked habitat type at the 2nd order of selection. Generally, Bachman's sparrows avoided oak hammocks within their home ranges. True oak hammocks included Munson Slough that ran north to south near the western boundary of the property. Bachman's sparrows were rarely located in these habitat types. However, I sometimes located sparrows along the edges of smaller isolated hammocks surrounding wet weather ponds within home their home ranges. These areas had similar ground cover to the older growth longleaf stands. Oaks were relatively sparse in these areas permitting ample sunlight to the ground. These stands had not been previously cut and were burned as frequently as the upland sites. Also, during the drought of 2011, these areas may have had higher moisture content and cooler temperatures than surrounding upland pine forests.

Even with frequent prescribed fire on a 2 year return interval, habitats with relatively dense young pines were not selected by Bachman's sparrows. Pines in these areas were not so thick as to preclude development of ground cover, especially in the older sapling stands. These areas had relatively modest differences in ground story habitat conditions as compared to old growth saw timber stands, yet were not selected for home range selection, daily habitat use, or refuge following prescribed fire. There was higher litter in the sapling stands, but this was not the case for regeneration stands which had ground cover conditions similar to those in saw timber stands. This result suggests that tree density was an important variable for Bachman's sparrow habitat suitability. Thinning sapling stands to permit more sunlight to the ground to enhance vegetation, reduce litter accumulation, and reduce pine stem density would likely increase the suitability of these stands for Bachman's sparrows.

Habitat for Bachman's sparrows on sandhill habitat at Apalachicola National Forest was provided by intact native ground cover and relatively sparse mature longleaf pine. Younger stands were not selected and abundance of Bachman's sparrows was lower in areas with higher pine density and development of midstory. Despite frequent burning of all habitats on the study site, sapling stands up to 45 years of age and pole stands up to 59 years of age were not selected as habitat. Densities of Bachman's sparrows were highest in saw timber stands and lowest in more dense pine sapling stands. Regeneration areas that were 5 to 6 years of age were not heavily used as in other studies (Dunning and Watts 1990, Stober and Krementz 2006). Therefore, on my study site, it appears to require 6 decades or more years to recover habitat for Bachman's sparrows after cutting of saw timber. Clearcutting of old growth longleaf saw timber stands would reduce remaining habitat for Bachman's sparrows on the Apalachicola National Forest, Munson unit. Other tree harvesting methods, such as single tree selection and group selection with patch regeneration may be favorable for permitting harvest of mature longleaf while sustaining the understory and open nature of natural longleaf stands for Bachman's sparrows and other wildlife (Moser et al. 2002, Masters et al. 2003).

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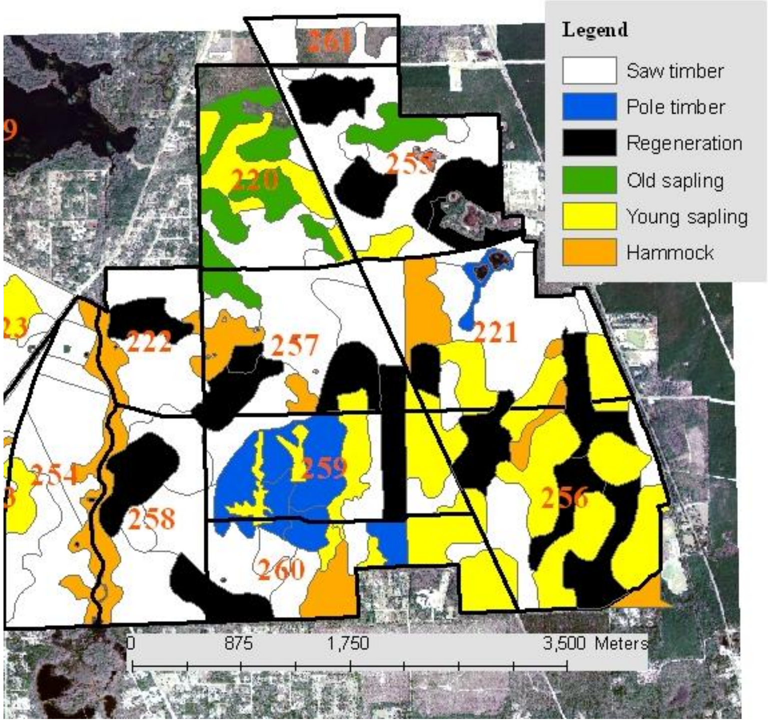

Figure 3.1. Forest stand types and burn units for the study area on Apalachicola National Forest, Munson Unit.

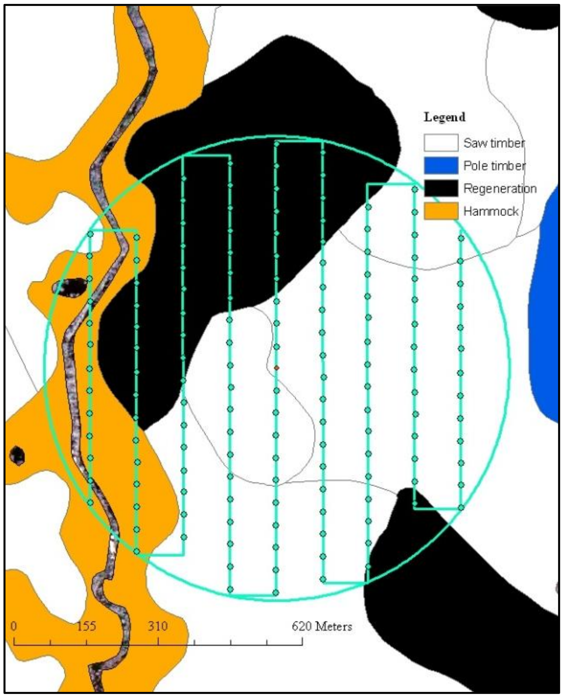

Figure 3.2. Vegetation sampling region used for habitat selection analysis.

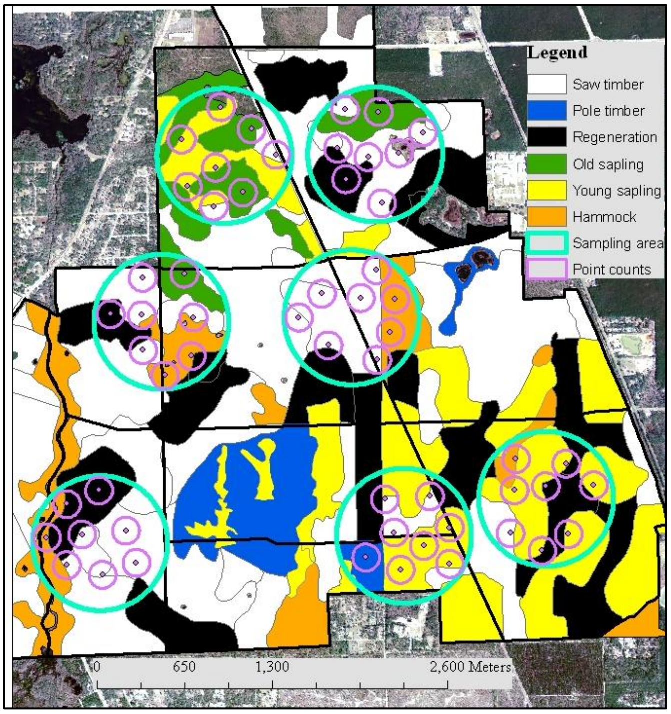

Figure 3.3. Sampling regions and point count locations within the study site.

Table 3.1. Ranking matrix from compositional analyses for second order selection of 31 radio-tagged Bachman sparrows on Munson Unit, Apalachicola National Forest, 2010-2011.

Habitat	S[1]	Saw timber	Pole timber	Sapling > 1980	Sapling < 1980	Regeneration	Oak hammock	Rank
Saw timber	t		16.47	10.77	4.72	7.66	14.42	1
	P		0.00	0.00	0.00	0.00	0.00	
Pole timber	t	-16.47		0.49	-3.69	-1.61	-0.07	5
	P	0.00		0.63	0.00	0.12	0.94	
Sapling	t	-10.77	-0.49		-4.66	-1.65	-0.51	6
> 1980	P	0.00	0.63		0.00	0.11	0.62	
Sapling	t	-4.72	3.69	4.66		1.72	3.59	2
< 1980	P	0.00	0.00	0.00		0.10	0.00	
Regeneration	t	-7.66	1.61	1.65	-1.72		1.52	3
	P	0.00	0.12	0.11	0.10		0.14	
Oak	t	-14.42	0.07	0.51	-3.59	-1.52		4
Hammock	P	0.00	0.94	0.62	0.00	0.14		

[1] S = Statistic

Table 3.2. Ranking matrix from compositional analyses for third order selection of 31 radio-tagged Bachman's sparrows on Apalachicola National Forest, Munson Unit, 2010-2011.

Habitat	Statistic	Saw timber	Sapling > 1980	Sapling < 1980	Regeneration	Oak hammock	Rank
Saw timber	T		2.32	2.80	2.64	2.40	1
	P		0.03	0.01	0.01	0.02	
Sapling > 1980	T	-2.32		0.42	0.59	-0.14	3
	P	0.03		0.68	0.56	0.89	
Sapling < 1980	T	-2.80	-0.42		0.15	-0.64	4
	P	0.01	0.68		0.88	0.52	
Regeneration	T	-2.64	-0.59	-0.15		-0.76	5
	P	0.01	0.56	0.88		0.45	
Oak hammock	T	-2.40	0.14	0.64	0.76		2
	P	0.02	0.89	0.52	0.45		

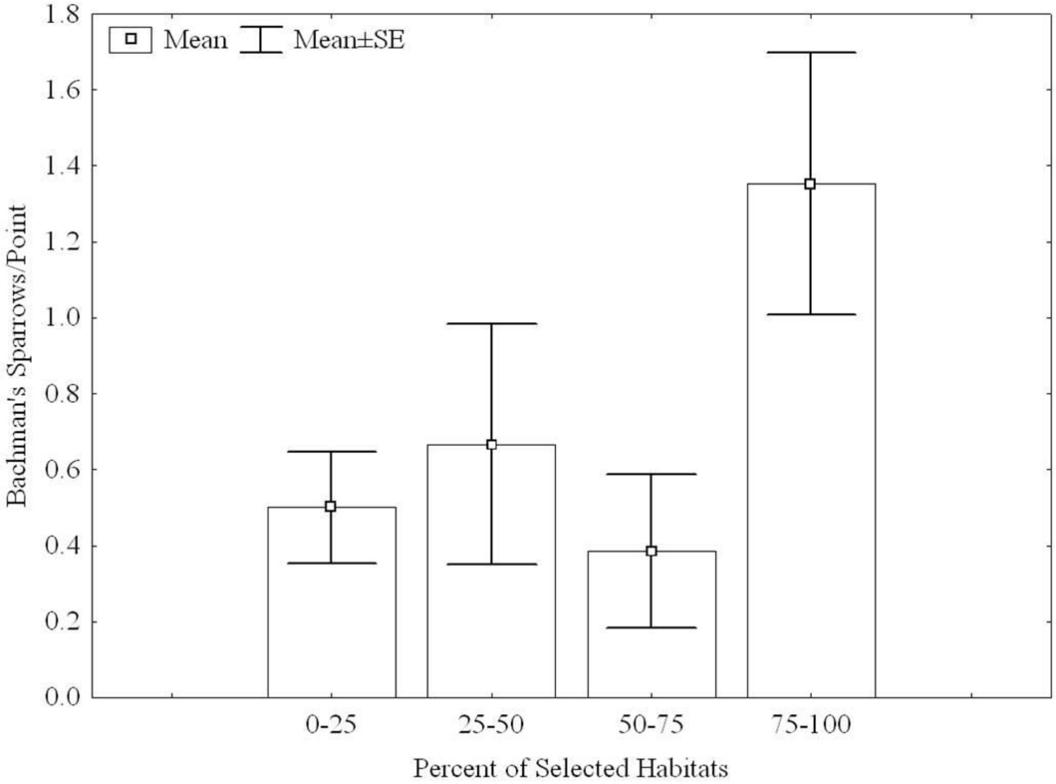

Figure 3.4. Percent of selected habitats versus number of Bachman's sparrows heard per point.

Table 3.3. Understory vegetation conditions by habitat type on Apalachicola Munson Unit, Leon County, Florida 2011

Habitat	*N*	Grass±SE	Forb±SE	Woody±SE	Litter±SE	Shrub height±SE
Saw timber	297	24.1±1.38	1.4±0.20	40.4±1.73	48.9±1.62	0.29±0.02
Sapling young	34	20.3±4.29	1.9±0.73	10.2±1.64	77.8±3.46	0.15±0.04
Sapling old	102	20.2±1.97	1.5±0.33	23.1±2.06	68.6±2.48	0.20±0.03
Regeneration	99	29.9±2.63	1.7±0.35	35.2±2.78	43.6±2.94	0.32±0.03
Hammock	49	18.2±3.58	0.8±0.37	27.0±3.66	59.4±4.46	0.21±0.04

Table 3.4. Basal area (m^2/ha) of hardwood and pines on Apalachicola Munson Unit, Leon County, FL 2011.

Habitat	Hardwood ±SE	Pine±SE
Saw Timber	7.3±1.83	24.1±1.54
Sapling Young	1.5±1.51	35.1±3.07
Sapling old	3.2±1.12	36.9±4.13
Regeneration	14.2±4.51	26.0±2.95
Hammock	2.2±1.23	27.3±3.76
Overall	6.6±1.19	27.6±1.29

CHAPTER 4

CONCLUSION AND MANAGEMENT RECOMMENDATIONS

Home range sizes and movements in this study were larger than previously reported for Bachman's sparrows, especially in 2011. Larger home range sizes are often attributed to poorer habitat quality and this study occurred on sandhill habitat which may have lower primary productivity and food resources relative to other sites (Cox and Jones 2007). However, the large movements I observed, even within a single day, by radio-tagged sparrows suggests previous studies using visual resighting estimates may have underestimated Bachman's sparrow movements and home range size. I believe that if I had aerial tracking capabilities (e.g., helicopter) movement measurements and home range sizes would likely have been even larger.

As distance from Bachman's sparrows' home ranges to the burn edge increased, Bachman's sparrows made larger movements to find suitable habitat. However, increased movements of Bachman's sparrows did not lower survival rates as has been previously speculated (Pulliam et al. 1992, Seamen and Krementz 2000).

I saw no evidence that the burn conducted on July 23, 2010 negatively impacted radio-tagged male Bachman's sparrows or would have inhibited their ability to produce another brood. It is possible that burns conducted in mid-August would cause site abandonment and potentially cut the breeding season short, but it is likely that the majority of sparrows would have completed clutches by mid-August. Moreover, I suspect that these results are more likely a function of preferred habitat surrounding the perimeter of the burn than the date of the burn.

Frequently burned, mature, open longleaf pine stands were selected for home ranges by Bachman's sparrows. Regeneration areas and older sapling stands were not used heavily by Bachman's sparrows despite frequent fire and similar ground cover possibly due to greater tree stem density. Bachman's sparrows forced from home ranges by fire did not use a broader range of habitats, but were located in saw-timber stands 90% of the time.

Habitat for Bachman's sparrow on a longleaf sandhill forest was provided by intact native ground cover and relatively sparse mature longleaf pine. Even with frequent prescribed fire on a 2-year return interval, habitats with relatively dense young pines were not selected by Bachman's sparrows, which suggests that tree density is an important variable for habitat suitability. Thinning sapling stands to permit more sunlight to the ground to enhance vegetation, reduce litter accumulation and reduce pine stem density would likely increase the suitability of these stands for Bachman's sparrows. Because it takes a considerable amount of time to recover habitat for Bachman's sparrows after the cutting of saw timber, I recommend other tree harvest methods besides clearcutting. Single tree selection and group selection with patch regeneration may be favorable for permitting harvest of mature longleaf while sustaining the understory for and open nature of natural longleaf stands for Bachman's sparrows and other wildlife (Moser et al. 2002, Masters et al. 2003).

The spatial distribution of suitable habitat is an important consideration for land managers interested in maintaining or increasing Bachman's sparrow densities within their area. For instance, on my sandhill study site, a few burn units contained a significant portion of the selected habitat (older sawtimber longleaf stands). Burning these burn units significantly reduces suitable habitat. By adjusting burn unit boundaries to increase the heterogeneity of burned versus unburned suitable habitats would provide Bachman's sparrows with habitat options post-burn.

Prescribed burning at various seasons may provide a way in which managers can maintain high fire frequency with large size fires while providing Bachman's sparrows forced to leave areas that are burned during the breeding season access to suitable habitat. Winter burns will provide habitat during summer for Bachman's sparrows forced out of home ranges with breeding season fires (Gobris 1992, Dunning 1993). Sparrow density may be increased by maintaining greater amounts of breeding season habitat on a management area.

Determining the "right" fire size for managing Bachman's sparrows is a complex matter and may be dependent upon a myriad of factors including distance to nearest suitable habitat, conspecific density of nearest suitable habitat, burn month, previous burn management, and drought conditions that affect post-burn vegetation growth. Although studies conducted at larger fire sizes (>200 ha) are needed, I recommend that land managers diversify both season of fires and juxtaposition of habitat if they want to provide Bachman's sparrows with suitable habitat within their management area.

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