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Original Article

Effects of Prescribed Fire on Northern Bobwhite Nesting Ecology

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ABSTRACT Repeated prescribed fire can create and maintain areas with sparse overstory tree cover and a dense grass-forb-shrub understory, providing habitat for northern bobwhite (*Colinus virginianus*; hereafter, bobwhite). Despite potential benefits of prescribed fires for conserving bobwhite habitat, burning during the nesting season may destroy bobwhite nests and reduce available nesting cover. We monitored radio-transmittered bobwhite (n = 104) from 2016 to 2018 to describe nest-site selection and determine the risk of nest destruction on a 17,000-ha North Carolina military installation, Fort Bragg, managed with rotational growing-season and dormant-season prescribed fires on an approximate 3-year return interval. We located 48 nests, of which 8 (16%) were in areas burned the same year, 9 (19%) were in one-year post fire, 25 (52%) were in 2-years post fire, and 6 (13%) were in ≥3-years post fire areas. We compared vegetation composition and structure at nests to nearby random locations and determined bobwhite selected nest sites with greater woody understory and wiregrass cover, lower basal areas of pines and hardwoods, and less distance to the nearest road. Two nests (6.7%) were destroyed during prescribed fires, but success of incubated nests was high (67%). We calculated the overall risk of nest destruction by prescribed fire as the proportion of active nests in areas with ≥3 years since last fire multiplied by the proportion of the study area burned each week. Overall, 11% (weekly $\bar{x} = 0.75\%$, range = 0–3%) of the study area was burned during the 2016 nesting season (3 June to 3 September), 4% (weekly $\bar{x} = 0.31\%$, range 0–2%) of the study area was burned during the 2017 nesting season (5 June to 2 September), and 7.5% (weekly $\bar{x} = 0.58\%$, range 0–5%) of the study area was burned during the 2018 nesting season (3 June to 31 August). We estimated that no more than 0.75% of bobwhite nests across the study site were exposed to fire annually. 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 older roughs (i.e. areas 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. Additionally, a shortened fire return interval would decrease available nesting cover, especially in regions with low soil fertility where vegetation change following fire is less rapid than on more productive soils. © 2021 The Wildlife Society.

KEY WORDS *Colinus virginianus*, ecological restoration, ground-nesting bird, growing-season fire, longleaf pine, nest-site selection, northern bobwhite, prescribed fire.

The northern bobwhite (*Colinus virginianus;* hereafter, bobwhite) is a ground-nesting bird whose habitat is characterized by a mixture of grass, forb, and shrub cover with ample bare ground (Cox and Widener 2008, Richardson et al. 2020). The bobwhite was once prevalent across the southeastern United States due in part to historic lightning-ignited or anthropogenic fires (Platt et al. 1991, Glitzenstein et al. 1995, Knapp et al. 2009). However, in the absence of fire or other disturbance, vegetation communities succeed, tree canopy cover increases, and the woody component increasingly dominates, making the

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landscape less suitable for bobwhite and contributing to range-wide population declines (Burger et al. 1999, Burger 2003, Riddle et al. 2008). Hence, fire is critical to create and maintain bobwhite habitat (Stoddard 1931, Speake 1967, Rosene 1969, Burger 2003).

Commonly, prescribed fires for bobwhite management are applied during the dormant season, partly to avoid bobwhite nesting activity occurring during the late spring and summer (Stoddard 1931, Rosene 1969, Landers and Mueller 1986, Wade and Lunsford 1989). However, growing-season prescribed fires are more effective than dormant-season fires in promoting growth of native grasses and forbs and for 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 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 exist that burning large (>20-ha) 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 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), research on the relationship between nesting ecology and growing-season prescribed fire has shown mixed results. Areas burned in May in Florida had greater bobwhite abundance (measured by hunting success) 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). Bobwhite 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 or to address specific vegetation management goals, could increase the risk that nests are destroyed by fire (Sparks et al. 1998, Cox and Widener 2008, Knapp et al. 2009).

We assessed 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, USA, 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 time since fire; and 2) the predictors of nest-site selection in the presence of frequent (approximately every 3 years) prescribed fire. We hypothesized that time since fire would influence bobwhite nest site selection. Our prediction was that bobwhite would avoid nesting in recently burned management units because they lacked woody and herbaceous cover relative to older roughs (2 years since fire), and that bobwhite would avoid roughs that had not burned in 3 or more years because of encroaching woody cover and matting of wiregrass cover. We predicted that nests in older roughs (≥3 years since fire) would be at greater risk to destruction by prescribed fire because they are more likely to be burned on a 3-year fire return interval. We also predicted that bobwhite would select nest sites with greater grass and forb cover than randomly available sites.

STUDY AREA

We conducted our study on Fort Bragg Military Installation (hereafter, Fort Bragg), located within Cumberland, Hoke, Harnett, and Moore counties, North Carolina, USA (Fig. 1). We constrained our 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 characterized by 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 (Sorrie et al. 2006), which mostly consisted of longleaf pine canopy, turkey oak (*Quercus laevis*) subcanopy, and variable ground cover, comprised largely of wiregrass. Interspersed throughout our 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 conserve rare, threatened, and endangered species (e.g., red-cockaded woodpecker; *Leuconotopicus borealis*) and maintain troop training facilities and infrastructure. Red-cockaded woodpecker cluster sites, the aggregate of cavity trees in which the woodpeckers nest and the surrounding forest with a 61-m buffer, were considered high quality if the site consisted of mature pines with ≥4.6 m^2/ha basal area with few or no hardwoods taller than 2.1 m (Walters et al. 2002, USFWS 2003). In accordance with focal management objectives, growing-season (late March–August) prescribed fires were applied primarily on a 3-year return interval to control hardwood stem encroachment into the forest midstory. Fort Bragg fire managers aimed to burn predominantly in the growing season, but due to limitations in resources and appropriate fire weather, some stands missed a scheduled burn and were burned in the following dormant season (January–March). Parachute drop zones comprised a large portion of our study area and were burned annually or biennially during the dormant season to reduce woody vegetation. In 2016, 9% of the study site was burned with dormant-season fire and 15% was burned with

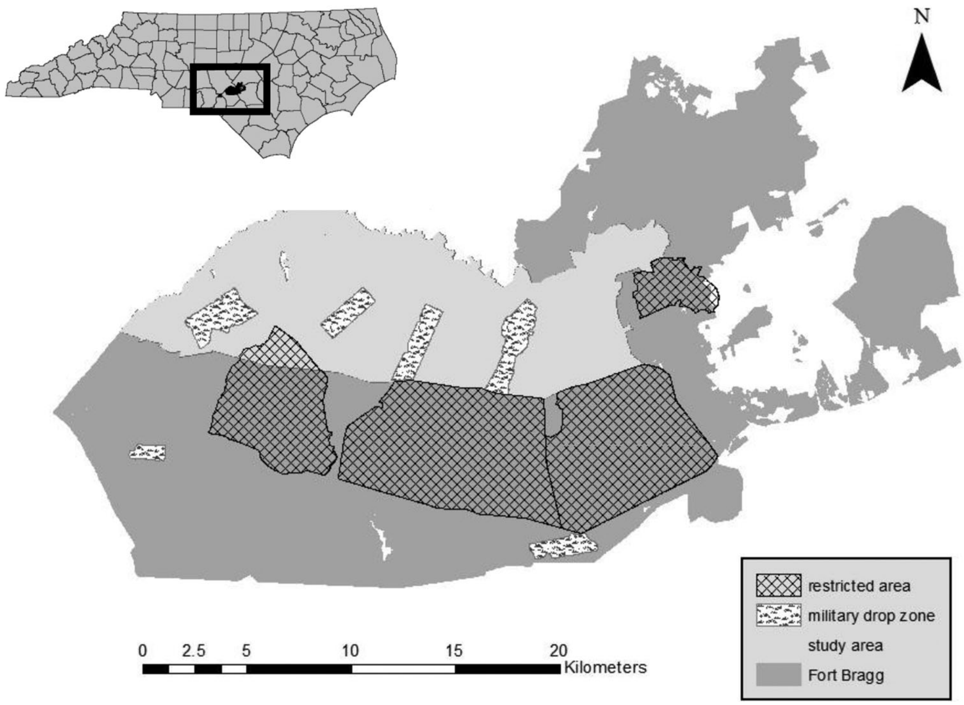

Figure 1. Location of the study area within Fort Bragg Military Installation, North Carolina, USA (2016–2018).

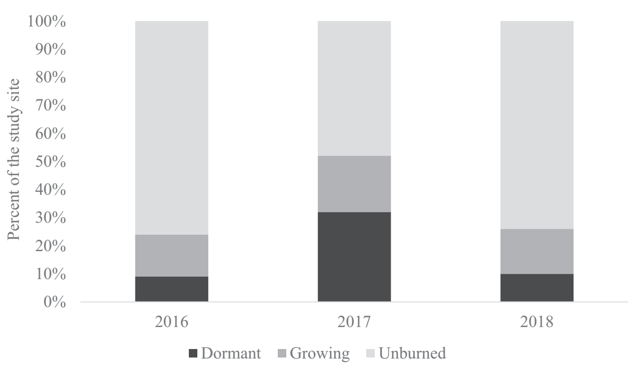

Figure 2. Percent of the study area burned in the dormant and growing season by prescribed fires or left unburned during 2016, 2017, and 2018 on Fort Bragg Military Installation, North Carolina, USA.

growing-season fire (Fig. 2). In 2017, 32% of the study area was burned with dormant-season fire, and 20% was burned with growing-season prescribed fire (Fig. 2). In 2018, 10% of the study area was burned with dormant-season fire, and 15% was burned with growing-season prescribed fire. We note that bottomland 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, 1 January to 21 April 2017, and 12 January to 25 April 2018 using modified walk-in funnel cage traps (Stoddard 1931). Traps measured 40 cm wide × 70 cm long × 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 individuals as juvenile or adult, according to plumage characteristics and molting stages (Haugen 1957). 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 300-g spring scale to measure weight. We affixed necklace-style, VHF radio transmitters (model# AWE-Q, American Wildlife Enterprise, Monticello, FL, USA) to individuals weighing greater than 130 g to ensure the mass of the radio transmitter did not exceed 5% of the individual bird's mass. The necklace-style radio transmitters weighed 6.2 g and we assumed did not affect 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). The transmitters contained a 12-hour mortality sensor (Fies et al. 2002). We used size #7 (5.56 mm) aluminum butt-end bands (National Band & Tag Company, Newport, KY, USA) 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).

Radiotelemetry

After a 7-day censorship period (Pollock et al. 1989), we located transmittered individuals 3–5 times per week from February through July in 2016 and January through August in 2017 and 2018. We located birds using R4000 VHF receivers attached with 3-element Yagi-style antennas (Advanced Telemetry Systems, Isanti, MN, USA) by homing to within 50 m (White and Garrott 1990). We used a handheld Garmin eTrex 20 Global Positioning System navigator (Garmin International, Inc., Olathe, KS, USA) to collect UTM locations for each individual or covey (i.e., we collected only one location for coveys with multiple marked birds). We retrieved transmitters as soon as a mortality signal was observed. 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 incubating when it was recorded in the same localized area for 2–3 consecutive days. Once incubation was suspected, we triangulated to the location from 30 to 50 m away and returned to the site the following day to verify the individual was incubating the nest. We marked the nest site >10 m away from the suspected nest location 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 or eggshell tops. 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. We determined random points using a list of randomly generated numbers to select an azimuth of 1–360° and a distance of 10–250 m from each nest. We selected the maximum distance of 250 m 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 vegetation survey plot could be measured outside of these obstructions. We collected vegetation measurements ≤10 days after 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. At each pole reading, we recorded whether woody understory, wiregrass, other grass, or forb touched anywhere on the Wiens pole. We recorded whether the bottom of the pole touched bare ground or leaf litter (Moorman and Guynn 2001). At each center point, we visually estimated 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. Using a spatial layer containing annual burn-history data from the Fort Bragg Forestry Branch, we measured percent of the study area available as 0, 1, 2, ≥3 years since last fire for every year of the study. 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.

Data Analysis

Nest-site Selection.—We used a generalized linear model in R (R Core Team 2017) to compare how vegetation structure and general landscape communities influenced nest site selection. We evaluated 13 covariates that described vegetation cover or distance to key landscape features (Table 1). We selected covariates that could be biologically important to bobwhite (e.g., bare ground cover, basal area, forb cover) and thus could influence nest-site selection. 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 the near tool in the proximity analysis toolset in ArcGIS (Environmental Systems Research Institute, Inc., Redlands, CA, USA). 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 (Dormann et al. 2013). If the correlation between

Table 1. Covariates used to describe northern bobwhite nest-site selection on Fort Bragg Military Installation, North Carolina, USA (2016–2018).

Abbreviation	Description
Canopy[a]	Categorical variable ranking canopy level cover within 5 20% divisions
BA.Pine	Basal area of pine trees (m^2/ha)
BA.Hard	Basal area of hardwood trees (m^2/ha)
Woody Cover	Percent of sample points with woody cover present (%)
Wiregrass	Percent of sample points with wiregrass present (%)
Other Grass	Percent of sample points with other grasses present (%)
Forb	Percent of sample points with forbs present (%)
Bareground	Percent of sample points with bare ground present (%)
Leaf litter[b]	Percent of sample points with leaf litter present (%)
Stream	Distance to nearest stream (m)
Road	Distance to nearest firebreak (m)
Wild Open	Distance to nearest wildlife opening (m)
DropZone	Distance to nearest drop zone (m)

[a] Removed from nest-site selection analysis because of VIF value was greater than 3.
[b] Removed from nest-site selection analysis because of collinearity with bareground.

2 covariates exceeded the thresholds we removed the covariate that would be more difficult to alter through habitat management. We evaluated the variance inflation factor (VIF) and dropped any covariates with a value greater than 3 (Zuur et al. 2010). We started with a global model using all possible uncorrelated covariates (Table 1), and we used stepwise selection to identify the model with lowest Aikaike Information Criterion corrected for small sample size (AIC_c) value. We reported model-averaged estimates to better determine the relative influence of covariates on nest-site selection. We used the R package MuMIn (Barton 2014) to average the models and used the full model-averaging approach wherein it assumes all variables were included in every model and in some cases set to zero (as was variance; Burnham and Anderson 2002, Lukacs et al. 2009). We considered a covariate to be significant if the p-value was <0.05.

Nesting Fire Exposure.—We calculated weekly fire exposure rates as the product of the proportion of nests incubated in the ≥3 years since last fire areas and the proportion of the study area burned each week. On Fort Bragg, only areas ≥3 year since fire areas are scheduled to be burned on their 3-year fire return interval and thus at risk. For example, if 30% of incubated nests were active in ≥3 years since fire areas from 15 June to 21 June and 5% of the study area was burned during that week, then 1.5% ($0.3 \times 0.05 = 0.015$) of incubated nests would be exposed to fire that week. We calculated total nest exposure to fire for both years as the sum of weekly exposure rates. Our approach assumed that burned units were burned completely during a prescribed fire (Kilburg et al. 2014).

RESULTS

Capture and Radiotelemetry

In 2016, during 3420 trap nights, we captured 59 individuals (28 males, 31 females; 52 juveniles, 7 adults), with one capture every 58 trap nights. In 2017, during 9646 trap nights, we captured 71 individuals (37 males, 34 females; 50 juveniles, 21 adults), with one capture every 135 trap nights. In 2018, during 8356 trap nights, we captured 86 individuals (48 males, 38 females; 59 juveniles, 27 adults), with one capture every 97 trap nights. All individuals (216) captured in all 3 years received a transmitter. Only 130 individuals survived to the start of the breeding season (i.e., the average date of covey breakup was April 25), and 104 (49 males, 55 females) survived to the start of the nesting season (location of first incubated nest, June 1).

Nesting

On Fort Bragg, incubation occurred from 3 June to 3 September 2016, 1 June to 6 September 2017, and 11 June to 31 August 2018, with the peak of incubation activity in mid-June and a small pulse in mid-July (Fig. 3). We considered the incubation time frame to be the nesting season. We located 16, 14, and 18 nests during the 2016, 2017, and 2018 field seasons, respectively, for a total of 48 nests. We observed only one renesting attempt over the 3 years. Combining the 3 years of data, we observed one incubated nest per 2 marked individuals alive at the start of incubation in early June. Nests were incubated by males (n = 23, 48%) and females (n = 25, 52%), and juveniles (n = 32, 67%) and adults (n = 16, 33%). The availability of the year since last burn categories (0, 1, 2, ≥3 years post burn) across the study area were relatively similar (range 19% to 33%) at the start of the 2016 nesting season. We documented a majority (69%) of nests in areas burned 2 years prior (Table 2). Even in the 2017 nesting season, with 49% of the study area in the 0 year since last fire category and the other 3 categories only available 16 to 18%, we still documented a majority (57%) of nests in areas burned 2 years prior. Availability of 0- and 1-year, post-fire units accounted for almost 70% of the study area at the start of the 2018 nesting season, and we documented similar number of nests (4, 6, and 6) in areas burned 0, 1, and 2 years prior, respectively (Table 2). Bobwhite nested in the 2 years since fire burn units at proportions greater than available over the study area during each year of the study, whereas they used other time-since-fire categories similar to, or at proportions less than, availability. We documented 2 nests (4%) burned by prescribed fire applied on 8 June and 1 July 2016; both nests were in areas ≥3 years since last burn. Thirty-two nests (67%) hatched during the study, with 8, 11, and 13 nests hatching in 2016, 2017, and 2018, respectively (Table 3). Three nests were abandoned, 2 of which were researcher induced, and

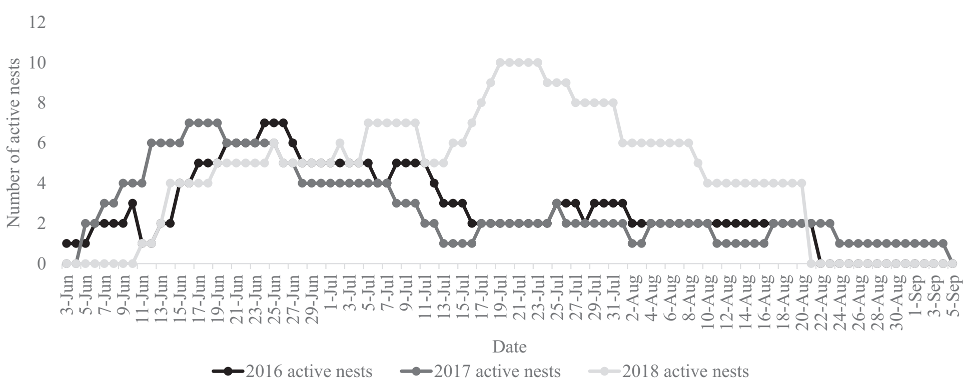

Figure 3. Number of monitored active northern bobwhite nests in 2016, 2017, and 2018 on Fort Bragg Military Installation, North Carolina, USA.

Table 2. Number and percentages of northern bobwhite nests located in each year-since-fire category (0, 1, 2, ≥3) and the percent of each category within Fort Bragg Military Installation, North Carolina, USA (2016–2018).

Year since fire	2016 Nests	Percent of 2016 study area in burn category	2017 Nests	Percent of 2017 study area in burn category	2018 Nests	Percent of 2018 study area in burn category
0	0 (0%)	19%	4 (29%)	49%	4 (22%)	29%
1	1 (6%)	21%	2 (14%)	17%	6 (33%)	39%
2	11 (69%)	27%	8 (57%)	16%	6 (33%)	15%
≥3	4 (25%)	33%	0 (0%)	18%	2 (12%)	17%

Table 3. Fates of northern bobwhite nests located during 2016, 2017, and 2018 on Fort Bragg Military Installation, North Carolina, USA.

Nest Fate	2016 Number (percent) of nests	2017 Number (percent) of nests	2018 Number (percent) of nests	Total Number (percent) of nests
Successful	8 (50%)	11 (79%)	13 (72%)	32 (67%)
Burned	2 (13%)	0 (0%)	0 (0%)	2 (4%)
Abandoned	2 (13%)	1 (7%)	0 (0%)	3 (6%)
Depredated	1 (6%)	2 (14%)	4 (22%)	7 (14%)
Incubator Killed	3 (18%)	0 (0%)	1 (6%)	4 (9%)

7 nests were depredated. In total, 5 out of 32 (16%) successful nests were located in areas 0 years since last burn, 7 (22%) were in areas 1 year since last burn, 17 (53%) were in areas 2 years since last burn, and 3 (9%) were in areas at least 3 years since last burn.

Nest-Site Selection

The equally plausible models ($\Delta AIC_c < 2$) all included hardwood basal area, pine basal area, percent woody cover, and percent wiregrass cover, though these models all had low model weights (Table 4). We model averaged to account for model selection uncertainty and help better determine the influence of covariates on nest-site selection (Table 5). Although basal area of hardwood and basal area of pine were included in the equally plausible models and showed a negative relationship with nest-site selection, they were not significant. Bobwhite were more likely to nest in sites with greater woody understory cover and greater wiregrass cover than available at paired locations (Fig. 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 area was burned during the growing season, of which 4% burned during the 14-week nesting season. In 2018, 15% of the study area was burned during the growing season, of which 7.5% burned during the 13-week nesting season. The proportion of the study area burned weekly during the nesting season ranged from 0% to 3.33% in 2016, 0% to 1.97% in 2017, and 0% to 5.1% in 2018 (weekly average of 0.5% combined for all 3 years). Assuming areas were completely burned by a prescribed fire, we estimated that 0.75%, 0%, and 0.14% of bobwhite nests were exposed to fire during the 2016, 2017, and 2018 nesting seasons, respectively.

DISCUSSION

Prescribed fire early in the growing season posed relatively low risk to bobwhite nests on Fort Bragg, and likely poses low risk to nests elsewhere in the species' range. Only a small number of nests were located in ≥3 years since fire areas (13%, n = 6), 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, 2017, and 2018) of the study area was burned each week during the nesting season each year, and the estimated average weekly exposure rate of nests to prescribed fire was relatively low (0.02%). While our risk exposure is site specific to Fort Bragg, similar risk calculations can be done elsewhere in the bobwhite 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 fire will determine the risk of nest destruction (Klimstra and Roseberry 1975). For example, a late April prescribed fire in Nebraska destroyed 2 bobwhite nests, but peak incubation activity in June and July on Fort Bragg was similar to other studies, indicating that burns in April or May are unlikely to destroy bobwhite nests (Lehmann 1946, Dimmick 1968, Simpson 1972b, Erwin and Stasiak 1979). Although we documented essentially no renesting on Fort Bragg, bobwhite studies across their range have documented bobwhite laying multiple nests in a

Table 4. The AIC_c, ΔAIC_c, and model weight (ω) for best-fitting models ($\Delta AIC_c < 2$) of northern bobwhite nest-site selection on Fort Bragg Military Installation, North Carolina, USA (2016–2018).

Model	AIC_c	ΔAIC_c	ω_i
BA.Pine + BA.Hard + Woody Cover + Wiregrass + DropZone + Road	103.9	0.00	0.043
BA.Pine + BA.Hard + Woody Cover + Wiregrass + Road	104.1	0.18	0.039
BA.Pine + BA.Hard + Woody Cover + Wiregrass + Bareground + Road	105.0	1.07	0.025
BA.Pine + BA.Hard + Woody Cover + Wiregrass + Bareground + DropZone + Road	105.2	1.30	0.022
BA.Pine + BA.Hard + Woody Cover + Wiregrass + Road + Wild Open	105.6	1.67	0.019
BA.Pine + BA.Hard + Woody Cover + Wiregrass + Bareground	105.6	1.73	0.018
BA.Pine + BA.Hard + Woody Cover + Wiregrass	105.7	1.81	0.017

Table 5. Parameter estimates for the full model averaged covariates for northern bobwhite nest-site selection on Fort Bragg Military Installation, North Carolina, USA (2016–2018).

Covariates	Estimate	Std. error	Z value	$P(>\|z\|)$
Woody Cover	3.995	1.645	2.402	0.016
Wiregrass	2.864	1.318	2.154	0.031
BA.Hard	−0.147	0.112	1.295	0.195
BA.Pine	−0.075	0.061	1.221	0.222
Road	−0.006	0.006	1.023	0.306
Bareground	−0.778	1.433	0.539	0.590
DropZone	0	0	0.488	0.625
Forb	0.569	1.292	0.437	0.662
Wild Open	0	0.001	0.216	0.829
Stream	0	0.001	0.213	0.832
Other Grass	0.103	1.078	0.094	0.925

single breeding season (Curtis et al. 1993, Burger et al. 1995). Thus, bobwhite can renest if a nest is destroyed by fire (Cox and Widener 2008).

The lack of renesting in our study was surprising given that bobwhite typically are prolific re-nesters (Rosene 1969, Curtis et al. 1993, Suchy and Munkel 1993, Burger et al. 1995). Despite the documented importance of renesting to bobwhite populations, we recorded only one renesting attempt over 3 years. The lack of renesting attempts could be attributed to low detection rates, but we are confident in our estimates, which were consistent across 2 distinct phases of the project. Instead, we suggest that the high success rate of initial nesting attempts (67%) reduced the probability of renesting. Additionally, bobwhite populations in the mid-Atlantic region are relatively understudied, so renesting rates may vary from those documented in other portions of the species' range. We encourage more research on nesting ecology of mid-Atlantic bobwhite populations, though low densities make capturing and monitoring a sufficient sample of wild birds a challenge.

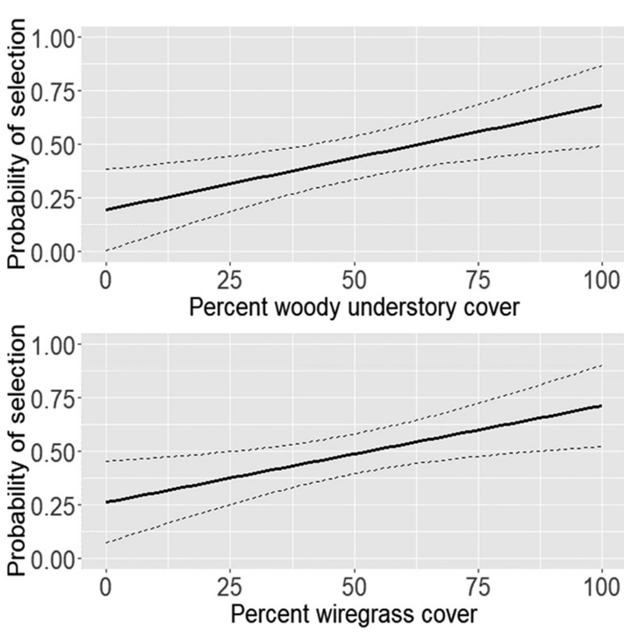

Figure 4. Probability of bobwhite nest-site selection related to the percent woody understory cover and the percent wiregrass cover on Fort Bragg Military Installation, North Carolina, USA (2016–2018).

Importantly, time since fire 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 predominantly 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 likely would increase potential risk of nest destruction from fire given that 52% 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 than on Fort Bragg, bobwhite may nest more frequently in areas 0- or 1-year since fire, which case a 2-year fire return interval would pose less risk to bobwhite nests than on Fort Bragg (Simpson 1972a).

Bobwhite appeared to select conditions that maximized the quality of nesting cover. Selection for nesting in areas with 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 or tree density is thought to underlie habitat quality for bobwhite across its range (Fies et al. 1992, Brennan et al. 1998, Rosche et al. 2019, Kroeger et al. 2020, Hannon et al. 2021), though we documented non-significant trends of selecting lower basal area for nest sites in our study. 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, although 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 herbaceous and woody cover conditions. Younger roughs (i.e., 0 and 1 year since fire) lacked substantial woody cover, whereas areas that were ≥3 years since fire typically contained taller woody sprouts and matted wiregrass that may restrict movement by bobwhite adults and chicks (Burger 2003, Burke et al. 2008, Taillie et al. 2015).

MANAGEMENT IMPLICATIONS

A fire return interval less frequent than every 2 years likely is necessary to maintain nesting cover and reduce risk of nest destruction, 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 heterogeneous application of fire return intervals would be more appropriate (Lashley et al. 2015). Hence, leaving some less-frequently burned areas across the landscape would provide nesting cover for bobwhite. Additionally, forest thinning paired with prescribed fire is critical to maintain lower basal area (i.e., less than 9 m^2/ha [<40 ft^2/ac] combined pine and hardwood basal area) that allows sufficient sunlight to encourage understory grasses, forbs, and wood species that constitute high quality cover for bobwhite.

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