ABSTRACT

ROSCHE, SARAH BYRNES. Effects of Prescribed Fire on Northern Bobwhite Nest Success and Breeding Season Habitat Selection. (Under the direction of Christopher E. Moorman and Christopher S. DePerno).

Traditionally, prescribed fire has been restricted to the late dormant-season in the southeastern United States, partly due to concerns that growing-season fires may destroy nests of ground-nesting species such as the northern bobwhite (*Colinus virginianus*). While growing-season prescribed fire benefits bobwhites by maintaining high quality vegetation structure and composition, little is known about bobwhite nesting success or breeding-season habitat selection following growing-season fire. Our objectives were to determine: 1) if growing-season prescribed fire destroyed bobwhite nests, and how the risk of nest destruction was related to prescribed fire frequency and timing and 2) the predictors of nest-site selection and breeding season habitat selection (at a microsite and burn unit scale) in the presence of frequent (~every 3 years) prescribed fire. We used VHF-telemetry to locate and monitor northern bobwhite nests and conducted vegetation surveys at nest-sites, recorded telemetry locations, and random points. Our results indicated that both timing and frequency play a critical role in determine risk of bobwhite nest destruction by growing-season prescribed fires. Two of 30 nests were destroyed by fires in June and July, respectively, and it appears the risk of nest destruction by fire on Fort Bragg was approximately proportional to the percent of the study area burned during the nesting season. Most growing-season fires occurred before the bobwhite nesting season, which limited direct effects of prescribed fire on bobwhite nest survival; however, shifting prescribed fires to later in the growing season to better match the historical lightning season (i.e., after 1 June) would increase the risk of nest destruction. Because bobwhite selected primarily 2 years since fire for nesting, shortening the fire return interval to less than 3 years would increase the

proportion of nests exposed to fire and decrease available nesting cover. Bobwhite breeding season habitat selection indicated the significance of woody understory as cover, and that relatively low tree basal area was critical to allow understory development. Because bobwhite selected for areas 1 and 2 years post fire and avoided 0 years and 3+ years since fire units, we recommend fire return intervals no more frequent than every 3 years so as not to eliminate high quality nesting cover. No matter the timing or season of prescribed fire, maintaining low tree basal area is critical to the development of shrubs, grasses, and forbs that provide essential cover for bobwhite during the breeding season.

Effects of Prescribed Fire on Northern Bobwhite Nest Success and Breeding Season Habitat Selection

by
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A Thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Fisheries, Wildlife, and Conservation Biology

Raleigh, North Carolina

2018

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Jamian Pacifici

DEDICATION

To my parents for their encouragement and support throughout my life.

BIOGRAPHY

Sarah was born and raised in rural southern Virginia, and spent her childhood exploring the forests and creeks surrounding her house. These countless hours spent outside, whether fishing for bluegill, hiking, catching lizards, scooping tadpoles to take home and watch grow, fostered a passion and curiosity for the natural world. Sarah completed her Bachelors of Science degree in Wildlife Sciences at Virginia Tech in 2013. Afterword, Sarah spent 2 years traveling around the eastern United States working as a wildlife research technician. In August 2015 she began her graduate studies in Fisheries, Wildlife, and Conservation Biology at North Carolina State University.

ACKNOWLEDGMENTS

I would like to thank my graduate committee Christopher Moorman, Christopher DePerno, and Krishna Pacifici for their guidance and expertise throughout my graduate career. Wildlife biologist Jeff Jones was an invaluable asset during my field season, helping locate coveys, providing logistical support, and offering advice. This project would not have been possible without the hard work of the field crew: Molly Conway, Amber Bledsoe, Franco Gigliotti, William White, and Roy Cruz. Additionally, none of this work would have been possible without financial support provided by the Department of Defense and North Carolina State University.

For my lab mates and friends at North Carolina State University, your support and comradery was essential during this journey. Special thanks to Alex Fish for his patience and friendship helping me navigate the maze that is graduate school. Thank you to my rugby team, Raleigh Venom, for providing amazing friendships and a necessary outlet. Thank you to my best friends, Leah Arold and Susan Pense, for always believing in me, even when I didn’t believe in myself. Lastly and most importantly, I would like to thank my family and my parents. For providing me with a childhood immersed in nature and showing me a work ethic that has allowed me to chase my dreams. Thank you for your love and support.

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CHAPTER 1

EFFECTS OF TIMING AND FREQUENCY OF PRESCRIBED FIRE ON NESTING ECOLOGY OF NORTHERN BOBWHITE

ABSTRACT

Repeated growing-season prescribed fires can create areas with sparse overstory tree cover and a dense grass-forb-shrub understory that provide habitat for northern bobwhite (*Colinus virginianus*). Despite the potential benefits of growing-season prescribed burns for conserving bobwhite habitat, burning during the nesting season may destroy bobwhite nests and reduce available nesting cover. In 2016 and 2017, we monitored radio-transmitted bobwhite to describe nest-site selection and determine the risk of nest destruction on a 17,000-ha military installation managed with frequent (~every 3 years) growing-season and dormant-season prescribed burns. We located 30 nests, of which 4 (13%) were in areas burned the same year, 3 (10%) were in 1 year post fire, 19 (63%) were in 2 years post fire, and 4 (13%) were in 3+ years post fire. We compared vegetation composition and structure at nests to nearby random locations and determined bobwhite selected nest sites with greater woody understory cover and lower basal areas of pines and hardwoods. Two nests (6.7%) were destroyed during prescribed fires, but overall nest success (63%) was high. We calculated the overall risk of nest destruction by prescribed fire as the proportion of active nests in 3 years+ since fire areas multiplied by the proportion of the study area burned each week. Overall, 11% (weekly average 0.75%, range 0-3%) of the study area was burned during the 2016 nesting season (3 June to 3 September) and 4% (weekly average 0.31%, range 0-2%) of the study area was burned during the 2017 nesting season (5 June to 2 September). We estimated that no more than 0.75% of all bobwhite nests were exposed to fire in as single year of our study. Most growing-season fires occurred before the bobwhite nesting season, which limited direct effects of prescribed fire on bobwhite nest

survival; however, shifting prescribed fires to later in the growing season to better match the historical lightning season (i.e., after 1 June) would increase the risk of nest destruction. Because bobwhite used 2 years since fire for nesting, shortening the fire return interval to less than 3 years would increase the proportion of nests exposed to fire and decrease available nesting cover, especially in regions with low soil fertility where vegetation change following fire is less rapid than on more productive soils.

INTRODUCTION

The northern bobwhite (*Colinus virginianus;* hereafter, bobwhite) is a ground-nesting bird that has important ecological, social, aesthetic, recreational, and economic values across its range (Burger et al. 1999, Burger 2003). Since the 1960s, bobwhite have experienced range-wide population declines attributed to significant habitat loss (Burger 2003). Bobwhite habitat, characterized by a mixture of grass, forb, and shrub cover with ample bare ground (Cox and Widener 2008, Richardson 2016), once was prevalent across the southeastern United States due in part to historic lightning-ignited or anthropogenic fires (Glitzenstein et al. 1990, Platt et al. 1991, Knapp et al. 2009). However, in the absence of fire and other disturbances (e.g., wind storms, insects and disease, timber harvest), vegetation communities succeed, tree canopy cover increases, and the woody component increasingly dominates, making the landscape less suitable for bobwhite (Riddle et al. 2008). Hence, fire is critical to create and maintain bobwhite habitat (Stoddard 1931, Speake 1967, Rosene 1969, Burger 2001).

Commonly, prescribed fires for bobwhite management were applied during the dormant season, partly to avoid bobwhite nesting activity that occurs during the late spring and summer (Stoddard 1931, Rosene 1969, Landers and Mueller 1986, Wade and Lundsford 1989). However, prescribed fires set during the growing season are more effective than dormant-season fires in promoting native grass and forb cover where shrubs and trees have encroached and in creating open ground to facilitate movements by bobwhite (Waldrop et al. 1987, Streng et al. 1993, Glitzenstein et al. 1995). Additionally, growing-season prescribed fires may maintain these desirable vegetation conditions longer than dormant-season burns (Cox and Widener 2008). Regardless of the established efficacy of growing-season burns to create bobwhite habitat, concerns still exist that burning large blocks during the spring and summer could temporarily reduce bobwhite nesting cover, destroy active bobwhite nests, or kill young chicks (Erwin and Stasiak 1979, Harper et al. 2016).

Despite manager concerns about bobwhite nest fate in the presence of growing-season fires and the importance of nesting productivity to sustainable bobwhite populations (Dimmick et al. 2002), the limited research on the relationship between nesting ecology and growing-season prescribed fire has shown mixed results. Areas burned in May had greater bobwhite abundance and high-quality habitat, measured by vegetation composition, than areas burned during the dormant season, suggesting that growing-season prescribed fires do not have short-term negative impacts on bobwhite (Brennan et al. 2000). Moreover, bobwhite nest success in Alabama did not vary with time since last prescribed fire or season of last prescribed fire (Folk 2006). Conversely, nesting success was poor (19%) when growing-season prescribed fires were applied over 60% of the landscape in Georgia (Simpson 1972a). Where bobwhite nesting begins relatively early, nests initiated as early as mid-April could be destroyed by early, growing-season prescribed fires (Erwin and Stasiak 1979). Additionally, shifts in prescribed burning to later in the growing season, to match the peak of the historical lightning season, could increase the risk that nests are destroyed by fire (Knapp et al. 2009).

We assessed northern bobwhite nest-site selection and nest success in a longleaf pine (*Pinus palustris*) – wiregrass (*Aristida stricta*) ecosystem in the Sandhills physiographic region of North Carolina managed predominantly with growing-season prescribed fire on a 3-year return interval. Our objectives were to determine: 1) if growing-season prescribed fire destroyed bobwhite nests, and how the risk of nest destruction was related to prescribed fire frequency and timing; and 2) the predictors of nest-site selection in the presence of frequent (~every 3 years) prescribed fire.

STUDY AREA

We conducted the study on Fort Bragg Military Installation (hereafter, Fort Bragg), located within Cumberland, Hoke, Harnett, and Moore counties, North Carolina, USA (Figure 1). We constrained the study to 17,000 ha of the 73,469-ha military base, which was further segmented by sandy firebreaks or streams into 34-ha (average) burn units (range 0.4-136 ha). Located in the Sandhills physiographic region of North Carolina, the topography was rolling hills with uplands of longleaf pines on well-drained, coarse sandy soils and interspersed with lowland drainage areas (Franklin 1997, Sorrie et al. 2006). The Sandhills were considered low productivity sites because of the well-drained, sandy soils (Sorrie at al. 2006). The most abundant and widespread plant community at Fort Bragg was the pine-scrub oak sandhill (described by Sorrie et al. 2006), which mostly consisted of longleaf pine canopy, turkey oak (*Quercus laevis)* subcanopy, and a variable herbaceous layer, comprised largely of wiregrass. Interspersed throughout the study site were planted wildlife openings, often consisting of bicolor lespedeza (*Lespedeza bicolor)*, meant to provide reliable food and cover for bobwhite and other wildlife species.

Land management at Fort Bragg was driven by efforts to create habitat for the federally endangered red-cockaded woodpecker (*Leuconotopicus borealis*) and maintain a sparse understory for ease of military training. In accordance with these management objectives, growing-season (late March-August) prescribed fires were applied primarily on a 3-year return interval to control woody stem encroachment into the forest midstory. Fort Bragg fire managers aim to burn predominantly in the growing season, but due to limitations in resources, personnel, and appropriate fire weather, some stands miss a scheduled burn and are burned in the following dormant season (January-March). Parachute drops zones comprised a significant portion of the study area and were burned annually or biennially during the dormant season to reduce woody vegetation. Of prescribed fires that were applied during this study, 38% and 61% were conducted during the dormant season in 2016 and 2017, respectively. In 2016, 9% of the study site was burned with dormant-season fire and 15% was burned with growing-season fires (Figure 2). In 2017, 32% of the study area was burned with dormant-season fire, and 20% was burned with growing-season prescribed fire (Figure 2). Lowland forest areas had saturated soils that sometimes suppressed prescribed fire, leaving patches of broadleaf plant community within the matrix of the fire-maintained uplands.

METHODS

Capture

We captured bobwhite from 2 February to 22 April 2016 and 1 January to 21 April 2017 using modified walk-in funnel cage traps (Stoddard 1931). Traps measured 40-cm wide x 70-cm long x 26-cm high and were baited with scratch feed, whole corn, or millet. We placed traps in areas of known covey locations or in areas with dense cover (e.g., wetland drainages adjacent to planted wildlife openings). We checked traps every evening starting no more than 30 minutes before sunset.

We aged, sexed, weighed, and marked captured birds. We aged individuals as juvenile or adult, according to plumage characteristic and molting stages (Haugen 1969). We classified birds as adults by the solid gray-brown colored covert feather tips and juveniles by the presence of buffy tips of the upper primary coverts (Haugen 1957). We assigned sex based on plumage patterns and coloration (Stoddard 1931). We placed individual birds in a cotton handling bag hung from a 300g spring scale to measure weight. We affixed necklace-style radio transmitters (model# AWE-Q, American Wildlife Enterprise) to individuals weighing greater than 130g to ensure the weight of the radio transmitter did not exceed 5% of the individual bird's weight. The transmitters weighed approximately 6.2g and contained a 12-hour mortality sensor (Fies et al. 2002). Necklace-style radio transmitters do not impact captive birds' body mass dynamics or physiology (Corteville 1998, Hernandez et al. 2004) or decrease survival of wild birds (Mueller et al 1988, Corteville 1998, Palmer and Wellendorf 2007, Terhune et al. 2007). We used size #7 (5.56mm) aluminum butt-end bands (National Band & Tag Company) to identify individuals. All capture and handling methods followed protocols approved by the North Carolina State University Institutional Animal Care and Use Committee (#15-136-O).

Radio-telemetry

After a 7-day censorship period (Pollock et al. 1989), we located radio-marked individuals 3-5 times per week between February through July in 2016 and January through August in 2017. We located birds using R4000 VHF receivers fixed with 3-element Yagi-style antennas (Advanced Telemetry Systems, Isanti, MN) by homing towards the individual to within 50m (White and Garrott 1990). We used a handheld Garmin eTrex 20 Global Positioning System navigator (Garmin International, Inc., Olathe, KS) to collect UTM locations for each individual or covey (i.e., we collected only 1 location for coveys with multiple marked birds). We retrieved transmitters as soon as the mortality signal was observed. We used the mortality site, bobwhite remains, and transmitter condition to identify the cause of mortality (i.e., mammalian predator, avian predator, unknown predator, and non-predation) (White and Garrott 1990). If an individual could not be located, we searched the last known location expanding outward using a truck mounted with an omnidirectional antenna. We continued searches at least 2 days a week until the individual was located or declared lost if the bird could not be located within 2 weeks.

Nest Monitoring

We assumed an individual was nesting when it was recorded in the same localized area for 2-3 consecutive days. Once nesting activity was suspected, we triangulated to the location from 30 to 50m away and returned to the site the following day to verify the individual was incubating the nest. We marked the nest site >10m away from the nest in a predetermined direction. If the incubating bird was not located at the nest site for 2 consecutive days, the nest was inspected to determine nest status (i.e., successful, depredated, abandoned, or burned). We categorized nests as successful if any eggs showed the presence of pipping. We categorized nests as depredated if broken eggshells were present or all eggs and eggshells were absent. We considered nests to be abandoned if eggs were present but left unattended for ≥3 monitoring days.

Vegetation Surveys

We documented vegetation cover at all nest sites and at paired random points. Random points were determined using a list of randomly generated numbers to select an azimuth of 1-360° and a distance of 10-250m from each nest. We selected the maximum distance of 250m based on the diameter of the average home range of individuals residing in areas with similar land cover (Terhune et al. 2006). For any random point falling outside of a vegetated area (i.e., road, body of water, or military building), we decreased the random distance measurement until the entire plot could be measured outside of these obstructions. We collected vegetation measurements ≤10 days of observing the outcome of a nest. Vegetation plots consisted of 2 10-m transects with perpendicular intersecting midpoints at the nest location and the paired random point. At each location, we measured vegetation using a 2-m tall Wiens' pole. We measured vegetation at the center point and at each meter along both transects, totaling 21 readings per survey point. For horizontal cover of woody understory, wiregrass, other grass, and forbs, we recorded the vegetation types that touched anywhere on the Wiens' pole. Also, we recorded whether the bottom of the pole touched bare ground or leaf litter ground cover (Moorman and Guynn 2001). At each center point, we visually assessed percentage of canopy cover as 1 of 5 categories (0-20%, 21-40%, 41-60%, 61-80%, and 81-100%). At the center point, we measured the basal area of hardwoods and pines using a 10-factor prism. We recorded the number or years since last burn (0, 1, 2+) based on the vegetation conditions (e.g., blackened ground, flowering wiregrass, matted wiregrass) present within the plot. The 0 years since last burn category included fires conducted during the dormant season and growing season fires conducted before the start of the nesting season in the same calendar year. We distinguished between 2 and 3+ years since last burn using GIS data because this distinction could not be made visually in the field.

Data Analysis

Nest-site Selection

We used a generalized linear model to compare vegetation structure between nest sites and random points (R Version 3.4.2, www.r-project.org, accessed 15 October 2017). We evaluated 13 covariates that described vegetation cover or distance to key landscape features (Table 1). We calculated the percent horizontal cover and percent ground cover metrics as the number of Wiens' pole readings with a vegetation type contact divided by the total of the 21 readings at a location. We calculated distance to nearest key landscape features using GIS. We tested for collinearity between predictor variables using Pearson's correlation coefficient with a maximum threshold of 0.6 and a minimum threshold of -0.6. If the correlation between 2 covariates exceeded this level, we removed the covariate that would be more difficult to alter through habitat management. We started with a global model using all possible uncorrelated vegetation covariates, and we used stepwise selection to identify the model with lowest AICc value.

Nesting Fire Exposure

We calculated weekly fire exposure rates as the product of the proportion of nests active in the 3+ years since last fire areas (only 3+ year since fire areas are scheduled to be burned on a 3-year fire return interval and thus at risk) and the proportion of the study area burned each week (Example: if 1% of nests were active in 3+ years since fire areas from 15 June - 21 June and 5% of the study area was burned during that week, then 0.05% [0.01 x 0.05 = 0.0005] of nests would be exposed to fire that week). We calculated total nest exposure during the nesting season for each year as the sum of weekly exposure rates. This approach assumed that burned units were burned completely during a prescribed fire and that all nests occurring in the burned unit would be destroyed (Kilburg et al. 2014).

RESULTS

Capture and Radio-telemetry

In 2016, during 3420 trap nights, we captured 59 individuals (52 juveniles, 7 adults), with 1 capture every 58 trap nights. In 2017, during 9,646 trap nights, we captured 71 individuals (50 juveniles, 21 adults), with 1 capture every 135 trap nights. All individuals (130) captured in both years received a transmitter, but only 87 survived to the start of the breeding season (i.e., the average date of covey breakup). We collected 845 individual locations for 42 birds during the 2016 breeding season (23 April – 3 September) and 1,745 individual locations for 45 birds during the 2017 breeding season (28 April – 2 September), but not all birds survived the entirety of the breeding season. We documented 29 mortalities (15 in 2016, 14 in 2017) during the breeding season, and assigned causes of mortality as mammalian predator (15, 52%), avian predator (6, 21%), and unknown predator (8, 28%).

Nesting

On Fort Bragg, the nesting season occurred from 3 June to 3 September 2016, and from 1 June to 6 September 2017, with the peak of nesting activity in mid-June (Figure 3). We located 16 and 14 nests during the 2016 and 2017 field seasons, respectively. We observed only 1 re-nesting attempt over both years. Combining both years of data, we observed 1 incubated nest per 2 marked individuals alive at the start of the nesting season. Nests were incubated by males (16, 53%) and females (14, 47%), or juveniles (23, 77%) and adults (7, 23%). In 2016, the availability of each year since last burn category (0, 1, 2, 3+ years post burn) was relatively consistent across the base (range 19% to 33%) at the start of the nesting season, and we documented 0 nests in 0 years since last burn, 1 in 1 year post burn, 11 in 2 years post burn, and 4 in 3+ years post burn. However, in 2017 almost half (49%) of the study area was in the 0 year since last burn category (Table 2) at the start of nesting season, and the other 3 categories were available across 16 to 18% of the study site. In 2017, we documented 4 nests in 0 years since last burn, 2 in 1 year post burn, 8 in 2 years post burn, and 0 in 3 years post burn. Bobwhite nested in the 2 years since fire burn units at proportions greater than available over the study area during both years, whereas they used other time-since-fire categories similar to or at proportions less than available (Table 2). We documented 2 nests (7%) burned by prescribed fire applied on June 8 and July 1, 2016; both nests were in areas 3+ years since last burn. Nineteen nests successfully hatched (63%) over both years of the study, with 8 and 11 nests hatching in 2016 and 2017, respectively (Table 3). Three nests were abandoned, 2 of which were researcher induced, and 3 nests were depredated. In total, 2 out of 19 (11%) successful nests were located in areas 0 years since last burn, 3 (16%) were in areas 1 year since last burn, 13 (68%) were in areas 2 years since last burn, and 1 (5%) was in areas at least 3 years since last burn (Table 4).

Nest-Site Selection

The best model to describe bobwhite nest-site selection included basal area of both hardwoods and pines, percent woody understory cover, and percent wiregrass cover (Table 5). Bobwhite nested in areas on Fort Bragg with lower hardwood basal area, lower pine basal area, and greater woody understory cover than at random points, but wiregrass cover had relatively low explanatory power even though it was included in the best model (Table 6). The probability of bobwhite nest-site selection exceeded 75% when pine basal area fell below ~7m^2/ha (30.5ft^2/ac) and hardwood basal area fell below 2m^2/ha (8.7ft^2/ac) (Figure 4).

Nesting Fire Exposure

In 2016, 15% of the study area was burned during the growing season (late March through August), of which 11% burned during the 14-week nesting season. In 2017, 20% of the study are was burned during the growing season, of which 4% burned during the 14-week nesting season. The proportion of the study area burned weekly during the nesting season ranged from 0% to 3.33% in 2016 and 0% to 1.97% in 2017. Assuming areas were completely burned by a prescribed fire, we estimated that 0.75% and 0% of bobwhite nests were exposed to fire during the 2016 and 2017 nesting seasons, respectively.

DISCUSSION

Early, growing-season prescribed fire posed relatively little risk to bobwhite nests on Fort Bragg, and likely poses the same low risks elsewhere in the species' range. Only a small number of nests were located in 3+ years since fire areas (13%, 4), which were scheduled to be burned on a 3-year fire return interval. Additionally, only a small portion (weekly average 0.5% combined for 2016 and 2017) of the study area was burned each week during the 14-week nesting season

(1 June – 3 September 2016, 3 June – 2 September 2017), and the estimated average weekly exposure rate of nests to prescribed fire was relatively low (0.03%). While this risk exposure is site specific to Fort Bragg, similar risk calculations can be done elsewhere in the species' range. Because bobwhite nest initiation can begin as early as mid-April and last until early September depending on geographic location, the specific timing of growing-season prescribed will determine the risk of nest destruction (Klimstra and Roseberry 1975). A late April prescribed fire destroyed 2 bobwhite nests in Nebraska, but peak nesting on Fort Bragg was similar to other studies suggesting that early, growing-season burns in April or May are unlikely to destroy bobwhite nests (Lehmann 1946, Dimmick 1968, Simpson 1972b, Erwin and Stasiak 1979). Additionally, bobwhite can lay multiple nests in a single breeding season (Curtis et al 1993, Burger et al 1995), and can re-nest if a nest is destroyed by fire (Cox and Widener 2008).

Although only 2 nests were destroyed by growing-season prescribed fire in our study, shifts to burning later in the growing season to match the historical lightning season (June-August) would increase the risk of nest destruction by growing-season prescribed fire (Robbins and Myers 1992). In fact, percentages of nests that were destroyed by fire in each year of our study changed relative to the amount of acreage burned during the nesting season. In 2016, 12.5% of nests were burned and 11% of the study site was burned; in 2017, 0% of nests were burned and 4% of the study site was burned. Hence, increased acreages burned during June to August could proportionally increase the number of nests that are destroyed.

However, fire return interval plays a critical role in determining risk of bobwhite nest destruction by growing-season prescribed fire. On Fort Bragg, the majority of nests were in 2-year-old rough not scheduled to be burned on a dominant 3-year fire return interval. Few nests were located in 3-year-old rough that was scheduled to be burned, thus reducing the risk of nest destruction by prescribed fire. However, a 2-year return interval would dramatically increase potential risk of nest destruction from fire given that 63% of nests were located in the 2-year-old rough. Yet, the interaction between the fire return interval and nest distribution amongst time-since-burn categories likely varies with soil productivity. For example, in areas with nutrient rich soil where plant regrowth returns more rapidly to pre-fire conditions, bobwhite may nest more frequently in areas 0- or 1-year since fire, in which case a 2-year fire return interval would pose less risk to bobwhite nests than on Fort Bragg (Simpson 1972).

Bobwhite appeared to select rough conditions that maximized the quality of nesting cover Selection for nesting in areas with lower basal area and greater woody understory cover, including shrubs and regenerating trees, likely is indicative of selection for the most limiting nest cover components on Fort Bragg. Basal area is a critical factor for determining habitat quality for bobwhite across its range (Stoddard 1931, Rosene 1969, Fies et al 1992, Brennan 1995). Midstory and overstory tree cover competes for sunlight with understory plants, and thus a lower basal area is more beneficial for bobwhite because it allows adequate sunlight required for development of the understory that provides nesting cover. Wiregrass was widely present across the longleaf pine uplands on Fort Bragg, but shrubs, which provide critical thermal and escape cover, were more patchily available (Stoddard 1931, Johnson and Guthery 1988, Winiarski et al. 2017). We suggest the 2-year-old rough offered the best combination of wiregrass and woody cover conditions. Younger rough (i.e., 0 and 1 year since fire) lacked substantial woody cover, whereas areas that were 3+ years since fire typically contained matted wiregrass that may restrict movement by bobwhite adults and chicks (Burger 2003, Burke et al. 2007, Taillie et al. 2015).

MANAGEMENT IMPLICATIONS

When northern bobwhite are a priority species, growing-season prescribed fires should be restricted to the early, growing season (April-May) or late growing season (September-October) to avoid nest destruction. Additionally, a fire return interval less frequent than every 2 years likely is necessary to provide nesting cover, especially on less productive soils as are common in the Sandhills physiographic region of the southeastern USA. Where more frequent fire is needed to conserve other components of the ecosystem (e.g., promoting rare plants, preventing midstory hardwood encroachment), a heterogenous application of fire return intervals would be more appropriate (Lashley et al. 2015). In this case, leaving some less frequently burned areas across the landscape would provide nesting cover for bobwhite. Additionally, thinning forest stands to reduce basal area (i.e., less than $9m^2$/ha ($<40\ ft^2$/ac) combined pine and hardwood on Fort Bragg and other sites with similar soil productivity) is critical to provide sufficient sunlight to encourage understory grasses, forbs, and shrubs that constitute high quality nesting cover for bobwhite.

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Table 1. Covariates used to describe northern bobwhite nest-site selection on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

Abbreviation	Description
Canopy	Categorical variable ranking canopy level cover within 5 20% divisions
BA.Pine	Basal area of pine trees
BA.Hard	Basal area of hardwood trees
Woody Cover	Percentage of sample points with woody cover present
Wiregrass	Percentage of sample points with wiregrass present
Other Grass	Percentage of sample points with other grasses present
Forb	Percentage of sample points with forbs present
Bareground	Percentage of sample points with bare ground present
Leaflitter[1]	Percentage of sample points with leaf litter present
ST_Dist	Distance to nearest stream
RO_Dist	Distance to nearest firebreak
WO_Dist	Distance to nearest wildlife opening
DZ_Dist	Distance to nearest drop zone

[1] Removed from nest-site selection analysis because of collinearity with bareground

Table 2. Percent of nests located in each year since fire category (0, 1, 2, 3+) and the percentage of each category from the start of nesting season on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

Year Since Fire	2016 Nests	% of Nests	% of Study Area in Burn Category	2017 Nests	% of Nests	% of Study Area in Burn Category
0	0	0%	19%	4	29%	49%
1	1	6%	21%	2	14%	17%
2	11	69%	27%	8	57%	16%
3+	4	25%	33%	0	0%	18%

Table 3. Fates of nests located during 2016 and 2017 field seasons on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

	2016		2017		Total	
Nest Fate	# Nests	Percent	# Nests	Percent	# Nests	Percent
Successful	8	50	11	79	19	63
Burned	2	13	0	0	2	7
Abandoned	2	13	1	7	3	10
Depredated	1	6	2	14	3	10
Incubator Killed	3	18	0	0	3	10

Table 4. Percent of nests located and successful in each post-burn interval on Fort Bragg Military Installation, North Carolina, USA (2016 - 2017).

Year Since Burn	Total # of Nests	# of Successful Nests	% of Nests Successful	% of Total Successful Nests
0	4	2	50	11
1	3	3	100	16
2	19	13	68	68
3+	4	1	25	5

Table 5. The AICc, ΔAICc, and model weight (ω) for models of northern bobwhite nest-site selection on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

Model	AICc	ΔAICc,	ω
BA.Pine + BA.Hard + Woody Cover + Wiregrass	58.0	0.00	0.159
BA.Pine + BA.Hard + Woody Cover + Bareground	58.5	0.46	0.126
BA.Pine + BA.Hard + Woody Cover	58.5	0.46	0.126
BA.Pine + BA.Hard + Forb + Woody Cover	58.5	0.52	0.123
BA.Pine + BA.Hard + Bareground + Woody Cover + Wiregrass	58.6	0.58	0.119
BA.Pine+ BA.Hard + Bareground + Forb + Woody Cover	59.3	1.33	0.082
BA.Pine + BA.Hard + Canopy + Forb + Woody Cover	59.6	1.60	0.072
BA.Pine + BA.Hard + DZ_Dist + Forbs + Woody Cover	59.7	1.68	0.069
BA.Pine + BA.Hard + DZ_Dist + Wiregrass + Woody Cover	59.7	1.74	0.067
BA.Pine + BA.Hard + Forb + Woody Cover + Wiregrass	60.0	1.98	0.011

Table 6. Parameter estimates for the best fitting model estimating nest-site selection on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

Covariates	Estimate	Std. Error	Z Value	Pr(>|z|)
BA.Pine	-0.054	0.021	-2.555	0.0106
BA.Hard	-0.671	0.025	-2.656	0.0079
Woody Cover	6.025	2.292	2.628	0.0086
Wiregrass Cover	2.237	1.363	1.642	0.1007

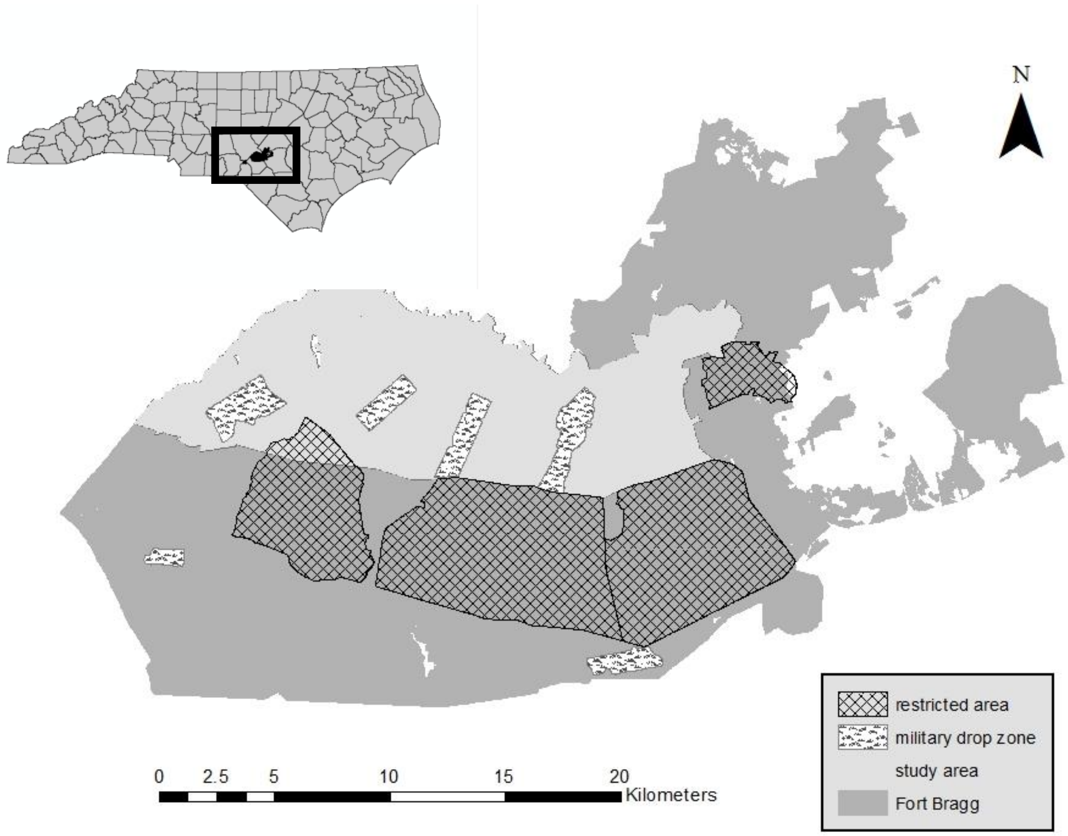

Figure 1. Location of Fort Bragg Military Installation in south-central North Carolina and the study area within Fort Bragg Military Installation, North Carolina, USA (2016-2017).

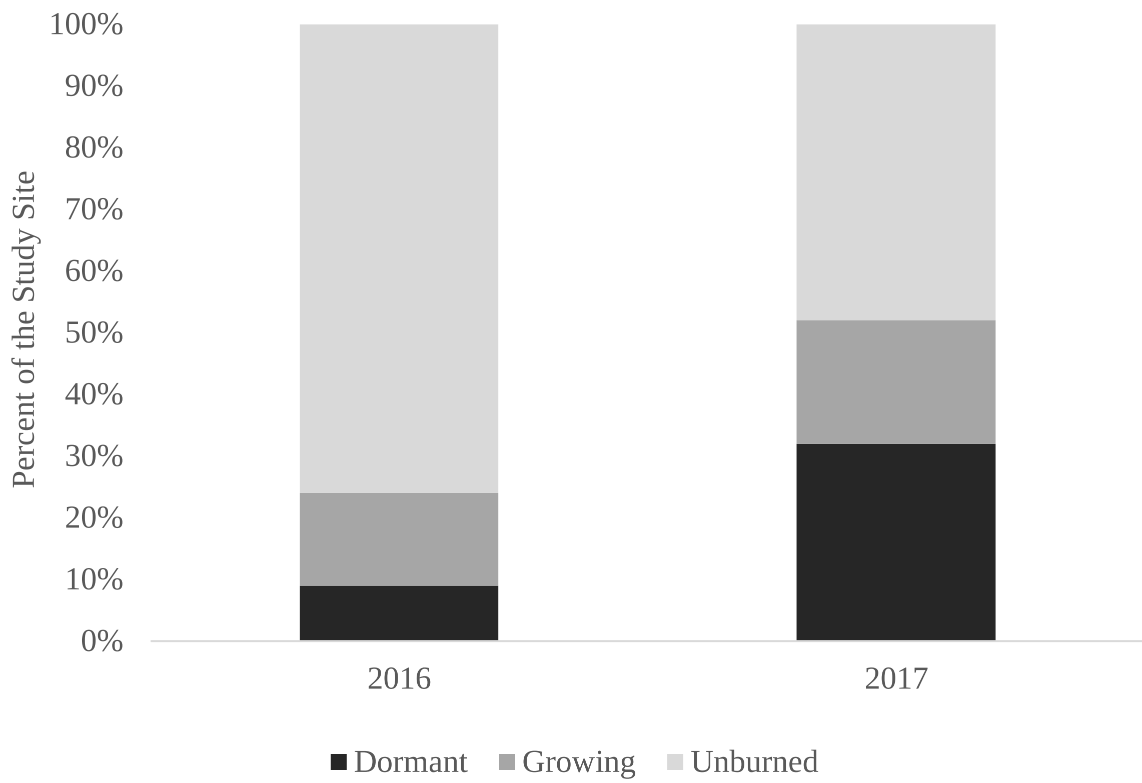

Figure 2. Percent of the study area burned with dormant-season and growing-season prescribed fires during 2016 and 2017 on Fort Bragg Military Installation, North Carolina, USA.

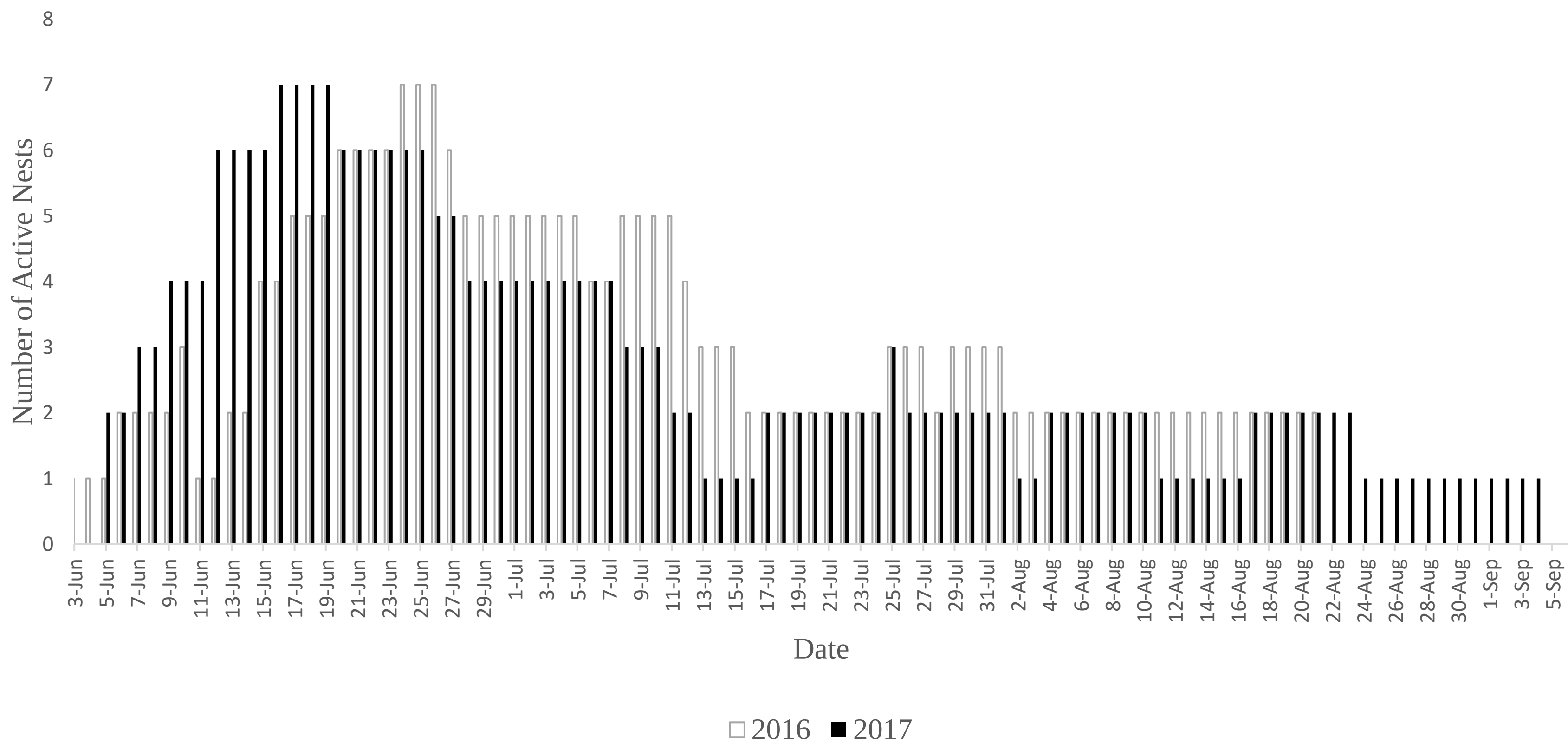

Figure 3. Number of monitored active nests for the 2016 and 2017 field seasons on Fort Bragg Military Installation, North Carolina, USA.

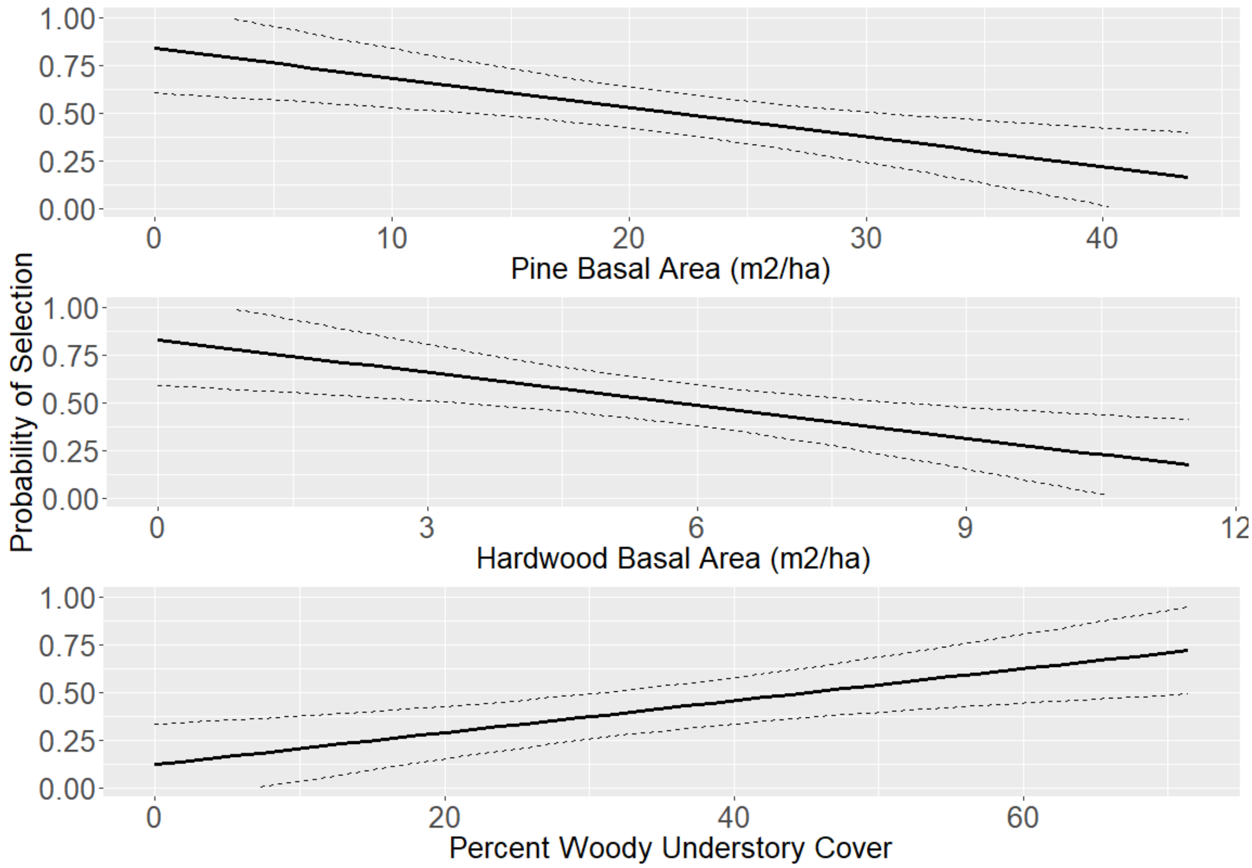

Figure 4. Probability of bobwhite nest-site selection related to the basal area of pines, basal area of hardwoods, and percent woody understory cover on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

CHAPTER 2

NORTHERN BOBWHITE BREEDING SEASON HABITAT SELECTION IN A FREQUENTLY BURNED LONGLEAF PINE ECOSYSTEM

ABSTRACT

Prescribed buring can be used to create critical nesting and brood rearing cover for northern bobwhite (*Colinus virginianus).* Despite the acknowledged importance of fire in creating northern bobwhite breeding cover, little research has investigated bobwhite breeding season habitat selection relative to frequency and timing of prescribed burning. In 2016 and 2017, we monitored radio-transmitted bobwhite on a ~17,000-ha portion of a military installation managed with frequent (every ~3 years) prescribed fires, commonly applied during the growing season, to determine which vegetation characteristics associated with prescribed burning were important to bobwhite breeding season habitat selection at the microsite (i.e., exact GPS location where bobwhite were located) or burn unit scale (i.e., the burn unit within which the location was recorded). We collected 2,315 bobwhite locations during the 2 breeding seasons and compared percent cover of vegetation, time since burn, basal area, and distance to key landscape features (e.g., stream, wildlife opening) at a subset of microsite locations (301 GPS locations during 2016 and 890 GPS locations during 2017) to paired random locations. At the microsite scale, bobwhite selected lower basal area of hardwoods, greater woody understory cover, greater forb cover, and greater grass cover than available. In 2016 and at the burn unit scale, bobwhite selected units with less than 4.6m^2/ha total basal area (combined hardwoods and pines) and units 3 years post-fire at proportions greater than available and units 0 years post-fire at proportions less than available. In 2017 and at the burn unit scale, bobwhite selected units with less than 9.2m^2/ha total basal area (combined hardwoods and pines) and units 1 and 2 years post-fire at proportions greater than available across the study area and units 0 years post-fire and 3+ post-fire at

proportions less than available. Bobwhite habitat selection highlighted the importance of woody understory as cover, and that relatively low tree basal area was critical to allow understory development. We recommend fire return intervals no more frequent than every 3 years, especially in regions with lower soil productivity such as the Sandhills, because more frequent fire would eliminate high quality nesting and breeding season cover. However, without management to maintain low tree basal area, prescribed fire effects would be limited by shading from the overstory, and the shrubs, grasses, and forbs that provide critical cover for bobwhite during the breeding season will not develop.

INTRODUCTION

Northern bobwhite (*Colinus virginianus*, hereafter bobwhite) populations have declined rangewide, primarily due to habitat loss (Burger 2003, Hernández 2013, Sauer et al. 2014), including loss of grass-forb-shrub communities that provide critical nesting and brood cover during the breeding season (Brooke et al. 2017, Richardson 2016). Maintenance of high quality nesting and brood cover is imperative to maintain bobwhite populations because productivity may be the most vital driver of bobwhite population demography (Roseberry and Klimstra 1984). Vegetation that contributes to nest concealment (i.e., shrubs, forbs, grasses) is important for nest-site selection and subsequent nest success, whereas high forb cover and bare ground is critical for brood cover (Stoddard 1931, Taylor et al. 1999, Lusk et al. 2006, Richardson 2016). Thus, an ideal landscape for breeding bobwhite must contain vegetation conditions that allow for nesting and brood cover across a large area (Riddle et al. 2008, Bowling et al. 2014).

Fire helps maintain the aforementioned vegetation conditions required by breeding bobwhite, but habitat quality may vary with season and frequency of prescribed burning. Growing-season prescribed burning is more effective at reducing hardwood tree and shrub cover than dormant-season fires (Brender and Cooper 1968, Glitzenstein et al. 1995, Hardy 2003) and is often used to restore native grass and forb cover where woody plants have encroached (Waldrop et al. 1987, Streng et al. 1993, Glitzenstein et al. 1995), improving nesting and foraging cover for bobwhite. Also, growing-season fires result in increased insect biomass, a critical component of bobwhite chick diet, in post-burn conditions (Hurst 1972, Provencher et al. 1998) and provide a greater abundance of insects throughout brood-rearing months (Brennan et al. 2000). Additionally, fire frequency influences subsequent plant community composition and structure (Sparks 1998, Harper 2007, Knapp et al. 2009). Frequently burned areas often are dominated by grasses and forbs (Streng et al. 1996), which provide excellent bobwhite brooding cover (Brooke et al. 2017). Conversely, less frequently burned areas contain a greater abundance of woody plants (Streng et al. 1996), which may provide escape or nesting cover for bobwhite (Taylor and Burger 2001, Cram et al. 2002, Brooke et al. 2017, Rosche 2018). The provision of high quality brooding and nesting cover depends on application of the appropriate fire-return interval that fosters grasses and forbs along with a mix of woody understory cover without allowing the encroaching woody component to reach the point where it shades the understory.

Influence of fire on breeding season habitat for bobwhite may vary regionally because of differences in vegetation communities or soil conditions. Deep, coarse-textured sandy soils have poor water retention and create xeric conditions that may favor certain plant species, such as turkey oak (*Quercus laevis*) or longleaf pine (*Pinus palustris*) (Christensen 1988). Conversely, soils with greater clay content retain more moisture and are more fertile, generally favoring mesic-loving plant species and a more lush herbaceous layer (Gilliam et al. 1993). Moreover, vegetation on nutrient poor soils is slower to return to pre-burn conditions following a prescribed fire than areas with more fertile soils (Hardy 2003, Rosche 2018). Thus, areas with nutrient poor soils might require a relatively longer fire return interval when managing for bobwhite to allow adequate woody understory cover to develop post-disturbance. However, a fire return interval that is too long will allow extensive woody encroachment, which may reduce habitat suitability for bobwhite because the dense midstory and overstory blocks sunlight from reaching the forest floor and does not promote herbaceous growth. Further, too frequent application of growing-season prescribed fires may remove large areas of escape and nesting cover for bobwhite during the breeding season (Simpson 1972, Rosche 2018).

Despite the acknowledged importance of fire in creating vegetation communities favored by northern bobwhite, little research has been conducted to investigate bobwhite breeding season habitat selection relative to seasonality and frequency of prescribed burning. Therefore, we determined how time since fire and associated vegetation characteristics were important to bobwhite habitat selection at the microsite (exact GPS location bobwhite were located) and burn unit scale in a longleaf pine ecosystem of the Sandhills physiographic region of central North Carolina, USA.

STUDY AREA

We assessed northern bobwhite breeding season habitat selection on a 17,000-ha portion of Fort Bragg Military Installation (hereafter Fort Bragg), an active army base owned and managed by the U.S. Department of Defense and located within Cumberland, Hoke, Harnett, and Moore counties, North Carolina, USA. Located in the Sandhills physiographic region of North Carolina, the topography was rolling hills with uplands of longleaf pine ovestory on well-drained, coarse sandy soils and interspersed with lowland drainage areas (Franklin 1997, Sorrie et al. 2006). Because of the well-drained, sandy soils present, the Sandhills are considered low productivity (Sorrie at al 2006, Shea and Osbourne 1995). The pine-scrub oak (*Quercus* spp.) sandhill (described by Sorrie et al. 2006) is the most widespread plant community, which mostly consisted of a longleaf pine canopy, oak subcanopy, and wiregrass (*Aristida stricta*) ground layer.

Land management at Fort Bragg was driven by efforts to conserve habitat for the federally endangered red-cockaded woodpecker (*Leuconotopicus borealis*), which require open, mature longleaf pine communities maintained by frequent prescribed fire, and to maintain a herbaceous understory for ease of military training. In forested uplands, growing-season (March-

August) prescribed fires were applied primarily on a 3-year return interval to limit woody understory encroachment into the forest midstory and to promote herbaceous groundcover. Non-forested areas (e.g., open military drop zones) were burned annually to remove most woody growth. However, to meet burn quotas, some forest stands were burned during the dormant season (January-March). In 2016, 38% of prescribed fires were applied during the dormant season, and in 2017, 62% were during the dormant season. Overall, in 2016, 24% of the study site was burned (9% dormant, 15% growing season) and during 2017, 52% was burned (32% dormant, 20% growing season) (Figure 1). Lowland forest areas were burned on the same 3-year rotation as forested uplands, but had saturated soils that sometimes suppressed prescribed fire, creating a mixed broadleaf-pine plant community within forested stands. Firebreaks and streams divided the study area into 34-ha (average) burn units (range 0.4-136 ha).

We classified vegetation community types on Fort Bragg as:

Upland Pines (63% of study area) – Overstory was dominated by longleaf pine in open canopy stands with an understory of wiregrass, dwarf huckleberry (*Gaylussacia dumosa*), turkey oak (*Quercus laevis*), and blackjack oak (*Quercus marilandica*).

Ecotone (12% of study area) – Ecotones were lowland pine communities located alongside streams and transitional areas between bottomland hardwoods and upland pines. We estimated land coverage for ecotone by constructing a 20-m buffer adjacent to the bottomland hardwoods vegetation type. Loblolly (*Pinus taeda*), pond *(P. serotina*), and longleaf pine commonly occurred in the overstory. Understory communities consisted of switchcane (*Arundinaria tecta*), huckleberry (*Gaylussacia frondosa*), inkberry (*Ilex glabra*), wild blueberry (*Vaccinium* spp.), swamp redbay (*Persea palustrus*), cinnamon fern (*Osmunda cinnamomea*), and bracken fern (*Pteridium aquilinum*).

Bottomland hardwoods (9% of study area) – Sweetgum (*Liquidambar styraciflua*), blackgum (*Nyssa sylvatica*), red maple (*Acer rubrum*), and tulip-popular (*Liriodendron tulipifera*) formed closed canopy stands along perennial streams. Dense thickets of fetterbush (*Lyonia* spp.), gallberry (*Ilex coriacea*), inkberry (*Ilex glabra)*, and greenbrier (*Smilax* spp.) were common along edges.

Drop Zones (9% of study area) – Treeless drop zones were burned and mowed annually or biennially to reduce woody vegetation. Four aerial drop zones (100 – 450 ha) were dominated by a variety of grasses and forbs, including weeping lovegrass (*Eragrostis curvula*), sericea lespedeza (*Lespedeza cuneata*), broomsedge (*Andropogon virginicus*), and wiregrass. Small patches of brambles (*Rubus* spp.) and shrub cover were located along low-lying areas that meandered the outskirts of the drops zones.

Other (8% of study area) – The other category included any vegetation community that did not fall within the previous 4 categories. These included managed wildlife openings, small pockets of upland hardwoods, and areas containing military training structures.

METHODS

Bobwhite Capture

We captured bobwhite from 2 February to 22 April 2016 and 1 January to 21 April 2017 using modified walk-in funnel cage traps (Stoddard 1931). We placed traps in areas of known covey locations or in areas with dense shrub cover adjacent to managed wildlife openings and checked traps every evening starting no earlier than 30 minutes before sunset.

We aged, sexed, weighed, and marked captured birds. We divided captured individuals into 2 age classes, juvenile and adult, according to plumage characteristic and molting stages (Rosene 1969). We classified birds as adults if solid gray-brown colored covert feather tips were present, and juveniles if buffy tips of the upper primary coverts were present (Haugen 1957). We determined sex by observing plumage pattern and coloration (Stoddard 1931). We weighed birds by placing them individually in a cotton handling bag hung from a 300-g spring scale. To ensure the weight of the radio transmitter (6.2g) did not exceed 5% of the individual bird's weight, only individuals weighing greater than 130g were affixed with necklace-style radio transmitters (model# AWE-Q, American Wildlife Enterprise). We marked individual bobwhite using size #7 (5.56mm) aluminum butt-end bands (National Band & Tag Company). The North Carolina State University Animal Care and Use Committee (#15-136-0) approved all capture and handling protocols.

Radio-telemetry

After a 7-day censorship period (Pollock et al. 1989), we located radio-marked individuals 3-5 times per week starting at the initiation of spring covey break up, which was considered the start of the breeding season. We located birds using R4000 VHF receivers fixed with 3-element Yagi-style antennas (Advanced Telemetry Systems, Isanti, MN) by homing towards the individual to within 50m (White and Garrott 1990). We used a handheld Garmin eTrex 20 Global Positioning System navigator (Garmin International, Inc., Olathe, KS) to collect UTM locations for each observed individual. If an individual could not be located, we searched the last known location expanding outward using an omnidirectional antenna mounted on a truck. We continued searches at least 2 days a week until the individual was located or declared lost if it could not be located within 2 weeks.

Vegetation Surveys

We measured microsite (i.e., exact GPS location of observed bobwhite) vegetation cover at a subset of locations collected between 23 April and 31 July 2016 and between 28 April and

31 July 2017, and at paired random locations (Table 1). Due to limitations in time and personnel, we removed a day's worth of GPS locations per week from the pool of viable locations for which we collected vegetation data. Each paired random location was determined with a randomized azimuth (1-360°) and a randomized distance (10-250m) from each telemetry location. The maximum distance for random points was based on the average home range of bobwhite in an area with similar land cover (Terhune et al. 2006). We collected vegetation measurements within 10 days of collecting a telemetry location. We documented the number of years since last burn (0, 1, 2+) at each locations based on the vegetation structure and composition present (i.e., blackened ground, flowering wiregrass, matted wiregrass, and woody regrowth). We later used GIS fire history data to divide the 2+ category into 2 and 3+ years since last fire. Vegetation plots consisted of 2 10-m transects with perpendicular intersecting midpoints at the recorded location. At each center point, we rapidly assessed percentage of canopy cover as 1 of 5 categories (0-20%, 21-40%, 41-60%, 61-80%, and 81-100%) and measured the basal area of hardwoods and pines using a 10-factor prism. We measured vegetation cover using a 2-m tall Wiens' pole at each meter along both transects and at the center point, totaling 21 readings per plot. We calculated percent horizontal cover from the Wien's pole data for wiregrass, other grasses, woody understory, and forbs, by dividing the total number of sampling points where the specified vegetation type touched anywhere on the pole by the total number of sampling points at each plot (21). For any random point falling outside of a vegetated area (i.e., road, body of water, military building), we decreased the random distance measurement until the entire plot could be measured outside of these obstructions.

Data Analysis

Microsite Habitat Selection

We developed a generalized linear mixed model using the “lme4” package in R to compare vegetation characteristics between telemetry locations and paired random locations (R Version 3.4, www.r-project.org, accessed 5 November 2017). We evaluated 7 covariates that described vegetation cover and 2 that described distance to key landscape features (Table 1). We tested for collinearity among predictor variables using Pearson’s correlation coefficient with a maximum/minimum threshold of +/- 0.6. We included all covariates as fixed-effects, but included individual bird as a random effect (random intercepts) in the mixed effect model because we had repeat observations of individual birds and needed to account for the temporal autocorrelation. Because of limited data and to ensure the model was still parsimonious and provided precise estimates, we ran all possible combinations of a maximum of 4 covariates (all subsets) in the model and chose the model with the lowest AICc value. In addition, we selected 2 variables *a priori* that we thought would have a potential quadratic effect and added them to the top model. If the quadratic effect of each variable was significant it remained in the model, but was removed if not significant. Because woody understory provides critical nesting and escape cover but too much woody cover leads to dramatic reductions in grass and forb cover, we believed that bobwhite selection would increase with increased percent woody understory cover initially and then decline beyond a threshold. Additionally, we sought to identify whether there was a threshold of basal area for bobwhite above which selection would decline dramatically.

Burn Unit Habitat Selection

Firebreaks divided the study site into sections we called burn units (average 34 ha). We classified the burn units as 0, 1, 2, or 3+ years since fire and analyzed each study year separately because the amount of burning and hence the distribution of years since fire changed dramatically between years. We considered burns conducted in the same calendar year, including dormant-season burns, as 0 years since fire. We divided the area of prescribed burns conducted after 1 May (i.e., the date of the first prescribed fire that occurred after the start of the breeding season) equally into 0 years since last burn and 3+ years since last burn to account for the change in availability of these 2 burn unit classes. We calculated the proportion available in each post-burn category by summing the total area of each category and dividing by the total area of the study site. We calculated the proportion used by dividing the number of bobwhite locations, using all GPS locations, in each post-burn category by the total number of locations.

We used a Chi-square test to determine selection of time-since-burn categories and Bonferroni confidence intervals to distinguish selection among the post-burn categories (Neu et al. 1974). Similarly, we used a Chi-square test and Bonferroni confidence intervals to determine selection of basal area classes and vegetation community types. We binned the basal area for burn units into the following groups: 0-4.6, 4.8-9.2, 9.4-13.7, 14-18.4, 18.6-23.0, 23.2-27.5, and 27.8-36.7 m^2/ha. We calculated the proportion available in each binned basal area group by summing the total area in each category and dividing it by the total area of the study site. We included drop zones in the 0-4.6m^2/ha category. We calculated proportion used by dividing the number of bobwhite locations, using all GPS locations, in each category by the total number of bobwhite locations. Based on GIS layers, we delineated the following vegetation community types: uplands, bottomland hardwoods, ecotone, drop zone, and other. We calculated the proportion available in each vegetation community type by summing the total area of each type and dividing it by the total area of the study site. We calculated proportion used by dividing the number of bobwhite locations, using all GPS locations, in each vegetation community type by the total number of bobwhite locations.

RESULTS

Capture and Radio-telemetry

In 2016, during 3420 trap nights, we captured 59 individuals (52 juveniles, 7 adults), and in 2017, during 9,646 trap nights, we captured 71 individuals (50 juveniles, 21 adults). All 130 captured individuals received a transmitter, but only 87 survived to the start of the breeding season (i.e., the average date of covey breakup). We collected 752 individual locations for 42 birds during the 2016 breeding season (23 April – 3 September) and 1,563 individual locations for 45 birds during the 2017 breeding season (28 April – 2 September) (Table 2). However due to time and personnel limitations, we only collected vegetation data at 602 locations (301 GPS location and 301 paired random locations) during 2016 and 1780 locations (890 GPS location and 890 paired random location) during 2017. During the breeding season, we documented 29 mortalities, 15 in 2016 and 14 in 2017. We assigned the following mortality causes: mammalian predator (15, 52%), avian predator (6, 21%), and unknown (8, 28%). During the breeding season, 7 individuals left the study area, the transmitter malfunctioned on an additional 15 individuals, and 2 individuals moved into restricted access areas on Fort Bragg (Figure 2), where they could not be monitored.

Habitat Selection

Microsite.

The best model for characterizing microsite selection on Fort Bragg included the basal area of hardwoods, percent woody understory cover, percent forb cover, and percent other grass cover (i.e., grasses not including wiregrass) (Table 3). The quadratic effect of hardwood basal area and percent woody understory cover were both significant when included with the top model (Table 4). The probability of bobwhite breeding season habitat selection declined dramatically once hardwood basal area exceeded $10m^2$/ha (Figure 3). The probability of bobwhite habitat selection increased with increasing percent woody understory cover and exceeded 90% when percent woody understory cover reached 50%, but probability plateaued when percent woody understory cover reached 60% (Figure 3). Percent forb and other grass cover were weakly associated with probability of habitat selection (Figure 3).

Burn unit.

In 2016, 0, 1, 2, and 3+ years since fire burn units were similarly available (24%, 22%, 21%, 33%, respectively) at the start of the breeding season (Table 5). During the 2016 breeding season, 16% (117) of bobwhite locations were in 0 years since last fire, 25% (188) were in 1 year since fire, 19% (140) were in 2 years since fire, and 41% (307) were in 3 or more years since last fire (Figure 4). In 2017, 0, 1, 2, 3+ years since fire burn units comprised 47%, 18%, 16%, and 19% of the study area, respectively (Table 5). During the 2017 breeding season, 30% (468) of bobwhite locations were in 0 years since last fire, 29% (456) were in 1 year since fire, 32% (497) were in 2 years since last fire, and 9% (142) were in 3 or more years since last fire (Figure 4).

Time since fire affected bobwhite habitat selection in both years (chi-square = 44.13, df = 3, p-value < 0.001 for 2016, chi-square = 521.39, df = 3, p-value <0.001 in 2017). Constructed Bonferroni confidence intervals (alpha =0.05, k = 4, $z_{1-\alpha/2k} = z_{.11875} = 1.18$) indicated that bobwhite selected for 3+ years since last fire in 2016 and avoided units burned in the same calendar year (0 years since last fire) (Table 6). Bonferroni confidence intervals indicated that bobwhite used units 0 years since last burn and units 3+ years since last burn less than available in 2017 (Table 6). Bobwhite used units burned the previous year (i.e., 1 year since last burn) and 2 year since last burn more than available in 2017 (Table 6).

Burn unit basal area affected bobwhite habitat selection in both years (chi-square = 25.59, df = 5, p-value = <0.001 for 2016, chi-square = 418.94, df = 5, p-value <0.001 for 2017). Bonferroni confidence intervals indicated bobwhite selected areas with 0-4.6m2/ha basal area in 2016 (Table 7). In 2017, bobwhite selected areas with 0-4.6 m^2/ha and 4.8-9.2 m^2/ha basal area and avoided areas with 14-18.4 m^2/ha basal and 18.6-23.0 m^2/ha basal area (Table 7).

Bobwhite used vegetation community types disproportionate to availability in both years (chi-square = 75.87, df = 4, p-value < 0.001 for 2016, chi square = 795.51, df = 4, p-value < 0.001 for 2017). Bonferroni confidence intervals (alpha =0.05, k = 5, $z_{1-\alpha/2k} = z_{.095} = 1.31$) showed bobwhite used ecotone vegetation types equal to their availability for both years, but other vegetation types (e.g., bottomland hardwood, uplands, and drop zones) were used inconsistently (i.e., selected for in 2016 but no selection in 2017) between the 2 years (Table 8).

DISCUSSION

Bobwhite consistently avoided units burned the same year and selected units burned 1 to 2 years prior in 2017, likely because they provided the ideal compositional and structural conditions for nesting and foraging during the breeding season. Vegetation in the 1-year post burn units apparently recovered enough post-fire to provide adequate cover during the breeding season. Additionally, bobwhite selected for areas 2 years post fire for nesting, indicating these areas provided the ideal combination of woody and herbaceous understory for nesting cover (Rosche 2018). Bobwhite avoidance of recently burned areas (i.e., burned in the dormant or early, growing season of the same calendar year) can be explained by the lack of understory woody structure that provides critical escape or nesting cover (Brooke et al. 2017, Rosche 2018).

Whereas the woody structure that provides cover increases with year since fire, bobwhite avoided areas in 2017 that were burned 3+ years previously, likely due to the matted wiregrass, commonly present in these areas, that restricts movement by bobwhite adults and chicks and other ground-dwelling birds (Burger 2001, Burke et al. 2008, Taillie et al. 2015). Also, longer fire return intervals allow the woody structure to encroach to levels where it shades the understory, deterring the herbaceous plants beneficial to bobwhite (Stoddard 1931, Brockway and Lewis 1997, Cain et al. 1998).

Similar to other studies across their range, bobwhite on Fort Bragg selected for areas with lower basal area at multiple scales. Forests with lower basal area allow more sunlight to reach the forest floor, promoting herbaceous plants that provide food resources and nesting cover for bobwhite (Stoddard 1931, Rosene 1969, Moser and Palmer 1997, Brennan 1999). Bobwhite on Fort Bragg selected areas with basal area < 9.2 m^2/ha, which was lower than the average (12.2 m^2/ha, range 0-43.2 ft^2/ac) across the study site. Additionally, the drop zones were included in 0-4.6m^2/ha basal area category, and thus accounted for a substantial percentage of the areas selected by bobwhite on Fort Bragg. Moreover, more than 50% of the Fort Bragg study site had a basal area between 9.4-18.4 m^2/ha, and hence was low quality for bobwhite. Fort Bragg and other properties within the Sandhills region are characterized by low-fertility soils and require exceptionally low basal area to promote habitat conditions ideal for bobwhite. However, timber density management options in many longleaf pine communities are driven by habitat requirements and recovery guidelines for the red-cockaded woodpecker, which have distinct lower thresholds for pine and hardwood stem density and basal area (Garabedian et al. 2017).

At a microsite scale, bobwhite selected locations with woody understory structure that likely provided cover from predators and thermal cover, but they also selected locations with a greater percentage of grasses and forbs that likely provided nesting or foraging cover. An interspersion of woody understory with grasses and forbs is known to provide ideal nesting and brooding cover (DeVos and Mueller 1993, Tayler et al. 1999, Cram et al. 2002). Additionally, forbs produce seeds and attract insects that provide food sources for bobwhite chicks (Cross 1956, Hurst 1972, DeVos and Mueller 1993). Although grass/forb cover is a critical component of bobwhite habitat, bobwhite selection for woody understory on Fort Bragg corroborates the importance of the woody understory component demonstrated by other studies across the species' range (Kopp et al. 1998, Taylor and Burger 2001, Cram et al. 2002, Ransom et al. 2008).

MANAGEMENT IMPLICATIONS

Consistent with other studies, bobwhite on Fort Bragg selected areas with low basal area and patches of woody understory cover. Although less than 9.2 m^2/ha of basal area is optimal for bobwhite (Burger 2001, Brennan 1999, Rosene 1969), populations generally can be maintained with a basal are of 9.2-13.7 m^2/ha (Little et al. 2009), which is suitable for other pine forest species including the red-cockaded woodpecker (Engstrom and Palmer 2005, Garabedian et al. 2017). Hence, thinning timber stands to the minimum levels compliant with red-cockaded woodpecker recovery standards (9m^2/ha) is likely the best option when both species are a priority in the Sandhills region (U.S. Fish and Wildlife Service 2000, Engstrom and Palmer 2005), with the added incentive of economic returns on any timber sold. Additionally, we suggest a fire return interval of no less than 3 years in the Sandhills and other low productivity soil types as this allows pockets of denser woody structure to develop that is sufficient for nesting and escape cover (Rosche 2018), but also allows stands to be burned frequently enough to prevent matted wiregrass that inhibits bobwhite movement and the development of midstory that shades the herbaceous layer.

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Table 1. Covariates used to describe north bobwhite breeding season habitat selection on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

Abbreviation	Description
Canopy	Categorical variable ranking canopy cover within 5 20% divisions
BA.Pine	Basal area of pine trees
BA.Hard	Basal area of hardwood trees
Woody Cover	Percentage of sample points with woody cover present
Wiregrass	Percentage of sample points with wiregrass present
Other Grass	Percentage of sample points with other grasses present
Forb	Percentage of sample points with forbs present
ST_Dist	Distance from point to nearest stream
WO_Dist	Distance from point to nearest wildlife opening

Table 2. Number of individual breeding season locations for northern bobwhite on Fort Bragg Military Installation (2016-2017).

2016		2017	
Bird ID	# of Locations	Bird ID	# of Locations
001	13	025	41
002	30	038	65
003	24	039	61
004	2	040	27
005	40	042	7
007	1	043	46
009	1	045	59
012	24	046	20
013	12	047	19
014	34	048	24
018	19	049	55
019	7	052	52
020	17	053	48
021	6	054	4
023	39	055	49
025	29	056	52
027	21	057	36
028	29	058	0
029	29	059	2
030	21	060	40
031	1	061	8
032	2	123	74
033	32	137	1
034	38	138	12
035	18	139	58
036	28	140	40
037	25	143	18
103	1	145	71
104	28	146	68
105	22	147	2
106	2	148	37
107	9	150	20
108	29	152	17
109	19	153	54
110	7	154	57
112	30	157	56

Table 2. (continued)

113	25	158	3
114	1	159	52
115	21	211	39
117	14	213	39
119	1	215	29
121	1	216	23
		217	55
		218	3
		219	20
	752		1563

Table 3. The AICc, ΔAICc, and model weight (ω) for the top 10 models for the assessment of influence of covariates on northern bobwhite breeding season habitat selection on Fort Bragg Military Installation, NC (2016-2017).

Model	**AICc,**	**ΔAICc**	**ω**
BA.Hard, Woody Cover, Forb, Other Grass	2693.4	0.0	0.557
BA.Hard, Other Grass, Forb, ST_Dist	2697.0	3.60	0.092
BA.Hard, Woody Cover, Other Grass, ST_Dist	2697.3	3.86	0.081
BA.Hard, Woody Cover, Forb, WO_Dist	2697.8	4.39	0.062
BA.Hard, Woody Cover, Other Grass, WO_Dist	2698.4	4.99	0.046
BA.Hard, BA.Pine, Woody Cover, Forb	2698.7	5.28	0.040
BA.Hard, Wiregrass, Woody Cover, Forb	2698.7	5.31	0.039
BA.Hard, Wiregrass, Woody Cover, Other Grass	2698.8	5.37	0.038
BA.Hard, BA.Pine, Woody Cover, Other Grass	2699.2	5.77	0.031
BA.Hard, BA.Pine, Woody Cover, ST_Dist	2703.2	9.77	0.004

Table 4. Parameter estimates from the top model, and including significant quadractics, for assessing the influence of vegetation characteristics on northern bobwhite breeding season habitat selection on Fort Bragg Military Installation, NC (2016-2017).

Covariates	Estimate	Std Error	z Value	Pr >|z|
Hardwood Basal Area	-2.92	0.33	-8.70	<0.01
Hardwood Basal Area ^{2}	-1.42	0.18	-8.06	<0.01
Woody Cover	1.08	0.09	12.05	<0.01
Woody Cover ^{2}	-0.36	0.06	-5.93	<0.01
Other Grass Cover	0.16	0.06	3.00	0.002
Forb Cover	0.16	0.05	3.04	0.002

Table 5. Percent of northern bobwhite breeding season locations in each postburn interval per year on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

Years Since Fire	# of Locations	% of Locations	% of each burn unit category in the study area
2016			
0	117	16%	24%
1	188	25%	22%
2	140	19%	21%
3+	307	41%	33%
2017			
0	468	30%	47%
1	456	29%	18%
2	497	32%	16%
3+	142	9%	19%

Table 6. Selection by northern bobwhite of units 0, 1, 2, 3+ years since last burn on Fort Bragg Military Installation, North Carolina, USA (2016, 2017).

Years Since Burn	Total Acreage (ha)	Percentage[a] of Total Acreage	Number of bobwhite locations	Expected[b] number of bobwhite locations	Percentage observed in each area	Confidence interval on proportion of occurrence[c]
2016						
0	4,152	24%	117	183	16%	0.12 < p1 < 0.20
1	3,693	22%	188	163	25%	0.21 < p2 < 0.29
2	3,583	21%	140	158	19%	0.15 < p3 < 0.23
3+	5,609	33%	307	248	41%	0.38 < p4 < 0.44
Total	17,038	100%	752	752	100%	
2017						
0	7,991	47%	468	733	30%	0.28 <p1 < 0.33
1	3,042	18%	456	279	29%	0.26< p2 < 0.32
2	2,768	16%	497	254	32%	0.30 < p3 < 0.35
3+	3,237	19%	142	297	9%	0.04 < p4 < 0.10
Total	17,038	100%	1563	1563	100%	

[a] Percentages of total acreage represent expected bobwhite observation values as if bobwhite occurred in each post-burn interval in exact proportion to its availability.

[b] Calculated by multiplying proportion of total acreage X total number of observed bobwhite locations.

[c] Represents the theoretical proportion of occurrence and is compared to its corresponding proportion of total acreage to determine if hypothesis of proportional use is accepted or rejected.

Table 7. Selection of basal area categories by northern bobwhite on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

Basal Areas (m^2/ha)	Total Acreage (ha)	Percentage[a] of Total Acreage	Number of bobwhite locations	Expected[b] number of bobwhite locations	Percentage observed in each area	Confidence interval on proportion of occurrence[c]
2016						
0-4.6	3,485	20%	189	149	25%	0.21 < p1 < 0.30
4.6-9.2	1,413	8%	44	60	6%	0.01 < p2 < 0.11
9.4-13.7	4,583	26%	202	196	27%	0.23 < p3 < 0.31
14-18.4	4,728	27%	176	202	23%	0.19 < p4 < 0.28
18.6-23.0	2,541	14%	120	109	16%	0.11 < p5 < 0.21
23.2-36.7	821	5%	21	35	3%	-0.05< p6 < 0.08
Total	17,571	100%	752	752	100%	
2017						
0-4.6	3,485	20%	564	310	36%	0.31 < p2 < 0.36
4.6-9.2	1,413	8%	184	126	12%	0.09 < p2 < 0.15
9.4-13.7	4,583	26%	418	408	27%	0.24 < p3 < 0.30
14-18.4	4,728	27%	305	421	20%	0.17 < p4 < 0.23
18.6-23.0	2,541	14%	48	226	3%	-0.01 < p5 < 0.07
23.2-36.7	821	5%	44	73	3%	-0.01 < p6 < 0.07
Total	17,571	100%	1563	1563	100%	

[a] Percentages of total acreage represent expected bobwhite observation values as if bobwhite occurred in each post-burn interval in exact proportion to its availability.

[b] Calculated by multiplying proportion of total acreage X total number of observed bobwhite locations.

[c] Represents the theoretical proportion of occurrence and is compared to its corresponding proportion of total acreage to determine if hypothesis of proportional use is accepted or rejected.

Table 8. Selection of vegetation community types by northern bobwhite on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

Vegetation Type	Total Acreage (ha)	Percentage[a] of Total Acreage	Number of bobwhite locations	Expected[b] number of bobwhite locations	Percentage observed in each area	Confidence interval on proportion of occurrence[c]
2016						
Ecotone	2,036	12%	70	89	9%	0.05 < p1 < 0.14
Bottomland Hardwood	1,433	8%	93	63	12%	0.08 < p2 < 0.16
Uplands	10,844	63%	508	474	68%	0.65 < p3 < 0.71
Drop Zone	1,470	9%	76	64	10%	0.06 < p4 < 0.15
Other	1,421	8%	5	62	1%	-0.04 < p5 < 0.06
Total	17,204	100%	752	752	100%	
2017						
Ecotone	2,036	12%	131	185	8%	0.05 < p1 < 0.12
Bottomland Hardwood	1,433	8%	163	130	10%	0.07 < p2 < 0.14
Uplands	10,844	63%	847	985	54%	0.52 < p3 < 0.56
Drop Zone	1,470	9%	422	134	27%	0.24 < p4 < 0.30
Other	1,421	8%	0	129	0%	0.00 < p5 < 0.00
Total	17,204	100%	1563	1563	100%	

[a] Proportions of total acreage represent expected bobwhite observation values as if bobwhite occurred in each postburn interval in exact proportion to its availability.

[b] Calculated by multiplying proportion of total acreage X total number of observed bobwhite.

[c] Represents the theoretical proportion of occurrence and is compared to its corresponding proportion of total acreage to determine if hypothesis of proportional use is accepted or rejected.

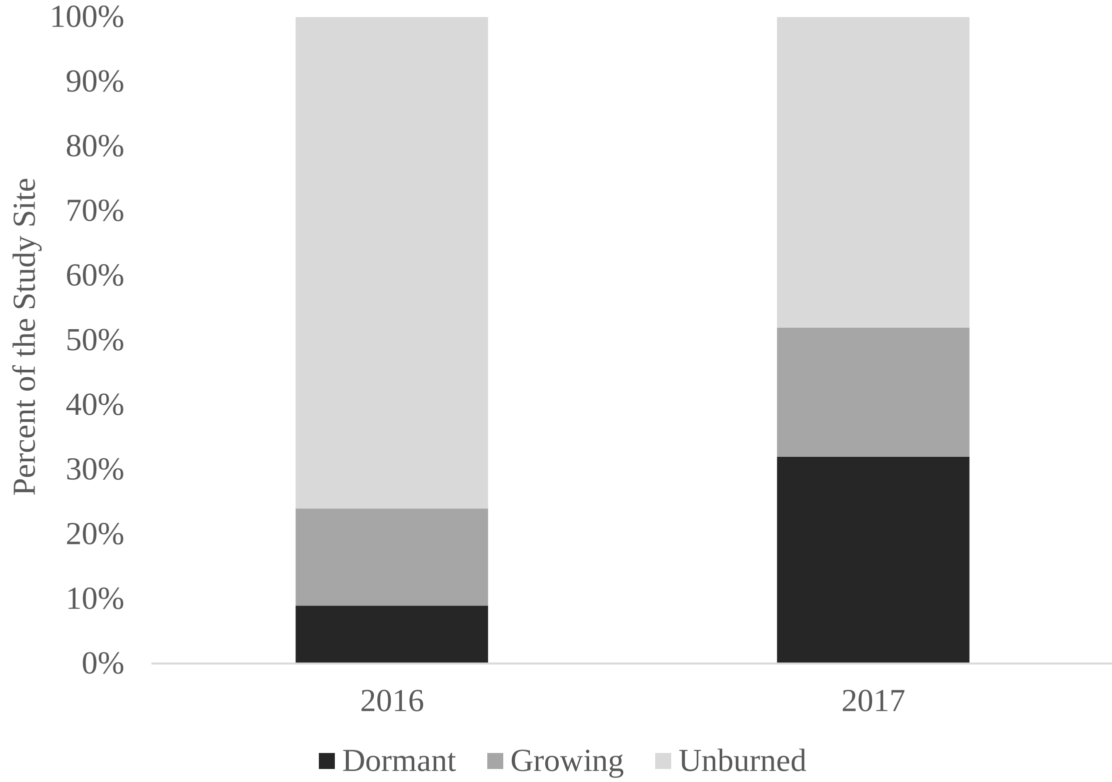

Figure 1. Percent of the study site burned in the dormant season, growing season, and left unburned for each year on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

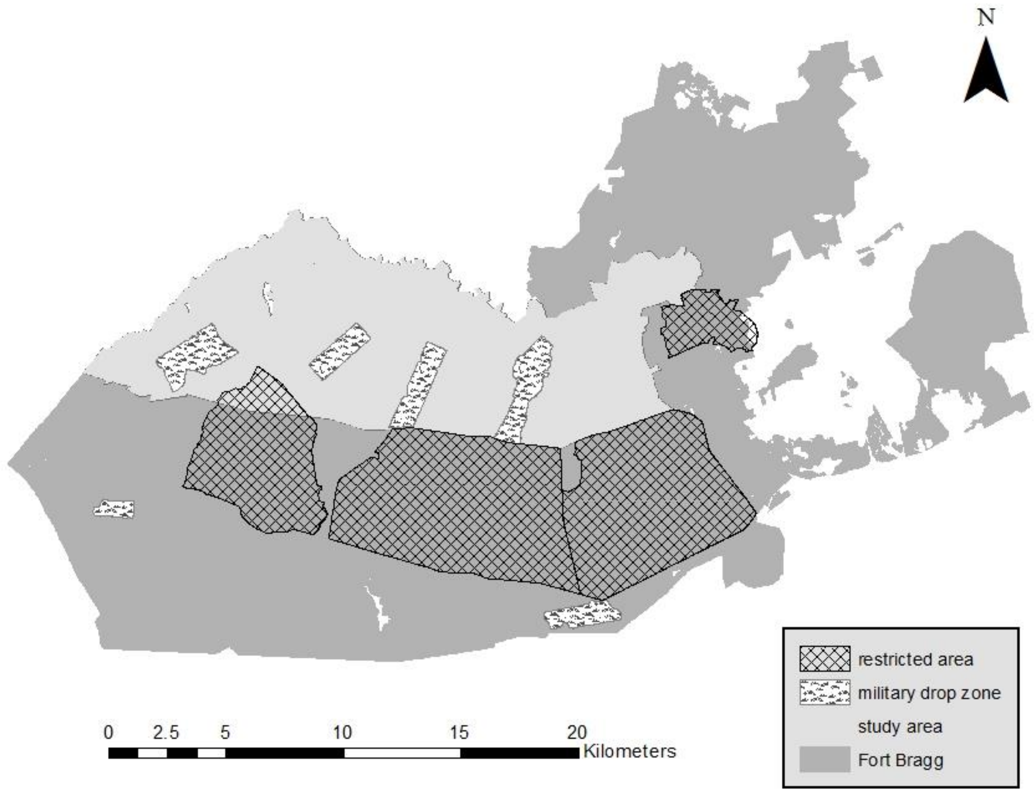

Figure 2. Map of the study site and restricted areas on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

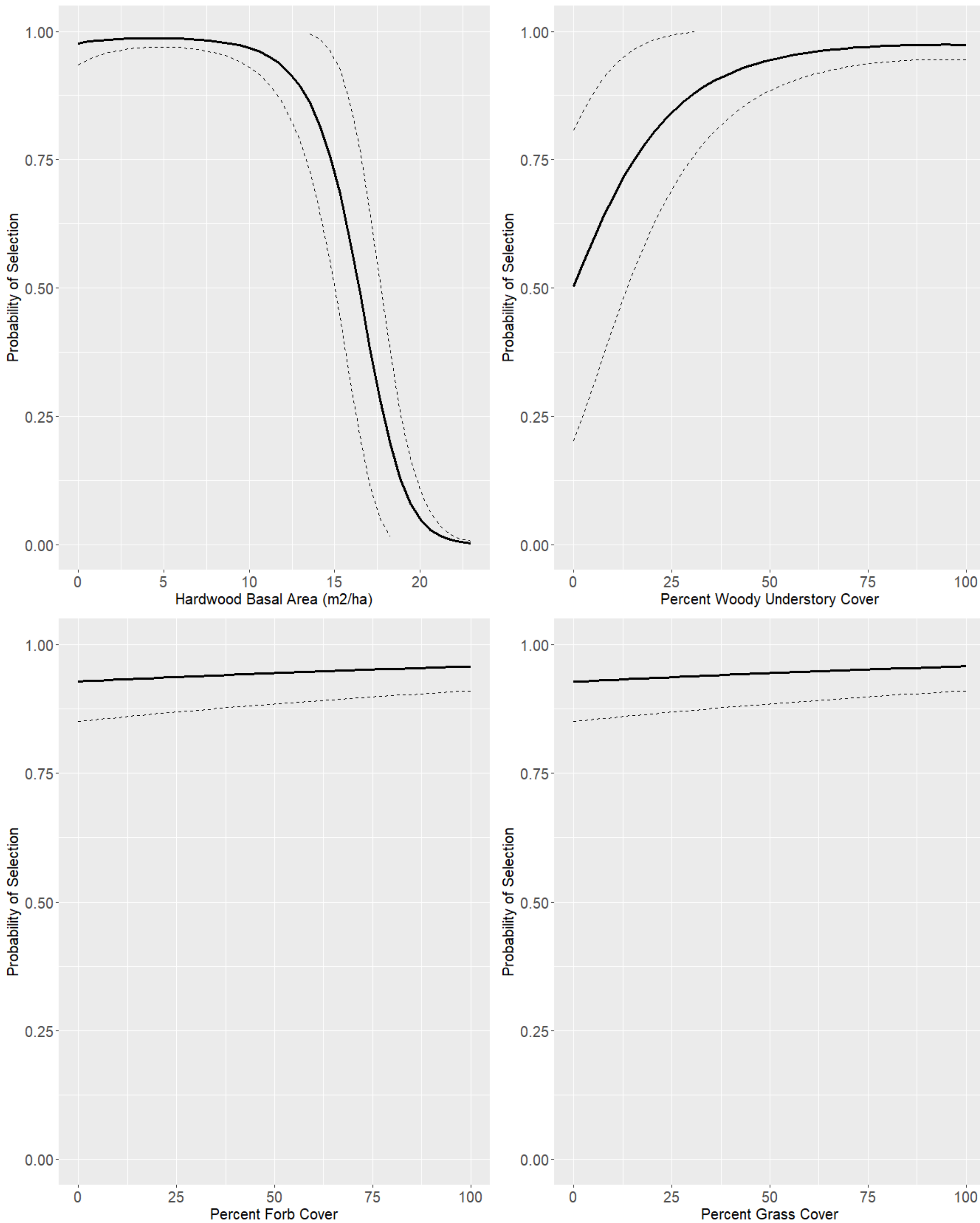

Figure 3. Probability of bobwhite habitat selection related to the basal area of hardwoods, percent forb cover, percent woody understory cover, and percent grass cover on Fort Bragg Military Installation, North Carolina, USA (2016-2017).

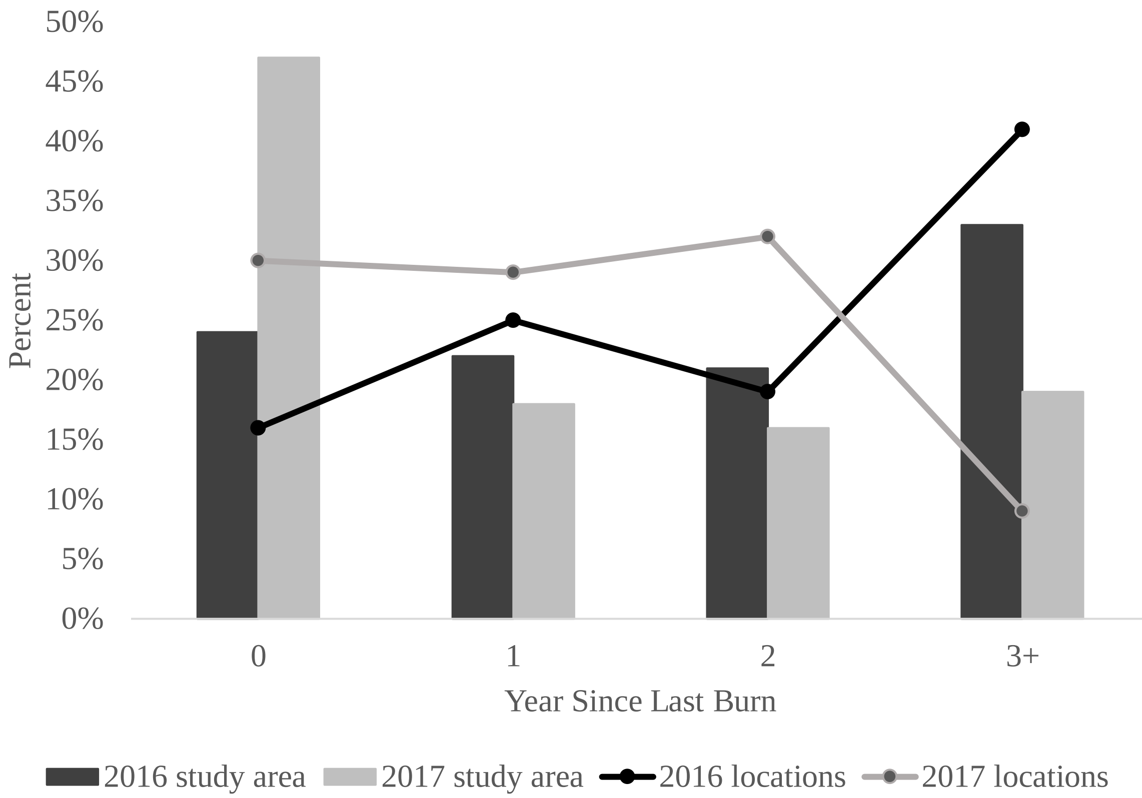

Figure 4. Percent of the study area and percent of the breeding season locations within each post-burn interval on Fort Bragg Military Installation, North Carolina, USA (2016-2017).