ECOLOGY OF FEMALE EASTERN WILD TURKEYS (*MELEAGRIS GALLOPAVO SILVESTRIS*) IN FREQUENTLY-BURNED PINE SAVANNAS IN SOUTHWESTERN GEORGIA

by

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(Under the Direction of Michael J. Chamberlain)

ABSTRACT

Longleaf pine savannas (*Pinus palustris*) are currently being restored throughout the southeastern United States due to their economic and ecological importance. However, little information exists on Eastern wild turkey (*Meleagris gallopavo silvestris*) ecology in pine savannas. Therefore, I evaluated nest site selection, nest and brood survival, habitat selection, and survival of adult, female wild turkeys. I conducted my research on the 11,735-ha Joseph W. Jones Ecological Research Center at Ichauway (Jones Center) located in Baker County, Georgia and the 3,900-ha Silver Lake Wildlife Management Area owned by the Georgia Department of Natural Resources located in Decatur County, Georgia (Silver Lake WMA). Nest site (15-m scale) habitat metrics (mean visual obstruction [cm], total ground cover [%], and canopy closure [%]) had the greatest influence on nest site selection. Nest survival was not influenced by habitat characteristics at the nest-site and patch-level, which suggests that once a nest site is chosen nest predation occurs randomly with respect to habitat characteristics. Annual survival was 0.53 (95% CI: 0.42-0.65). Seasonal survival estimates varied from a high during fall ($\hat{S}$ = 0.92; 95% CI: 0.77-0.97) to a low during spring ($\hat{S}$ = 0.77; 95% CI: 0.66-0.85). Nesting status (incubating a nest or not) did not influence survival during the spring nesting season. Predation was the leading cause of mortality with 35.1% of mortalities attributed to mesocarnivore predation (bobcat [*Lynx rufus*], coyote [*Canis latrans*], and gray fox [*Urocyon cinereoargenteus*]) and 18.9% to great-horned owl (*Bubo virginianus*) predation. Females used mature pine stands less than available, instead selecting for hardwoods, shrub/scrub, and young pine habitats. Time-since-fire did not influence female turkey use of pine-dominated stands, suggesting they can coexist with frequent fire regimes in pine savannas. I recommend biologists and land managers balance objectives of wild turkey habitat management with those of threatened and endangered species (e.g., gopher tortoise [*Gopherus polyphemus*]) in pine savannas by creating early-successional habitat for nesting and brood-rearing cover as well as . Additionally, I recommend the promotion of habitat diversity through the retention of hardwoods and recognize the importance of openings to management of wild turkey populations in pine savannas.

INDEX WORDS: Eastern wild turkey, *Meleagris gallopavo silvestris*, prescribed fire, radio-telemetry, survival, habitat selection, nest survival, nest site selection, longleaf pine

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M.S., Mississippi State University, 2011

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2015

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December 2015

DEDICATION

This dissertation is dedicated to my entire family: my wife Laura, daughter Gennavieve, parents Durand and Jane, Grandmother Jewell, and father- and mother-in-law Neal and Susan Hoff. They all deserve credit for whom and where I am today. Most importantly, I dedicate this dissertation to my Lord and Savior, Jesus Christ. He has walked with me through the ups and downs of life, and no matter what, I could always trust that He would be there for me. A guiding Biblical verse that I've held close to my heart during my graduate career is Proverbs 3:5-6, "Trust in the Lord with all your heart and lean not on your own understanding; in all your ways submit to him, and he will make your paths straight." Thank you to my entire family and to my Lord and Savior, Jesus Christ, for your love and support throughout the pursuit of my Ph.D.

ACKNOWLEDGEMENTS

I would first like to thank my major advisor, Dr. Michael Chamberlain, for his unwavering support and guidance over the past few years. You have prepared me for the next step in life as I transition from being a wildlife graduate student to wildlife professional. I will forever be grateful for your ability to teach me how to become the 90/10 guy. You have also taught me how to become a more effective scientific writer. I cannot thank you enough for these past few years and your willingness to provide me with research and teaching opportunities. I was fortunate to also be advised by Drs. Bob Warren, Mike Conner, and Nate Nibbelink. Dr. Warren's support and guidance throughout the past few years has been remarkable. He provided me with numerous opportunities to improve my teaching skills and become a more effective wildlife teacher and communicator. Dr. Warren has also been an incredible mentor and for this I will be forever grateful. Dr. Conner provided countless hours of analytical support over the past few years and was always willing to sit down and discuss topics related to my dissertation or other theoretical ideas. I will always remember those thought-provoking discussions we had over a cup of coffee and your desire to get me to think "outside of the box." Dr. Nibbelink provided spatial analysis support and was always willing to discuss my interests in animal movements and resource selection modeling. I cannot thank my committee enough for their support and guidance over the past few years. Each of you have challenged me to critically think and develop innovative ways to address research questions. I will forever be grateful for everything that each of you has taught me.

I would like to thank the University of Georgia–Warnell School of Forestry and Natural Resources, Joseph W. Jones Ecological Research Center at Ichauway, and the Georgia Wildlife Resources Division for providing financial support for this research. I consider myself very fortunate to have had the opportunity to complete my dissertation at a world-renown natural resources institution like the University of Georgia–Warnell School of Forestry and Natural Resources. I want to thank the many faculty and staff in Warnell that have made the past few years some of the most memorable in my life time. I want to specifically thank Dr. John Maerz for his guidance in my pursuit of my Interdisciplinary Teaching Certificate in University Teaching. He challenged me to improve my teaching skills and incorporate an active-learning approach to teaching students. I want to thank Drs. Clint Moore and Brian Irwin with the Georgia Cooperative Fish and Wildlife Research Unit for their statistical guidance during my dissertation research. I want to also thank a great friend and colleague, Dr. Stephen L. Webb (Landscape Ecologist–Samuel Roberts Noble Foundation), who always challenged me to think “outside of the box” and develop innovative approaches to address wildlife research questions. Likewise, Dr. Webb provided statistical guidance during my dissertation research and has always been a great support to bounce off ideas. I will forever be grateful for everything that you, Dr. Webb, have taught me during my graduate career.

I also consider myself very fortunate to have had the opportunity to conduct part of my dissertation research on the Joseph W. Jones Ecological Research Center at Ichauway. I am deeply indebted to the Jones Center and all the staff that contributed to my dissertation. I thank Jean Brock for her spatial analysis assistance and willingness to teach me more about ArcGIS. I want to thank Liz Cox for locating those difficult to find publications that I cited in my dissertation. I want to thank Dr. Lindsey Boring, Jimmy Atkinson, Scott Smith, Mark Melvin, Brandon Rutledge, Michael Simmons, and Bobby Bass for their support and friendship. I also want to thank Gail Morris, Joseph Warden, and Nick Deuel for their assistance with wild turkey trapping and tracking. Last but not least, I would not be where I’m at today without the friendship and support from the “turkey team” which includes: Meg Streich, Drew Ruttinger, Derek Colbert, and Christina Perez. Thank you all for your guidance during the past few years!

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

The longleaf pine-grassland (*Pinus palustris-Poaceae;* hereafter, pine savannas) ecosystem historically occupied over 30 million ha in the southeastern United States (Brockway et al. 2005, Van Lear et al. 2005). This ecosystem is both ecologically and economically important due to the rich flora and fauna biodiversity, and high tolerance to fire events (Alavalapati et al. 2002). Pine savannas were historically maintained by low- to moderate-intensity fires ignited by lightning or humans, which maintained the early successional grassland community and prevented bottomland hardwood encroachment (Komarek 1964, Pyne 1982, Robbins and Myers 1992, Kennamer et al. 1992, Van Lear et al. 2005). Pine savannas are also considered one of the most ecologically diverse ecosystems in North America containing a variety of habitat types (e.g., depressional wetlands, hammocks, and upland/wetland ecotones; Van Lear et al. 2005). Unfortunately, land use change [e.g., conversion from longleaf pine to faster growing loblolly pine (*Pinus taeda*) and slash pine (*Pinus elliottii*), and increase in agricultural practices and urban development] led to their decline (Frost 1993, Alavalapati et al. 2002, Van Lear et al. 2005). Additionally, lack of reforestation efforts combined with government policies that encouraged landowners to exclude fire from their properties also contributed to the decline of pine savannas (Alavalapati et al. 2002). Today, 1.2 million ha remain in the southeastern United States primarily in fragmented sections (Van Lear et al. 2005).

The decline of pine savannas has had dramatic impacts on endemic flora and fauna. Landers et al. (1995) reported that over 30 plant and animal species that occur in this ecosystem are now considered threatened or endangered. An important upland game species found in pine savannas is the Eastern wild turkey (*Meleagris gallopavo silvestris*; hereafter, wild turkey). Wild turkey populations have also experienced dramatic declines dating back to the late 1800's to early 1900's primarily due to overharvest and loss of habitat (Kennamer et al. 1992). Wild turkeys prefer early-successional habitat provided by a system managed with frequent fire (Hurst 1981, McGlincy 1985, Landers and Mueller 1986, Exum 1988, Provencher et al. 1998). Fortunately, natural resource professionals recognized the abundant biodiversity supported by pine savannas and began implementing restoration efforts to restore landscapes in the Southeastern United States (Barnett 1999, Alavalapati et al. 2002, Brockway et al. 2005). A common method to incentivize landowners to restore their properties to pine savannas is the use of financial support (e.g., carbon sequestration benefits) from private and governmental agencies to replant longleaf pine and maintain their property in a pine savanna condition through the use of prescribed fire (Alavalapati et al. 2002). Natural resource professionals also recognized the declining wild turkey populations and implemented restocking programs to reverse the drastic population declines (Kennamer and Kennamer 1990, Kennamer et al. 1992). With pine savanna restoration efforts underway and little existing information on wild turkey populations in this system, research is needed to address aspects of their general ecology to direct future management efforts. Specifically, research is needed to balance management objectives of wild turkey habitat management with those of threatened and endangered species (e.g., gopher tortoise [*Gopherus polyphemus*], red-cockaded woodpecker [*Picoides borealis*]).

WILD TURKEY ECOLOGY AND PRESCRIBED FIRE

Wild turkey populations are strongly influenced by reproductive success (Palmer et al. 1993, Roberts et al. 1995, Roberts and Porter 1996, Miller et al. 1999, Thogmartin and Johnson 1999). Palmer et al. (1993) reported an average nest success of 30.8% (n = 104 nests) and poult survival to >50 days was 22.7% for 27 broods (n = 203 poults). They attributed the low reproduction to predation and environmental factors (e.g., food, rainfall). Similarly, Thogmartin and Johnson (1999) reported low nest success (13%) and small clutch sizes (9.0/adult hen, 7.8/subadult hen) and partially attributed the low reproduction to poor physiological conditions of female turkeys prior to nesting. Other studies have reported higher nest success ranging from 47% (Nguyen et al. 2003) to 68% (Vander Haegen et al. 1988). However, a significant knowledge gap exists on wild turkey reproductive ecology in systems managed by frequent fire, which makes management for turkeys difficult in this system.

Nest site selection can influence survival and reproductive performance of avian species (Martin and Roper 1988, Badyaev 1995, Thogmartin 1999). For example, Badyaev (1995) found successful nests had greater vegetation density relative to depredated nests, which suggests that nest site selection can influence reproductive success. Wild turkey nests are typically located in areas with greater understory vegetation (Speake et al. 1975, Healy 1981, Badyaev 1995, Byrne and Chamberlain 2013, Streich et al. 2015) and in areas with reduced canopy closure (e.g., shrub/scrub habitat) presumably to reduce the risk of predation (Hillestad and Speake 1970, Hurst and

Stringer 1975, Martin and McGinnes 1975, Sisson et al. 1991, Streich et al. 2015). Previous research has indicated that selection of nest sites with greater understory vegetation may reduce transmission of olfactory and visual cues for potential nest predators and impede foraging efficiency by restricting predator movements (Bowman and Harris 1980, Lehman et al. 2008). Additionally, turkey nest site selection may also depend on multi-scale processes including differences in vegetation structure around nest sites, habitat composition and configuration at larger spatial scales, and predator densities (Thogmartin 1999). Females may select a nest site based not only on the vegetation characteristics at a nest site, but also the surrounding habitat composition to reduce the risk of predation (Martin and Roper 1988). However, little research has focused on multi-scale nest site selection for wild turkeys.

Prescribed fire is a common management tool used in pine savannas to reduce undesirable competing vegetation (e.g., hardwoods) while promoting a diverse understory plant community (Waldrop et al. 1992, Cain et al. 1998, Brockway and Lewis 1997, Barnett 1999, Steen et al. 2013). Prescribed fire has even been shown to increase insect abundance (McGlincy 1985, Landers and Mueller 1986, Exum 1988, Provencher et al. 1998). Traditionally, fire in pine savanna ecosystems occurred mostly during the growing-season from lightning-ignition (Komarek 1964, Pyne 1982, Robbins and Myers 1992). Biologists and land managers have raised concerns over potentially excessive nest loss due to growing-season prescribed fire during the turkey nesting season (1 April – 30 June). For example, Moore (2006) reported that 9% of turkey nests were destroyed by growing-season fire. A loss of nests from fire coupled with predation losses could have long-term impacts on turkey population growth and sustainability. Sisson and Speake

(1994) recommended that growing-season prescribed fire be withheld until after the turkey nesting and brood-rearing season to ensure turkey populations were not negatively impacted by fire. Growing-season prescribed fires are considered an important part of silvicultural practice in pine savannas to improve the fruiting and flowering of native flora, while avoiding reduction of growth and survival of pines (Streng et al. 1993). For example, wiregrass (*Aristida* spp.) is one of the most common plant species found in pine savannas and requires growing-season fire to induce flowering and propagation (Mulligan and Kirkman 2002, Fill et al. 2012).

Prescribed fire is also a critically important habitat management tool in pine savannas for the successful restoration of the endangered red-cockaded woodpecker, which requires open, park-like conditions (Alavalapati et al. 2002). Therefore, simply withholding growing-season prescribed fire during the turkey nesting and brood-rearing season as recommended by Sisson and Speake (1994) may not be a viable option for land managers that are focused on promoting biodiversity in pine savannas. Research is needed to address the potential impacts of growing-season prescribed fire on turkey nest and brood survival in a system that is managed by frequent prescribed fire to direct future management decisions.

Wild turkey seasonal habitat selection is not clearly understood in systems managed by frequent fire, which may lead to poor management decisions for turkeys in this system. In pine-dominated forests, female wild turkeys typically use hardwood forests during fall and winter and move into upland pine or pine-hardwood forests prior to nesting (Speake et al. 1975, Kennamer et al. 1980, Miller and Conner 2007, Martin et al. 2012). During spring, females typically select areas characterized by relatively dense ground cover and woody vegetation (Hillestad 1970, Speake et al. 1975, Streich et al. 2015). During summer, females select areas with abundant herbaceous vegetation (e.g., thinned pine stands, Speake et al. 1975, Hurst and Dickson 1992) and agricultural fields (Miller and Conner 2007) presumably due to abundant food resources. Habitat selection may also be influenced by time-since-fire. Martin et al. (2012) found female wild turkeys preferred pine savannas burned within 1.4 years. They attributed the avoidance of stands with longer burn rotations to the inability of females to effectively find food resources after 500 days post-fire. However, previous research in pine-dominated systems has recommended longer burn intervals ranging from 3 to 7 years to aid in development of concealment cover to reduce impacts of predation on wild turkeys and other ground-nesting birds (Stoddard 1963, Miller et al. 2000, Miller and Conner 2007). Therefore, research is warranted to better understand the influence of prescribed fire on wild turkey habitat selection in a forested system managed with frequent fire.

Adult wild turkey survival is not clearly understood in pine savannas. Turkey population growth is regulated by nest success, brood survival, and adult survival (Roberts et al. 1995, Vanguilder and Kurzejeski 1995, Godfrey and Norman 1999). Low survival of female wild turkeys and broods may limit population productivity (Miller and Leopold 1992, Palmer et al. 1993, Peoples et al. 1995, Miller et al. 1998). However, a significant knowledge gap currently exists regarding our understanding of wild turkey population dynamics in frequently-burned pine savannas. Williams (2012) reported a greater initial nest success in 2 pine savannas relative to other published studies in the region (Palmer et al. 1993, Miller et al. 1998, Thogmartin and Johnson 1999, Wilson et al. 2005, Byrne and Chamberlain 2013). Williams (2012) also observed similar renesting rates and success relative to other published studies in the region (Palmer et al. 1993, Miller et al. 1998, Thogmartin and Johnson 1999, Wilson et al. 2005, Byrne and Chamberlain 2013), suggesting that females were likely to renest after nest loss. Williams (2012) observed brood survival rates similar to previous studies (Exum et al. 1987, Sisson et al. 1991, Peoples et al. 1995). However, survival of adult, female wild turkeys has not been studied previously in pine savannas, yet this information is critical to effectively manage turkey populations.

Herein, I present information on nest site selection, nest survival, nest success, brood survival, habitat selection, and survival of female Eastern wild turkeys in 2 frequently-burned pine savannas. Chapter 2 describes nest site selection at multiple spatial scales to assess the important habitat components that drive nest site selection. Chapter 3 describes nest and brood success, and the effects of microhabitat and landscape level habitat components, and time of nest initiation, on nest survival. Chapter 4 describes habitat selection during fall-winter (1 October – 31 January), preincubation (1 Februrary – 19 April), and summer (16 June – 30 September). Chapter 5 describes survival and cause-specific mortality. The final chapter provides conclusions and management implications for wild turkey management in pine savannas. I also include suggestions for future research directions.

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CHAPTER 2

EASTERN WILD TURKEY NEST SITE SELECTION IN 2 FREQUENTLY-BURNED PINE SAVANNAS: A MULTI-SCALE ANALYSIS[1]

[1]Little, A. R., M. J. Chamberlain, L. M. Conner, and R. J. Warren. To be submitted to Ecological Processes

ABSTRACT

Reproductive success is a critical factor affecting avian demographics, and can be influenced by many factors including nesting chronology, predation risk, and fine-scale nest site selection. We modeled the relative influences of habitat-related covariates at 5 spatial scales (nest site, 15-m; 40-m, 80-m, 120-m, and 160-m radius) on nest site selection by Eastern wild turkey (*Meleagris gallopavo silvestris)* in 2 pine savannas managed by frequent prescribed fire (≤ 3 years) in southwestern Georgia during 2011-2013. Nest site (15-m scale) habitat metrics (mean visual obstruction [cm], total ground cover [%], and canopy closure [%]) had the greatest influence on nest site selection relative to covariates measured at larger spatial scales. Scaled odds ratios suggested that nests were 28.7% more likely to occur for every 10 cm increase in mean vegetation height and 21.4% less likely to occur for every 10% increase in canopy closure. Patch density (e.g., number of shrub/scrub patches) and percent habitat type (e.g., mature pine, mixed pine/hardwood, shrub/scrub) had little influence on nest site selection. Management of pine savanna habitat for turkey nest sites should focus on creating early-successional vegetation to conceal nests from potential predators by using periodic prescribed fire (2-3 years).

INTRODUCTION

Wild turkey populations are strongly influenced by reproductive success (Palmer et al. 1993, Roberts et al. 1995, Roberts and Porter 1996, Miller et al. 1999, Thogmartin and Shaeffer 2000), and predation is a driver of this success (Speake 1980, Still and Baumann 1990, Miller and Leopold 1992, Lovell et al. 1997). Lower nesting success of turkeys may depend on multi-scale processes including differences in vegetation structure around nest sites, habitat composition and configuration at larger spatial scales, and predator densities (Thogmartin 1999). For example, Martin and Roper (1988) suggested that habitat selection at larger scales surrounding the nest site could affect predation risk; therefore, females may select a nest site based not only on the vegetation characteristics at a nest site, but also the surrounding habitat composition. Research is needed to fill this knowledge gap in our understanding of wild turkey nest site selection in pine savannas to direct our future management decisions. Additionally, few studies have evaluated the role of spatial scale on turkey nest site selection; therefore, we evaluated whether Eastern wild turkey (*Meleagris gallopavo silvestris*) nest site selection in 2 pine savannas was influenced by habitat composition at multiple spatial scales.

Wild turkeys primarily select nest sites with greater understory vegetation (Speake et al. 1975, Healy 1981, Badyaev 1995, Byrne and Chamberlain 2013, Streich et al. 2015) and less canopy closure (i.e., shrub/scrub habitat) presumably because these areas are considered important to broods for foraging and cover (Hillestad and Speake 1970, Hurst and Stringer 1975, Martin and McGinnes 1975, Sisson et al. 1991, Streich et al. 2015). Selection of nest sites with greater understory vegetation may reduce transmission of olfactory and visual cues to potential nest predators and impede predator foraging efficiency (Bowman and Harris 1980, Lehman et al. 2008). For example, Lehman et al. (2008) found that coyotes (*Canis latrans*) were the primary predator of turkey nests, and as nesting season progressed, temporally, precipitation declined and vegetation cover increased, suggesting that coyotes may have difficulty locating nests later in the nesting season. Roads have have been shown to be a detrimental influence on wild turkey nest survival (Thogmartin 1999), likely due to the high probability of use of roads as travel corridors by mesocarnivores (e.g., raccoon; Frey and Conover 2006). Similarly, edge habitat has also been shown to be important to nest site selection with females nesting closer to edges (Thogmartin 1999).

Nest site selection is thought to be a hierarchical process (Lazarus and Porter 1985, Martin and Roper 1988, Badyaev 1995, Thogmartin 1999) such that turkeys first locate a general area to establish a nest and within this area select a suitable nest site. For example, Thogmartin (1999) suggested that wild turkey nest site selection and success likely depend on patterns and processes at multiple spatial scales such as fine-scale vegetation structure within patches (nest site), broader scale habitat composition and configuration, and mesocarnivore densities. Lehman et al. (2008) evaluated the effects of multiple spatial scales on turkey nest site selection and survival, and found that successful turkey nests were located in larger habitat patches that contained greater visual obstruction surrounding the nest site. Conversely, Fuller et al. (2013) evaluated the effects of nest site and patch-level metrics on turkey nest site selection and survival, and found little support for a hierarchical process concluding that vegetation around the nest site was most important. Recently, Conley et al. (2015) studied mean area used by turkeys during incubation and suggested future habitat assessments associated with turkey nests should be focused on small spatial scales (e.g., < 3 ha). Uncertainty regarding the influence of spatial scale on turkey nest site selection warrants research to help guide future decisions directed at managing habitats for wild turkeys.

Little research has evaluated effects of spatial scale on turkey nest site selection in frequently burned (≤ 3 year fire return interval) pine savannas. Streich et al. (2015) did not consider the hierarchical process that may influence turkey nest site selection because they evaluated effects of nest site and landscape-level habitat composition on turkey nest site selection separately. Additionally, Streich et al. (2015) used distance metrics to evaluate nest site selection, which do not incorporate the juxtaposition and potential importance of multiple habitat types that may be biologically relevant to nest site selection. Frequently-burned pine systems provide a unique opportunity to evaluate the effects of spatial scale on turkey nest site selection, because this system is primarily characterized by open, park-like conditions with a predominantly herbaceous understory, which is not characteristic of habitat conditions in many previous studies (e.g., Lehman et al. 2008, Fuller et al. 2013). Therefore, our objective was to evaluate whether nest site selection was a hierarchical process in a pine-dominated system managed by frequent fire ($\leq$ 3 years).

STUDY AREA

Our study was conducted on the 11,735-ha Joseph W. Jones Ecological Research Center at Ichauway (hereafter, Jones Center) located in Baker County, Georgia and the 3,900-ha Silver Lake Wildlife Management Area (hereafter, Silver Lake WMA) owned by the Georgia Department of Natural Resources located in Decatur County, Georgia. The Jones Center was comprised of approximately 39% mature pine, 24% mixed pine/hardwood, 11% agriculture/food plot, 8% young pine, 7% hardwoods, 4% scrub-shrub, 3% wetland, 3% open water, and 1% residential/barren. Wiregrass and old-field grasses (e.g., *Andropogon* spp.) were the dominant understory habitat in the pine and mixed pine/hardwood stands (Goebel et al. 1997). However, >1,000 vascular plant species occur on the site (Drew et al. 1998). Silver Lake WMA was comprised of approximately 56% mature pine, 22% young pine, 10% open water, 9% mixed pine/hardwood, 1% shrub/scrub, 1% hardwood, 1% residential/barren, and < 1% wetlands and agriculture/food plots. The Georgia Department of Natural Resources provided all habitat classification data for Silver Lake WMA, which we used to create similar habitat classes across both study sites. Paved, gravel, and dirt road densities were 5.48 km/km^2 and 6.59 km/km^2 on the Jones Center and Silver Lake WMA, respectively. Total rainfall during the nest and brood-rearing season (1 April–31 July) at the Jones Center was 28.32 cm in 2011, 36.35 cm in 2012, and 52.02 cm in 2013. Similarly, total rainfall at Silver Lake WMA was 25.48 cm in 2011 and 36.55 cm in 2012. Average daily temperature at the Jones Center was 25.09° C in 2011, 24.56° C in 2012, and 23.62° C in 2013 (Jones Center; Georgia Automated Environmental Monitoring Network; http://georgiaweather.net). Likewise, average daily temperature at Silver Lake WMA was 25.77° C in 2011 and 25.24° C in 2012 (Lake Seminole; Georgia Automated Environmental Monitoring Network; http://georgiaweather.net).

METHODS

Turkey Capture and Monitoring

We captured female wild turkeys using rocket nets baited with corn during December–March of 2011-2013 and June–August of 2011-2012. We fitted all captured females with serially numbered, butt-end (left leg) and riveted (right leg) aluminum leg bands (National Band and Tag Co., Newport, KY). We also affixed a backpack-style VHF radio-transmitter, weighing approximately 60-g, (Sirtrack, Havelock North, New Zealand; and Telenax, Playa del Carmen, México) to all females. All birds were released at the capture site immediately after processing. The Institutional Animal Care and Use

Committee at the University of Georgia approved all turkey capture, handling, and marking procedures (Protocol #A2013 05-034-Y1-A0).

We used a hand-held, 3-element Yagi antenna and Wildlife Materials TRX 2000S receiver (Wildlife Materials, Murphysboro, Illinois) to locate radio-marked females ≥2 times per week from mid-July to mid-March and ≥ 1 time per day from mid-March to mid-July. We triangulated each female and recorded the locations using a mobile phone containing Location Of A Signal-SD software (LOAS™ [2010] Ecological Software Solutions LLC. Hegymagas, Hungary, Version 4.0.3.8.) and a Bluetooth-Global Positioning System unit. We considered a female to be incubating if she did not move for 3 consecutive days during the nesting season. Once a female was determined to be incubating, we approached to within 25 m of the nest and recorded compass bearings toward the nest. After termination of incubation, we approached nest sites to determine nest fate, clutch size, and possible brood size, and a GPS location was recorded for future analyses.

Habitat classification

We classified stands as pine if they consisted of loblolly, longleaf, slash, and shortleaf (*Pinus echinata*) pine with > 90% pine. We classified stands as mature pine if trees were > 20 years old and in large pole (12.6-25.4 cm) or saw timber (> 25.4 cm) size classes; these stands had an average basal area of 4.9 m^2 (range: 0.2 to 12.6 m^2). We classified stands as young pine if trees were ≤ 20 years old and in seedling/sapling (0-12.7 cm) or small pole timber (12.7-25.4 cm) size classes; these stands had an average basal area of 2.0 m^2 (range: 0 to 10.43 m^2).

Mixed pine/hardwood stands contained a variety of species (e.g., loblolly, longleaf, slash pine, southern red oak [*Quercus falcata*], turkey oak [*Quercus laevis*], live oak [*Quercus virginiana*], laurel oak [*Quercus laurifolia*], and sweetgum [*Liquidambar styraciflua*]). We classified stands as mixed pine/hardwood if they were 50 to 80% hardwood or pine. Within these stands, tree sizes ranged from seedling/sapling through saw timber; however, most (> 90%) were in the pole to saw timber classes. Average basal area was 2.8 m^2 (range: 0 to 8.8 m^2) for pine and 3.2 m^2 (range: 0 to 20.8 m^2) for hardwoods.

Hardwood stands consisted of a variety of species (e.g., southern red, turkey, live, laurel oaks, and sweetgum) with tree sizes ranging from seedling/sapling to saw timber; however, most (> 90%) were in the pole to saw timber classes. Average basal area was 9.8 m^2 (range: 2.9 to 30.1 m^2) and consisted of > 90% hardwoods. We classified stands as agriculture/food plot if they consisted of cropland, pasture land, wildlife food plots, or horticultural crops (e.g., pecan orchard). Shrub/scrub stands consisted of abandoned agricultural fields and pastures, clear-cuts, grassland, and shrubby areas.

To successfully restore and maintain pine savannas on our study sites, land managers used prescribed fire and mechanical hardwood removal. Fire was applied to mature pine, young pine, mixed pine/hardwood, and shrub/scrub habitats. Prescribed fire was conducted throughout the year with > 95% of burns conducted during January-June. Prescribed fire application occurred in a mosaic fashion, which promoted landscape diversity. Average patch size burned at the Jones Center was 21.41 ha (SE = 0.83; range = 0.02 – 240.57 ha), whereas average patch size burned at Silver Lake WMA was 14.41 ha (SE = 0.58; range = 0.66 – 88.27 ha). Fire return interval typically ranged from 1-3 years, but most (≥ 95%) fires applied to our study sites were ≤ 2-years (38.4%, 0-year; 34.9%, 1-year; 21.7%, 2-year; 4.9% of stands with 3-year time-since-fire). Land managers often used mechanical removal to remove large off-site hardwoods [e.g., water oak (*Quercus nigra*)] from within mature pine stands.

Habitat Characteristics Across Scales

One issue with multi-scale studies is the selection of an appropriate set of scales based on the biology of the species. Biotic and abiotic processes operate and interact at multiple spatial scales on the landscape (Turner 1989), which suggests that no single spatial scale likely exists for multiple landscape metrics that may influence avian nest success and/or survival (Stephens et al. 2005, Webb et al. 2012). Therefore, we evaluated non-random turkey nest site selection at multiple spatial scales (15-m [nest site], 40-m, 80-m, 120-m, and 160-m radius) by comparing used (i.e., nest sites) to available locations (i.e., potential nest sites). We arbitrarily selected the larger spatial scales (i.e., 40-m, 80-m, 120-m, and 160-m radius) by increasing the buffer size by 40-m but focused our scale selection on smaller sizes based on Conley et al.'s (2015) suggestion that future turkey nest ecology studies should focus on habitat within 3 ha surrounding the nest. Streich et al. (2015) evaluated turkey nest site selection on the same study sites using 52 nests (including 3 found opportunistically) from 2011-2012 that contained nest site vegetation metrics. However, they did not consider the potential hierarchical process that may influence turkey nest site selection. Therefore, we included 22 (27.8%) additional nests from 2013 and evaluated whether nest site habitat metrics, landscape metrics, or a combination of both influenced nest site selection.

At the nest site (15-m spatial scale), we measured understory vegetation height (cm), percent canopy cover, and percent ground cover immediately following nest hatch or nest loss. To evaluate understory vegetation height, we measured the average visual obstruction (cm) at each nest site using a Robel pole (Robel et al. 1970). The Robel pole was placed in the nest bowl and viewed from a distance of 15-m in each cardinal direction from the nest site at a height of 1 m. We measured percent canopy cover using a spherical densiometer (Lemmon 1956) and percent ground cover using a 1-m^2 Daubenmire frame (Daubenmire 1959) at the center of the nest-bowl and at a distance of 15-m in each cardinal direction from the nest site. Ground cover was partitioned into 6 cover types: debris, fern, forb, grass, vine, and woody. We then combined the 6 cover types into one variable (total ground cover).

At larger spatial scales (i.e., 40-m, 80-m, 120-m, and 160-m radius), we used FRAGSTATS (McGarigal and Marks 1995) to calculate class and landscape level metrics. We calculated the percentage of mature pine, mixed pine/hardwoods, hardwoods, young pine, agriculture/food plots, and shrub/scrub habitats at the class-level. We then calculated patch density (number of patches/100 hectares) and interspersion and juxtaposition index. The interspersion and juxtaposition index is based on patch adjacencies and measures the interspersion or intermixing of patch types (McGarigal and Marks 1995). We also used ArcGIS® 10.2 to measure the distance from each used and random nest site location to the nearest road (paved, gravel, and dirt) and distance to nearest edge between 2 habitat types.

Statistical Analysis

We used logistic regression in an information-theoretic framework (Burnham and Anderson 2002) to evaluate the effect of each landscape variable at multiple spatial scales (i.e., 40-m, 80-m, 120-m, and 160-m radius) on turkey nest site selection. We selected the spatial scale for each landscape variable using Akaike's information criterion (AIC) adjusted for small sample size (AICc; Burnham and Anderson 2002). For example, we evaluated percent mature pine at 40-m, 80-m, 120-m, and 160-m radius and selected the scale with the lowest AICc. In cases where all models for a landscape variable had AICc scores < 4.0 units, we selected the scale that provided the simplest biological interpretation. We used generalized linear models (GLM) implemented in R (R Core Team 2013) and a use vs. availability resource selection approach to evaluate non-random nest site selection by comparing used (i.e., actual nest sites) to available (i.e., potential nest sites) in a logistic regression framework where nests were represented as a binary response (1 = actual nest site; 0 = potential nest site). We combined nest sites for all 3 years across both study sites to increase sample size. After only one spatial scale was selected for each landscape variable, we then evaluated pairwise correlations among the nest site (15-m) and landscape (40-m, 80-m, 120-m, and 160-m radius) explanatory variables using Pearson correlation. We removed any variables that were highly correlated ($r \geq 0.6$) and retained the variable that provided the simplest biological interpretation. We developed 18 models to describe nest site selection with 4 models describing nest site variables (i.e., mean visual obstruction, canopy cover, and total ground cover), 6 models describing landscape variables (e.g., percentage of mature pine, patch density), and 8 models describing a combination of nest site and landscape variables. We developed these models based on our interest in evaluating whether nest site habitat metrics, landscape metrics, or a combination of both influenced nest site selection. We used AICc to compare models (Akaike 1973, Burnham and Anderson 2002). We considered the model with the lowest AIC*c* to be the best model, and all models with AIC*c* < 4.0 units from the best model as the best set of approximating models. We calculated the Akaike weight (*wi*) for each model as an estimate of the probability of the model being the most parsimonious. We then used model-averaging to calculate parameter estimates, conditional standard errors, and variable weights of the top-performing models within 4 AICc units based on their adjusted Akaike weights (w*i*, Burnham and Anderson 2002). We only considered parameter estimates with 95% confidence intervals that excluded zero to be informative.

RESULTS

We monitored 84 nests during 2011-2013, and 79 nests were initiated by 45 individual females (78 adults and 1 juvenile). We excluded 12 nests from the analysis because vegetation at the nest site was altered by prescribed fire and/or mowing (n = 7) and little information existed for the opportunistically found nests (n = 5). Our final dataset used for analysis consisted of 72 nests.

We removed the interspersion and juxtaposition index variable because it was highly correlated with patch density (r =0.61). Our predictive models of nest site selection included nest site and landscape-level variables collected at multiple spatial scales (Table 2.1). We found that the nest site model (15-m scale) was the most parsimonious model (w*i* = 0.45; Table 2.2) and the best set of approximating models (< 4 AICc units) contained ≥ 1 nest site habitat covariate. Patch density and percent habitat type had little influence on nest site selection. Model-averaged parameter estimates suggested that mean visual obstruction, percent ground cover, percent canopy closure, distance to nearest road, and distance to edge were important predictors of nest site selection (Table 2.3). Scaled odds ratios suggested that nests were 28.7% more likely to occur for every 10 cm increase in mean vegetation height (Table 2.3). Mean visual obstruction at used nest sites was 113.7 cm (SE = 3.1) and 82.4 cm (SE = 5.3) at random sites with a range from 50.0 to 150.0 on our study sites. Scaled odds ratios suggested that nests were 21.4% less likely to occur for every 10 percent increase in canopy closure (Table 2.3). Mean percent canopy cover at used nest sites was 56.6% (SE = 3.4) and 64.1% (SE = 3.2) at random sites with a range from 0.0% to 97.8% on our study sites.

DISCUSSION

Wild turkey nest site selection was strongly influenced by habitat structure at the nest site (15-m scale) relative to other habitat variables at larger spatial scales. We found that visual obstruction and canopy closure most influenced selection of nest sites, which is consistent with findings of Streich et al. (2015). However, we found habitat metrics measured at larger spatial scales (i.e., patch density and percent habitat type) had little influence on turkey nest site selection, which is contrary to Streich et al. (2015). Streich et al. (2015) found that turkeys selected nests farther from mature pine and mature pine-hardwood stands and closer to shrub/scrub habitats than expected. We suggest that the difference we observed is primarily due to the evaluation of multiple spatial scales in the same modeling procedure, compared to separately evaluating nest site and landscape-level metrics on nest site selection as reported in Streich et al. (2015). Our analytical approach accounted for the potential hierarchical process in nest site selection, and evaluated influences of habitat metrics measured at multiple spatial scales on turkey nest site selection. Additionally, we used percent habitat composition and patch density metrics, which incorporate in the habitat composition around the nest sites compared to using distance-based metrics as reported by Streich et al. (2015). Our findings also illustrate the importance of evaluating the influence of spatial scale on wildlife-habitat relationships, because metrics measured at larger spatial scales had little influence on where female turkeys established nest sites. This suggests that turkeys are primarily focused on finding nest sites that provide adequate visual obstruction from predators. Our study provides evidence that vegetation at the nest site-level is the primary driver of nest site selection in pine savannas managed by frequent prescribed fire (≤ 3 year fire-return interval).

Mean visual obstruction was an important predictor of nest site selection followed by percent canopy closure. Our findings are consistent with previous studies that found turkeys select nest sites in areas with increased vegetation height (Badyaev 1995, Chamberlain and Leopold 1998, Byrne and Chamberlain 2013, Fuller et al. 2013). Visual obstruction surrounding nests may reduce transmission of olfactory and visual cues for potential nest predators and impede foraging efficiency by restricting predator movements (Bowman and Harris 1980, Lehman et al. 2008). Fuller et al. (2013) found that daily survival rate of turkey nests during incubation increased as percent understory cover (vegetation < 1 m tall) increased, but also that nest survival declined with increasing density of woody shrubs and saplings and herbaceous stems < 1 m tall (understory vegetation density) around the nest. They suggested survival was likely dependent on a balance of sufficient understory cover around nests to provide concealment, but not so great as to impede a female's ability to detect and escape predators. Percent canopy closure was also an important predictor of nest site selection occurring in 3 of the 4 best approximating models for nest site selection. Likewise, reduced canopy closure also allows for greater sunlight and presumably greater understory growth.

Contrary to Thogmartin (1999), we found habitat metrics measured at larger spatial scales (i.e., patch density and percent habitat type) had little influence on nest site selection. A key difference between our study and Thogmartin (1999) is that we conducted our research in a pine savanna system managed by frequent prescribed fire. Frequent prescribed fire reduces small hardwoods and shrubs resulting in a corresponding increase in grasses and forbs creating open, park-like conditions (Waldrop et al. 1992, Brockway and Lewis 1997, Glitzenstein et al. 2012). Additionally, frequent prescribed fire in pine savannas increases understory plant species richness, diversity, and evenness (Brockway and Lewis 1997), which potentially provides wild turkeys with an abundance of suitable nesting habitat. Previous research has indicated that prescribed fire is an important factor in maintaining quality early-successional understory habitat conditions and herbaceous vegetation while increasing insect abundance for wild turkeys (McGlincy 1985, Landers and Mueller 1986, Exum 1988, Provencher et al. 1998). Our research suggests open, pine savannas managed by frequent prescribed fire (≤ 3 years) and at small-scales (12-22 ha) are beneficial for the development of early-successional nesting habitat.

Multi-scale studies facilitate an improved understanding of how scale can influence ecosystem functions (Wheatley and Johnson 2009). Our study is one of only a few studies that has used a multi-scale approach to evaluate the effects of vegetation composition across multiple spatial scales on turkey nest site selection. Fuller et al. (2013) evaluated Eastern wild turkey nest survival in Connecticut as a function of nest site and patch-level habitat metrics, and found the nest site scale (i.e., vegetation surrounding the nest site) was most important to nest site selection and survival. Lehman et al. (2008) evaluated Merriam's turkey (*Meleagris gallopavo merriami*) nest site selection and survival in South Dakota as a function of multiple habitat components collected at multiple spatial scales. They provided evidence for a hierarchical nest site selection process because they found land cover patch size (ha) and visual obstruction at the nest site to be the 2 primary habitat components that influenced nest site selection and survival. Most recently, Conley et al. (2015) found that the mean area used by turkeys during incubation was < 3 ha, suggesting smaller spatial scales may be important to turkey nest site selection. These studies all illustrate the importance of scale when evaluating turkey nest site selection because some habitat components (e.g., patch size) measured at larger spatial scales may be important to turkeys; however, all of these studies illustrate that turkeys are primarily focused on finding nest sites that provide adequate visual obstruction from predators. Therefore, we concur with Conley et al. (2015) that future studies evaluating nest site selection and survival should primarily focus on smaller spatial scales surrounding the nest site.

MANAGEMENT IMPLICATIONS

Our research indicates that turkey nest site selection is primarily influenced by the habitat composition immediately surrounding the nest site. Mean visual obstruction and percent canopy closure were the primary drivers of nest site selection on our study sites. Patch density (e.g., number of shrub/scrub patches) and percent habitat type (e.g., mature pine, mixed pine/hardwood, shrub/scrub) had little influence on turkey nest site selection. Our study suggests that management of pine savannas with frequent (≤ 3 years) prescribed fire return intervals can be beneficial to turkeys by providing early-successional vegetation for nest site establishment. We suggest land managers balance management objectives of wild turkey habitat management with those of threatened and endangered species (e.g., gopher tortoise [*Gopherus polyphemus*] and red-cockaded woodpecker [*Picoides borealis*]) by promoting early-successional vegetation in pine savannas through use of small-scale (12-22 ha) and periodic prescribed fire (2 -3 years).

ACKNOWLEDGEMENTS

We are grateful for funding provided by the Georgia Wildlife Resources Division through the Wildlife Restoration Program (Grant No. W75), the Joseph W. Jones Ecological Research Center at Ichauway, and the Warnell School of Forestry and Natural Resources at the University of Georgia. We thank the staff at the aforementioned organizations for their technical assistance on this project, and M. Streich, C. Perez, D. Colbert, and D. Ruttinger for their assistance with data collection.

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Table 2.1. Variables and spatial scales considered important to Eastern wild turkey (*Meleagris gallopavo silvestris*) nest site selection in 2 pine savannas (Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area) located in southwestern Georgia, USA, 2010-2013.

Variable[a]	Scale (m)
Nest site	
Mean visual obstruction	15
Canopy closure	15
Total ground cover	15
Landscape	
Mature pine (%)	40
Mixed pine/hardwoods (%)	40
Hardwoods (%)	40
Young Pine (%)	40
Agriculture (%)	40
Shrub/scrub (%)	40
Patch density	160
Distance to nearest road	N/A
Distance to edge	N/A

[a]Information-theoretic approach was used to evaluate each larger landscape variable at multiple spatial scales (i.e., 40-m, 80-m, 120-m,

and 160-m radius). The spatial scale for each landscape variable was selected using Akaike's information criterion (AIC) adjusted for small sample size (AICc). In cases where all models for a landscape variable had AICc scores < 4.0 units, the scale that provided the simplest biological interpretation was selected.

Table 2.2. Nest site[a] and landscape-level[b] models of Eastern wild turkey (*Meleagris gallopavo silvestris*) nest site selection in 2 pine savannas (Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area) located in southwestern Georgia, USA, 2010-2013.

Model	*K*	AICc	Δ AICc	w_i
Nest site	4	176.84	0.00	0.45
Nest site + distance to edge	5	178.94	2.10	0.16
Nest site + distance to nearest road	5	178.97	2.13	0.16
Mean visual obstruction	2	179.93	3.09	0.10
Nest site + distance to edge + distance to nearest road	6	181.10	4.26	0.05
Landscape + mean visual obstruction	8	181.54	4.70	0.04
Landscape + nest site	10	181.87	5.03	0.04
Global model	12	185.78	8.94	0.01
Landscape + total ground cover	8	200.12	23.28	0.00
Canopy closure	2	201.05	24.21	0.00
Distance to edge	2	201.06	24.22	0.00
Landscape	7	202.04	25.20	0.00
Landscape + distance to nearest road	8	203.21	26.38	0.00
Total ground cover	2	203.32	26.48	0.00
Landscape + distance to edge	8	203.45	26.61	0.00
Distance to nearest road	2	203.68	26.84	0.00
Landscape + canopy closure	8	204.14	27.30	0.00

Landscape + distance to edge + distance to nearest road	9	204.75	27.91	0.00

[a]Nest site (15-m spatial scale): total ground cover (percentage of debris, fern, forb, grass, vine, and woody cover), canopy cover, and mean visual obstruction.
[b]Landscape-level (refer to Table 2.1 for spatial scale selected for each variable): percentage of mature pine, mixed pine/hardwoods, hardwoods, young pine, agriculture/food plots, shrub/scrub, and patch density (number of patches/100 hectares).
[c]Global model: landscape + nest site + distance to edge + distance to nearest road.

Table 2.3. Model-averaged parameter estimates of important variables from top-performing models used to predict nest site selection of female Eastern wild turkey (*Meleagris gallopavo silvestris*) in 2 pine savannas (Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area) located in southwestern Georgia, USA, 2010-2013.

Variable	Estimate	SE	Scalar	Variable weight	Odds ratio	Lower 95% odds ratio	Upper 95% odds ratio
Mean visual obstruction	0.252	0.056	10[a]	1.000	1.287	1.153	1.436
Canopy closure	-0.193	0.074	10[b]	0.890	0.824	0.713	0.954
Total ground cover	0.121	0.163	10[b]	0.890	1.129	0.821	1.553
Distance to edge	-0.038	0.181	50[c]	0.180	0.962	0.675	1.372
Distance to nearest road	0.024	0.181	50[c]	0.180	1.025	0.719	1.460

[a]Biologically relevant scaler in centimeters (cm).
[b]Biologically relevant scaler in percent (%).
[c]Biologically relevant scaler in meters (m)

CHAPTER 3

EASTERN WILD TURKEY REPRODUCTIVE ECOLOGY IN FREQUENTLY-BURNED LONGLEAF PINE SAVANNAS[1]

[1]Little, A. R., M .M . Streich, M. J. Chamberlain, L. M. Conner, and R. J. Warren. 2014. Forest Ecology and Management 331:180–187. Reprinted here with permission of publisher.

ABSTRACT

Longleaf pine (*Pinus palustris*) savannas are economically and ecologically important throughout the southeastern United States; however, deforestation and other land use changes have led to their decline. Fortunately, natural resource professionals have recognized the importance of restoring these ecologically important forests that support a diversity of native flora and fauna. Although efforts are underway to restore longleaf pine savannas, little information exists on Eastern wild turkey (*Meleagris gallopavo silvestris*) reproductive ecology within these systems. Therefore, we used radio telemetry to investigate Eastern wild turkey reproductive ecology in 2 longleaf pine-dominated forests in southwestern Georgia during 2011-2013. Forty-two percent of nests (n=78) were successful (≥ 1 egg hatched) with most nest loss resulting from predation. Five nests were exposed to prescribed fire events (2 were successful; 3 were unsuccessful). Thirty-seven percent of females renested following loss to predation, fire, or other factors. Of these, 43% successfully hatched (≥ 1 egg hatched). We monitored 34 broods post-hatch. Of the 34 broods, 11 (32%) survived the 14-day flightless period. Of the remaining 11 broods, 7 (64%) survived the following 2-week period (i.e., days 15-30). One of 34 broods was lost to growing-season prescribed fire during the study. Females frequently selected nest sites in areas at the end of their burn rotation (i.e., prior to the next scheduled burn; $\bar{x}$ = 613.7 days since burn for all nests from nest initiation date; SE = 44.7 days). Habitat characteristics at the nest-site and patch-level had little influence on nest survival, suggesting that once a nest site is chosen, nest predation occurs randomly with respect to habitat characteristics. In addition, timing of nest initiation did not significantly improve nest survival. Management of longleaf pine savannas should

focus on applying prescribed fire every 1-2 years to maintain native flora communities while enhancing nest and brood cover. Our results also indicate that growing-season prescribed fire has minimal impact on wild turkey production.

INTRODUCTION

Longleaf pine (*Pinus palustris*) savannas historically occupied over 30 million ha in the southeastern United States (Brockway et al. 2005, Van Lear et al. 2005). Historically, frequent fire ignited by lightning or humans maintained the early successional grassland community found in these pine savannas and prevented bottomland hardwood encroachment (Komarek 1964, Pyne 1982, Robbins and Myers 1992, Kennamer et al. 1992). Likewise, longleaf pine savannas sustain a diversity of ecological communities (e.g., depressional wetlands, hammocks, and upland/wetland ecotones; Van Lear et al. 2005). An important upland game species found in longleaf pine savannas is the Eastern wild turkey (Meleagris gallopavo silvestris; hereafter, wild turkey). However, land use change (e.g., conversion from longleaf pine to faster growing loblolly pine (*Pinus taeda*) and slash pine (*Pinus elliottii*), and increase in agricultural practices and urban development) throughout the southeastern United States led to a decline in virgin forests (e.g., longleaf pine savannas; Frost 1993, Alavalapati et al. 2002, Van Lear et al. 2005) and wild turkey populations (Kennamer et al. 1992). Likewise, over 30 plant and animal species that occur in this ecosystem are now threatened or endangered (Landers et al. 1995). Lack of reforestation efforts combined with government policies that encouraged landowners to exclude fire from their properties also contributed to the decline of longleaf pine savannas (Alavalapati et al. 2002). By the early-mid 1900's, longleaf pine savannas were reduced to 1/6 of the original acreage

(Frost 1993) and wild turkey populations were nearly extirpated (Kennamer et al. 1992). Natural resource professionals recognized the diversity of flora and fauna in longleaf pine savannas (Barnett 1999, Alavalapati et al. 2002). As a result, restoration efforts are often implemented in an attempt to convert altered landscapes back to longleaf pine savannas (Brockway et al. 2005). Likewise, wildlife biologists enacted restocking programs to reverse the drastic wild turkey population declines, which are today largely attributed to the population increase (Kennamer and Kennamer 1990, Kennamer et al. 1992). Today, the economic benefits derived annually from wild turkey hunting are in excess of $500 million U.S. dollars (Baumann et al. 1989). With the restoration efforts of longleaf pine savannas underway during the past 30+ years and the substantial economic benefit of wild turkey hunting, research is needed to address the population demographics of wild turkeys in this ecosystem. Therefore, we evaluated population demographics of wild turkeys to understand how longleaf pine management affects this species.

Longleaf pine savannas are primarily managed by fire to reduce undesirable competing vegetation while stimulating growth and development of a diverse understory (Waldrop et al. 1992, Cain et al. 1998, Barnett 1999, Steen et al. 2013). This practice promotes the availability of nesting and brood-rearing cover for ground-nesting birds (Dickson 1981, Hurst 1981, Landers 1981). In addition, prescribed fire helps maintain early-successional understory habitat and herbaceous vegetation while increasing insect abundance for wild turkeys (McGlincy 1985, Landers and Mueller 1986, Exum 1988, Provencher et al. 1998). Land managers frequently use growing-season prescribed fire to mimic lightning ignition in their efforts to control invading hardwoods and understory shrubs. Likewise, frequent prescribed fire (1-2 years) may provide adequate nesting cover while reducing the risk of predation due to a reduction in forage quality (e.g., reduction in soft mast for raccoons [*Procyon lotor*], Chamberlain et al. 2003, Jones et al. 2004; and gray fox [*Urocyon cinereoargenteus*], Johnson and Landers 1978, Temple et al. 2010).

Despite the benefits of longleaf pine restoration efforts, consideration must also be given to their potential negative effects on wild turkey populations. Previous research has focused on the impacts of prescribed fire on wild turkey ecology in other pine systems (Stoddard 1963, Miller et al. 2000, Jones et al. 2005, Miller and Conner 2007, Martin et al. 2012); however, those interested in wild turkey ecology have raised concerns over potentially excessive nest loss from growing-season prescribed fire. Moore (2006) reported that 9% of turkey nests were destroyed by growing-season fire. In addition, Miller et al. (1999) recommended providing mature pine stands, burned every 3 years and juxtaposed to riparian areas and bottomland hardwoods to increase wild turkey nest success. However, hardwood patches have been shown to be important sources of refugia for bobcats (Godbois et al. 2003) and raccoons (Chamberlain et al. 2002) in pine forests; therefore, reducing and/or isolating hardwood patches shown to be important for wild turkey success may lead to increased risk of predation of nearby wild turkey nests.

Biotic and abiotic processes operate and interact at multiple spatial scales on the landscape (Turner 1989); no one spatial scale likely exists for multiple landscape metrics that may influence avian nest success and/or survival (Stephens et al. 2005, Webb et al. 2012). Wild turkey populations are strongly influenced by reproductive success (Palmer et al. 1993, Roberts and Porter 1996, Miller et al. 1999) with the primary cause of reproductive loss due to predation from mesocarnivores (Speake 1980, Still and Baumann 1990, Miller and Leopold 1992, Lovell et al. 1997). Therefore, reproductive success may be influenced by nest-site and patch-level habitat metrics. Greater understory vegetation cover has been shown to increase the probability of wild turkey nest survival (Badyaev 1995, Badyaev and Faust 1996, Fuller et al. 2013). Conversely, patch-level metrics have been shown to have little effect on nest survival (Thogmartin 1999, Fuller et al. 2013). Roads have also been shown to be a detrimental influence on wild turkey nest survival (Thogmartin 1999), likely due to the high probability of use of roads as travel corridors by mesocarnivores (e.g., raccoon; Frey and Conover 2006). Likewise, timing of nest initiation has been found to affect nest survival of multiple avian taxa (e.g., lesser prairie-chicken [*Tympanuchusp allidicinctus*] and greater prairie-chicken [*Tympanuchusc upido*], Fields et al. 2006; willow ptarmigan [*Lagopus lagopus*], Wilson et al. 2007; greater sage-grouse [*Centrocercus urophasianus*], Webb et al. 2012). Similarly, Thogmartin and Johnson (1999) found heavier females (i.e., better body condition) laid larger clutches and initiated nests earlier in the nesting season presumably due to healthier body conditions relative to females in poor body condition.

To address the effects of longleaf pine savanna restoration efforts on wild turkey production, we addressed the following objectives: (1) estimate nest and brood survival, (2) evaluate the effect of growing-season prescribed fire on nest and brood survival, and (3) evaluate whether habitat characteristics and time of nest initiation affect nest survival. We hypothesized that nest and brood survival would be greater in a longleaf pine savannas relative to other forested ecosystems in the southeastern United States because management (e.g., prescribed fire) of this ecosystem maintains the availability of early successional cover. We hypothesized that growing-season prescribed fire would not significantly affect nest and brood survival because the scale of fires is relatively small across a large landscape. We hypothesized that nest site vegetation would be a strong predictor of nest survival relative to metrics quantified at the patch-level because females would likely select for security cover adjacent to the nest site compared to habitat types at larger spatial scales. Lastly, we hypothesized that nests initiated early in the nesting season would have a greater probability of survival because females entering the nesting season may be in healthier condition relative to other females that initiate a nest later in the nesting season.

STUDY AREA

The study was conducted on the 11,735-ha Joseph W. Jones Ecological Research Center at Ichauway (hereafter, Jones Center) located in Baker County, Georgia and the 3,900-ha Silver Lake Wildlife Management Area owned by the Georgia Department of Natural Resources located in Decatur County, Georgia (hereafter, Silver Lake WMA). The Jones Center was comprised of approximately 39% mature pine (>20 years old), 24% mixed-pine hardwood, 11% agriculture/food plot, 8% young pine (<20 years old), 7% hardwoods, 4% scrub-shrub, 3% wetland, 3% open water, and 1% urban/barren. Silver Lake WMA was comprised of approximately 56% mature pine (>20 years old), 22% young pine (<20 years old), 10% open water, 9% mature pine-hardwood, 1% shrub-scrub, 1% hardwood, and 1% urban/barren. Paved, gravel, and dirt road densities were 5.48 km/km^2 and 6.59 km/km^2 on the Jones Center and Silver Lake WMA, respectively. Total rainfall during the nest and brood-rearing season (1 April–31 July) at the Jones Center was 28.32 cm in 2011, 36.35 cm in 2012, and 52.02 cm in 2013. Similarly, total rainfall at Silver Lake WMA was 25.48 cm in 2011 and 36.55 cm in 2012. Average daily temperature at the Jones Center was 25.09° C in 2011, 24.56° C in 2012, and 23.62° C in

2013 (Jones Center; Georgia Automated Environmental Monitoring Network; http://georgiaweather.net). Likewise, average daily temperature at Silver Lake WMA was 25.77° C in 2011 and 25.24° C in 2012 (Lake Seminole; Georgia Automated Environmental Monitoring Network; http://georgiaweather.net).

To successfully restore and maintain longleaf pine savannas at the Jones Center and Silver Lake WMA, land managers used prescribed fire and mechanical hardwood removal. Prescribed fire was typically conducted during the dormant and growing seasons (1 January – 31 July) and occurred in a mosaic fashion, which promoted landscape diversity. Average patch size burned at the Jones Center was 21.43 ha (SE = 0.84; range = 0.02 – 240.57 ha). Whereas, average patch size burned at Silver Lake WMA was 14.37 ha (SE = 0.58; range = 0.66 – 88.27 ha). Fire-return interval ranged from 1-3 years during the study. Hardwood trees that were too large to be controlled by fire were removed mechanically. Mechanical removal efforts were primarily focused in areas where fire was either historically suppressed or in fire shadows (i.e., structural features that caused fire to go around a particular area and allowed hardwoods to mature).

METHODS

Turkey Capture and Monitoring

We captured female wild turkeys using rocket nets baited with corn during December–March of 2011-2013 and June–August of 2011-2012. We fitted all captured females with serially numbered, butt-end (left leg) and riveted (right leg) aluminum leg bands (National Band and Tag Co., Newport, KY). We also affixed a backpack-style VHF radio-transmitter, weighing approximately 60-g, (Sirtrack, Havelock North, New Zealand; and Telenax, Playa del Carmen, México) to all females. All birds were released at the capture site immediately after processing. The Institutional Animal Care and Use Committee at the University of Georgia approved all turkey capture, handling, and marking procedures (Protocol #A2013 05-034-Y1-A0).

We used a hand-held, 3-element Yagi antenna and Wildlife Materials TRX 2000S receiver (Wildlife Materials, Murphysboro, Illinois) to locate radio-marked females ≥2 times per week from mid-July to mid-March and ≥ 1 time per day from mid-March to mid-July to evaluate nest and brood ecology. We triangulated each female and recorded the locations using a mobile phone containing Location Of A Signal-SD software (LOAS™ [2010] Ecological Software Solutions LLC. Hegymagas, Hungary, Version 4.0.3.8.) and a Bluetooth-Global Positioning System unit. We considered a female to be incubating if she did not move for 3 consecutive days during the nesting season. Once a female was determined to be incubating, we approached to within 25-m of the nest and recorded compass bearings toward the nest. After termination of incubation, we approached nest-sites to determine nest fate, clutch size, and possible brood size, and a GPS location was recorded for future analyses. If a nest could not be located, we used the point of triangulation as an estimate for the nest location. We categorized nests as successful (≥ 1 egg hatched) or unsuccessful (no eggs hatched). In addition, we considered nests as depredated if eggs were found destroyed, trampled, or moved away from the nest-site. We considered nests abandoned if the female left the nest and did not return.

For each brood, we conducted 3-4 brood-surveys approximately 30 minutes prior to dawn during the brood flightless period (≤ 14 days post-hatch) or until all poults were lost. The presence of poults was determined by an observer approaching to within 15 m of the brood-rearing female while she was ground-roosted, and recording 3-4 compass bearings in the direction of the female. In dense vegetation where it was difficult to determine whether the female was tree-roosted without poults or ground-roosted with poults, the observer flushed the female and counted the number of poults. We continued monitoring broods until 30 days post-hatch when brood mixing rendered broods indistinguishable from each other. In all cases, we recorded a GPS location at the brood location.

Habitat Characteristics

At each nest-site we measured understory vegetation height (cm), percent canopy cover, and percent ground cover immediately following nest hatch or nest loss. To evaluate understory vegetation height, we measured the average visual obstruction at each nest site using a Robel pole (Robel et al. 1970). The Robel pole was placed in the nest bowl and viewed from a distance of 15-m in each cardinal direction from the nest-site at a height of 1-m. We measured percent canopy cover using a spherical densiometer (Lemmon 1956) and percent ground cover using a 1-m^2 Daubenmire frame (Daubenmire 1959) at the center of the nest-bowl and at a distance of 15-m in each cardinal direction from the nest-site. Ground cover was partitioned into 6 cover types: debris, fern, forb, grass, vine, and woody. We then combined the 6 cover types into one variable (total ground cover).

To investigate the influence of patch-level metrics on wild turkey nest survival, we used a geographic information system (ArcGIS® 10.1, Environmental Systems Research Institute Inc., Redlands, CA, USA) to map anthropogenic and landscape features known to influence wild turkeys. We mapped 6 land cover types available on both study areas: mature pine (>20 years old), young pine (<20 years old), mature pine-hardwood, hardwood, shrub-scrub, and agriculture/food plot. We assumed, given structural similarities of mature pine (>20 years old) and young pine (<20 years old), that females perceived these habitat classes similarly within the class. Likewise, frequent fire return intervals implemented on both study sites create relatively homogenous understory conditions in the mature pine and young pine classes. We calculated the linear distance from each nest-site to each of the nearest land cover types. To evaluate whether roads as a form of travel corridors for mesopredators affected nest survival, we calculated the linear distance from each nest-site to the nearest road (paved, gravel, and dirt). We calculated the Julian day for the date of nest initiation because nest survival may be influenced by when a nest was initiated. We also calculated the number of days-since-last prescribed fire until the first day of incubation for each nest to describe nest site selection in a frequently burned landscape.

Statistical Analysis

To evaluate nest success, we calculated initial nesting rate, initial nest success, renest rate, and renest success. We defined the beginning of the nesting season each year as the earliest nest initiation of all monitored females across both study sites (5 April, 2011; 27 March, 2012; 4 April, 2013). We calculated initial nesting rate as the number of females initiating incubation relative to all females entering the nesting season. We calculated initial nest success as the number of nests that successfully hatched ≥ 1 egg of those that initiated a nest. We calculated renest rate as the number of females that renested following failure of their first nest or early brood loss. We calculated renest success as the number of renests that successfully hatched ≥ 1 egg. We also evaluated nest success following exposure to growing-season prescribed fire.

To evaluate brood survival (≥1 poult survived to the end of the monitoring period), we calculated the percent of broods that survived the flightless period (i.e., days 1-14 post-hatch). We then calculated the percent of broods that survived the following 2-week period (i.e., days 15-30). We also evaluated brood success following impact by growing-season prescribed fire.

We evaluated the influence of nest-site and patch-level habitat characteristics on nest survival using a Cox proportional hazards model (Cox 1972). We used the PHREG procedure in SAS 9.3® (SAS Institute Inc., Cary, NC, USA) to evaluate risk of nest failure based on habitat characteristics. The Cox proportional hazards model provides hazard ratios for each covariate term included in the model. Hazard ratios >1.0 indicate increasing risk of an event (e.g., nest failure) with increasing values for the covariate, whereas hazard ratios <1.0 indicate decreasing risk of an event with increasing values for the covariate. Prior to data analysis, we assessed the proportional hazards assumption for our models. We removed any variables that were highly correlated ($r > 0.6$) and retained the variable that provided the simplest biological interpretation. We used Breslow's approximation for the likelihood calculation to partition deaths with equal failure times (Breslow 1974). We developed 16 models to evaluate nest survival as a function of nest-site, patch-level, and Julian day covariates. We used Akaike's Information Criteria adjusted for small sample size (AICc) to compare models (Akaike 1973, Burnham and Anderson 2002). The model with the lowest AIC*c* was considered to be the best model, and all models with AIC*c* < 2.0 units from the best model as the best set of approximating models. The Akaike weight (*wi*) for each model was calculated as an estimate of the probability of the model being the most parsimonious of the developed models. We combined all nest and brood data for all 3-years across both study sites due to small sample size.

RESULTS

We monitored 79 nests initiated by 45 individual females (78 adults and 1 juvenile) resulting in 34 broods during 2011-2013 across both study sites. Average onset of incubation for initial nests was 18 April (range: 27 March–12 June; Table 3.1). One nest survived to 39 days likely due to infertility. We removed this nest from subsequent analyses since it was an outlier and not representative of the other nests. Three individual females each initiated 3 nests in a given nesting season. Average length of incubation for successful nests was 28 days (n = 33, range 24–30 days). Of 78 nests, 33 (42.3%) were successful, including 2 (6.1%) nests exposed to growing-season prescribed fire. Of the unsuccessful nests, 32 (71.1%) were depredated, 10 (22.2%) were abandoned due to observer error, and 3 (6.7%) were exposed to growing-season prescribed fire.

Females selected nest sites in areas towards the end of their burn rotation (i.e., prior to the next scheduled burn; $\bar{x}$ = 613.7 days since burn for all nests from nest initiation date; SE = 44.7 days). Thirty-seven percent of females renested following nest loss. Of these, 43% hatched (Table 3.2). Eleven of 34 broods (32%) survived the entire flightless period (Table 3.3); of the remaining 11 broods, 7 (64%) survived the following 2-week period (i.e., days 15-30). One of 34 broods was lost to prescribed fire during the study.

To evaluate nest-site, patch-level, and Julian day models of nest survival, we first excluded 17 nests from the analysis because they were abandoned due to observer error (n=10) and vegetation was altered by prescribed fire and/or mowing (n=7). We removed one outlier nest from the analysis since the distance to patch-level types were not similar to other nests. Our final dataset used for this analysis consisted of 60 nests. Distance to mature-pine hardwoods was highly correlated with distance to agriculture (r =0.79); therefore, we retained distance to agriculture in the survival analysis. Nest-site, patch-level, and Julian day covariates did not significantly influence nest survival (Tables 3.4 and 3.5). The null model was the most parsimonious model, but there were several models within 2 ΔAICc units of the null model suggesting great model uncertainty and providing evidence that nest predation is a random event relative to habitat characteristics used in our models

DISCUSSION

Longleaf pine savannas are an ecologically and economically important system in the southeastern United States due to the rich flora and fauna biodiversity and longleaf pine's high tolerance to fire events and resistance to fusiform rust and bark beetle attacks relative to other commercial timber species (e.g., loblolly and slash pine; Alavalapati et al. 2002). Longleaf pine savanna management using frequent prescribed fire (≤ 2 year fire-return interval) is compatible with wild turkey reproduction. Contrary to our hypothesis, nest and brood survival in longleaf pine savannas was similar to other forested ecosystems in the southeastern United States. As hypothesized, growing-season prescribed fire had minimal impact on wild turkey production. Contrary to our hypothesis, nest-site and patch-level habitat metrics, and Julian day had little influence on nest survival. These findings provide evidence that pine savannas managed by frequent prescribed fire (≤ 2 year fire-return interval) can be beneficial to the success of a game species; thereby, providing land managers with social and economic incentive for proper land management.

The initial nesting rate we observed was comparable to previous studies in the southeastern United States (Palmer et al. 1993, Miller et al. 1998, Thogmartin and Johnson 1999, Wilson et al. 2005, Byrne and Chamberlain 2013). We observed a higher initial nest success relative to other published studies in the region (Palmer et al. 1993, Miller et al. 1998, Thogmartin and Johnson 1999, Wilson et al. 2005, Byrne and Chamberlain 2013). We observed similar renest rate and renest success relative to other published studies in the region (Palmer et al. 1993, Miller et al. 1998, Thogmartin and Johnson 1999, Wilson et al. 2005, Byrne and Chamberlain 2013).These findings suggest that although overall nest success on initial nesting attempts is comparable to other forested landscapes in the Southeast, females in the pine savanna systems we studied are likely to renest after nest loss.

The first 2-weeks post-hatch is the greatest period of vulnerability to wild turkey broods (Barwick et al. 1971, Glidden and Austin 1975, Speake et al. 1985, Peoples et al. 1995, Spears et al. 2007). Similarly, we found most brood loss occurred during the first 2-weeks post-hatch (Glidden and Austin 1975, Speake et al. 1985, Peoples et al. 1995, Lehman et al. 2001, Spears et al. 2007). After 2-weeks of age, brood survival tends to increase because poults can roost in trees to avoid risk of terrestrial predators (Barwick et al. 1971). Similarly, brood survival following the 14-day flightless period was comparable to previous studies in the coastal plain pine forests that used prescribed fire to improve understory habitat conditions (Peoples et al. 1995, Exum et al. 1987, Sisson et al. 1991).

Growing-season prescribed fire is an important factor in maintaining quality early-successional understory habitat conditions and herbaceous vegetation while increasing insect abundance for wild turkeys (McGlincy 1985, Landers and Mueller 1986, Exum 1988, Provencher et al. 1998). Our findings suggest that prescribed fire, specifically growing-season prescribed fire, had little impact on wild turkey reproductive success. Our results are consistent with previous studies that found little impacts of prescribed fire on wild turkey nest and brood survival (Carlisle 2003, Jones et al. 2005, Moore 2006). For example, Jones et al. (2005) reported 3% (n=2) of 64 nests were destroyed by growing-season fire. However, the population-level impacts due to loss of a few nests to growing-season prescribed fire are further mitigated by renesting. Longer fire-return intervals (3-7 years) in pine stands have previously been recommended to manage for wild turkeys (Stoddard 1963, Miller et al. 2000, Miller and Conner 2007). However, to balance management objectives of wild turkey habitat management with those of threatened and endangered species (e.g., gopher tortoise [*Gopherus polyphemus*]); frequent fire-return intervals (≤ 2 years) are recommended in pine savanna ecosystems (Martin et al. 2012). Likewise, restoration of longleaf pine savannas is essential to the recovery of the endangered red-cockaded woodpecker (*Picoides borealis*; Alavalapati et al. 2002).

Nest-site and patch-level metrics, and Julian day were not important predictors of nest survival in a longleaf pine savannas. Habitat characteristics have previously been shown to be important to wild turkey during nest site selection (Schmutz et al. 1989, Day et al. 1991, Thogmartin 1999, Williams 2012). On our study site, Williams (2012) found that females selected nest sites with reduced canopy cover, greater woody ground cover, and greater vegetation height relative to random sites on our study areas. Likewise, areas with ≥ 1.5 years of vegetative growth post-fire on our study areas were highly preferred by females for nest site selection, which suggests these locations provide some level of visual obscurity. Although females selected nest sites with greater cover (Williams 2012), our findings suggest that doing so did not lead to increased nest survival. Patch-level metrics were not important predictors of nest survival. This finding is consistent with previous studies that have found little support for the influence of patch-level habitat characteristics on wild turkey nest survival (Thogmartin 1999, Fuller et al. 2013). Furthermore, wild turkeys may be selecting for landscape features to maximize survival that were not measured in this study. Likewise, Julian day was not an important predictor of nest survival. Despite previous studies that found the timing of nest initiation affects avian nest survival (Thogmartin and Johnson 1999, Fields et al. 2006, Wilson et al. 2007, Webb et al. 2012), we suggest that body condition may not be an important factor affecting timing of nest initiation primarily due to the abundance of early successional habitat and food resources from a frequently burned landscape (McGlincy 1985, Landers and Mueller 1986, Exum 1988, Provencher et al. 1998).

Prescribed fire is an important management tool in longleaf pine savannas (Barnett 1999). With frequent fire-return intervals (≤ 2 years), herbaceous plant communities do not shift to dense hardwood understory communities (Glitzenstein et al. 2012). In addition, frequent use of prescribed fire in longleaf pine forests increases understory plant species richness, diversity, and evenness (Brockway and Lewis 1997). These impacts on understory plants contribute to providing suitable nesting habitat for wild turkeys. Likewise, frequent fire-return intervals (≤ 2 years), have been shown to decrease predator use of early successional stands (Chamberlain et al. 2003, Jones et al. 2004). Jones et al. (2004) found that raccoon use of longleaf pine stands during avian nesting season was reduced by 62% if the stand had been burned since the last growing season. Furthermore, Byrne and Chamberlain (2012) did not find area restricted search behavior (foraging) by raccoons in openings and dry areas with sparse ground-level vegetation. Additional research to address predator – wild turkey dynamics relative to season and frequency of prescribed fire would enhance our understanding of wild turkey nesting ecology within longleaf pine savannas.

MANAGEMENT IMPLICATIONS

The environmental benefits derived from reforestation of longleaf pine savannas (e.g., diversity of flora and fauna, resistance to fire, and certain diseases and pests) combined with the economical value of wild turkey hunting provide supportive evidence towards future reforestation efforts of longleaf pine savanna in the southeastern United States. Our research indicates that longleaf pine management with frequent fire-return intervals (≤ 2 years) is compatible with wild turkey production. We observed comparable initial nest success, renesting rates, renest success, and brood survival relative to other studies in the southeastern United States. Our results suggest that small-scale (12-22 ha) and frequent fire-return intervals (≤ 2 years) will have little impacts on wild turkey production. We suggest land managers focus on small-scale and frequent burns in longleaf pine savannas to manage for wildlife diversity while maintaining suitable nesting conditions for wild turkeys.

ACKNOWLEDGEMENTS

We are grateful for funding provided by the Georgia Wildlife Resources Division through the Wildlife Restoration Program (Grant No. W75), the Joseph W. Jones Ecological Research Center at Ichauway, and the Warnell School of Forestry and Natural Resources at the University of Georgia. We thank the staff at the aforementioned organizations for their technical assistance on this project, and C. Perez, D. Colbert, and D. Ruttinger for their assistance with data collection. We also thank S. L. Webb and C. Moore for statistical guidance.

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Table 3.1. Mean and ranges of dates for the onset of incubation of Eastern wild turkeys (*Meleagris gallopavo silvestris*) at the Joseph W. Jones Ecological Research Center (JC) and Silver Lake Wildlife Management Area (SL), southwestern Georgia, USA, 2011-2013.

Year	Site	*n*	Mean Date	Range
2011	JC	6	13-April	5 April – 26 April
	SL	5	22-April	5 April – 9 May
2012	JC	14	19-April	27 March – 12 June
	SL	16	21-April	1 April – 2 June
2013	JC	16	19-April	4 April – 7 May

Table 3.2. Nesting ecology of Eastern wild turkeys (*Meleagris gallopavo silvestris*) at the Joseph W. Jones Ecological Research Center (JC) and Silver Lake Wildlife Management Area (SL), southwestern Georgia, USA, 2011-2013. Numbers in parentheses correspond to the number of nesting attempts or successful nesting attempts.

Year	Site	n[a]	% Initial Nesting (n)[b]	% Initial Nest Success (n)[c]	% Renest (n)[d]	% Renest Success (n)[e]
2011	JC	7	85.7 (6)	83.3 (5)	50.0 (3)[f]	33.3 (1)
	SL	8	62.5 (5)	60.0 (3)	0	0
2012	JC	19	73.7 (14)	35.7 (5)	57.1 (8)	50.0 (4)
	SL	25	64.0 (16)	25.0 (4)	31.3 (5)[f]	20.0 (1)
2013	JC	23	69.6 (16)	43.8 (7)	37.5 (6)[f]	50.0 (3)
Pooled Sites and Years		82	70.0 (57)	42.1 (24)	36.8 (21)	42.9 (9)

[a]Number of radio marked females monitored from the earliest known nesting attempt (2011: 5 April; 2012: 27 March; and 2013: 4 April).
[b]Number of females to successfully initiate incubation.
[c]Number of first nesting attempts to hatch ≥ 1 egg. Nests suspected of abandonment due to observer error were censored from estimates.
[d]Number of females to renest following nest loss.
[e]Number of successful renest attempts to hatch ≥ 1 egg. Nests suspected of abandonment due to observer error were censored from estimates.
[f]One female renested twice

Table 3.3. Brood survival of Eastern wild turkeys (*Meleagris gallopavo silvestris*) at the Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area, southwestern Georgia, USA, 2011-2013. Numbers in parentheses correspond to the number of broods (≥ 1 poult) that survived during the time period.

Year	Site	*n* *(broods)*	Day 1-14 (% survived)	Day 15-30 (% survived)
2011	JC	6	16.7 (1)	0
	SL	3	66.7 (2)	33.3 (1)
2012	JC	9	22.2 (2)	11.1 (1)
	SL	5	60.0 (3)	40 (2)
2013	JC	11	27.3 (3)	100.0 (3)
Pooled Sites and Years		34	32.4 (11)	20.6 (7)

Table 3.4. Nest-site[a], patch-level[b], and Julian day[c] models associated to Eastern wild turkey (*Meleagris gallopavo silvestris*) nest survival at the Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area, southwestern Georgia, USA, 2011-2013.

Model	*K*	AICc	Δ AICc	Relative Likelihood	w_i
Null	1	160.51	0.0	1.00	0.20
Julian day	2	161.92	1.42	0.49	0.10
Canopy cover	2	161.93	1.42	0.49	0.10
Distance to young pines	2	162.10	1.59	0.45	0.09
Total ground cover	2	162.35	1.84	0.40	0.08
Distance to nearest road	2	162.40	1.89	0.39	0.08
Distance to hardwoods	2	162.51	2.00	0.37	0.07
Distance to agriculture	2	162.54	2.03	0.36	0.07
Distance to shrub/scrub	2	162.54	2.03	0.36	0.07
Mean visual obstruction	2	162.62	2.11	0.35	0.07
Distance to mature pines	2	162.64	2.13	0.34	0.07
Nest-site	4	166.02	5.52	0.06	0.01
Nest-site+Temporal	5	167.85	7.35	0.03	0.01
Patch-level	7	172.82	12.31	0.00	0.00
Patch-level+Temporal	8	173.28	12.77	0.00	0.00
Nest-site+patch-level	10	179.51	19.00	0.00	0.00
Nest-site+patch-level+temporal	11	180.89	20.38	0.00	0.00

[a]Nest-site: total ground cover, canopy cover, and mean visual obstruction.
[b]Patch-level: distance to mature pines, hardwoods, agriculture, shrub/scrub, young pines, and nearest road.
[c]Julian day: date of nest initiation.

Table 3.5. Results for Cox proportional hazards models of risk of Eastern wild turkey (*Meleagris gallopavo silvestris*) nest failure at the Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area, southwestern Georgia, USA, 2011-2013.

Model	β	SE	*P*	Hazard ratio	95% hazard ratio CI
Julian day	-0.0060	0.0072	0.4045	0.9940	0.9800–1.0080
Canopy cover	0.0057	0.0068	0.3978	1.0060	0.9920–1.0190
Distance to young pines	0.0004	0.0005	0.4512	1.0000	0.9990–1.0010
Total ground cover	0.0134	0.0250	0.5933	1.0130	0.9650–1.0640
Distance to nearest road	0.0021	0.0041	0.6077	1.002	0.9940–1.0100
Distance to hardwoods	-0.0007	0.0020	0.7125	0.9990	0.9950–1.0030
Distance to agriculture	-0.0001	0.0003	0.7446	1.0000	0.9990–1.0010
Distance to shrub/scrub	-0.0005	0.0016	0.7333	0.9990	0.9960–1.0030
Mean visual obstruction	-0.0013	0.0066	0.8395	0.9990	0.9860–1.020
Distance to mature pines	-0.0004	0.0033	0.9021	1.0000	0.9930–1.0060
Nest-site					
Total ground cover	0.0150	0.0246	0.5427	1.0150	0.9670–1.0650
Canopy cover	0.0063	0.0069	0.3608	1.0060	0.9930–1.0200
Mean visual obstruction	-0.0008	0.0064	0.9015	0.9990	0.9870–1.0120
Nest-site+Temporal					
Total ground cover	0.0179	0.0246	0.4702	1.0180	0.9700–1.0690
Canopy cover	0.0048	0.0070	0.4938	1.0050	0.9910–1.0190

Mean visual obstruction	-0.0007	0.0063	0.9173	0.9990	0.9870–1.0120
Julian day	-0.0056	0.0075	0.4565	0.9940	0.9800–1.0090
Patch-level					
Distance to mature pines	-0.0004	0.0037	0.9138	1.0000	0.9920–1.0070
Distance to hardwoods	-0.0003	0.0021	0.9004	1.0000	0.9960–1.0040
Distance to agriculture	-0.0003	0.0004	0.3952	1.0000	0.9990–1.0000
Distance to young pine	0.0008	0.0007	0.2585	1.0010	0.9990–1.0020
Distance to shrub/scrub	-0.0006	0.0016	0.6805	0.9990	0.9960–1.0020
Distance to nearest road	0.0021	0.0042	0.6271	1.0020	0.9940–1.0100
Patch-level+Temporal					
Distance to mature pines	-0.0017	0.0040	0.6749	0.9980	0.9910–1.0060
Distance to hardwoods	0.0007	0.0022	0.7344	1.0010	0.9960–1.0050
Distance to agriculture	-0.0006	0.0004	0.1491	0.9990	0.9990–1.0000
Distance to young pine	0.0011	0.0007	0.1283	1.0010	1.0000–1.0030
Distance to shrub/scrub	-0.0013	0.0015	0.3940	0.9990	0.9960–1.0020
Distance to nearest road	0.0018	0.0043	0.6801	1.002	0.993–1.0100
Julian day	-0.0129	0.0090	0.1511	0.9870	0.9700–1.0050
Nest-site+patch-level					
Total ground cover	0.0171	0.0266	0.5212	1.0170	0.9660–1.0720
Canopy cover	0.0108	0.0088	0.2171	1.0110	0.9940–1.0280
Mean visual obstruction	0.0031	0.0107	0.7753	1.0030	0.9820–1.0240
Distance to mature pines	0.0013	0.0041	0.7445	1.0010	0.9930–1.0090
Distance to hardwoods	-0.0008	0.0022	0.7236	0.9990	0.9950–1.0030

Distance to agriculture	-0.0002	0.0005	0.6618	1.0000	0.9990–1.0010
Distance to young pine	0.0008	0.0007	0.2483	1.0010	0.9990–1.0020
Distance to shrub/scrub	-0.0020	0.0019	0.2866	0.9980	0.9940–1.0020
Distance to nearest road	0.0019	0.0058	0.7448	1.0020	0.9910–1.0130
Nest-site+patch-level+temporal					
Total ground cover	0.0250	0.0267	0.3545	1.0250	0.9730–1.0800
Canopy cover	0.0051	0.0091	0.5729	1.0050	0.9870–1.0230
Mean visual obstruction	-0.0005	0.0107	0.9607	0.9990	0.9790–1.0210
Distance to mature pines	-0.0001	0.0042	0.9843	1.0000	0.9920–1.0080
Distance to hardwoods	0.0008	0.0023	0.7466	1.0010	0.9960–1.0050
Distance to agriculture	-0.0006	0.0005	0.2480	0.9990	0.9980–1.0000
Distance to young pine	-0.0022	0.0007	0.1361	1.0010	1.0000–1.0030
Distance to shrub/scrub	-0.0022	0.0018	0.2180	0.9980	0.9940–1.0010
Distance to nearest road	0.0004	0.0060	0.9464	1.0000	0.9890–1.0120
Julian day	-0.0133	0.0102	0.1950	0.9870	0.9670–1.0070

CHAPTER 4

HABITAT SELECTION OF FEMALE EASTERN WILD TURKEYS IN 2 FREQUENTLY-BURNED PINE SAVANNAS[1]

[1]Little, A. R., M. J. Chamberlain, L. M. Conner, and R. J. Warren. Submitted to Journal of Wildlife Management, 09/09/2015

ABSTRACT

Pine savannas (e.g., longleaf pine [*Pinus palustris*]) contain a diversity of flora and fauna, making them one of the most ecologically important ecosystems in North America. However, these ecosystems have experienced drastic declines during the past 100+ years across the southeastern United States due to disruption of historical fire regimes, land conversion, and logging. There currently is much interest in maintaining and restoring pine savannas and frequent prescribed fire is often used as a primary tool when addressing these issues. Eastern wild turkeys (*Meleagris gallopavo silvestris*) are an important game species found in open pine habitats and their habitat selection in these frequently burned (≤ 3 year fire return intervals) systems is not clearly understood. Therefore, we investigated seasonal habitat selection of female Eastern wild turkeys in 2 pine savannas managed by frequent fire in southwestern Georgia during 2011-2013. Female wild turkeys used mature pine stands less than available while selecting for hardwoods, shrub/scrub, and young pine habitats. In cases where female turkeys used pine-dominated stands (i.e., mature pine, young pine, and mixed pine/hardwoods), selection was not influenced by time-since-fire, suggesting they can coexist with frequent fire regimes in pine savannas. Habitat selection also varied across seasons and spatial scales, so we suggest land managers consider scale of selection by turkeys when developing habitat management strategies. In addition to creating early-successional habitat by using prescribed fire, we recommend managers retain hardwoods and and recognize the importance of openings to management of turkey populations in pine savannas.

INTRODUCTION

Pine savanna (e.g., longleaf pine [*Pinus palustris*]) forests are one of the most biologically diverse systems in North America and commonly support hundreds of species of flora and fauna (Alavalapati et al. 2002). This ecosystem historically occupied over 30 million ha in the southeastern United States (Brockway et al. 2005, Van Lear et al. 2005) and was maintained by fire ignited by natural and anthropogenic sources, but today are commonly managed by prescribed fire (Komarek 1964, Pyne 1982, Robbins and Myers 1992). Frequent fire events are critically important to many species found in this ecosystem. For example, wiregrass (*Aristida* spp.) is one of the most common plant species found in pine savannas and the lifecycle of this species requires frequent fire to induce flowering and propagation (Mulligan and Kirkman 2002, Fill et al. 2012). Researchers have documented over 40 plant species per square meter in this system with many of these species endemic to pine savannas (Peet and Allard 1993). Today, approximately 1.2 million ha of pine savannas exist in isolated patches (Van Lear et al. 2005), primarily due to land use change (e.g., conversion to agriculture and establishment of intensively-managed pine plantations were the primary goal is timber production) and government policies that encouraged landowners to exclude fire from their properties (Alavalapati et al. 2002). Over 30 plant and animal species endemic to pine savannas are now considered to be threatened or endangered (Landers et al. 1995). Simultaneously, wild turkeys have experienced population declines due to similar land conversion issues (e.g., removal of fire from landscapes; Kennamer et al. 1992).

Fire is the primary tool for management of pine savannas and has been shown to increase understory plant species richness, diversity, and evenness (Brockway and Lewis

1997). Without fire disturbance, pine savannas are replaced by hardwoods and other pine species (Landers et al. 1995, Glitzenstein et al. 2012). Fire is also beneficial to fauna found in a fire-maintained system, as it promotes the availability of nesting and brood-rearing cover for ground-nesting birds (Dickson 1981, Hurst 1981, Landers 1981) and maintains open, park-like conditions needed by species such as the endangered red-cockaded woodpecker (Alavalapati et al. 2002). Land managers commonly apply prescribed fire every 1-3 years in pine savannas to balance objectives of managing for species that rely on frequent fire regimes and for other wildlife species that prefer early-successional habitats (e.g., northern bobwhite quail [*Colinus virginianus*]). Martin et al. (2012) found female wild turkeys preferred pine savannas burned within 1.4 years, and attributed the avoidance of stands with longer burn rotations to the inability of females to effectively find food resources beginning at about 500 days post-fire. Palmer and Hurst (1998) also noted that longer burning rotations resulted in most upland habitats being unsuitable to female wild turkeys during spring, which corresponds to the nesting and brood-rearing season. However, previous research in pine-dominated systems has recommended longer burn intervals ranging from 3 to 7 years to aid in development of concealment cover to reduce impacts of predation for wild turkeys and other ground-nesting birds (Stoddard 1963, Miller et al. 2000, Miller and Conner 2007). Therefore, research is warranted to better understand the influence of prescribed fire on wild turkey habitat selection in a forested system managed by frequent fire.

In pine-dominated forests of the southeastern United States, female wild turkeys typically use hardwood forests during fall and winter and move into upland pine or pine-hardwood forests prior to nesting season (Speake et al. 1975, Kennamer et al. 1980, Miller and Conner 2007, Martin et al. 2012). Forests selected during spring are typically characterized by relatively dense ground cover presumably used for nesting and brood-rearing (Hillestad 1970, Speake et al. 1975, Streich et al. 2015). Knowledge of wild turkey habitat selection in pine savannas will enable land managers to balance management objectives for wild turkeys with those of threatened and endangered species endemic to pine savannas. Therefore, our objectives were to: (1) evaluate seasonal habitat selection of female wild turkeys in pine savannas, and (2) assess effects of prescribed fire on turkey habitat selection.

STUDY AREA

Our study was conducted on the 11,735-ha Joseph W. Jones Ecological Research Center at Ichauway (hereafter, Jones Center) located in Baker County, Georgia and the 3,900-ha Silver Lake Wildlife Management Area owned by the Georgia Department of Natural Resources located in Decatur County, Georgia (hereafter, Silver Lake WMA). The Jones Center was comprised of approximately 39% mature pine, 24% mixed pine/hardwood, 11% agriculture/food plot, 8% young pine, 7% hardwoods, 4% scrub-shrub, 3% wetland, 3% open water, and 1% urban/barren. Wiregrass and old-field grasses (e.g., *Andropogon* spp.) were the dominant understory habitat in the pine and pine/hardwood stands (Goebel et al. 1997). However, >1,000 vascular plant species occur on the site (Drew et al. 1998). Silver Lake WMA was comprised of approximately 56% mature pine, 22% young pine, 10% open water, 9% mixed pine/hardwood, 1% shrub/scrub, 1% hardwood, 1% urban/barren, and < 1% wetlands and agriculture/food plots. The Georgia Department of Natural Resources provided all habitat classification data for Silver Lake WMA, which we used to create similar habitat classes across both study sites.

We classified stands as pine if they consisted of loblolly, longleaf, slash, and shortleaf (*Pinus echinata*) pine with > 90% pine. We classified stands as mature pine if trees were > 20 years old and in large pole (12.6-25.4 cm) or saw timber (> 25.4 cm) size classes; these stands had an average basal area of 4.9 m^2 (range: 0.2 to 12.6 m^2). We classified stands as young pine if trees were ≤ 20 years old and in seedling/sapling (0-12.7 cm) or small pole timber (12.7-25.4 cm) size classes; these stands had an average basal area of 2.0 m^2 (range: 0 to 10.43 m^2).

Mixed pine/hardwood stands contained a variety of species (e.g., loblolly, longleaf, slash pine, southern red oak [*Quercus falcata*], turkey oak [*Quercus laevis*], live oak [*Quercus virginiana*], laurel oak [*Quercus laurifolia*], and sweetgum [*Liquidambar styraciflua*]). We classified stands as mixed pine/hardwood if they were 50 to 80% hardwood or pine. Within these stands, tree sizes ranged from seedling/sapling through saw timber; however, most (> 90%) were in the pole to saw timber classes. Average basal area was 2.8 m^2 (range: 0 to 8.8 m^2) for pine and 3.2 m^2 (range: 0 to 20.8 m^2) for hardwoods.

Hardwood stands consisted of a variety of species (e.g., southern red, turkey, live, laurel oaks, and sweetgum) with tree sizes ranging from seedling/sapling to saw timber; however, most (> 90%) were in the pole to saw timber classes. Average basal area was 9.8 m^2 (range: 2.9 to 30.1 m^2) and consisted of > 90% hardwoods. We classified stands as agriculture/food plot if they consisted of cropland, pasture land, wildlife food plots, or horticultural crops (e.g., pecan orchard). Shrub/scrub stands consisted of abandoned agricultural fields and pastures, clear-cuts, grassland, and shrubby areas.

To successfully restore and maintain pine savannas on our study sites, land managers used prescribed fire and mechanical hardwood removal. Fire was applied to mature pine, young pine, mixed pine/hardwood, and shrub/scrub habitats. Prescribed fire was conducted throughout the year with > 95% of burns conducted during January-June. Prescribed fire application occurred in a mosaic fashion, which promoted landscape diversity. Average patch size burned at the Jones Center was 21.41 ha (SE = 0.83; range = 0.02 – 240.57 ha), whereas average patch size burned at Silver Lake WMA was 14.41 ha (SE = 0.58; range = 0.66 – 88.27 ha). Fire return interval typically ranged from 1-3 years, but most (≥ 95%) fires applied to our study sites were ≤ 2-years (38.4%, 0-year; 34.9%, 1-year; 21.7%, 2-year; 4.9% of stands with 3-year time-since-fire). Land managers often used mechanical removal to remove large off-site hardwoods (e.g., water oak [*Quercus nigra*]) from within mature pine stands. d

METHODS

Turkey Capture and Monitoring

We captured female wild turkeys using rocket nets baited with corn during December–March of 2011-2013 and June–August of 2011-2012. We fitted all captured females with serially numbered, butt-end (left leg) and riveted (right leg) aluminum leg bands (National Band and Tag Co., Newport, KY). We also affixed a backpack-style VHF radio-transmitter, weighing approximately 60-g, (Sirtrack, Havelock North, New Zealand; and Telenax, Playa del Carmen, México) to all females. All birds were released at the capture site immediately after processing. The Institutional Animal Care and Use

Committee at the University of Georgia approved all turkey capture, handling, and marking procedures (Protocol #A2013 05-034-Y1-A0).

We used a hand-held, 3-element Yagi antenna and Wildlife Materials TRX 2000S receiver (Wildlife Materials, Murphysboro, Illinois) to locate radio-marked females ≥2 times per week from mid-July to mid-March and ≥ 1 time per day from mid-March to mid-July. We located females by triangulation and recorded locations using a mobile phone containing Location Of A Signal-SD software (LOAS™ [2010] Ecological Software Solutions LLC. Hegymagas, Hungary, Version 4.0.3.8.) and a Bluetooth-Global Positioning System unit. We obtained azimuths within a 15-minute time period to reduce error caused by animal movement. To minimize telemetry error, locations were only used if observer distances were determined to be < 800 m from the estimated turkey locations by LOAS-SD.

Habitat Selection Analysis

To investigate wild turkey habitat selection, we examined selection at 2 spatial scales: study area and seasonal areas of use. We used a use vs. availability resource selection approach to evaluate non-random habitat selection by comparing used (i.e., turkey locations) to available locations following Design II and III approaches suggested by Manly et al. (2002). We determined study area habitat availability by calculating a 100% minimum convex polygon (MCP) that surrounded all turkey locations at each study site. To develop seasonal areas of use, we delineated biologically meaningful seasons based on the reproductive chronology of turkeys on our study areas and previous research (Miller et al. 1999, Miller and Conner 2005, Miller and Conner 2007). We used median nest initiation date to define the start of a 2-month nesting season (Little et al.

2014). We defined nesting season as 20 April–15 June, summer as 16 June–30 September, fall-winter as 1 October–31 January, and preincubation as 1 February–19 April. We did not evaluate habitat selection during nesting because nesting females represent a point location. Habitat selection during nesting for females on our study sites can be found in Streich et al. (2015). We calculated 95% MCP in the Adehabitat Package (Calenge 2006) for program R version 3.1.3 (R Core Team, Vienna, Austria). We required each turkey to have ≥ 10 locations during each season to calculate seasonal areas of use similar to Miller and Conner (2007).

To quantify habitat selection, we used a geographic information system (ArcGIS® 10.2, Environmental Systems Research Institute Inc., Redlands, CA, USA) to create a vector layer of habitat classes available on the study areas. We then converted the vector layer to a 10-m raster layer and used the Euclidean Distance tool in ArcGIS® 10.2 to calculate the distance from every 10-m pixel to the nearest habitat type. We used a distance-based approach because distance-based metrics are not restricted to linear or point habitat features, require no explicit error handling, and permit extraction of more information than classification-based analyses such as compositional analysis (Conner et al. 2003). Due to similarities in habitat types between both study areas, we combined the spatial data across both sites. We used ArcGIS® 10.2 to generate an equal number of available locations each season to turkey locations within the study area boundaries and seasonal areas of use. We extracted all distance values to both used and available locations using ArcGIS® 10.2.

We modeled resource selection at each spatial scale using a logistic regression approach. Due to model convergence issues and no variability found among individual turkeys according to the zero variance and standard error estimate for the random effect of animal ID, we implemented our analysis in the GLM procedure in R (R Core Team 2013). Lack of variability in resource selection among individual turkeys is not surprising given that females are commonly found in flocks. We included an interaction term for season (i.e., fall-winter, preincubation, and summer) and each covariate in the model to assess whether habitat selection differed among seasons. We considered fall as the reference group for the interaction. Prior to data analysis, we scaled all distance values for used and available locations by dividing the linear distance by 100 m to eliminate model convergence issues. We evaluated pairwise correlations between the explanatory variables at each scale using Spearman rank correlation. We removed any variables that were highly correlated ($r \geq 0.6$) and retained the variable that provided the simplest biological interpretation. We then evaluated variance inflation factors of all variables to assess the extent of any remaining collinearity. All variables contained a variance inflation factor ≤ 2.0, which suggested that collinearity was not likely an issue (Zuur et al. 2009). We constructed a full model for each spatial scale and evaluated whether habitat selection changed among seasons. We made inference to only those variables that were statistically significant ($\alpha = 0.05$). We then output season-specific beta coefficient estimates for development of predictive RSF maps. We also provide scaled odds ratios for interpretation based on the scaled distance metrics used in our analysis.

Model Validation

We developed relative probability of resource selection maps (hereafter, RSF maps) based on the beta coefficient estimates for each covariate. First, we scaled all raster layers by multiplying each cell value by 100 m to ensure our beta coefficient estimates were comparable from the model that contained scaled distance values to the development of the RSF maps. We then used the Raster Calculator tool in ArcGIS® 10.2 to create predictive probability of habitat selection maps for each season using the following equation:

$$w(x) = \exp\left(\sum_{k=1}^{K} \beta_k^* x_k\right)$$

where w(x) was the relative probability of use, β_k^* was the parameter estimate for covariate k ($k = 1 \ldots K$), and raster data had values x (Manly et al. 2002). We partitioned cells from the seasonal RSF maps into quantiles based on cell values. We reclassified cell values based on quantiles establishing 3 ranks of relative probability of selection (low, moderate, and high).

Model assessment is important when developing predictive models because it provides evidence that the model is robust and applicable to data other than the model data (Boyce et al. 2002). Therefore, we used a random number generator to withhold approximately 20% of the individual turkeys each season (preincubation = 14 turkeys; and summer = 10 turkeys) from model development to use as a validation sample to assess our model. For example, at each spatial scale during preincubation, we overlaid 563 validation locations from the withheld turkey data set onto the preincubation RSF maps for each study area and tested whether the number of locations positively increased with bin rank (low to high relative probability of habitat selection) using Spearman rank correlation (ρ; Dzialak et al. 2012).

Habitat Selection in Relation to Prescribed Fire

To evaluate effects of prescribed fire on turkey habitat selection, we subset our telemetry data set to only those turkey locations occurring on the study areas and in stands that received frequent fire (i.e., mature pine, young pine, and mixed pine/hardwoods). We subset our data set to the study area boundary because time-since-fire data were not available outside of the study areas. We used the Union tool in ArcGIS® 10.2 to create a time-since-fire (i.e., number of days) landcover map for each study area. We used a logistic regression framework to evaluate non-random habitat selection relative to prescribed fire by comparing used (i.e., turkey locations) to available locations based on the number of days between each turkey location to the previous fire event. We used ArcGIS® 10.2 to generate an equal number of available locations to turkey locations within stands that received frequent fire. We extracted time-since-fire to both used and available locations using ArcGIS® 10.2. We modeled the effect of time-since-fire on turkey habitat selection using a logistic regression approach implemented in the GLM procedure in R (R Core Team 2013).

RESULTS

We monitored 86 wild turkeys during 2011-2013 across both study sites. During the study period, 16.5% of turkey locations occurred off of the study sites. We constructed 141, 95% seasonal areas of use from our final data set.

To evaluate habitat selection at the study area scale, we evaluated correlation amongst the habitat variables and found no highly correlated variables; therefore, we retained all variables in the modeling procedure. During preincubation, turkeys selected for shrub/scrub and young pine while avoiding mature pine and agriculture/food plots (Table 4.1). Distance to mixed pine/hardwoods and hardwood habitats were not statistically different ($P > 0.10$; Table 4.1). Scaled odds ratios suggested that turkeys were 17.1% less likely to occur for every 100 m farther away from shrub/scrub. Conversely, turkeys were 8.0% more likely to occur for every 100 m farther from mature pines and 2.9% more likely to occur for every 100 m farther from agriculture/food plots (Table 4.1). During summer, turkeys selected for shrub/scrub, hardwoods, and young pine while avoiding mature pine, mixed pine/hardwoods and agriculture/food plots (Table 4.1). Scaled odds ratios suggested that turkeys were 15.9% less likely to occur for every 100 m farther away from shrub/scrub, 6.9% less likely to occur for every 100 m farther away from hardwoods, and 4.3% less likely to occur for every 100 m farther from young pine. Conversely, turkeys were 17.7% more likely to occur for every 100 m farther from mature pines, 5.8% more likely to occur for every 100 m farther from mixed pine/hardwoods, and 2.9% more likely to occur for every 100 m farther from agriculture/food plots (Table 4.1). At the study area scale, our preincubation RSF map validated well ($\rho = 1.0$, $df = 2$, $P < 0.001$) indicating a positive monotonic relationship among the number of model validation locations found in the low, moderate, and high bins (Table 4.2). Conversely, the summer RSF map did not validate as well ($\rho = 0.5$, $df = 2$, $P = 0.667$; Table 4.2).

To evaluate habitat selection at the seasonal area of use scale, we first removed distance to agriculture because it was highly correlated with distance to hardwoods ($r = 0.61$). During preincubation, turkeys selected for shrub/scrub while avoiding hardwoods and young pine (Table 4.3). Distance to mature pine and mixed pine/hardwoods were not statistically different ($P > 0.10$; Table 4.3). Scaled odds ratios suggested that turkeys were 6.0% less likely to occur for every 100 m farther away from shrub/scrub. Conversely, turkeys were 4.1% more likely to occur for every 100 m farther from hardwoods and 5.9% more likely to occur for every 100 m farther from young pines (Table 4.3). During summer, turkeys selected for shrub/scrub while avoiding mixed pine/hardwoods, hardwoods, and young pine (Table 4.3). Distance to mature pine was not statistically different (Table 4.3). Scaled odds ratios suggested that turkeys were 10.1% less likely to occur for every 100 m farther away from shrub/scrub. Conversely, turkeys were 5.7% more likely to occur for every 100 m farther from mixed pine/hardwoods, 4.9% more likely to occur for every 100 m farther from hardwoods, and 10.9% more likely to occur for every 100 m farther from young pine (Table 4.3). At the seasonal area of use scale, our preincubation and summer RSF maps did not validate well (Table 4.2).

Time-since-fire did not influence turkey use of stands ($P = 0.086$). Females on average used stands 425 days (SE = 4) after fire, whereas expected use was 437 days (SE = 5).

DISCUSSION

Pine savannas (e.g., longleaf pine) are one of the most biologically diverse systems in North America supporting hundreds of flora and fauna species (Alavalapati et al. 2002). We found female wild turkeys used mature pines less than available while exhibiting selection for hardwoods, young pine, and shrub/scrub habitats albeit at different spatial scales. Time-since-fire did not influence selection of stands managed by frequent fire. Our results also indicate that habitat selection operates at multiple spatial scales, which is important for land managers to consider when developing wild turkey management strategies. Overall, our findings provide evidence that turkeys require habitat diversity in pine savannas but can adapt to a system managed by frequent prescribed fire intervals ($\leq$ 3 years).

Similar to Martin et al. (2012) and Streich et al. (2015), we found female turkeys used mature pines less than available. Additionally, a noteworthy finding was that 16.5% of turkey locations occurred off of our mature pine-dominated study sites. We suggest that the avoidance of mature pine stands is likely a function of food availability and predation risk. Interestingly, Martin et al. (2012) found that selection of pine savannas was dependent on time-since-fire and that turkeys selected pine stands that were recently burned up to approximately 500 days post-fire. They attributed the lack of selection post-500 days to increased vegetation thickness making foraging increasingly difficult. In addition to difficulty searching for food resources, mature pine stands may also be riskier later in the growing season because female turkeys cannot easily observe predators due to increased visual obstruction. Wild turkeys have excellent visual acuity and commonly rely on visual detection of predators (Pelham and Dickson 1992). Therefore, we suggest that female turkeys on our study areas likely avoid mature pine stands due to increased vegetation thickness that likely cause this habitat type to be riskier from both a predation and food acquisition standpoint.

Hardwoods were generally important to female turkeys, which is comparable to previous studies (Speake et al. 1975, Kennamer et al. 1980, Miller and Conner 2007). Specifically, our results suggest that hardwoods were important to turkeys during summer; turkeys use hardwood habitats for food acquisition and roosting sites (Chamberlain et al. 2000). We also suggest that hardwood stands may serve as travel corridors between forage patches and be used as protective cover from summer heat in pine savannas. Our findings also provide further support for the ecological value of retaining hardwoods within pine savannas (Hiers et al. 2014).

Shrub/scrub and young pine habitats were selected by females during preincubation and summer. Streich et al. (2015) reported that females nested in areas containing shrub/scrub habitats on our study sites. During summer, females commonly renested on both study areas (Little et al. 2014), which may partially explain why females were closer to shrub/scrub habitat. Females also prefer areas with greater visual obstruction (e.g., shrub/scrub habitat) for broods during summer months to reduce the risk of predation (Spears et al. 2007). Selection of young pines by female turkeys during preincubation and summer is contrary to previous research in another pine-dominated landscape within the southeastern United States (Miller and Conner 2007). Miller and Conner (2007) reported that > 90% of turkey nests were in pine stands ≥ 15 years old. Streich et al. (2015) found that turkeys commonly nested in shrub/scrub habitats on our study areas and used mature pine stands less than available. Likewise, shrub/scrub habitats were commonly associated (i.e., juxtaposed) to young pine stands on our study areas; therefore, turkeys were likely selecting for shrub/scrub habitats for nesting and brooding and young pines were spatially correlated to these areas leading to their relative importance to turkeys.

Our findings suggest that time-since-fire did not influence turkey habitat selection and that turkeys can adapt to a system managed by frequent fire (≤ 3 years). Previous studies have recommended longer fire return intervals for turkey management in pine-dominated forests. Miller and Conner (2007) recommended 3 to 7 year fire return intervals to aid in development of concealment cover to reduce impacts of predation.

Miller et al. (2000) recommended fire return intervals of 3 to 4 years for wild turkeys in mature pine forests. Speake (1975) recommended fire return intervals of 2 to 4 years to ensure soft fruit production for turkeys. However, longer burn rotations in pine savannas (e.g., longleaf pine) would be detrimental to endemic flora and fauna that are dependent on frequent fire intervals to create open, park-like conditions. Frequent prescribed fire in longleaf forests reduces small hardwoods and shrubs resulting in a corresponding increase in grasses and forbs creating open, park-like conditions (Waldrop et al. 1992, Brockway and Lewis 1997). Without frequent fire, herbaceous plant communities would shift to dense hardwood understories (Glitzenstein et al. 2012). Therefore, to balance management objectives of wild turkey habitat management with those of threatened and endangered species (e.g., gopher tortoise [*Gopherus polyphemus*]), frequent fire-return intervals (≤ 3 years) are recommended in pine savanna ecosystems (Martin et al. 2012).

Our study illustrates the importance of evaluating habitat selection at multiple spatial scales. Our interpretation of results differed based on the scale examined, suggesting that scale indeed acts in a hierarchy distinguishing population-level questions from more fine-scale activity patterns for female turkeys. Additionally, findings similar to ours may occur when habitat types are spatially correlated. Similar to Conner and Leopold (1996), we suggest that decisions made at one scale are limited and could result in poor management decisions and managers should consider the effects of scale on habitat selection. For example, if a land manager was provided with the results from the seasonal area of use scale only, and subsequently used those results for landscape level planning (e.g., restoration of large tracts of longleaf pine), then they may erroneously conclude that hardwoods are not important for wild turkeys. However, by also examining the coefficients for the study area scale, land managers are able to conclude that hardwoods are indeed important to wild turkeys when establishing their seasonal areas of use on the landscape. Notably, when the extent of availability was restricted from the study area boundary to a smaller seasonal area of use boundary, our results indicated that turkeys avoided hardwoods. The advantage of examining multiple spatial scales is that it enables land managers to identify, focus, and potentially monitor the impending costs and benefits of their management decisions (Ciarniello et al. 2007).

Our spatially explicit models of habitat selection generally validated well at the study area scale with most withheld locations occurring in the moderate to high probability of use bins but poorer at the seasonal area of use scale. Despite the poorer model validation, we believe poor validation at the seasonal area of use scale does not necessary imply low model accuracy, because wild turkeys are generalists and poor validation is common for species with broad resource requirements (Lobo et al. 2008). Other validation methods such as area under the curve (AUC) values also tend to validate predictive models better at larger geographic extents (e.g., study area scale) compared to smaller extents (e.g., seasonal area of use). In our case, available locations were spatially farther from turkey locations at the study area scale relative to seasonal area of use scale. It is likely that we could not assess the true accuracy of our models due primarily to the geographic extent at each scale, which has been shown by other methods (e.g., AUC) to artificially inflate model validation values (Lobo et al. 2008).

MANAGEMENT IMPLICATIONS

Pine savannas are ecologically and economically important to the southeastern United States due to the significant biodiversity, tolerance to frequent fire events, and resistance to pestilences relative to other commercial timber species (e.g., loblolly [*Pinus taeda*] and slash pine [*Pinus elliottii*]; Alavalapati et al. 2002). Our research provides evidence that hardwoods, shrub/scrub, and young pine habitats found within pine savannas are important to wild turkeys, whereas mature pine stands are used less than available. Our findings are similar to previous studies that found turkeys prefer areas containing a diversity of habitat types in a pine-dominated landscape (Miller et al. 1999, Wilson et al. 2005, Miller and Conner 2007, Martin et al. 2012). We suggest that land managers maintain remnant hardwoods for wild turkey management in pine savannas and recognize the importance of openings to management of turkey populations in pine savannas. Our results suggest that time-since-fire does not influence wild turkey habitat selection, but turkeys can coexist with frequent fire in pine-dominated habitats if other habitat types are available. We suggest land managers focus on small-scale (12-22 ha) and frequent burns (≤ 3 years) in pine savannas while providing a diversity of other habitat types to balance the objectives of managing for wild turkey habitat with those of threatened and endangered species within pine savannas. Our results also support the recognition that habitat selection operates at multiple spatial scales, so we suggest land managers consider habitat selection at multiple spatial scales by turkeys when developing management strategies.

ACKNOWLEDGEMENTS

We are grateful for funding provided by the Georgia Wildlife Resources Division through the Wildlife Restoration Program (Grant No. W75), the Joseph W. Jones Ecological Research Center at Ichauway, and the Warnell School of Forestry and Natural Resources at the University of Georgia. We thank the staff at the aforementioned organizations for their technical assistance on this project, and C. Perez, M. Streich, D. Colbert, and D. Ruttinger for their assistance with data collection.

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Table 4.1. Probability of seasonal habitat selection for female Eastern wild turkeys (*Meleagris gallopavo silvestris*) based on distance metrics (m) at the study area spatial scale at the Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area, southwestern Georgia, USA, 2011-2013.

Variable[a,b]	Season[c]	β	SE	Scaled Odds Ratio[d]	Scaled Lower 95%	Scaled Upper 95%
Mature pine	Preincubation	0.077	0.039	1.080	1.003	1.168
	Summer	0.163	0.040	1.177	1.090	1.277
Mixed pine/hardwoods	Preincubation	0.028	0.021	1.028	0.987	1.071
	Summer	0.056	0.023	1.058	1.012	1.106
Hardwoods	Preincubation	0.009	0.020	1.009	0.970	1.049
	Summer	-0.065	0.022	0.937	0.897	0.978
Young pine	Preincubation	-0.044	0.021	0.957	0.918	0.997
	Summer	-0.055	0.023	0.946	0.904	0.990
Agriculture	Preincubation	0.028	0.009	1.029	1.011	1.047
	Summer	0.039	0.010	1.039	1.020	1.059
Shrub/scrub	Preincubation	-0.188	0.026	0.829	0.787	0.872
	Summer	-0.173	0.029	0.841	0.794	0.890

[a]Distance to nearest habitat types.
[b]Coefficient estimates for habitat types are relative to fall-winter (1 October–31 January).
[c]Season: Preincubation (1 February – 19 April) and summer (16 June – 30 September).
[d]100-m scalar.

Table 4.2. Seasonal habitat selection model validation based on withholding approximately 20% of individual female Eastern wild turkeys (*Meleagris gallopavo silvestris*) from model development during each season (preincubation = 14 turkeys; summer = 10 turkeys) at the study area and seasonal area of use spatial scales at the Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area, southwestern Georgia, USA, 2011-2013.

		Relative probability of selection[a]					
Spatial scale	Season[b]	Low	Moderate	High	Total	ρ[c]	*P*-value
Study area	Preincubation	219	264	369	852	1.00	< 0.001
	Summer	136	175	147	458	0.50	0.667
Seasonal area of use	Preincubation	337	325	190	852	-1.00	< 0.001
	Summer	138	133	187	458	0.50	0.667

[a]Number of withheld telemetry locations from 20% of female Eastern wild turkeys withheld from model validation in each relative probability of selection bin.
[b]Preincubation (1 February – 19 April) and summer (16 June – 30 September).
[c]Spearman rank correlation.

Table 4.3. Probability of seasonal habitat selection for female Eastern wild turkey (*Meleagris gallopavo silvestris*) based on distance metrics (m) at the seasonal area of use spatial scale at the Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area, southwestern Georgia, USA, 2011-2013.

Variable[a,b]	Season[c]	β	SE	Scaled Odds Ratio[d]	Scaled Lower 95%	Scaled Upper 95%
Mature pine	Preincubation	0.076	0.053	1.079	0.971	1.198
	Summer	0.104	0.055	1.109	0.995	1.237
Mixed pine/hardwoods	Preincubation	0.041	0.024	1.042	0.995	1.093
	Summer	0.055	0.025	1.057	1.006	1.112
Hardwoods	Preincubation	0.040	0.020	1.041	1.002	1.082
	Summer	0.048	0.022	1.049	1.005	1.095
Young pine	Preincubation	0.057	0.020	1.059	1.018	1.102
	Summer	0.104	0.023	1.109	1.059	1.161
Shrub/scrub	Preincubation	-0.062	0.028	0.940	0.890	0.992
	Summer	-0.106	0.031	0.899	0.846	0.955

[a]Distance to nearest habitat types.
[b]Coefficient estimates for habitat types are relative to fall-winter (1 October–31 January).
[c]Season: Preincubation (1 February – 19 April) and summer (16 June – 30 September).
[d]100-m scalar.

CHAPTER 5

SURVIVAL AND CAUSE-SPECIFIC MORTALITY OF FEMALE EASTERN WILD TURKEYS IN 2 FREQUENTLY-BURNED PINE SAVANNAS[1]

[1]Little, A. R., M. J. Conroy, M. J. Chamberlain, L. M. Conner, and R. J. Warren. Submitted to Journal of Wildlife Management, 09/09/2015.

ABSTRACT

Pine savannas (e.g., longleaf pine [*Pinus palustris*]) have declined throughout the southeastern United States due to land-use change. Fortunately, natural resource professionals are currently restoring these ecologically and economically important savannas. Although efforts are underway to restore pine savannas, little information exists on female Eastern wild turkey (*Meleagris gallopavo silvestris*) population dynamics in these systems. Therefore, we evaluated survival of female Eastern wild turkeys in 2 pine savannas in southwestern Georgia. We radio-marked 126 female wild turkeys during 2010-2013 and monitored their survival; 66 (52.4%) radio-marked females died during the study. We estimated causes of death for 37 mortality events, with most deaths attributable to unknown causes (43.2%). Predation was the leading known cause of mortality, with 35.1% of mortalities attributed to mesocarnivore predation (e.g., bobcat [*Lynx rufus*], coyote [*Canis latrans*], and gray fox [*Urocyon cinereoargenteus*]) and 18.9% to great-horned owl (*Bubo virginianus*) predation. Seasonal survival estimates varied from a high during fall ($\hat{S}$ = 0.92; 95% CI: 0.77-0.97) to a low during spring ($\hat{S}$ = 0.77; 95% CI: 0.66-0.85). Nesting status (incubating a nest or not) did not influence survival during the spring nesting season. Annual survival was 0.53 (95% CI: 0.42-0.65). To ensure sustainable wild turkey populations in pine savannas, we suggest managers monitor relationships between survival and productivity.

INTRODUCTION

Pine savannas (e.g., longleaf pine [*Pinus palustris*]) are one of the most biologically diverse systems found in North America containing numerous species of flora and fauna (Alavalapati et al. 2002). Historically, pine savannas occupied over 30 million ha in the southeastern United States (Brockway et al. 2005, Van Lear et al. 2005), and were disturbed by fire ignited by lightning or humans. These fires created an early successional grassland community and prevented bottomland hardwood encroachment (Komarek 1964, Pyne 1982, Kennamer et al. 1992, Robbins and Myers 1992). However, land-use changes (e.g., conversion from slower growing longleaf pine to faster growing loblolly pine (*Pinus taeda*) and slash pine (*Pinus elliottii*); increase in agricultural practices and urban development) throughout the southeastern United States led to a decline in pine savannas (Frost 1993, Alavalapati et al. 2002, Van Lear et al. 2005). Government policies also encouraged landowners to exclude fire from their property, which led to changes in forest structure (Alavalapati et al. 2002).

Prescribed fire is the primary tool used to reduce undesirable competing vegetation in pine savannas while stimulating growth and development of a diverse plant community in the understory (Waldrop et al. 1992, Cain et al. 1998, Barnett 1999, Steen et al. 2013). Prescribed fire has been shown to increase understory plant species richness, diversity, and evenness in pine savannas (Brockway and Lewis 1997). Prescribed fire also promotes the availability of nesting, brood-rearing, and escape cover for ground-nesting birds (Dickson 1981, Hurst 1981, Landers 1981). Various species found in pine savannas, such as the endangered red-cockaded woodpecker (*Picoides borealis*) and gopher tortoises (*Gopherus polyphemus*) are dependent on the use of fire to maintain open, park-like conditions for their survival (Alavalapati et al. 2002). Therefore, land managers commonly apply prescribed fire every 1-3 years to reduce hardwood encroachment and enhance grass and forb development in pine savannas (Glitzenstein et al. 2012).

Currently, over 30 plant and animal species endemic to pine savannas are now considered to be threatened or endangered (Landers et al. 1995). Fortunately, natural resource professionals have recognized the importance of restoring pine savannas, which will potentially benefit a variety of species in the southeastern United States. Wild turkeys (M*eleagris gallopavo*) have historically been an important species present in pine savannas, and are adapted to the early-successional understory habitat created by periodic fire that also promotes insect abundance (Hurst 1981, McGlincy 1985, Landers and Mueller 1986, Exum 1988, Provencher et al. 1998*).* Today, the economic benefits derived annually from wild turkey hunting exceed US $500 million (Baumann et al. 1990). Current efforts to restore pine savannas, coupled with the substantial economic benefit of wild turkey hunting, justify research to address population dynamics of wild turkeys in this ecosystem to help guide management decisions.

Wild turkey populations are controlled by nest success, brood survival, and adult survival (Roberts et al. 1995, Vanguilder and Kurzejeski 1995, Godfrey and Norman 1999). Low survival of female wild turkeys and broods may limit population productivity (Miller and Leopold 1992, Palmer et al. 1993, Peoples et al. 1995, Miller et al. 1998). Therefore, to effectively manage wild turkey populations, biologists and land managers need information on nest success, brood survival, and adult survival in pine savannas. Little et al. (2014) reported a greater initial nest success in 2 pine savannas relative to other published studies in the region (Palmer et al. 1993, Miller et al. 1998, Thogmartin and Johnson 1999, Wilson et al. 2005, Byrne and Chamberlain 2013). Little et al. (2014) also observed similar renest rates and success relative to other published studies in the region (Palmer et al. 1993, Miller et al. 1998, Thogmartin and Johnson 1999, Wilson et al. 2005, Byrne and Chamberlain 2013), suggesting that females in pine savannas were likely to renest after nest loss. Additionally, Little et al. (2014) observed brood survival rates similar to previous studies in coastal plain pine forests that used prescribed fire to improve understory habitat conditions (Exum et al. 1987, Sisson et al. 1991, Peoples et al. 1995). Survival of female wild turkeys in pine savannas has not been previously studied, yet is critical to manage turkey populations effectively and sustainably.

Our primary objectives were to (1) estimate annual and seasonal survival rates of female wild turkeys, and (2) document cause-specific mortality. Given earlier findings (Little et al. (2014), we hypothesized that nesting status (i.e., incubated or did not incubate a nest) could influence survival of females. Therefore, our secondary objective was to evaluate the effect of nesting status on survival. We hypothesized that annual and seasonal survival estimates would be comparable to previous studies in forested systems. We hypothesized that survival would be lowest during the nesting season because incubating females remain on or close to the nest, which could make them more vulnerable to predation. Lastly, we hypothesized that reproductive activity would negatively influence survival during the nesting season (i.e., nesting females would experience lower survival than non-nesting females).

STUDY AREA

Our study was conducted on the 11,735-ha Joseph W. Jones Ecological Research Center at Ichauway (hereafter, Jones Center) located in Baker County, Georgia and the 3,900-ha Silver Lake Wildlife Management Area owned by the Georgia Department of Natural Resources located in Decatur County, Georgia (hereafter, Silver Lake WMA). The Jones Center was comprised of approximately 39% mature pine, 24% mixed pine/hardwood, 11% agriculture/food plot, 8% young pine, 7% hardwoods, 4% scrub-shrub, 3% wetland, 3% open water, and 1% residential/barren. Wiregrass and old-field grasses (e.g., *Andropogon* spp.) were the dominant understory habitat in the pine and mixed pine/hardwood stands (Goebel et al. 1997). However, >1,000 vascular plant species occur on the site (Drew et al. 1998). Silver Lake WMA was comprised of approximately 56% mature pine, 22% young pine, 10% open water, 9% mixed pine/hardwood, 1% shrub/scrub, 1% hardwood, 1% residential/barren, and < 1% wetlands and agriculture/food plots. Paved, gravel, and dirt road densities were 5.48 km/km^2 and 6.59 km/km^2 on the Jones Center and Silver Lake WMA, respectively. Total accumulated rainfall from 14 December to the following 13 December varied at the Jones Center for 2011 (89.15 cm), 2012 (96.42 cm), and 2013 (156.79 cm) (Jones Center; Georgia Automated Environmental Monitoring Network; http://georgiaweather.net), and at Silver Lake WMA for 2011 (73.13 cm) and 2012 (118.57 cm) (Lake Seminole; Georgia Automated Environmental Monitoring Network; http://georgiaweather.net).

To successfully restore and maintain pine savannas on our study sites, land managers used prescribed fire and mechanical hardwood removal. Fire was applied to mature pine, young pine, mixed pine/hardwood, and shrub/scrub habitats. Prescribed fire was conducted throughout the year with > 95% of burns conducted during January-June. Prescribed fire application occurred in a mosaic fashion, which promoted landscape diversity. Average patch size burned at the Jones Center was 21.41 ha (SE = 0.83; range = 0.02 – 240.57 ha), whereas average patch size burned at Silver Lake WMA was 14.41 ha (SE = 0.58; range = 0.66 – 88.27 ha). Fire return interval typically ranged from 1-3 years, but most (≥ 95%) fires applied to our study sites were ≤ 2-years (38.4%, 0-year;

34.9%, 1-year; 21.7%, 2-year; 4.9% of stands with 3-year time-since-fire). Land managers often used mechanical removal to remove large off-site hardwoods (e.g., water oak [*Quercus nigra*]) from within mature pine stands.

METHODS

Turkey Capture and Monitoring

We captured female wild turkeys using rocket nets baited with corn during December–March of 2010-2013 and June–August of 2011-2012. We fitted all captured females with serially numbered, butt-end (left leg) and riveted (right leg) aluminum leg bands (National Band and Tag Co., Newport, KY). We also affixed a backpack-style VHF radio-transmitter, weighing approximately 60-g, (Sirtrack, Havelock North, New Zealand; and Telenax, Playa del Carmen, México) to all females. All birds were released at the capture site immediately after processing. The Institutional Animal Care and Use Committee at the University of Georgia approved all turkey capture, handling, and marking procedures (Protocol #A2013 05-034-Y1-A0).

We used a hand-held, 3-element Yagi antenna and Wildlife Materials TRX 2000S receiver (Wildlife Materials, Murphysboro, Illinois) to locate radio-marked females ≥2 times per week from mid-July to mid-March and ≥ 1 time per day from mid-March to mid-July. We triangulated each female and recorded the locations using a mobile phone containing Location Of A Signal-SD software (LOAS™ [2010] Ecological Software Solutions LLC. Hegymagas, Hungary, Version 4.0.3.8.) and a Bluetooth-Global Positioning System unit. We investigated mortality events immediately following detection of a mortality signal, except during the nesting season when inactive incubating females often triggered the mortality sensor. During the nesting season, we delayed investigation of mortality signals until 28 days from the estimated incubation start date so as not to disturb females that may have been nesting. We classified mortality events into 4 categories: (1) mesocarnivore (e.g., bobcat [*Lynx rufus*], coyote [*Canis latrans*], and gray fox [*Urocyon cinereoargenteus*]; (2) great-horned owl [*Bubo virginianus*]); (3) unknown cause of death; and (4) other (e.g., vehicle collision). We based classification on evidence recovered at the site of the carcass (i.e. presence or absence of head and neck, chew characteristics on carcass and radio transmitter, detection of hair or feathers, and evidence of caching; Thogmartin and Schaeffer 2000).

To determine seasonal survival, we delineated biologically meaningful seasons based on the reproductive chronology of turkeys on our study areas (Little et al. 2014) and previous research (Miller et al. 1999; Miller and Conner 2005, 2007). We defined winter as 1 January – 31 March, spring as 1 April – 30 June, summer as 1 July – 30 September, and fall as 1 October – 31 December.

Statistical Analysis

To evaluate annual and seasonal survival rates of female wild turkeys, we used the known-fate modeling procedure in program MARK (White and Burnham 1999) as implemented in RMark (Laake 2013). Prior to developing candidate models, we censored all mortalities occurring within 7 days of capture from analyses (Vangilder and Sheriff 1990). We censored turkeys with radio transmitter failure or those that went missing on the last day of observation. We do not suspect that any mortalities that occurred during our study were caused by illegal harvest. We pooled capture-recapture data across both study sites to increase sample size, and created capture histories based on monthly survival of females. For example, we had 32 monthly survival periods from which we could estimate annual and seasonal survival. We developed 3 candidate models to estimate annual and seasonal survival. Model 1 held survival constant across the 32 monthly periods, model 2 allowed for survival to vary across the 32 monthly periods, and model 3 allowed for survival to vary seasonally. We estimated average annual survival for 2011- 2013 as the product of the seasonal 3-month survival estimates from the model with a seasonal effect, with variances estimated by the delta method (Laake 2013).

To determine if survival was influenced by nesting status, we estimated survival for nesting (incubated a nest) and non-nesting (did not incubate a nest) females during the spring season on our study areas (see also Little et al. 2014). Prior to developing candidate models, we built a data set that contained only females where reproductive status was known. For example, if females were lost during the nesting season and reappeared later in the season, then we excluded these individuals from the analysis as we could not determine if they initiated a nest. We created capture histories based on monthly survival of nesting and non-nesting females. We developed 4 candidate models to determine if survival was influenced by nesting status: Model 1 held monthly survival constant, model 2 allowed for monthly survival to vary during the study, model 3 allowed for monthly survival to vary across years, and model 4 allowed for monthly survival to vary between nesting (incubated a nest) and non-nesting (did not incubate a nest) females. We used an information-theoretic approach for model selection and assessed model strength based on Akaike's Information Criteria adjusted for small sample size (AICc) and Akaike's weights (w_i; Burnham and Anderson 2002). In cases where we found evidence of model selection uncertainty ($w_i < 0.8$), we used multimodel inference and provide model-averaged estimates of survival based on all models (Burnham and

Anderson 2002). We computed the standard error of the resulting products via a delta approximation for model-averaged estimates of survival (Laake 2013).

RESULTS

We captured and radio-marked 126 female wild turkeys and 66 (52.4%) died during the study. We estimated causes of death for 37 mortality events, with most deaths attributable to unknown causes (43.2%). Predation was the leading known cause of mortality, with 35.1% attributed to mesocarnivore predation and 18.9% to great-horned owl predation. One female (2.7%) was hit by a vehicle.

The constant- and seasonally-varying survival models were nearly tied for AIC support with little support for the time-varying model (Table 5.1); we provide estimates based on the seasonally-varying model, with annual survival as the product of these seasonal rates (Table 5.2). Annual survival was 0.53 (95% CI: 0.42-0.65), and survival varied seasonally with lowest survival during spring ($\hat{S}$ = 0.77; 95% CI: 0.66-0.85) and highest survival during the fall ($\hat{S}$ = 0.92; 95% CI: 0.77-0.97; Table 5.2).

We estimated survival for 64 females (40 incubated a nest and 24 did not incubate a nest) in which nesting status was known during the 2011-2013 nesting seasons. Because of the wider distribution of AIC values (Table 5.3), we provided model-averaged estimates of survival for the nesting and non-nesting periods (Table 5.4). Monthly survival was similar for nesting (incubated a nest) and non-nesting (did not incubate a nest) females with estimates ranging from 0.86 to 0.93 (Table 5.4).

DISCUSSION

Pine savannas are an economically and ecologically important system throughout the southeastern United States, supporting a diversity of flora and fauna (Landers et al.

1995, Alavalapati et al. 2002, Brockway et al. 2005). Restoration of this ecosystem is important to the recovery efforts of threatened and endangered species (e.g., red-cockaded woodpecker; Alavalapati et al. 2002). Likewise, understanding cause-specific mortality and survival of wild turkeys in pine savannas is important for future wild turkey management. We found that annual survival of female turkeys was similar to previous studies. As hypothesized, survival was lowest during the spring; however, nesting status (incubate or did not incubate a nest) did not affect survival during the spring.

Predation was the leading known cause of mortality for female turkeys in our study, which is consistent with many previous studies (Miller and Leopold 1992, Palmer et al. 1993, Wright et al. 1996, Miller et al. 1998, Humberg et al. 2009). However, we could not determine cause of mortality for 43.2% of mortality events. Similarly, previous studies have attributed high percentages of mortalities to unknown causes (Miller et al. 1998, Humberg et al. 2009). This finding is likely a result of scavenging activities by various predators, which may delay onset of mortality signals until carcasses were completely consumed or displaced from their transmitters (Humberg et al. 2009). Alternatively, Thogmartin and Shaeffer (2000) suggested that frequent monitoring for mortality signals likely reduces the source of bias caused by scavenging after predation. However, most (48.6%, n = 18) mortality events in our study occurred during the spring nesting season. We delayed investigation of mortality signals until 28 days from the estimated incubation start date because transmitters would periodically switch to a mortality signal while the female remained on the nest. Regardless, we remained able to identify cause of death for 11 of 18 mortalities during this period. Mesocarnivore predation was the most common source of mortality followed by great-horned owls. Our findings are generally consistent with previous studies in this regard (Miller and Leopold 1992, Palmer et al. 1993, Wright et al. 1996, Miller et al. 1998, Humberg et al. 2009), but great-horned owls were a significant source of mortality in our study. Great horned-owls are known predators of wild turkeys (Miller and Leopold 1992, Palmer et al. 1993, Thogmartin and Shaeffer 2000) but are not typically considered a primary predator such as bobcats, foxes, and other mesopredators (Speake 1980, Wright et al. 1996). Our findings suggest that great-horned owls may represent an important source of mortality to female turkeys in pine savannas.

Annual survival was comparable to other forested systems in the southeastern United States (Palmer et al. 1993, Miller et al. 1998, Wilson et al. 2005). Miller et al. (1998) reported a mean annual survival of 0.51 with variation among years ranging from 0.22 to 0.77. However, compared to other studies in a variety of other habitat types, our findings suggest that our annual survival estimate was low (Hubbard et al. 1999, Humberg et al. 2009, Moore et al. 2010). For example, Humberg et al. (2009) found annual survival of female turkeys was 0.80 in a northern Indiana wild turkey population. In a Louisiana bottomland hardwood forest, Wilson et al. (2005) reported a higher annual survival (0.67) than we observed, but they found low nest initiation (33%; 8 out of 24 females) and success rates (38%; 3 out of 8 nests). Wilson et al. (2005) suggested that low productivity during the nesting season was likely due to persistent disturbances caused by annual flooding, which resulted in relatively little understory vegetation for nesting cover. They suggested that this may concentrate females during nest initiation, thereby leading to increased nest predation. They also suggested that the wild turkey population on their study area balanced low productivity with relatively high adult female survival. Conversely, Little et al. (2014) observed high nest initiation (70%; 57 out of 82 females), success rates (42%; 24 out of 57 nests), renest initiation (37%; 21 out of 57 females), and renest success rates (43%; 9 out of 21 nests) on our study sites. Our data suggest that females are able to balance lower annual survival with greater productivity, which may be influenced by the physiological conditions of females prior to nesting and availability of quality nesting cover created by frequent fire (≤ 3 years) on our study sites. Previous research has found that females in poor physiological condition were more prone to nest failure (Thogmartin and Johnson 1999). Miller et al. (1995) suggested that increased habitat diversity may increase the physiological conditions of females prior to nesting. Thogmartin and Johnson (1999) suggested that one way to increase habitat diversity is the use of prescribed fire. Our study areas were managed by frequent prescribed fire (most fire-return intervals were ≤ 2-years), which increases understory plant species richness, diversity, and evenness (Brockway and Lewis 1997). Previous research on our study areas indicated that female body condition is not likely a factor affecting timing of nest initiation, which is likely due to the abundance of early successional habitat and food resources on our study areas (Little et al. 2014). Therefore, we suggest that lower annual female survival observed on our study sites is likely offset by high nest and renest success, in part due to the availability of nesting and brood-rearing cover and is likely influenced by their ability to adapt to a landscape that has been historically disturbed by frequent fire events.

Our seasonal survival estimates were comparable to previous studies (Palmer et al. 1993, Roberts et al. 1995, Hubbard et al. 1999, Wilson et al. 2005, Humberg et al. 2009). Survival was highest during the fall (flock re-establishment) followed by winter (large flocks on wintering areas), summer (brood-rearing), and spring (nesting). Previous studies have documented high survival rates during the fall (Palmer et al. 1993, Roberts et al. 1995, Hubbard et al. 1999, Wilson et al. 2005, Humberg et al. 2009). Increased fall survival is likely attributable to stable foraging resources and a lack of illegal and legal harvest (Wilson et al. 2005). Additionally, survival would be expected to be higher during the fall relative to the spring because females are not nesting (e.g., stationary). We observed similar survival estimates for winter and summer. This finding is partially attributed to a greater risk of predation because 43% (10 mortalities during winter; 6 mortalities during summer) of 37 mortalities where cause of death could be assigned occurred during winter and summer. Mesocarnivores and great-horned owls were the primary causes of death for female turkeys during these seasons. Additionally, we also censored 14 individuals during winter and summer due to transmitter loss or loss in radio-contact. Summer survival on our study areas was similar to previous studies (Palmer et al. 1993, Roberts et al. 1995, Hubbard et al. 1999, Wilson et al. 2005, Humberg et al. 2009). Survival commonly increases during summer, which is likely due to the end of nesting season and increased mobility of broods. Our estimate of spring survival was within the range of survival estimates previously reported (0.75, Wilson et al. 2005; 0.91, Humberg et al. 2009). Lower survival during spring is commonly attributed to females remaining on or near a nest site, which leads to a greater risk of predation (Little et al. 1990).

Similar to other studies, survival was lowest during the nesting season (Roberts et al. 1995, Vangilder and Kurzejeski 1995, Wright et al. 1996, Miller et al. 1998, Wilson et al. 2005). However, few studies have documented differences in survival of nesting (incubated a nest) and non-nesting (did not incubate a nest) females. Our findings suggest that incubation in itself did not influence survival of female turkeys on our study sites. Survival of nesting and non-nesting females was relatively high (range: 0.86–0.93; Table 5.4). Similarly, Miller et al. (1998) found no difference in survival of nesting and non-nesting females. They also found that nesting females were more susceptible to predation, whereas non-nesting hens were more likely to be killed illegally. Our data suggest that non-nesting females were equally as likely to be killed by predators as nesting females. This finding is supported by Little et al. (2014), who found nest predation was likely a random occurrence with respect to habitat characteristics on our study areas. Streich et al. (2015) found that females selected nests in shrub/scrub habitats on our study areas, and recommended land managers focus on maintaining open-canopy forests with adequate understory vegetation for nest and brood-rearing cover. Areas with increased understory vegetation likely make detection of nests and broods increasingly difficult for visual and olfactory predators (Lehman et al. 2008). We suggest further research is needed to evaluate predator – wild turkey dynamics in pine savannas.

MANAGEMENT IMPLICATIONS

Restoration of pine savannas provides environmental benefits (e.g., diversity of flora and fauna). The additional economic value of wild turkey hunting provides additional justification for future reforestation efforts of pine savannas in the southeastern United States. Consistent with previous research, predation was the leading known cause of mortality for female wild turkeys, especially during the spring. However, females were able to balance lower survival by increased nest and renest success, as was observed previously on our study areas. Provision of adequate nesting cover in pine savannas may be important to decrease predation rates during the spring. Our data also indicate that non-nesting females were equally as likely to be killed by predators as nesting females. Given that we observed lower annual survival than some studies, we recommend that land managers monitor relationships between survival and productivity of turkeys in pine savannas to ensure the sustainability of turkey populations.

ACKNOWLEDGEMENTS

We are grateful for funding provided by the Georgia Wildlife Resources Division through the Wildlife Restoration Program (Grant No. W75), the Joseph W. Jones Ecological Research Center at Ichauway, and the Warnell School of Forestry and Natural Resources at the University of Georgia. We thank the staff at the aforementioned organizations for their technical assistance on this project, and C. Perez, D. Colbert, M. Streich, and D. Ruttinger for their assistance with data collection. We also thank B. Collier for his statistical assistance in earlier versions of this manuscript.

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Table 5.1. Candidate models used to examine constant, seasonally-varying, and time-varying survival of female Eastern wild turkeys (*Meleagris gallopavo silvestris*) in 2 pine savannas (Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area) located in southwestern Georgia, USA, 2010-2013.

Model notation	Number of parameters	AICc	ΔAICc	w_i
S(Constant)	1	289.05	0.00	0.54
S(Seasonally-varying)	4	289.42	0.38	0.45
S(Time-varying)	32	306.47	17.42	<0.01

Table 5.2. Seasonal survival estimates for female Eastern wild turkeys (*Meleagris gallopavo silvestris*) in 2 pine savannas (Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area) located in southwestern Georgia, USA, 2010-2013.

Season[a]	Survival estimate	2.5% CI	97.5% CI
Winter	0.87	0.78	0.93
Spring	0.77	0.66	0.85
Summer	0.87	0.74	0.94
Fall	0.92	0.77	0.97

[a]Seasons included: winter (1 January – 31 March), spring (1 April – 30 June), summer (1 July – 30 September), and fall (1 October – 31 December).

Table 5.3. Candidate models used to examine monthly survival for nesting (incubated a nest) and non-nesting (did not incubate a nest) female Eastern wild turkeys (*Meleagris gallopavo silvestris*) during 1 April–30 June in 2 pine savannas (Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area) located in southwestern Georgia, USA, 2011-2013.

Model notation	Number of parameters	AICc	ΔAICc	w_i
S(Nesting and non-nesting)[a]	2	172.18	0.00	0.72
S(Constant)	1	174.42	2.24	0.23
S(Year-varying)	3	177.63	5.45	0.04
S(Time-varying)	14	193.09	20.91	<0.01

[a]Nesting females incubated a nest and non-nesting females did not incubate a nest.

Table 5.4. Monthly survival estimates for nesting (incubated a nest) and non-nesting (did not incubate a nest) female Eastern wild turkeys (*Meleagris gallopavo silvestris*) during 1 April–30 June in 2 pine savannas (Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area) located in southwestern Georgia, USA, 2011-2013.

		Nesting			Non-nesting		
Month	Year	Survival estimate	SE	95% CI[a]	Survival estimate	SE	95% CI[a]
	2011	0.926	0.055	0.817-1.034	0.860	0.053	0.757-0.964
	2012	0.928	0.055	0.819-1.037	0.863	0.053	0.759-0.966
April	2013	0.929	0.057	0.818-1.040	0.864	0.054	0.758-0.970
	2011	0.926	0.056	0.817-1.035	0.860	0.053	0.757-0.964
	2012	0.928	0.056	0.819-1.037	0.863	0.053	0.759-0.966
May	2013	0.929	0.057	0.818-1.041	0.864	0.054	0.757-0.970
	2011	0.928	0.057	0.816-1.040	0.862	0.054	0.756-0.969
	2012	0.930	0.058	0.817-1.043	0.865	0.055	0.757-0.972
June	2013	0.931	0.059	0.816-1.046	0.866	0.056	0.756-0.975

[a]Normal approximation CIs that are symmetric about the estimate ($\hat{S} \pm$ se*1.96).

CHAPTER 6

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Eastern wild turkey (*Meleagris gallopavo silvestris*) management requires knowledge of factors that influence population growth (e.g., nest success, brood survival, and adult survival) and sustainability (Roberts et al. 1995, Vanguilder and Kurzejeski 1995, Godfrey and Norman 1999). Currently, natural resource professionals are restoring pine savannas throughout the southeastern United States, which are considered one of the most ecologically and economically important ecosystems in North America (Alavalapati et al. 2002). However, few studies have evaluated female wild turkey ecology in this ecosystem. Therefore, my research provides information on nest site selection, nest and brood survival, habitat selection, and survival of adult, female Eastern wild turkeys to help direct future management decisions in pine savannas.

Nest site selection can influence survival and reproductive performance of avian species (Martin and Roper 1988, Badyaev 1995, Thogmartin 1999). My results indicate that wild turkey nest site selection was strongly influenced by habitat structure adjacent to nest sites (15-m scale) relative to other habitat variables at larger spatial scales. Mean visual obstruction and percent canopy closure had the greatest influence on where females established nest sites, with nests commonly occurring in areas with greater visual obstruction and reduced canopy closure. However, my research also suggests that habitat structure adjacent to nest sites had little influence on nest survival, which may indicate that once turkeys select a nest site that nest predation occurs randomly with respect to habitat characteristics. My research suggests that land managers should focus on creating early-successional vegetation in pine savannas to conceal nests from potential predators but recognize that nests may still be lost to random predation events.

Wild turkey populations are strongly influenced by reproductive success (Palmer et al. 1993, Roberts et al. 1995, Roberts and Porter 1996, Miller et al. 1999, Thogmartin and Johnson 1999). My research indicates that initial nesting and renesting rates, and renesting success were similar to previous studies in the southeastern United States (Palmer et al. 1993, Miller et al. 1998, Thogmartin and Johnson 1999, Wilson et al. 2005, Byrne and Chamberlain 2013); however, I observed higher initial nest success relative to these same studies. My research also supports previous studies that found the first 2-weeks post-hatch is the greatest period of vulnerability for wild turkey broods (Barwick et al. 1971, Glidden and Austin 1975, Speake et al. 1985, Peoples et al. 1995, Spears et al. 2007). After 2-weeks of age, brood survival usually increases because poults can roost in trees to avoid risk of terrestrial predators (Barwick et al. 1971). My research supports this conclusion as brood survival increased following the 14-day flightless period but was comparable to previous studies in the coastal plain pine forests (Peoples et al. 1995, Exum et al. 1987, Sisson et al. 1991).

Wild turkey population growth is also regulated by adult survival (Roberts et al. 1995, Vanguilder and Kurzejeski 1995, Godfrey and Norman 1999). My research indicates that mesocarnivore predation was the most common source of mortality for adult, female turkeys followed by great-horned owls with the majority of predation events occurring during the spring. One unique aspect of my survival study was that I was able to evaluate survival of nesting (incubated a nest) and non-nesting (did not incubate a nest) females. Similar to Miller et al. (1998), I found no difference in survival of nesting and non-nesting females suggesting that non-nesting females were equally as likely to be killed by predators as nesting females. My research also indicated that annual survival of adult, female turkeys in Southeastern pine savannas was low compared to previous studies (Hubbard et al. 1999, Humberg et al. 2009, Moore et al. 2010, Byrne et al. 2015). For example, Byrne et al. (2015) found an average annual survival rate of 0.68 for female turkeys in the southeastern United States. My research suggests that lower annual survival observed on my study sites is likely offset by high nest and renest success, which may be a function of the availability of nesting and brood-rearing cover created by frequent prescribed fire at small spatial scales (12-22 ha) and the ability of females to adapt to frequent fire by renesting after nest loss.

Prescribed fire is an important management tool in pine savannas and helps promote early-successional understory habitat and herbaceous vegetation while increasing insect abundance for wild turkeys (McGlincy 1985, Landers and Mueller 1986, Exum 1988, Provencher et al. 1998). My research indicates that female turkeys used mature pine stands less than available but selection was not influenced by time-since-fire. Previous research has found female turkeys used mature pines less than available (Martin et al. 2012, Streich et al. 2015). Avoidance of mature pine stands is likely a function of food availability and predation risk. Martin et al. (2012) suggested that this avoidance was due to increased vegetation thickness, which would make foraging increasingly difficult especially after 500 days post-fire. In addition, mature pine stands may also become riskier as time-since-fire increases because female turkeys cannot easily observe predators due to increased visual obstruction. My research also indicated that prescribed fire did not adversely affect nest and brood survival, with only 3 out of 79 nests and 1 out of 34 broods lost to prescribed fire. These findings are consistent with previous studies that found minimal impacts of prescribed fire on wild turkey nest and brood survival (Carlisle 2003, Jones et al. 2005, Moore 2006). My research indicates that wild turkey management in pine savannas is compatible with the application of frequent prescribed fire (≤ 3 years) at small spatial scales (12-22 ha). Therefore, land managers can balance management objectives of wild turkey habitat management with those of threatened and endangered species (e.g., gopher tortoise [*Gopherus Polyphemus*] and red-cockaded woodpecker [*Picoides borealis*]; Martin et al. 2012) in pine savannas by applying frequent prescribed fire (≤ 3 years).

Female wild turkeys selected hardwoods, shrub/scrub, and young pine habitats on my study sites. My research found hardwoods to be important to female turkeys, which is comparable to previous studies (Speake et al. 1975, Kennamer et al. 1980, Miller and Conner 2007). Hardwoods provide turkeys with food resources and potential roosting sites (Chamberlain et al. 2000) but may also be used as travel corridors between food patches or as protective cover from summer heat in pine savannas. Shrub/scrub habitats are considered important for nesting cover in pine savannas (Streich et al. 2015). Females also prefer areas with greater visual obstruction (e.g., shrub/scrub habitat) for broods during summer months to reduce the risk of predation (Spears et al. 2007). Young pine stands were also selected by female turkeys; however, these stands were commonly juxtaposed to shrub/scrub habitat. This finding suggests that turkeys may have been selecting for shrub/scrub habitat but young pines were spatially correlated to these areas leading to their relative importance.

Overall, management of pine savannas in the southeastern United States should focus on 3 key aspects for proper wild turkey management. First, my research indicated that wild turkeys select nest sites in areas with greater visual obstruction and reduced canopy closure. I recommend that land managers focus on providing open canopy areas within pine-dominated stands to ensure adequate nesting cover. Additionally, my research indicates that growing-season prescribed fire does not negatively impact turkey nest survival when small-scale (12-22 ha) fires are applied in a mosaic fashion across the landscape. Therefore, land managers can still apply growing-season prescribed fire in pine savannas at small scales to develop early-successional nesting habitat for turkeys while benefiting native flora (e.g., wiregrass [*Aristida* spp.]). Secondly, my research indicated that biologists should monitor relationships between adult female survival and productivity in pine savannas to ensure wild turkey populations are sustainable. This can be accomplished through mark-capture-resight methods (Weinstein et al. 1995) and line-transect–based distance sampling (Butler et al. 2007). Thirdly, my research indicated that female wild turkeys used mature pine stands less than available while selecting for hardwoods, shrub/scrub, and young pine habitats. Therefore, land managers can focus on promoting landscape diversity by retaining hardwoods and recognize the importance of openings to management of turkey populations in pine savannas.

To improve our understanding of wild turkey ecology in pine savannas, I recommend a few potential areas where future research is warranted for wild turkey management in pine savannas. First, future research should focus on addressing predator – wild turkey dynamics relative to season and frequency of prescribed fire. Specifically, research is needed to improve our understanding of how mesopredators and turkeys interact in a system managed by frequent fire. Secondly, female turkeys selected hardwood stands while avoiding mixed pine/hardwood stands. Future research should evaluate the hardwood density requirements of turkeys in upland pine savannas to direct future management decisions. Specifically, hardwood basal area information is needed by land managers to direct future hardwood retention or removal efforts. Thirdly, future research should evaluate food habits of wild turkeys in pine savannas to improve our understanding of why turkeys use mature pines less than available.

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