RESPONSE OF BACHMAN'S SPARROWS (*AIMOPHILA AESTIVALIS*) TO GROWING-SEASON PRESCRIBED FIRES IN LONGLEAF PINE SAVANNAS OF SOUTHERN GEORGIA

by

Clark David Jones

(Under the Direction of Robert J. Cooper)

ABSTRACT

In the remaining pine savannas of the southeastern United States, land managers employ growing-season (late April – July) prescribed fires to control hardwood encroachment and promote the growth of grasses and forbs. Some studies suggest that Bachman's sparrows (*Aimophila aestivalis*), a species requiring frequent fire, may be negatively affected by growing-season prescribed fire due to elimination of nesting habitat during the breeding season. The classification of Bachman's sparrow as a *Species at Risk* by United States Fish and Wildlife Service underscores the importance of determining factors that influence the reproduction and distribution of this species. This study examined the effects of growing-season prescribed fire at two spatial extents on Bachman's sparrow survival, breeding status, and home-range characteristics. Growing-season burns had minimal impacts on survival and may promote better nesting habitat. Incorporating growing-season burns into existing management strategies is recommended for the conservation of this species.

INDEX WORDS: Bachman's sparrow, Aimophila aestivalis, prescribed fire, survival, home range, longleaf pine, Pinus palustris, Wade tract, growing season

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DEDICATION

This thesis is dedicated to Jeptha Wade III, whose foresight and generosity ensured the persistence of one of the most pristine tracts of longleaf pine remaining.

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Additionally, a multitude of people made this thesis possible in one way or another and I am indebted and thankful for the experiences and encouragement they have provided. To Moon Draper who opened my eyes to the rest of world by driving me across the western United States. To Bruno Georgeton for convincing me to stop cooking breakfast and scrubbing toilets in the Big Sky of Montana to pursue a higher education. To Jim Cox for inspiring me in every step of this research and working harder than any person I've ever met. To all those who assisted with field work and data collection including Matt Klostermann, Colleen Sacco, Emily Toriani, Emily Pipher, Steve Padgett, Brent Widener, Kim Sash, Chuck Martin, and Eric Staller. I would also like to thank my office mates Ryan Malloy and Brian Nuse for listening to me gripe and providing insight. Colin Shea, Krishna Pacifica, Brady Mattsson, Scott Rush, and Kirk Stodola provided valuable suggestions throughout this process. Lastly, I would like to thank my family for supporting me through all my adventures that weren't always scholastic in nature.

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CHAPTER 1

INTRODUCTION, LITERATURE REVIEW, AND STUDY OVERVIEW

INTRODUCTION

Prior to European settlement, early successional habitat in the southeastern United States was maintained by natural and anthropogenic fires that occurred predominantly during the breeding season of many resident and migratory bird species (Bartram 1791; Ware 1993; Glitzenstein et al. 2003; Huffman 2006). Today, prescribed fires have replaced wildfires as one of the primary mechanisms used to preserve early successional habitat that is important to a multitude of avian species that are in precipitous decline (Askins 1993; Butcher and Niven 2007). One of these species, Bachman's sparrow (*Aimophila aestivalis*), possesses a life history that is intimately linked to frequent fire and whose observed population decline (Dunning 2006) is linked to declines in available habitat, indicating the need for increased use of prescribed fire.

Historically, fire-dependent longleaf pine (*Pinus palustris*) savannas stretched from Virginia, west through the Coastal Plain, and into Texas and Arkansas (Earley 2004). Fire return intervals in this system are estimated to have been <5 years and may have occurred at 2 - 3 year intervals in many areas (Frost 1998; Huffman 2006). Absence of fire leads to the decline of many organisms inhabiting this system, including Bachman's sparrow (Jose et al. 2006). The distribution of Bachman's sparrow, an endemic ground-nesting species, overlaps largely with the historical range of the longleaf pine forests. If suitable habitat goes without fire for 3 years, sparrows typically abandon these locations and this aversion is tightly linked to structural and compositional changes in the vegetation (Engstrom et al. 1984). Numerous studies also suggest that habitat quality and population demographics may be influenced by the timing and frequency of prescribed burns (e.g., Tucker 1998; Seaman and Krementz 2000; Stober and Krementz 2000). The overall goal of my thesis is to investigate the effects of burns applied during the growing (i.e. nesting) season on Bachman's sparrows in longleaf pine savannas of southern Georgia.

LITERATURE REVIEW

Habitat

The longleaf wiregrass (*Aristida* sp.) ecosystem contains the highest diversity of plants north of Mexico (Earley 2004) and the majority of this diversity can be found in the ground cover, a unique aspect of this system (Simberloff 1993). Previous studies of sites occupied by Bachman's sparrows found that increases in percent ground cover, forb height, percent grass cover, and vertical vegetation density between 0-90 cm were negatively correlated with home-range size (Haggerty 1998). Size of home range is often used as an indicator of habitat quality for many species of birds and mammals. Smaller home ranges may indicate better habitat quality presumably due to decreases in energy expenditure required for foraging, while larger home ranges may be indicators of lower quality habitat (Hinde 1956). However, larger home ranges have also been shown to infer greater breeding success for some species (Whitaker et al. 2006). Several reports indicate that a dense layer of grasses and forbs are typically associated with the territories of Bachman's sparrows (Hardin et al. 1982; Dunning and Watts 1990). Forest management practices, such as prescribed fire, that enhance these ground cover features may lead to greater breeding densities for birds adapted to this ecosystem (Haggerty 1998).

Although many sources describe Bachman's sparrow habitat as mature pine forest (Allaire and Fisher 1975; Meanley 1988), others point out that they are often found in clearcuts, abandoned pastures, and power line rights-of-way (Dunning 1993, Haggerty 1988). However, clearcuts are only occupied by this species for 4-7 years (Dunning 1993) due to the eventual growth of an unsuitable understory. Many clearcuts may lead to a landscape pattern impeding dispersal (Dunning et al. 1995, Dunning and Watts 1990); for example commercially managed timber that is maintained with the primary goal of maximizing future timber production may be situated in locations surrounded by large areas of unsuitable habitat. A recent study reported smaller home ranges in young pine stands composed of longleaf and loblolly (*Pinus taeda*) than mature pine stands with similar species composition (Stober and Krementz 2006). This result may suggest a preference for younger forest stands with higher stem densities than previously thought (Stober and Krementz 2006). In summary, a comprehensive description of this species' preferences in a native, old growth setting is lacking.

Species account

Bachman's sparrow is the only endemic sparrow in United States and is a year-round resident of Georgia and Florida. Nesting begins in late March in the southern portions of its range and continues into early October (Haggerty 1988). All nests are placed on the ground and contain an average of 4 eggs (Haggerty 1988). Two broods are common in many populations of this species (Dunning 2006), but the extremely cryptic location of nests has made it difficult to document precisely what proportion of the population engages in this behavior.

Breeding Bird Surveys report a range-wide population decline of 15-20% between 1966 and 2005 (USGS 2006) for Bachman's sparrows. Consequently, it is recognized as a *Species at Risk* (Stober and Krementz 2000) and was considered a Category 2 species under the federal

Endangered Species Act until Category 2 designations were discontinued in 1997. The Category 2 designation was originally established to indicate that classification as threatened or endangered may have been appropriate, but more information would be needed to warrant listing as an endangered species (Seaman and Krementz 2000). Bachman's sparrow was also included on the National Audubon Society's Blue List of species of concern every year it was compiled (Tate 1986) and is classified as near threatened by the International Union for the Conservation of Nature and Natural Resources (IUCN 2008).

Influence of Fire

Fire is an essential tool for the preservation of southeastern pine savannas. Pine savannas support large numbers of rare and declining species (Noss et al. 1995), and prescribed fires maintain appropriate habitat by reducing understory woody vegetation and promoting grasses and forbs (Robbins and Myers 1992). As the time since application of prescribed fire (or wildfire) advances, woody vegetation increases and grasses and forbs decrease. This results in a shift in the vegetation structure from a savanna to a brush dominated landscape. Scores of species across many taxa in the longleaf pine ecosystem depend on frequent fire to replenish the vegetative structure.

Fire suppression and reduced fire frequency result in the rapid decline of habitat suitable for Bachman's sparrow and the many other longleaf pine inhabitants (Seaman and Krementz 2000, Engstrom et al. 1984). Bachman's sparrows require frequent fire and rapidly disappear from pine forests when fire is excluded for more than 3 years (Engstrom et al. 1984), thus serving as an indicator of fire frequency. Numerous studies suggest that Bachman's sparrow survival rates and nesting success may be influenced by the timing and frequency of prescribed burns (Seaman and Krementz 2000; Stober and Krementz 2000; Tucker et al. 1998).

Although the interval of prescribed fire is important, the seasonal timing of fires also may have some bearing on vegetation structure (Robbins and Myers 1992). Previous examinations of the effects of burning at different times of the year in southern pine forests contrast the effects of applying treatments during the winter against those occurring during the summer and late spring (i.e. growing-season fires) (Robbins and Myers 1992). Growing-season fires reduce the dominance of woody vegetation in comparison to winter burns and the result is a landscape where grasses are prevalent (Waldrop et al. 1987) which may benefit many species. Wiregrass, a dominant grass associated with many pine savannas, typically flowers more prolifically when burned during the growing season (Platt et al. 1991). This, coupled with other observations, have led many to conclude that growing season fires were the historical regime (Frost 1998; Robbins and Myers 1992; Hiers et al. 2002; Huffman 2006).

Although growing-season prescribed fires coincide with the nesting season, Bachman's sparrows should be well adapted to fires during this time of year since this is likely the time of year when fires historically occurred. However, one of the few studies examining Bachman's sparrow habitat use immediately following growing-season prescribed fire, reported that nearly all radioed birds dispersed from the study sites and did not return within 50 days (Seaman and Krementz 2000). Due to the small size of transmitters required to use on such a small species, it is possible that battery life was insufficient to determine if any of the radioed birds returned to the site following recovery of vegetation. In contrast, Bachman's sparrows have been observed setting up territories a few days after growing-season prescribed burns and staying through the remainder of the breeding season (Shriver and Vickery 2001; Tucker et al. 2006).

STUDY OVERVIEW

Many examinations of the effects of fire on Bachman's sparrow habitat focus on the use of fire prior to the growing season (Haggerty 1988; Gobris 1992). However, growing-season burns (late April-August) increasingly are being applied because of their ability to decrease hardwood regeneration and improve grass and forb cover (Seaman and Krementz 2000). Hardwood regeneration, if allowed to mature, results in habitats less suitable for early successional species, such as Bachman's sparrow and northern bobwhite (Stoddard 1931). In years following growing-season prescribed fires, breeding habitat for sparrows may be enhanced (Tucker 1998). Some have suggested however, that because these fires coincide with the nesting season, they may be detrimental to Bachman's sparrow populations (Liu 1995; Plentovich 1998).

This study examined the effects of growing-season prescribed fires on Bachman's sparrows in a native longleaf pine setting in southern Georgia. The primary objectives of this inquiry were to examine how burning during this time of year influenced the vegetation structure of the habitat and population demographics of this declining species. Understanding relationships between changing ground cover conditions and variables often linked to demographic parameters (Tucker 1998) could help land managers, and the public, understand the potential effects of growing-season prescribed fires.

This thesis is divided into 4 chapters, with each chapter written in such a way that it is able to stand alone, but together achieve the primary objectives stated above. The first chapter has provided a brief historical perspective of changes in fire frequency in the southeastern United States, the effects this has had on early successional species, and motivation for this study. Chapter 2 examines how growing-season prescribed fires affected the density and survival of Bachman's sparrows over the two years of this study. I then examine how vegetation structure and composition influences home-range size, breeding status, and nest placement in chapter 3. Finally, chapter 4 gives a brief overall summary and provides management suggestions and avenues for future research. In the end, I hope this study illustrates the enduring need for increasing the amount and frequency of prescribed fire in the southeastern United States in order to abate many of the declines experienced by early successional species in this region.

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CHAPTER 2

SURVIVAL AND DENSITY OF BACHMAN'S SPARROWS (*AIMOPHILA AESTIVALIS*) IN RESPONSE TO GROWING-SEASON PRESCRIBED FIRES IN SOUTHERN GEORGIA

Jones, C.D., J.A. Cox, and R. J. Cooper. To be submitted to The Auk.

ABSTRACT

Bachman's sparrow (*Aimophila aestivalis*) is an endemic passerine of the southeastern United States that requires frequent disturbances, typically fires occurring at least every 3 years, to replenish the vegetation structure it prefers. Prescribed fires applied during the nesting season (i.e. growing-season fires) may be detrimental to this ground-nesting species if population recovery time is slow. To determine how growing-season prescribed fires affected survival and density of Bachman's sparrows, we monitored two color-banded populations that received prescribed fires at two spatial extents (100 ha and <25 ha) during 2006 and 2007. Monthly survival derived from Cormack-Jolly-Seber models was 0.93 (95% CI 0.87 – 0.96) and did not differ significantly between burned and unburned plots. Significant changes in density during months immediately following application of treatment were only observed on unburned plots which showed increases in density later in the season during both years of the study. Growing-season prescribed fires appear to have little impact on the survival and density of Bachman's sparrows and are an important management tool that can be used to increase burn frequencies by burning more area each year.

INTRODUCTION

Habitat suitability for many wildlife and plant species has been negatively impacted by human development, land use change, and disruption of natural ecosystem processes. Although large-scale deforestation can be blamed for the loss of habitat across vast expanses of the United States, the disruption of natural disturbance regimes in the form of fire suppression and flood control have been devastating to ecosystem functions as well. Applications of surrogate processes, such as prescribed fire, are necessary to ensure the preservation of species that are dependent on these ecosystem processes for their persistence.

Much of the landscape of the southeastern United States was historically maintained by natural and anthropogenic fires that occurred primarily during the growing season when lightning strikes are common (Bartram 1791; Ware 1993; Glitzenstein et al. 2003; Huffman 2006). Prescribed fire serves as a surrogate for wildfire to ensure the preservation and maintenance of early seral stages that are important for many wildlife species. Many of these habitats are diminished in extent or have disappeared entirely from some regions, however, and many declining wildlife species, especially birds, are associated with these habitats (Askins 1993; Butcher and Niven 2007). Bachman's sparrow is one species whose life history is tightly linked to frequent fire and whose population decline reflects the need for increased use and study of prescribed fire (Dunning 2006).

Fire suppression and reduced fire frequency result in the rapid decline of habitat suitable for Bachman's sparrow and many other species that inhabit the longleaf pine (*Pinus* palustris) ecosystem (Engstrom et al. 1984; Seaman and Krementz 2000). Bachman's sparrows require frequent fire and are typically absent in pine forests where fire has been excluded for >3 years (Engstrom et al. 1984). Numerous studies suggest that their survival rates may be influenced by the timing and frequency of prescribed burns (Tucker 1998; Seaman and Krementz 2000; Stober and Krementz 2000). Many examinations of the effects of fire on Bachman's sparrow habitat focus on the use of dormant season fires (Haggerty 1986; Gobris 1992). However, growing-season burns (late April-August) are now being applied increasingly because of their ability to decrease hardwood regeneration and improve grass and forb cover (Seaman and Krementz 2000). Hardwood regeneration, if allowed to mature, results in habitats less suitable for early successional species, such as Bachman's sparrow and northern bobwhite (Stoddard 1931). In years following growing-season prescribed fires, breeding habitat for Bachman's sparrows may be enhanced (Tucker 1998). Some have suggested, however, that because these fires coincide with the nesting season, they may be detrimental to Bachman's sparrow populations (Liu 1995; Plentovich 1998).

From an evolutionary viewpoint, Bachman's sparrows, as well as other inhabitants of fire dependent ecosystems in the southeast, should be well adapted to growing-season fires. Historically, most naturally occurring fires in the longleaf pine ecosystem were the result of lightning strikes during the late spring and early summer (Robbins 1992) and many plants found in this region require fires during this time of year for successful propagation (Clewell 1989; Duever 1989; Platt et al. 1991). Bachman's sparrows have been observed setting up territories within a few days following growing-season prescribed burns and staying through the remainder of the breeding season (Shriver and Vickery 2001; Tucker et al. 2006). In contrast, Seaman and Krementz (2000) reported that nearly all radioed Bachman's sparrows in their study dispersed from sites where growing-season burns were applied and did not return. These conflicting observations suggest that some applications of prescribed fire may have negative implications for this declining species.

Prescribed fire applications likely have varying effects depending on factors that are sometimes difficult to control, but should be considered. Huffman (2006) suggested growing-season burns were characteristic of the original fire regimes shaping southern pine forests and these likely occurred at across large spatial extents. The threat that growing-season fires pose to Bachman's sparrows will depend on the amount of area treated (i.e., burn extent; Lyon et al. 2000), the intensity of the fire (Lyon and Marzluff. 1985), the specific timing within the season that fires are applied (Shriver et al. 1999; Tucker et al. 2006), as well as management activities conducted on adjacent areas (Seaman and Krementz 2000). Using a model (Fig. 2.1) that depicts hypothetical sparrow territory distributions, the potential effects of the extent of burn can be assessed. If prescribed fires are applied to half the total area and are conducted at an extent much larger than sparrow territories (Fig. 2.1), most territories either are burned extensively (i.e., >75%) or not burned at all. Extensively burned territories may result in higher instances of site abandonment (i.e., apparent survival). In contrast, if the extent of each burn is reduced, but the acrea treated is held constant (Fig. 2.1), more territories have intermediate levels of burning and fewer territories are extensively burned.

We sought to assess the effects of growing-season prescribed fires on survival and density of Bachman's sparrows at two spatial extents in native longleaf wiregrass systems in southern Georgia. Large-extent burns generally are less costly to implement than small-extent burns (Rideout and Omi 1995), but the advantages associated with large-extent burning need to be weighed against potential negative effects to declining species such as Bachman's sparrow (Tucker et al. 2006). Seaman and Krementz (2000) suggested that the negative effects of growing-season burning could be mitigated by providing unburned sparrow habitat adjacent to growing-season burns. One method for applying this recommendation is to burn at smaller spatial extents. Having more small extent fires will create more edge of unburned habitat and decrease dispersal distances required to occupy adjacent unburned habitat (Fig. 2.1). Understanding the impacts of extent and seasonality of fire on sparrow populations will help guide land management strategies seeking to protect and promote populations of this, and other declining species in the southeast.

METHODS

Study Areas and Fire Application

Growing-season prescribed fires were applied in 2006 and 2007 on two properties managed by Tall Timbers Research Station in Thomas (30° 45' N, 84° 0' W) and Grady (30° 46' N, 84° 5' W) counties, Georgia. Pebble Hill Plantation and the Wade Tract are characterized by mature longleaf pine woodlands. Ground cover conditions on each study site are dominated by native vegetation composed primarily of warm-season grasses such as wiregrass (*Aristida* sp.) (Ambrose 2001). Longleaf pine (*Pinus palustris)* is the dominant tree species and all sites share territories with the endangered red-cockaded woodpecker (*Picoides borealis*), an indicator species for mature pinelands (Jackson 1994). Consequently, only very selective harvesting has taken place on Pebble Hill and all timber harvest has ceased on the Wade Tract. Each site has been maintained for decades using annual and biennial prescribed fires during both growing and dormant seasons (Tall Timbers Research Station, unpubl. data). The long history of selective timber harvest and regular application of prescribed fire has resulted in large Bachman's sparrow populations in high densities on both sites.

Two large-extent plots were burned in a single fire (70 - 100 ha.) each year on the Wade Tract (Fig. 2.2) and 4 small-extent fires (5 - 15 ha.) were applied each year on Pebble Hill Plantation (Fig. 2.3). Prescribed fire treatments were ignited during the last week of April and the first week of May during 2006 and the last two weeks of June 2007. Drought conditions during the second half of the study delayed the application of fire in 2007; annual variation in application is typical on managed lands. All study areas have similar burn histories and were not

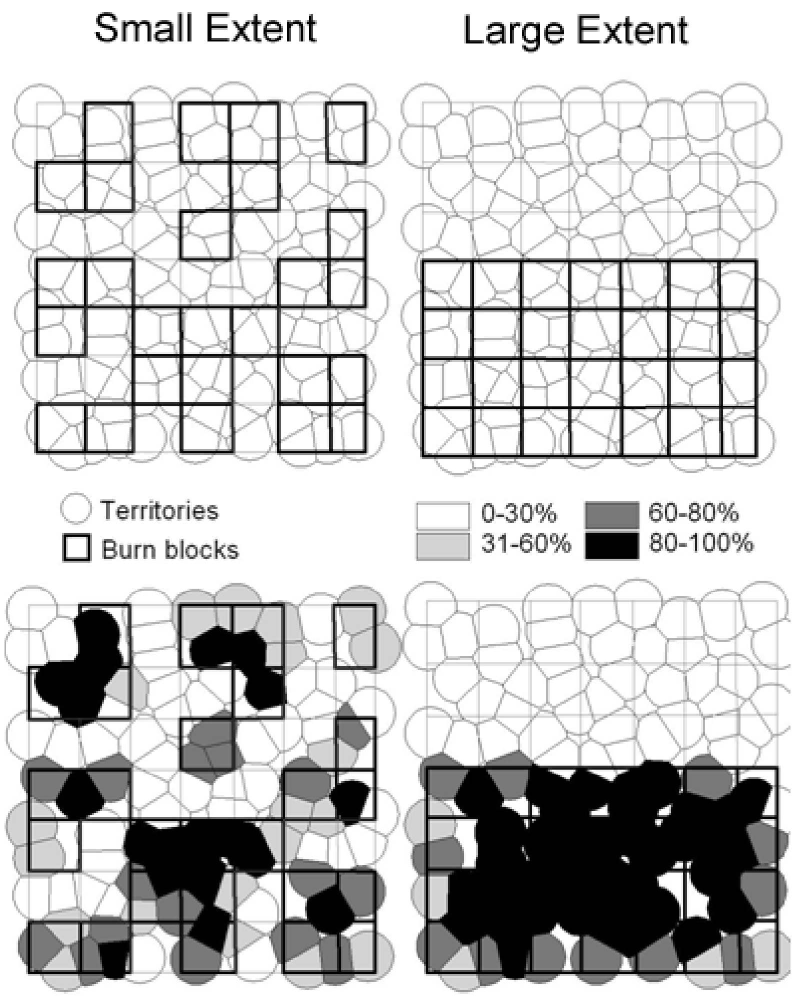

Figure 2.1. Hypothetical model depicting effects of extent of fire on Bachman's sparrow territories. A single large extent burn block results in higher proportions of each territory burned within a given area. Multiple, smaller extent burn blocks have lower proportions of territories burned when area is held constant.

burned in the year preceding experimental treatment (Tall Timbers Research Station, unpubl. data). This approach resulted in approximately half of each study area on both sites burned each year to allow for within-year controls. One small-extent fire plot is not included in this analysis due to accidental ignition of a portion of the study area during the dormant season immediately preceding commencement of this study. This resulted in a slightly altered burn history on a portion of one of the plots that did not resemble the other study plots and therefore was excluded.

Population Monitoring

Spot-mapping was performed using techniques similar to those used in previous studies of Bachman's sparrow (Haggerty 1998; Shriver et al. 1999; Stober and Krementz 2006). We walked transects spaced 100-150 m apart within each plot. Recordings of male songs were used at this time to aid in the mapping process and all bird locations were georeferenced in the field using a handheld Trimble Geo XM accurate to within 5 m. Although spot-mapping may generate variable estimates of density (Verner and Milne 1990), most of the individuals were uniquely color-banded (see below) and were identified during censusing, thus minimizing the probability of double-counting. All locations were then analyzed in ArcView GIS 3.2 (ESRI 1998) to generate monthly estimates of density by dividing the number of birds mapped in each plot by the total area surveyed. Using GIS routines have been shown to improve estimates of density from spot-mapping because of increased precision of point locations (Witham and Kimball 1996) and may overcome many of the problems often associated with this technique (Enemar et al. 1978; Verner and Milne 1990). Densities were pooled by study site and treatment and averaged for months prior to application of treatment and post-treatment months. Approximately 70% of all mapped locations were of banded males. In 2006, 2 months of observations preceded treatments and 3 months of observations followed treatments. In 2007, 4

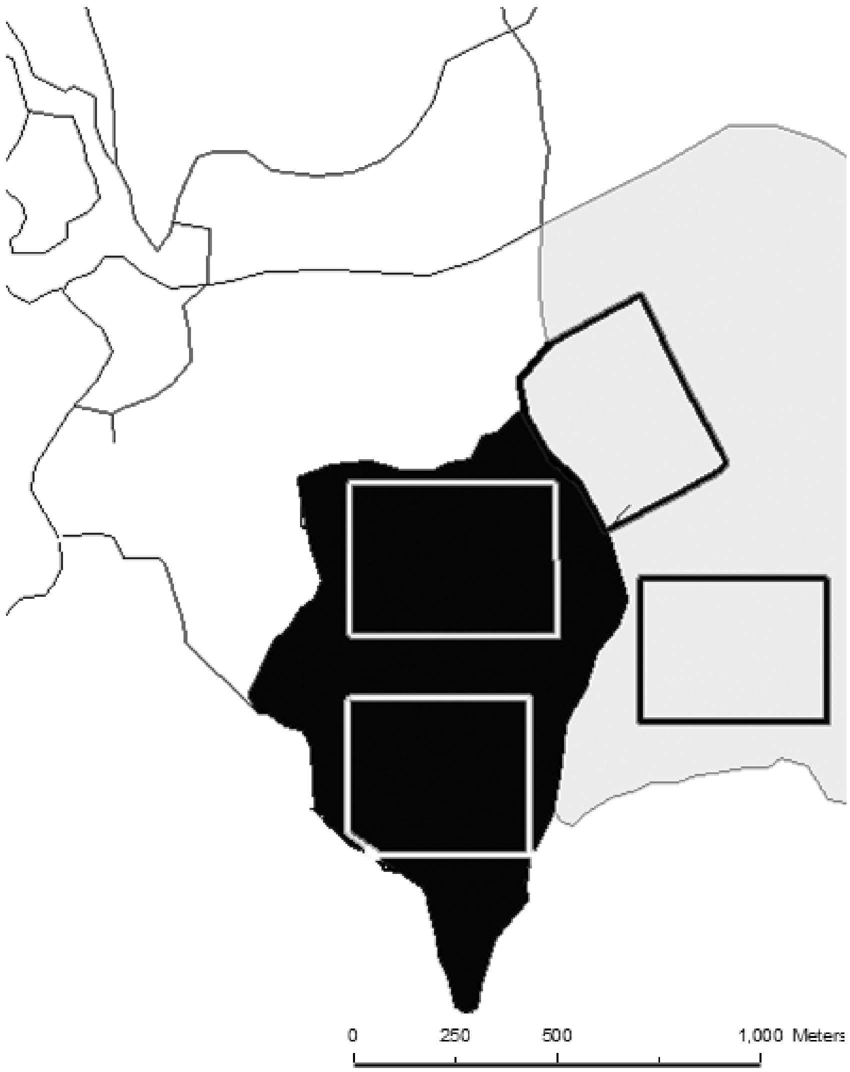

Figure 2.2. Wade Tract – Thomas County, Georgia. Thick lines indicate large-extent study plots. Thin lines indicate jeep trails and fire breaks. Gray area was burned in 2006 (100 ha.) and black area (70 ha.) was burned in 2007.

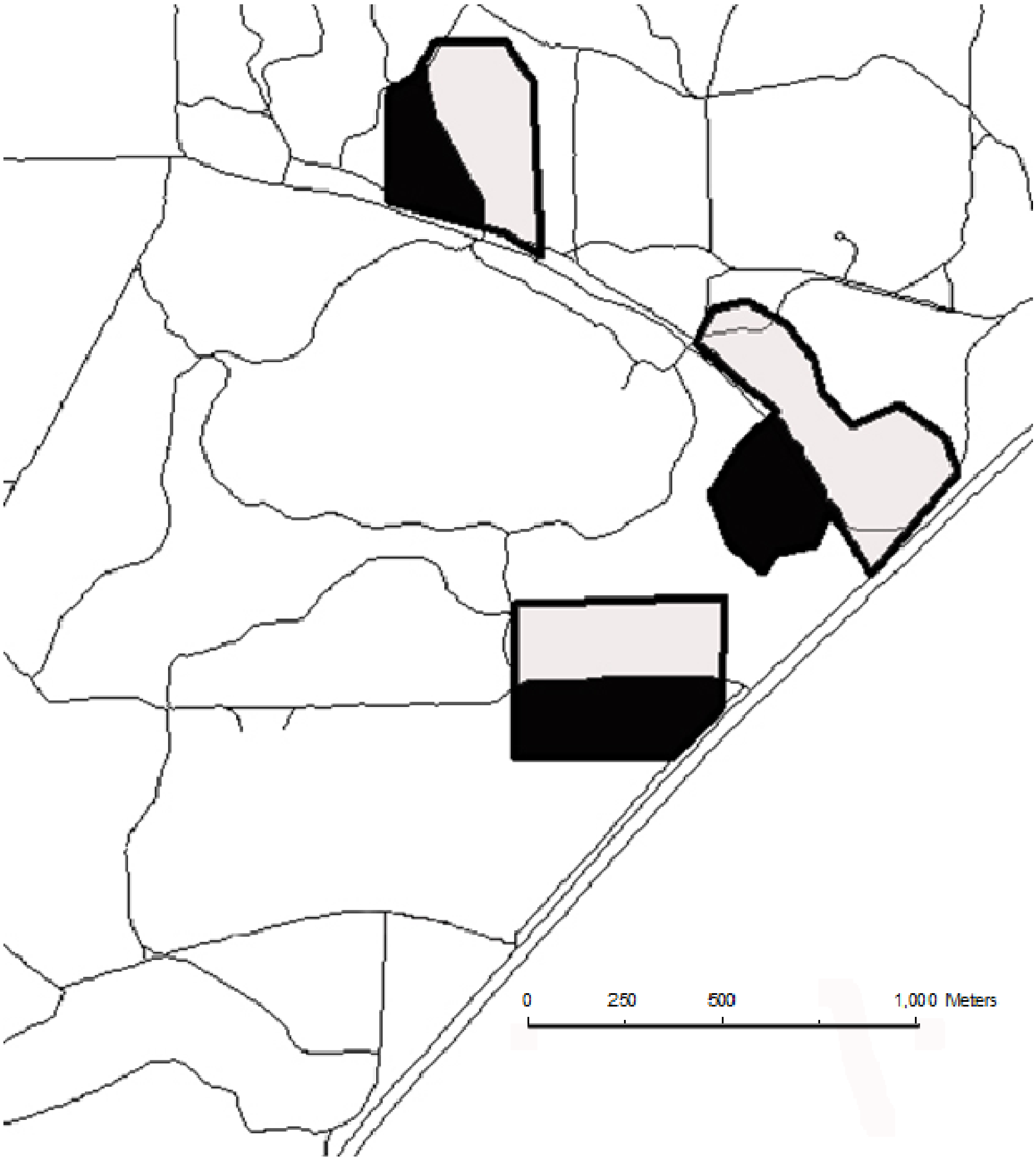

Figure 2.3. Pebble Hill Plantation – Thomas and Grady County, Georgia. Thick black lines indicate small-extent study plots. Thin lines indicate jeep trails and fire breaks. Gray indicates areas burned in 2006 and black indicates those areas burned in 2007. Plot sizes range in size from 16-23 ha and are dictated by location of fire breaks. One plot is excluded due to different fire history.

months of observations preceded treatments and 2 months followed treatments.

A two-period crossover repeated measures ANOVA (Grizzle 1965) was conducted to test for the significance of changes in density by treatment across both years of the study. In this study, two treatments were applied to each study plot: prescribed fire and suppression of fire. Crossover designs have the advantage of allowing each study site to serve as its own control thereby reducing the necessity for dedicating individual plots as controls throughout the entire study. However, they have been criticized because it may be difficult to discern carryover effects from previous treatments after the application of the second treatment. Due to the similar burn histories of all our study sites, we believe carryover effects were properly controlled for.

Capture and resighting

Target-netting techniques (Jones and Cox 2007) were used to capture territorial males on each study plot prior to the application of growing-season burns. Males were fitted with unique color band combinations to facilitate resighting. Females and hatch year (HY) birds were also captured during the course of the study, however data pertaining to these groups were not used for this analysis due to small sample size, the inconspicuous nature of females, and propensity of HY birds to disperse from natal territories.

At least four surveys were performed per plot each month in 2006 and 2007 to locate marked individuals. Surveys were conducted from early April through mid August in 2006 and from late March through early September in 2007. We followed the same transects used for density estimates within each plot and searched an additional 200 m buffer outside plots. Surveys typically took 5-6 hours to complete and were conducted on a rotational basis among plots. Color-band combinations were determined using spotting scopes, and approximate (<5m) locations of marked males were again recorded using GPS.

Survival Analysis

Cormack-Jolley-Seber (CJS) models within program MARK were used to estimate seasonal and annual survival for experimental treatment groups and to assess the effects of fire, extent of treatment application, and territory tenure on male survival (White and Burnham 1999). CJS models assume that a population is not closed and have the added benefit of incorporating the probability of resighting when an individual is lost from the population being sampled (Williams et al. 2001). This feature allows survival estimates to be generated across all sampling periods without being constrained by the detection or lack of detection of individuals during a single sampling period.

Currently, no method has been found to consistently age Bachman's sparrows beyond HY using molt characteristics (Pyle 1997). Therefore, we classified newly banded males as "initial banding year" (IBY) and males banded in the previous season as "after banding year" (ABY) to assess whether or not differences in survival were evident between sparrows holding territories > 1 year and those establishing new territories on the study plots (i.e. site tenure). Some sparrows banded on the Wade Tract as part of a longer term study prior to the commencement of this study also were included as part of this analysis.

Models were created based on *a priori* knowledge of habitat relationships suspected to be driving differences in survival and detection. Competing models were compared using Akaike's Information Criterion (AIC) in program MARK. The model with the lowest AIC value of all candidate models was selected as the most parsimonious model with the best fit. To account for over-dispersion of data, 1000 bootstrap simulations were used to calculate the mean deviance derived from the simulation. The observed deviance of the global model was then divided by the simulated deviance to calculate $\hat{c}$, the variance inflation factor. This was then applied to the

AICc value generated from program MARK to create QAICc (Burnham and Anderson 2002) for those data showing evidence of overdispersion (i.e., $\hat{c} > 1$). No adjustments were made for data lacking evidence of overdispersion. All models with a Δ QAICc ≤ 2 of the best fitting model (i.e., close to the best fitting model) were considered part of the confidence set of models (Burnham and Anderson 2002), however the top five models are reported here.

RESULTS

Bachman's Sparrow Density

The average density of Bachman's sparrows on small-extent plots was 0.36 (SE = 0.08) birds/ha during 2006 and 0.41 (SE = 0.05) birds/ha during 2007. On large-extent plots densities were higher in both years with 0.57 (SE = 0.09) birds/ha in 2006 and 0.54 (SE = 0.15) birds/ha in 2007. Changes in densities in response to application of treatment differed by year and by extent (Fig. 2.4, Fig. 2.5). Following the application of fire in 2006, large-extent burns increased in density, but small-extent burns decreased by 0.11 (SE = 0.03) birds/ha. In 2007, sparrow density in both large- and small-extent burns declined following fire. However, small-extent fires decreased an average of 0.2 (SE = 0.09) birds/ha, whereas large-extent fires decreased only 0.04 (SE = 0.1) birds/ha.

Results from the crossover repeated measures ANOVA (Grizzle 1965) indicated that changes in density in response to fires at the large-extent were not significant ($F_{1,2} = 3.55$; $P = 0.21$), however changes in density on the small-extent plots were significant ($F_{1,4} = 26.42$; $P = 0.01$). When the overall effect of fire at both extents was examined, the treatment effect was

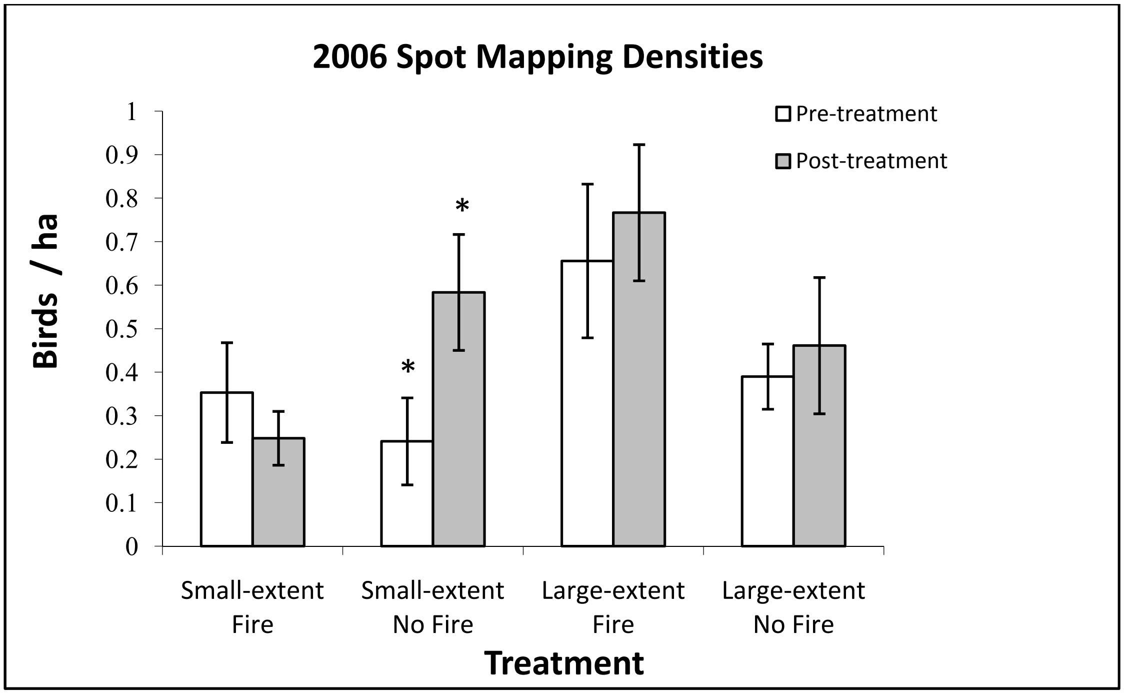

Figure 2.4. Changes in density of Bachman's Sparrows based on spot-mapping during 2006. Density estimates were pooled for months preceding application of prescribed fire and those following application. Error bars are 95% confidence intervals.

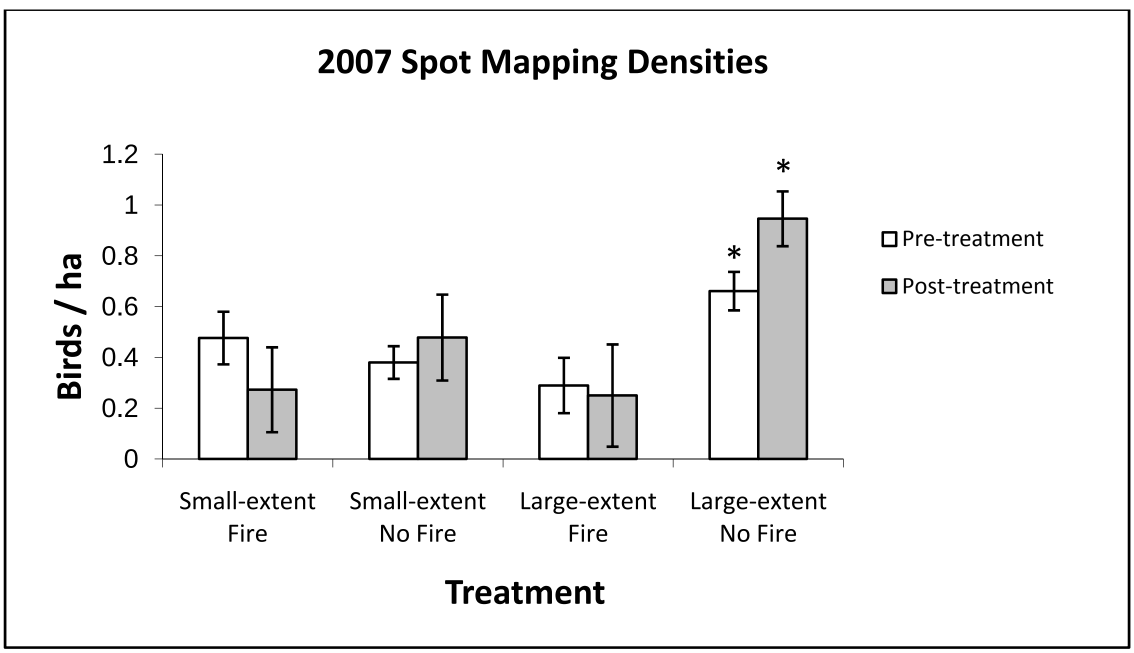

Figure 2.5. Changes in density of Bachman's Sparrows based on spot-mapping during 2007. Density estimates were pooled for months preceding application of prescribed fire and those following application. Error bars are 95% confidence intervals.

significant ($F_{1,8} = 20.84$; $P = 0.002$), however a significant treatment*year interaction was also significant ($F_{1,8} = 5.6$; $P = 0.05$) indicating that the effect varied by year.

Survival

In total, 90 territorial males were monitored during 2006 (n=48 on the Wade Tract; n = 42 on Pebble Hill Plantation). In 2007, 115 territorial males were monitored and 43 males were resighted in both years of the study. For 2006, the most parsimonious model derived from MARK had constant survival among time periods, but variable detection probability [φ(.)p(t); Table 2.1]. It was approximately 1.5 times more likely than the next best model that incorporated burning into probability of survival and variable detection probability [φ(Burn)p(t)]. Constant survival with variable detection probability was 2 times more likely than the model containing site tenure with variable detection probability [φ(Tenure)p(t)]. The survival model containing extent [φ(Extent)p(t)] and the fully time-dependent model [φ(t)p(t)] had lower QAICc weights than the previous two models.

Survival estimates from different groups ranged from 0.91 for Bachman's sparrows within the burned treatment area to 0.96 for sparrows in the unburned plots (Table 2.2). Large-extent plots had similar probabilities of survival (0.93) as small-extent plots (0.94). Likewise, ABY sparrows had similar probabilities of survival in 2006 as IBY sparrows (0.95 vs 0.96) and confidence intervals overlapped for all groups. The overall probability of monthly survival for all male sparrows on all plots during 2006 was 0.93. The probability of resighting for the breeding season during 2006 fluctuated throughout the season from a low of 0.48 during the May – June resighting interval to 0.81 for the June – July interval (Fig. 2.6). When survival and probability of resighting were modeled to remain constant, resighting probability across all groups was 0.60 (95% CI 0.53 - 0.67).

Table 2.1. Model selection for the effects of growing-season prescribed fire (Burn), extent of fire (Extent), and tenure (Tenure) on male Bachman's Sparrows during 2006. The top five models are shown. Those with ΔQAICc ≤ 2 are considered part of the confidence set.

Model	QAICc	ΔQAICc	w_i	Model Likelihood	Number of estimable parameters
φ(.)p(t)	420.133	0	0.288	1	5
φ(Burn)p(t)	420.873	0.740	0.199	0.691	6
φ(Tenure)p(t)	421.842	1.709	0.123	0.426	6
φ(Extent)p(t)	422.115	1.981	0.107	0.371	6
φ(t)p(t)	422.144	2.011	0.105	0.366	7

φ = probability of survival, **p =** probability of resighting, t = time dependence, · = constant

Table 2.2. 2006 monthly (March – July) survival estimates and 95% confidence intervals for burned, unburned, large-extent, small-extent, after banding year (ABY), and initial banding year (IBY) male Bachman's Sparrows.

Group	Survival probability	95% CI
Monthly		
Average	0.93	0.87 - 0.96
Burn	0.91	0.84 - 0.95
Unburned	0.96	0.85 - 0.98
Small-extent	0.94	0.83 - 0.98
Large-extent	0.93	0.86 - 0.96
ABY	0.95	0.81 - 0.98
IBY	0.92	0.85 - 0.96

For 2007, the most parsimonious model from MARK contained variable probability of survival and with probability of detection varying according to burn treatment [φ(t)p(Burn);Table 2.3]. It was 8 times more likely than the next model containing time-dependent probability of survival and constant probability of resighting [φ(t)p(.)]. Extent was present in the top 5 reported models, but was not contained in the confidence set.

Estimates for monthly probability of survival ranged from 0.89 on small-extent plots to 0.94 in the unburned group (Table 2.4). ABY sparrows had a probability of survival of 0.93 and IBY sparrows had a probability of 0.91. Burned and unburned groups did not have significantly different probabilities of survival as evidenced by overlapping confidence intervals. Large-extent plots had a higher probability of survival (0.94) than small-extent plots (0.89), but again confidence intervals overlapped. The overall probability for survival for all groups in all treatments when survival and probability of resighting are held constant was 0.93. The probability of resighting ranged between 0.55 and 0.70 throughout the season (Fig. 2.7) with a mean probability of resighting of 0.64 (95% CI 0.57 - 0.70).

DISCUSSION

Changes in density and survival of Bachman's sparrows following growing-season prescribed fire were minimal in this study. Fire treatments appeared to reduce survival by approximately 5% during the breeding season in both years of the study. These results are similar to the observed proportions of banded birds seen before and after prescribed fires in a previous study by Cox and Jones (2007), but survival was much higher than that observed by Seaman and Krementz (2000) in which nearly all of their radioed birds abandoned the burned area. However, their observations were limited by the short battery of life of the transmitters.

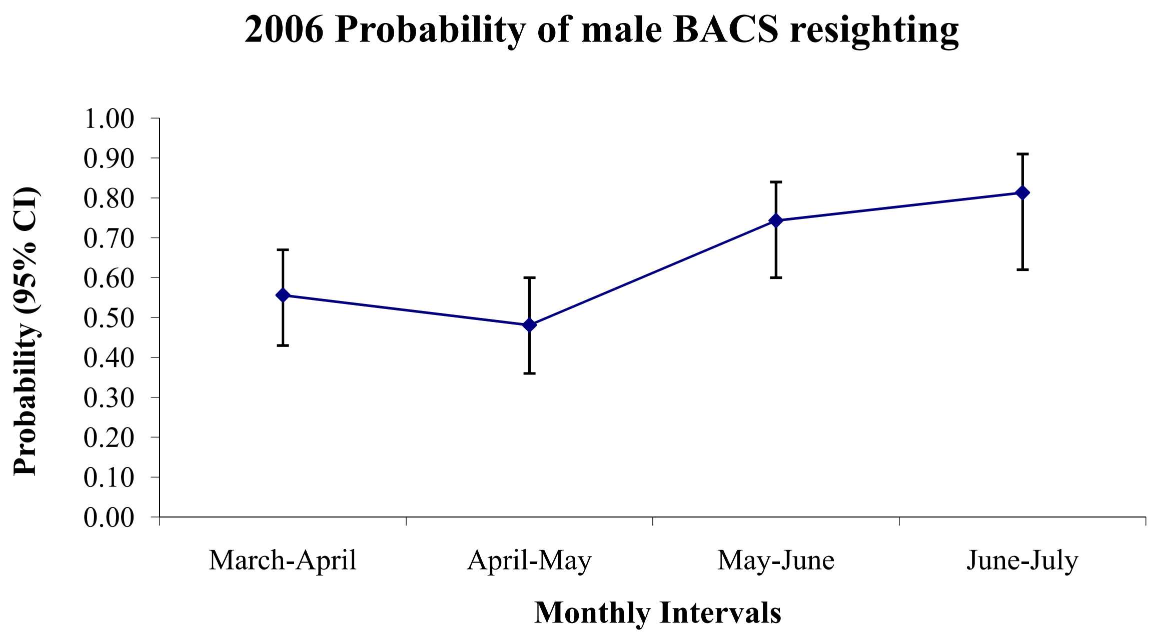

Figure 2.6. Probability of resighting color-marked Bachman's Sparrows during 2006.

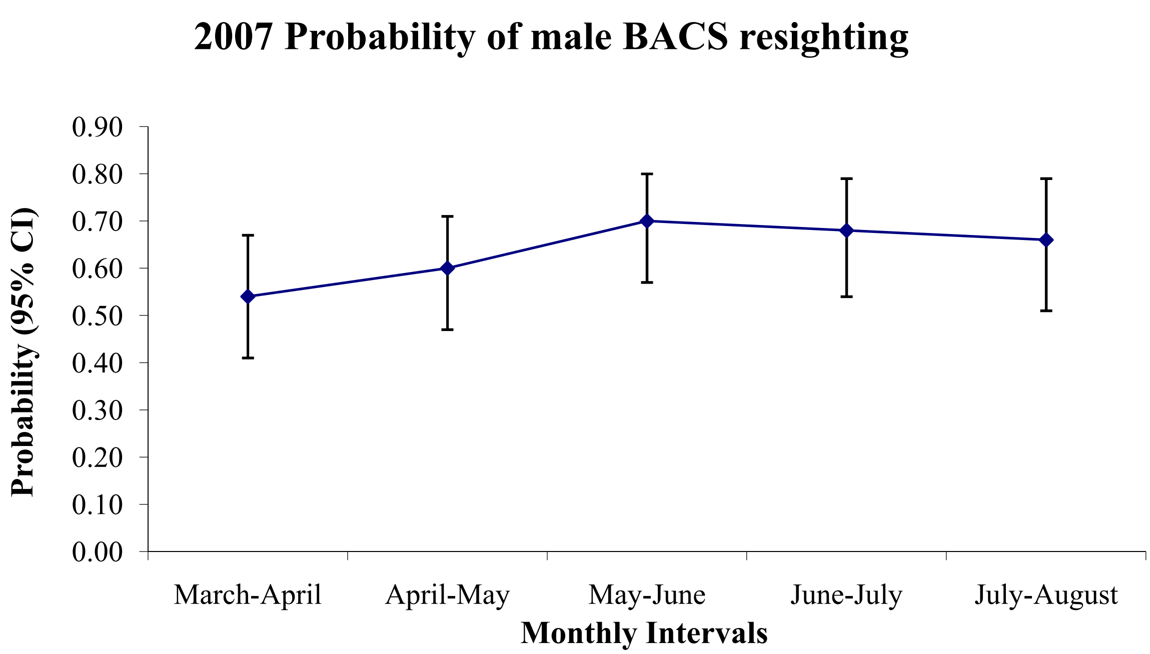

Figure 2.7. Probability of resighting color-marked Bachman's Sparrows during 2007.

Table 2.3. Model selection for the effects of growing-season prescribed fire (Burn), extent of fire (Extent), and tenure (not in top 5 models) on male Bachman's Sparrows during 2007. The top five models are shown. Those with $\Delta AIC_c \leq 2$ are considered part of the confidence set.

Model	AICc	Delta AICc	w_i	Model Likelihood	Number of estimable parameters
φ(t)p(Burn)	555.37	0	0.64	1.00	8
φ(t)p(.)	559.53	4.17	0.08	0.12	7
φ(.)p(t)	559.95	5.58	0.07	0.10	7
φ(Extent)p(t)	560.29	4.92	0.06	0.09	8
φ(t)p(Extent)	561.34	5.94	0.03	0.05	8

φ = probability of survival, **p =** probability of resighting, t = time dependence, · = constant

Table 2.4. 2007 average monthly (March – September) survival estimates and 95% confidence intervals for burned, unburned, large-extent, small extent, after banding year (ABY), and initial banding year (IBY) male Bachman's Sparrows during 2007.

Group	Survival probability	95% CI
Mean	0.93	0.87 - 0.96
Burn	0.90	0.80 - 0.96
Unburned	0.94	0.86 - 0.97
Large-extent	0.94	0.88 - 0.97
Small-extent	0.89	0.77 - 0.95
ABY	0.93	0.86 - 0.97
IBY	0.91	0.81 - 0.96

Little research has been conducted investigating the effect of extent of disturbance on population demographics of Bachman's sparrows, but Seaman and Krementz (2000) suggested that shorter dispersal distances, which would be facilitated by burning at a smaller extent, may result in higher survival rates for Bachman's sparrows. The effect of extent was present in the confidence set of survival models during 2006 (Table 2.1), but small-extent plots did not consistently have higher survival than large-extent plots (Table 2.2; Table 2.4). Although this result seems counter-intuitive because large-extent fires should burn a higher percentage of territories within a given area (Fig. 2.1), the lower survival on the small-extent plots may have been an effect of site rather than a treatment effect.

In order to conduct effective management using prescribed fire, treatments should be large enough to allow burns to be conducted on a 2 to 3 year interval in southern pine ecosystems to mimic the historic fire return interval (Huffman 2006). On some federally managed lands such as the Apalachicola National Forest, this requires burning over 40,000 ha each year and is only accomplished using prescribed fires that encompass, on average, 550 ha or more (Picotte, TTRS, pers. comm.). Further research may be needed to determine if extent of treatments larger than those used in this study have a greater impact on population demographics than treatments at smaller spatial extents.

Declines in sparrow densities were evident on small-extent plots in both years, but both extents incurred decreases in the second year, when treatments occurred slightly later in the growing season. A previous study examining the timing of prescribed fires on changes in density of Bachman's and Florida grasshopper sparrows (Shriver et al. 1999) found that timing of prescribed fire had no effect on Bachman's sparrows. Sparrow densities either increased or were similar to those before treatments were applied. However, it should be noted that that study took place on dry prairie habitat and regional differences in habitat have been documented (Dunning 1990). Shriver et al. (1999) observed decreases in sparrow density on half of their control plots suggesting that sparrows began abandoning these areas in late June and early July two years after fire application. In contrast, increases in density were observed on unburned plots in both years of this study (Fig. 2.4, Fig. 2.5). Both sites in our study were burned on a 2 year fire interval prior to the commencement of this study. Therefore, our unburned plots in each year of the study had been burned the previous year whereas those in Shriver et al.'s (1999) were burned 2 years before. The difference between these findings and those of Shriver et al. (1999) suggest sparrow densities begin to decline 2 years following fire and further corroborates previous studies that advocate the need for frequent fire (Engstrom et al. 1984; Tucker et al. 2004).

Although we observed small declines in both density and survival in response to treatments during both years of our study, none of the evidence suggests these effects jeopardize population stability. A long term analysis of Bachman's sparrow survival that began in 2003 on the Wade Tract found that annual sparrow survival is >70% in some years (Cox and Jones 2007) despite being burned on a 2 year frequency during the growing season. This value is similar to survival estimates reported for the congeneric rufous-crowned sparrow (*Aimophila ruficeps*) (Morrison et al. 2004) whose life-history is not as tightly linked to disturbance frequencies as Bachman's sparrow. From a breeding standpoint, the worst-case scenario would result in the loss of an entire breeding season for a portion of the population (which we illustrate is not the case). However, it has been shown that stable meta-populations can be maintained when they intermittently function as sources (Hanski et al. 1996). Therefore, if only portions of the breeding season are being disrupted, there is little cause for concern because it is known that breeding habitat for Bachman's sparrows tends to be enhanced in years following prescribed fire regardless of season of application (Tucker et al. 2004). Although many land managers may favor dormant-season prescribed fire because weather conditions are often more favorable, our study indicates growing-season prescribed fires can be used as a means to extend the window of time needed to meet burn goals without detrimental effects on Bachman's sparrow. By extending the amount of time available each year to burn, more area can be treated in order to achieve a burn frequency similar to what occurred historically.

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CHAPTER 3

INFLUENCE OF VEGETATION CHARACTERISTICS AND BURN HISTORY ON BACHMAN'S SPARROW (*AIMOPHILA AESTIVALIS*) BREEDING STATUS, NEST LOCATION, AND HOME-RANGE SIZE.

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ABSTRACT

Bachman's sparrows (*Aimophila aestivalis*) occur in the fire-dependent longleaf pine (*Pinus palustris*) forests that once blanketed the southeastern United States. Like the longleaf pine forests, Bachman's sparrow populations have declined precipitously throughout most of their range. Declines are primarily due to fire suppression and loss of early successional habitat. We evaluated the influence of vegetation characteristics and burn history on home-range size, breeding status, and nest location of Bachman's sparrows occupying mature longleaf pine stands maintained using growing-season prescribed fires in southern Georgia. Home-range sizes were larger for paired males than unpaired males (t_{71} = 2.41, P = 0.02). Top models used to predict home-range size indicated that larger home ranges were associated with higher percentages of forbs and increase as the time since burn progresses. The probability that a male was paired decreased as shrubs < 1 m increased and nest location was best explained by increases in bare ground and shrubs < 1 m. Bare ground, which is essential for nest placement, disappears rapidly in months following fire and is a critical habitat feature. Growing-season prescribed fires are likely beneficial to Bachman's sparrows due to their ability to reduce hardwood encroachment and may increase the amount of area burned each year by extending the burn calendar.

INTRODUCTION

Fire is an essential tool for the preservation of southeastern pine savannas. Pine savannas support scores of rare and declining species (Noss et al. 1995), and prescribed fires maintain appropriate vegetation structure for these species by reducing understory woody vegetation and promoting grasses and forbs (Robbins and Myers 1992). As the time since application of prescribed fire increases, woody vegetation increases and grasses and forbs decrease. This results in a shift in the vegetation structure from grasses to a brush dominated landscape. Many species depend on frequent fire to replenish the vegetative structure.

Bachman's sparrow (*Aimophila aestivalis*) is an endemic North American songbird that is tightly linked to frequent fire (Dunning 2006). The distribution of this ground-nesting species overlaps largely with the former range of longleaf pine forests. Fire return intervals in this system are estimated to have been <5 years and may have occurred at ≤3 year intervals in many areas (Frost 1998; Huffman 2006). Historically, longleaf pine savannas stretched from Virginia, west through the Coastal Plain, and into Texas and Arkansas (Earley 2004). Absence of fire leads to the decline of many organisms inhabiting this system, including Bachman's sparrow. If suitable habitat goes without fire for 3 years, sparrows typically abandon these locations (Engstrom et al. 1984) and this aversion is tightly linked to structural and compositional changes in the vegetation.

Although the interval of prescribed fire is important, the seasonal timing of fires also may have some bearing on vegetation structure (Robbins and Myers 1992). Previous examinations of the effects of burning at different times of the year in southern pine forests contrast the effects of applying treatments during the winter against those occurring during the summer and late spring (i.e., growing-season fires) (Robbins and Myers 1992). Growing-season fires reduce the dominance of woody vegetation in comparison to winter burns and the result is a landscape where grasses are prevalent (Waldrop et al. 1987) and many species may benefit from such regimes. For example, the dominant ground cover species associated with many southeastern pine savannas is wiregrass (*Aristida* sp.). Study has revealed that when burned during the growing season, wiregrass often flowers more prolifically (Platt et al. 1991). This, coupled with other observations such as fire scar analysis from tree ring data (Huffman 2006), have led some to suggest that growing-season fires were the historical regime (Frost 1998; Robbins and Myers 1992; Hiers et al. 2002; Huffman 2006).

We studied Bachman's sparrows for two years in native longleaf pine forests dominated by wiregrass and maintained using growing-season prescribed fires. Our objectives were to investigate how this fire regime influenced vegetation structure and Bachman's sparrow home-range size, breeding status, and nest location. The sparrow's apparent preference for grassy areas that are frequently burned indicates that subtle changes in ground cover conditions may cause shifts prior to local abandonment. Understanding relationships between changing ground cover conditions and variables often linked to demographic parameters (Tucker 1998) could help land managers, and the public, understand the potential effects of growing-season prescribed fires. We predicted that recently burned areas would be more favorable for Bachman's sparrows and that this would be reflected through observed differences in home-range size, breeding status, and nest placement.

METHODS

Study plots

This study was conducted on Pebble Hill plantation (Grady County, GA; 30° 46' N, 84° 06' W) and the Wade Tract (Thomas County, GA; 30° 46' N, 84° 00' W) in the Red Hills region of southwestern Georgia. Large tracts of native ground cover blanket this portion of North Florida and southern Georgia (Ambrose 2001) in much the same way they did over 100 years ago (Earley 2004). Our study plots were dominated by native forbs and grasses that included large areas dominated by wiregrass (*Aristida beyrichiana*) and broomsedge (*Andropogon* sp.), and all study plots also encompassed clusters of red-cockaded woodpeckers (*Picoides borealis*), an indicator of mature pine forests (Jackson 1994). These conditions have been maintained by application of prescribed fire at ≤ 2 years and correspondingly support large populations of Bachman's sparrows (estimated >800 individuals on each property) and the region. Prescribed fires applied during the growing season (i.e., fires occurring during the nesting season) have been used for ca. 10 years (TTRS unpublished data) and were applied to approximately half of each study site during this investigation.

Home-range estimation

Male Bachman's sparrows were captured using recorded vocalizations placed near mist nets (Jones and Cox 2007) on eight plots ranging in size from 15 – 24 hectares. Birds were sexed by identifying the presence (females) or absence (males) of brood patches, cloacal protuberances (Pyle 1997), and behavioral observations. Banded birds were fitted with one federal band and three color bands (two bands per leg). Banding was conducted under federal permit 24466, Florida permit WB08121, and Georgia permit 29-WMB-02-143.

We monitored birds on each plot at least 4 times a month and geo-referenced location records of color-banded birds using a hand-held Trimble global positioning system (GPS). Color-band combinations were determined using spotting scopes. Individuals with ≥10 location records collected over ≥ 2 months were analyzed. Examination of the number of points collected plotted against home-range size revealed that home-range size was not biased for birds that had >10 location records and were monitored ≥ 2 months. There was no correlation between the number of points collected and home-range size ($r^2 < 0.1$) when using these criteria.

Home-range estimations were performed using ArcView® (ESRI 1998) and the Animal Movement extension (Hooge and Eichenlaub 1997). Home-range polygons were created for those males meeting the minimum sample size requirement. Home-range polygons were generated using 95% fixed kernel procedures (Hooge and Eichenlaub 1997). Separate polygons were created for each breeding season if a male was observed >1 breeding season.

Breeding status

We recorded reproductive indices for marked males following Shriver and Vickery (2001) and Tucker et al. (2006). Our ability to detect adults tending young or nestlings improved in the second year of our study primarily due to increased experience with distinctive call notes used near young and nests. To reduce bias, our analysis is based exclusively on the breeding status of males as paired or unpaired. Bachman's sparrows are sexually monomorphic, so we defined a sparrow as paired with a female if the singing male was repeatedly observed associating with a non-singing individual in an un-aggressive manner, observed carrying food, or tending fledglings.

Vegetation measurements

Shrub and ground cover measurements were collected at four 0.04 ha plots established 25 m from the center of survey grid points along major compass headings (*n* = 128). Samples were collected at four periods during this study and corresponded to 2, 6, 12, and 18 months following application of prescribed fire. We quantified woody shrubs as <1 m or >1 m in height by walking two transects from the center of each survey point to the perimeter of the 0.04 ha plot and counting the number of shrubs in each height category within a 1m buffer of the transect (hereafter called low and high shrubs) similar to James and Shugart (1970) and Haggerty (1988). Low shrubs were quantified separately because they may be associated with nest sites (Haggerty 1988). We quantified the dominance of different categories of ground cover vegetation using a 1-m^2 cover grid with 16 cells (Bonham 1989). The grid was placed on the ground at 16 random locations per plot and the number of cells dominated by 4 classes of vegetation (bare ground [includes dead litter], forb, grass, or woody) was recorded. We also measured ground cover vegetation at nest sites ($n = 29$) using these procedures. Nest site measurements were collected < 4 weeks after nests failed or fledged.

Statistical analysis

Three methods were used to examine the influence of vegetation variables on home-range size, breeding status, and nest location. Linear regression (Neter et al. 1990) was used to assess the influence of vegetation characteristics and burn history on Bachman's sparrow home-range size. Home-range sizes were log transformed to meet model assumptions of normality for linear regression, and residuals were plotted to visually assess equality of variance. Model fit was determined by examining scaled Pearson chi-squared estimates.

We used logistic regression analysis (Hosmer and Lemeshow 1989) to examine relationships between vegetation characteristics, home-range size, year, and time since burn on the breeding status (paired or unpaired) of a male Bachman's sparrow. Logistic regression was also used to elucidate the influence of vegetation and burn history on nest location by comparing samples taken at the nest location to those at vegetation plots.

We selected predictor variables for measured parameters we thought may influence home-range size, breeding status, and nest location (Table 3.1). We created global models containing all predictor variables for each analysis (home range, breeding status, and nest location) and subsets of the global models were used to create the candidate models (Table 3.2). An information-theoretic approach (Burnham and Anderson 2002) was used to create and assess the relative fit of each model. Fit of each model was determined using Akaike's Information Criteria (AIC; Akaike 1973) with small sample bias adjustment (AICc; Hurvich and Tsai 1989). Relative fit was determined by evaluating Akaike weights which are calculated by:

$$w_i = \frac{exp\,(-\frac{1}{2}\,\Delta\,AIC_i)}{\sum_{r=1}^{R} exp\,(-\frac{1}{2}\,\Delta\,AIC_i)}$$

across the set of R models (see Burnham and Anderson 2002). Akaike weights range from 0 to 1, thus the most parsimonious model will be reflected by the largest Akaike weight (Burnham and Anderson 2002). The purpose of using this approach was to examine the fit of each model on the data to determine which candidate model, or set of models (models with a ΔAICc < 2 of the best fitting model), was the best approximating model of Bachman's sparrow home-range size, breeding status, and nest location. To assess potential problems associated with multicollinearity, Pearson correlation coefficients were calculated for each pairwise combination of predictor variables. Predictor variables that were correlated ($r^2 > 0.3$) were not included.

Model averaging (Burnham and Anderson 1998) was used to incorporate uncertainty in model selection into the parameter estimates. Estimates of the regression coefficients and standard errors were weighted for each model according to AICc weights and then used to assess the relative effect of each of the parameters used in each analysis. Where logistic regression was implemented, odds ratios were calculated to determine the relative effect of each parameter. Precision of model-averaged coefficients was evaluated with 95% confidence intervals.

RESULTS

Seventy-three home ranges overlapped with vegetation grids and were included in this analysis. The average 95% fixed kernel home-range size was 1.74 ha (±1.41), indicating substantial variation in the area utilized by individuals. Forty-four home ranges included in the

Table 3.1. Name and description of variables used to create models of home-range size, breeding status, and nest location of Bachman's sparrows. Correlated variables were not included in the model.

Variable	Description
Forb	Percentage of ground cover dominated by forbs
Bare	Percentage of ground cover dominated by bare ground
Burn month	Categorical variable indicating whether or not ground cover was burned in the past 12 months
Low shrubs	Number of shrubs < 1m
High shrubs	Number of shrubs ≥ 1m
Grass	Percentage of ground cover dominated by grasses
Year	Calendar year of observation
Home range	Size of home-range generated from Fixed 95% Kernel home-range

analysis had been burned in the past 12 months and 29 received prescribed fire treatment more than 12 months prior to estimation of home range.

Bachman's sparrows located in areas burned within the past 12 months had smaller home ranges than those burned >12 months prior (1.66 ha vs. 1.90 ha), but this difference was not significant ($t_{71} = -1.60$; $P = 0.12$). However, the mean home-range size for paired sparrows was significantly larger (1.73 ± 1.04) ha than unpaired birds (1.38 ± 1.35) ha ($t_{71} = 2.41$, $P = 0.02$). Comparisons of mean vegetation measurements indicated that sparrows observed with mates had lower counts of low shrubs compared with unpaired birds, but other vegetation characteristics were similar.

The confidence set of models used to predict home-range size included Forb and Burn month (Table 3.2). The Forb model was 1.7 times more likely to be the best model than Burn month. Parameter estimates from model averaging indicated that increases in percent forbs, high shrubs, and months since burn were associated with larger home ranges (Fig. 3.1). Increases in the low shrubs, bare ground, and grass-cover resulted in smaller home ranges. The models within the confidence set used to predict breeding status indicated that Home-range size and Low shrubs best explained status as paired or unpaired (Table 3.2), with the Low shrubs model nearly three times more likely than the next best model containing home-range size only. Parameter estimates (Fig. 3.2) suggested increases in Low shrubs decreased the chances an individual was paired, but this effect did not appear to be significant. However, increases in percent of ground cover dominated by Forbs as well as increases in percent Bare ground appeared to increase the probability of being paired, although the effect of Bare ground was weak.

Table 3.2. Model sets and candidate models for influential vegetation characteristics and burn histories affecting home-range size, breeding status, and nest site location of Bachman's sparrows in a frequently burned native longleaf pine forest. Selection criteria for best models was based on a ΔAICc < 2.

Candidate models	K	AICc	ΔAICc	w_i
Home range				
Forb	3	42.62	0.00	0.38
Burn month	3	43.60	0.98	0.23
High shrub	3	45.73	3.11	0.08
Low shrub	3	45.84	3.21	0.08
Grass	3	46.03	3.40	0.07
Bare	3	46.36	3.73	0.06
Global Model	9	46.91	4.29	0.04
Bare, High shrub	4	47.97	5.35	0.03
Bare, Low shrub	4	47.98	5.36	0.03
Breeding Status				
Low shrub	3	83.95	0	0.33
Home range	3	85.89	1.95	0.12
Bare, Low shrub	4	86.19	2.24	0.11
Year	3	86.99	3.04	0.07
High shrub	3	87.09	3.15	0.07
Bare	3	87.12	3.17	0.07
Forb	3	87.33	3.38	0.06
Grass	3	87.33	3.38	0.06
Burn month	3	87.33	3.38	0.06
Bare, High shrub	4	89.05	5.11	0.03
Global	10	98.15	14.2	0
Nest Site				
Bare, Low shrub	4	98.85	0.00	0.72
Global	8	100.71	1.86	0.28
Low shrub	3	126.17	27.32	0.00
Grass	3	146.87	48.02	0.00
Bare	3	162.28	63.42	0.00
Bare, High shrub	4	163.76	64.91	0.00
Forb	3	167.72	68.86	0.00
Burn month	4	170.18	71.33	0.00
High shrub	3	170.46	71.61	0.00

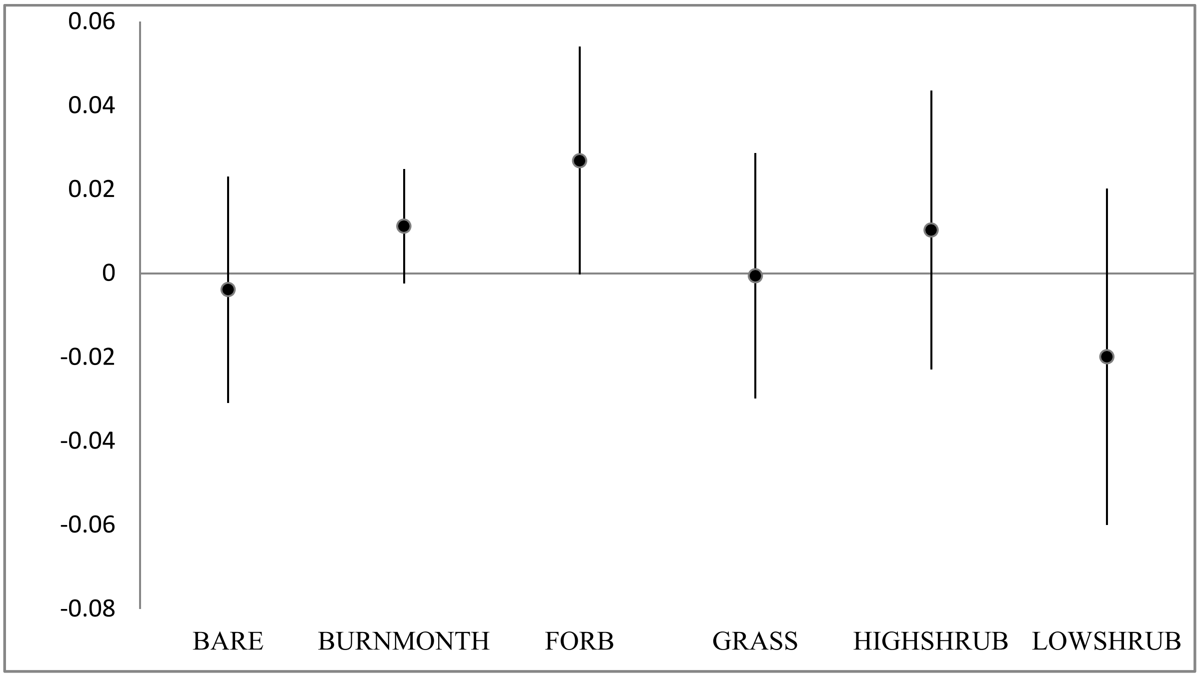

Figure 3.1. Model averaged parameter estimates from linear regression analysis of the influence of vegetation characteristics on Bachman's sparrow home-range size.

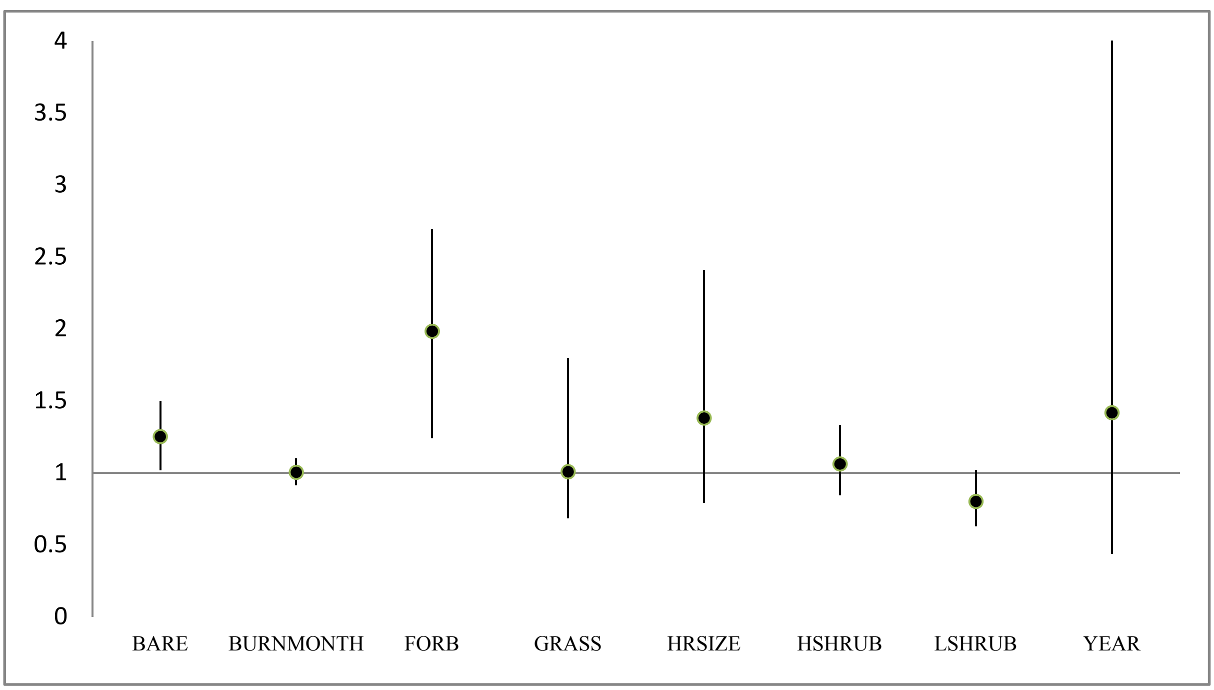

Figure 3.2. Model averaged parameter estimates from logistic regression analysis of the influence of vegetation characteristics, home-range size, burn history, and year on the breeding status of male Bachman's sparrows.

Logistic models used for predicting nest locations indicated that the model containing Bare and Low shrub was the most parsimonious, but the confidence set also included the global model. A model incorporating bare ground and low shrubs was >2.5 times more likely than the global model containing all parameters. Model-averaged parameter estimates from Low shrubs and Bare ground (both included in the top model) suggest increases in these vegetation measurements increased at the nest site. Burn month appeared to have the greatest positive effect on nest location (although there was much associated variability) and only 6 out of the 29 nests included in this analysis were found in areas burned >12 months. High shrub, Forb, and Grass had a negative effect on nest location, but all other variables had a positive effect on the probability of nest location (Fig. 3.3).

Our results indicated that low shrubs, bare ground, and burning may influence nest sites and we were interested in examining how these effects changed over time. Our results suggested that nest sites resembled recently burned areas in some aspects, but not others (Fig. 3.4; Fig. 3.5). Percent bare ground at nest locations was similar to locations burned 2 months previous and decreases substantially as months since prescribed fire increase (Fig. 3.4). By contrast, the Low shrub index indicated that many nest locations contain a shrub component that is greater than areas in the surrounding landscape; including areas that have not received fire in the previous 12 months (Fig. 3.5).

DISCUSSION

In our analyses several variables of interest emerged that were consistent across different life-history traits of Bachman's sparrows. For example, low shrubs and bare ground were present in the top models used to predict breeding status and nest location. Similarly, increases

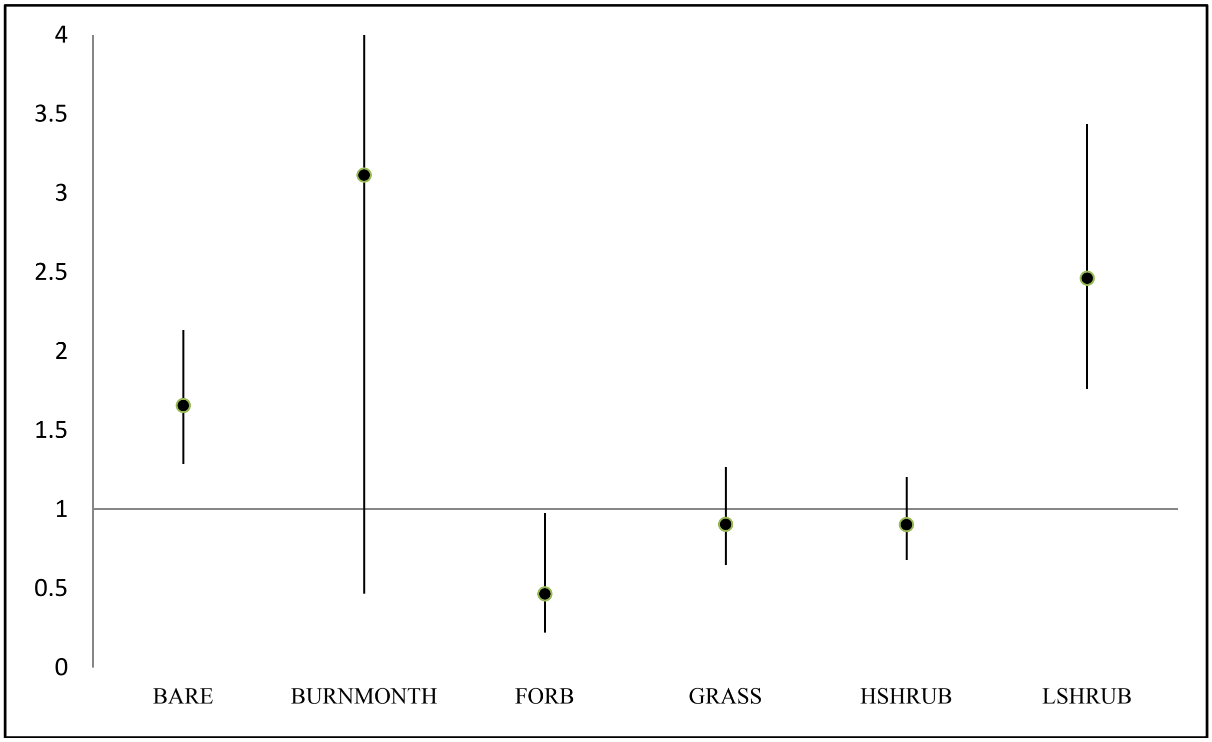

Figure 3.3. Model averaged parameter estimates from logistic regression analysis of the influence of vegetation characteristics and burn history on Bachman's sparrow nest location.

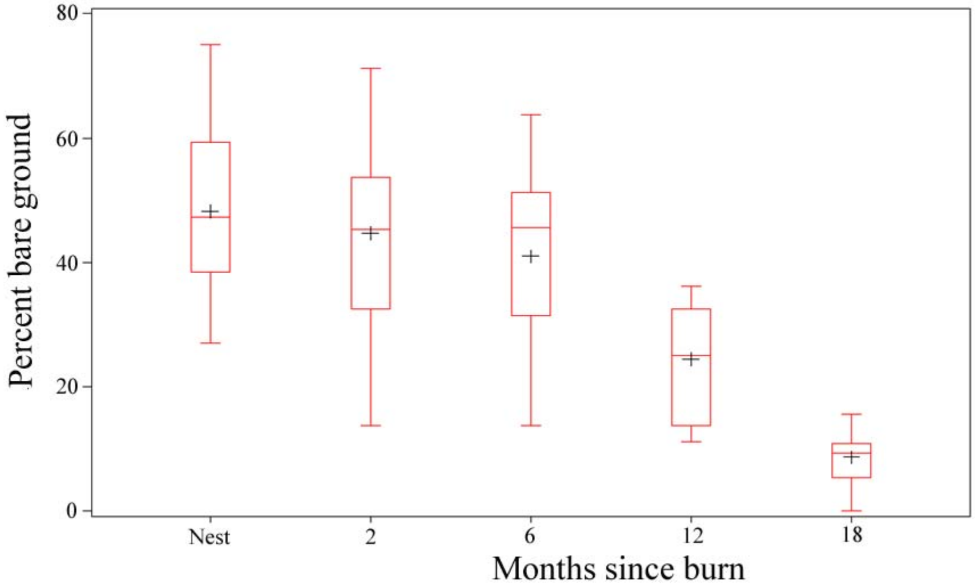

Figure 3.4. Boxplots of percent bare ground comparisons between Bachman's sparrow nest sites and average changes at vegetation points (non-nest locations) through time.

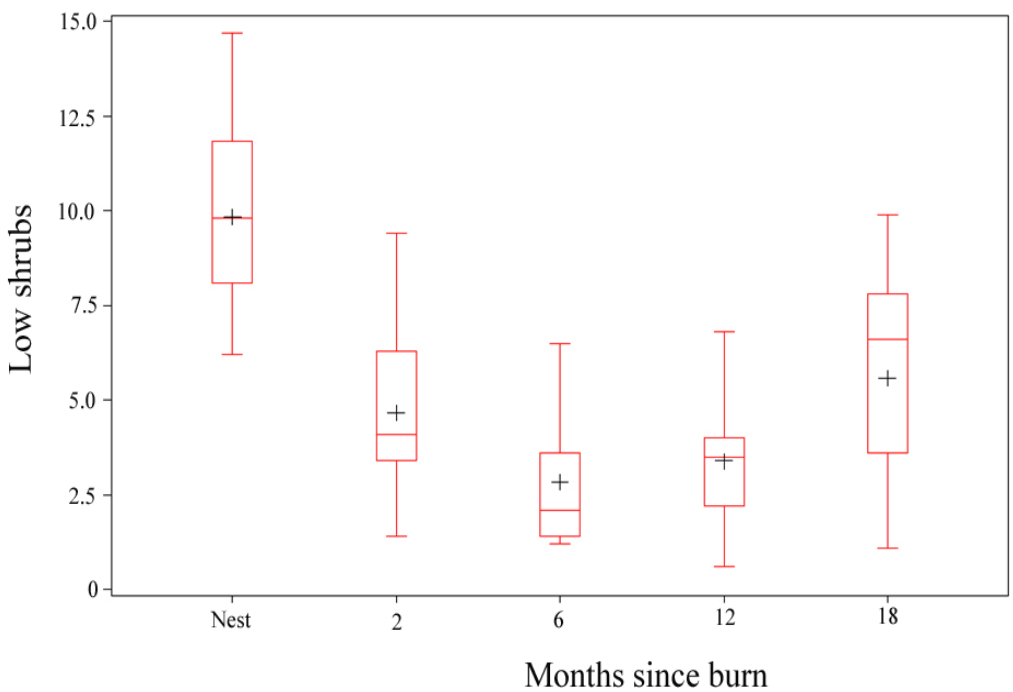

Figure 3.5. Boxplots of low shrub index comparisons between Bachman's sparrow nest sites and average changes at vegetation points (non-nest locations) through time.

in the amount of forbs present were associated with larger home ranges and increased the probability that a male was paired. This pattern is consistent with our finding that paired males had larger home ranges. Burn month, although not present in the top models predicting breeding status and nest location, had a positive effect in all of our analyses and reaffirms the importance of regular applications of prescribed fire.

We found that increases in percent forbs and time since burn were positively related to the home-range size of male Bachman's sparrows. Although parameter estimates indicated that this effect of this relationship was weak, it may illustrate that male sparrows are able to maintain smaller home ranges on areas that were recently burned. Male Bachman's sparrows have been observed to increase in density only a few weeks after growing-season prescribed fires (Shriver et al. 1999), which should correspond with a decrease in home-range size. This may be due to increases in bare ground (Fig. 3.4) that creates more usable space for foraging. The positive effect of forbs on home-range size suggests sparrows' preference for more upland locations. In the lower lying areas of our study sites, densities of sparrows were lower than upland sites and likely resulted in larger home ranges. These home ranges located near low-lying moist areas, ephemeral wetlands, and slopes of drainages, had higher forb cover in comparison to uplands, although forbs in upland areas may be important (see below).

In Arkansas, Haggerty (1998) reported the home-range size of Bachman's sparrows was negatively related to percent forb cover, ground cover, forb height, percent grass cover, and density of vegetation between 0 - 90 cm. These observations, while seemingly at odds with our results, are likely the result of the pine systems in which their investigations took place. Haggerty's study plots were commercial timber stands and therefore may not have possessed plant diversity and ground cover conditions similar to our study plots, which have not been heavily influenced by agriculture and timber operations. The variation in results between our study and Haggerty's points to the need for quantifying ground cover conditions more precisely because thresholds likely exist where conditions become too thick or too sparse.

Mean home-range sizes provided in other studies are comparable to ours. Haggerty (1998) reported a mean home-range size of 2.5 ha based on minimum convex polygon (MCP) estimates. Our mean home-range size was 1.74 ha, but was based on methods (FK95) thought to be more accurate and informative for passerines (Barg et al. 2005). Estimates of home-range size based on the use of radio transmitters (Stober and Krementz 2006) reported mean home-range sizes of 3.26 ha for males and 2.2 ha for females based on 95% MCP estimates.

Little is known about differences in home-range size that exist across the range of Bachman's sparrow, but Stober and Krementz (2006) reported that smaller home ranges were associated with younger pine stands than mature stands. In a previous examination of Bachman's sparrow home-range size on the Wade Tract, mean sparrow home-range size was 1.9 ha for sparrows whose territories were burned during the growing season and 3.1 ha for territories that were not burned the same year (Cox and Jones 2007). These averages were based on birds with $\geq$ 20 observations over 2 months and included long-distance movements (Cox and Jones 2007). Both Cox and Jones (2007) and Stober and Krementz (2006) showed that smaller home ranges were associated with areas that were either burned more recently or were in early stages of succession, indicating that recently burned habitats may support more male territories than habitats not burned within the previous 12 months.

In addition to associations between vegetation and home-range size, males with mates had home ranges that were significantly larger than males who lacked mates. Although smaller home ranges may indicate higher quality habitats (Hinde 1956), successfully breeding birds have been shown to have larger home ranges (Whitaker et al. 2006), possibly induced by increased distances required for retrieving prey items to feed nestlings and young. Additionally, we observed adult male and female Bachman's sparrows providing care for several weeks after the young fledged and we often observed juveniles hatched in one territory begging in neighboring territories. Therefore, this reason alone may explain why paired males have larger home ranges than unpaired males.

Increases in the low shrub index decreased the probability a male was paired. Shrub cover increases rapidly after fire suppression and may influence habitat suitability at the home-range level (Fig. 3.5). Both bare ground and percent forb cover increased the probability that a male was paired. Forbs may play an important role as host plants for sparrow prey that are fed to nestlings and recently fledged young. We regularly observed sparrows carrying Lepidoptera larvae to nests. In tall grass prairies, which also require regular disturbance for habitat maintenance, high quality sites favoring native forbs have been found to have greater species richness and abundance of Lepidoptera (Collinge et al. 2003). Therefore, it is likely that forbs play an important role as host plants for prey items at a critical stage of the Bachman's sparrow life-cycle.

Nest locations were characterized by vegetation features that resembled more recently burned habitat in many ways, but differed in others. Most nests were located in recently burned sites, but included more low shrubs than found in surrounding areas. A clear trend was seen in changes in bare ground (Fig. 3.4) as time since burn increased. Previous nest site descriptions of Bachman's sparrows mention bare ground as a distinctive characteristic of the nest location (Haggerty 1986), but no comparison to the surrounding landscape was made in that study. Nest-site selection may be driven by vegetation characteristics that reduce the probability of nest predation (Martin 1988). Similar to Haggerty (1986), Bachman's sparrows we observed delivering food (or carrying nesting material) to nests during this study flew to the ground first then walked 5–15 meters to the actual nest location. Bare ground allows alternate approaches to nest sites and may misdirect predators and brood parasitism from brown-headed cowbirds (*Molothrus ater*). Additionally, fledglings are often incapable of flight upon leaving the nest, so higher percentages of bare ground may provide good fledgling habitat as long as other vegetation characteristics are available for adequate cover. The presence of higher amounts of low shrubs at the nest site (Fig. 3.5) may provide such cover and could provide important concealment from predators during the first few days after fledging when flightless young are vulnerable (Dunning 2006).

Subtle heterogeneity in vegetation characteristics within forests maintained with frequent prescribed fires influenced breeding status and nest placement for Bachman's sparrows. Although we found some effects of vegetation differences on home-range size within our study plots, these relationships were generally weak. This may be due to the sampling methodology employed whereby we attempted to use fixed points within our study plots that home ranges overlapped instead of creating random sampling locations within each home range (see Haggerty 1988). Our finding that territories with increased low shrub densities had decreased probabilities of having a mate is consistent with observations that Bachman's sparrows are more frequently found in areas with higher percentages of grass and forb cover with few dense shrubs (Hardin 1982; Dunning 1990). We speculate that some of these unpaired individuals were younger males that occupied lower quality habitat, however since there is not a reliable method for aging Bachman's sparrows (Pyle 1997) we were unable to confirm this suspicion.

Nest location appears to be influenced by all of the variables we examined, but bare ground and low shrubs emerged as the most important (Table 3.2). This relationship is likely to hold in settings where native ground cover and open canopies dominate, however there is undoubtedly a threshold at which too much bare ground results in unsuitable nesting habitat. The strong connection between the use of prescribed fire (or other similar disturbances) and the ability of Bachman's sparrows to persist is most likely linked to increases in seed production for many low statured legumes and the prey items that use these plants as hosts. Different seasons of application of prescribed fire may have differing effects on the vegetation characteristics that this species prefers.

Although there is evidence that frequent growing-season prescribed fires were the historical norm (Robbins and Myers 1992; Frost 1998; Huffman 2006), there is some debate about the benefits they provide. Growing-season prescribed fires reduce the number of woody stems in comparison to dormant season fires (Waldrop et al. 1987; Robbins and Myers 1992) and our research, as well others (Haggerty 1998; Dunning 2006), illustrate that habitats dominated by woody shrubs are lower quality for Bachman's sparrows. Although many native grasses increase their flowering response after growing-season fires (Platt et al. 1989; Platt et al. 1991), conflicting reports exist on the effects to legumes during different seasons. Hiers et al. (2000) found that flowering responses of legumes were highly variable in response to growing versus dormant-season prescribed fires. However, others have noted increases in legume abundance in areas treated with growing-season fires over those receiving dormant-season fires (Mudder et al. 2006). Under either scenario, and across the range of this species, the management message is clear: frequent application of prescribed fire is necessary to perpetuate habitat appropriate for Bachman's sparrows. Growing-season prescribed fires are one tool that will likely enhance habitat conditions for Bachman's sparrow and should be integrated with management strategies for this species.

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CHAPTER 4

CONCLUSION AND MANAGEMENT RECOMMENDATIONS

The fraction of longleaf pine forest that currently remains in the southeast represents one of the greatest losses of an ecosystem in the history of the United States. Management strategies incorporating prescribed fire regimes are critical to maintaining ecosystem integrity. Simply purchasing the remaining land for conservation will not be enough. This study examined the effects of prescribed fires on a declining bird species, Bachman's sparrow, to quantify the impact of burning during the nesting season. I was interested in examining the effects of growing season prescribed fires because burning during this time of the year can often enhance habitat attributes for many species by increasing hardwood kill compared to dormant season fires. This aspect makes growing season prescribed fires attractive to many land managers and has become a common practice on many state and federal land parcels.

Survival analyses indicated that burning does decrease apparent survival, but may be offset by increases in habitat quality in subsequent seasons. Additionally, burning at different times during the nesting season may have different effects. Our results indicate that burning earlier in the breeding season may allow the vegetation time to recover and may trigger increases in density of Bachman's sparrows following prescribed fires during this time. These results are similar to the findings of other studies that examined changes in density following fires in the dry prairie of central Florida (Shriver and Vickery 2001). Burning later in the season may not allow enough time for vegetation to recover so that many birds abandon territories and may not return until after the breeding season has come to a close. Extent of fires may also play an important role in the ability of Bachman's sparrows to disperse to nearby unburned patches, however we were unable to definitively attribute differences in population responses due to extent of prescribed fire treatment. Future research investigating the extent of fires larger than those used in this study is warranted.

In longleaf pine forests, the diversity is found in the ground cover and this is where Bachman's sparrows spend most of their time. Home-range sizes for sparrows that were paired were larger than those that were unpaired. We also found that unpaired males tended to be in areas that contained higher amounts of shrubs than paired males. This confirms the importance of grass dominated habitats for this species. Vegetation structure at nest locations resembled recently burned areas primarily in the amount of bare ground present and were often associated with low shrubs. Bare ground likely plays a role in the ability of young to fledge without having to contend with significant obstruction. Additionally, adults bringing food to the nest or returning to incubate may be able to misdirect predators and parasitism from brown-headed cowbirds. As the time since fire application increases, much of the bare ground is covered up by litter and grass and creates a matted ground cover that is poor nesting habitat. Regular fire return intervals replenish the appropriate vegetation structure for Bachman's sparrows, as well as other organisms that spend their time foraging on the forest floor beneath the longleaf pines.

MANAGEMENT RECOMMENDATIONS

The importance of fire in the longleaf pine ecosystem is not a new revelation. However, season of fire application is often debated and some land managers express preference for one over another. Growing-season fires are often more difficult to implement due to less predictable winds and air quality concerns in locations near urban areas. In addition, growing-season fires may be difficult to control due to the spring drought that often precedes the wet season in areas in the southeast, particularly southern Georgia and Florida. These dry fuels are more combustible and can result in increased fire severity (Robbins and Myers 1992). However, increased combustibility is one reason that these fires can be so effective at controlling hardwood encroachment. The promotion of grasses and the reduction of woody vegetation resulting from growing-season prescribed fires make them a valuable management tool.

In order to conduct effective management using prescribed fire, treatments should be large enough to allow burns to be conducted on a 2 to 3 year interval in southern pine ecosystems to mimic the historic fire return interval (Huffman 2006). On some federally managed lands such as the Apalachicola National Forest, this requires burning over 40,000 ha each year and is only accomplished using prescribed fires that encompass, on average, 550 ha or more (Picotte, Tall Timbers Research Station, pers. comm.). Smaller fires are often more time consuming to implement and result less area burned each year. The increased price of applying prescribed fires in smaller patches (Rideout and Omi 1995) may not be warranted if larger fires are necessary to maintain the proper fire return interval. If future research finds that larger extent fires threaten population stability of Bachman's sparrows and other declining pine savanna species, it may be possible to implement burn regimes that incorporate fires at smaller extents. However, the evolutionary history of this species suggests that large extent fires were the norm and that fire frequency, not extent, is the driving factor of population stability.

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