ABSTRACT

RICHARDSON, ANDY DAVID. Summer Vital Rates and Movement of Northern Bobwhite in Response to Habitat Management on Working Farms. (Under the direction of Dr. Christopher Moorman).

Systematic fire suppression, urbanization, and agricultural intensification during the past century have led to a striking decline in early successional communities within the eastern United States. As a result, wildlife species associated with early successional plant communities have declined considerably. One such species is the northern bobwhite (*Colinus virginianus,* hereafter bobwhite), a revered gamebird highly dependent on early successional vegetation for food and cover in the eastern US. Much effort has focused on restoring early successional plant communities for the intention of bobwhite conservation. Working farms provide excellent potential for conserving bobwhite habitat in agricultural landscapes. Managing for areas of fallow vegetation can increase bobwhite abundance with little reduction in crop production on working farms, but the mechanisms behind the increase in abundance are not well known. We compared northern bobwhite nesting ecology, summer survival, and movement on a 1,740-ha working farm with 9% of the property managed for bobwhite habitat to 2 farms without bobwhite habitat management in southeastern North Carolina. We monitored 160 telemetered bobwhite during summer periods (15 April – 15 September) in 2014 and 2015. We compared vegetation cover at nest sites and telemetry locations to reference sites within 250 m. Summer survival (1 June – 30 September) rates were 0.497 (SE= 0.052) on the managed farm and 0.873 (SE= 0.063) on the unmanaged farms. Bobwhite on the managed farm moved further between winter and summer cover (t= -2.092, df= 30.50, P= 0.04) and held larger summer home ranges (t= -2.520, df= 40.79, P= 0.02), which likely indicated a greater separation on the managed farm between the shrubs

used for winter and escape cover and the herbaceous vegetation used for nesting and brood cover. Bobwhite on the farm with habitat management exhibited higher nest initiation rates (1 nest/2 marked individuals) than those on unmanaged farms (1 nest/4 marked individuals). Additionally, forb cover was the only analyzed cover type that occurred in greater proportions at nest sites on the managed farm (μ= 53.61 *SE*= 4.32) than on the unmanaged farms (μ= 17.01 *SE*= 2.49, t= -4.041, P= < 0.001), which suggests bobwhite populations within areas dominated by row crop agriculture are limited by low recruitment rates because of a lack of herbaceous nesting cover. Hence, creating field borders or non-linear patches of fallow, herbaceous cover on working farms can increase bobwhite recruitment within agricultural landscapes. Field borders and early successional vegetation should be created near shrub cover to limit the daily and seasonal movements of individuals seeking cover.

Summer Vital Rates and Movement of Northern Bobwhite in Response to Habitat Management on Working Farms

by
Andy David Richardson

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

2016

APPROVED BY:

Dr. Craig Harper

Dr. Beth Gardner

Dr. Christopher Moorman
Chair of Advisory Committee

DEDICATION

To my parents for all of their encouragement throughout my life, especially as I left behind a stable job to reenter college and traverse the country in order to seek a career in the field natural resources. To my wife, Bree, for her understanding as field jobs and graduate school transported me around the country and her support on my journey through the ordeal that is graduate school.

BIOGRAPHY

Andy grew up in rural central Wisconsin. His parents encouraged his passion for the outdoors and curiosity for the natural world from a young age. He was active in the Boy Scouts of America, earning the rank of Eagle Scout in 2000. After several years in the construction industry, he attended the University of Wisconsin-Stevens Point and graduated with a Bachelors' degree in Wildlife Ecology in August of 2012. He met his wife, Bree, while banding peregrine falcons around Kangerlussuaq, Greenland. After spending a year monitoring greater sage-grouse at Clear Lake National Wildlife Refuge, he moved to Raleigh in 2014 to begin his graduate education at North Carolina State University.

ACKNOWLEDGMENTS

I would like to thank my committee for their guidance and for pushing me to continually look deeper and question further. I greatly appreciate the North Carolina Wildlife Resources Commission for providing both the funding and field housing for this project. Thank you to my field technicians Sarah Rosche, Nathan Klopmeier, Kaili Stevens, Camryn Lewis, Allison Keith, and Britt Brown for enduring the daunting field work and extensive hours of data entry needed to make this project a success. Thank you to Benjy Strope and Mark Jones for their invaluable help locating coveys, obtaining access to land, coordinating field work, and reviewing my research. I thank all of the fellow graduate students I had the privilege of meeting during my time at NCSU for your friendship, advice, and camaraderie. I appreciate John Henry Harrelson, Kevin Cassel, and Carrie Harmon for their assistance in data collection. Marc Puckett of the Virginia Department of Game and Inland Fisheries provided trapping equipment and helpful insight into capture methods. Dawn Williamson and Smithfield Hog Production, Johnson Nash Farms, and Robert Livingston graciously provided farm access. Lastly, thank you to my wife, Bree, for your assistance in organizing data, capturing quail, providing constant support, and for picking up my slack while I focused my attention on this thesis.

TABLE OF CONTENTS

LIST OF TABLES .... **vi**
LIST OF FIGURES .... **vii**

SUMMER VITAL RATES AND MOVEMENT OF NORTHERN BOBWHITE IN RESPONSE TO HABITAT MANAGEMENT ON WORKING FARMS **1**
- **ABSTRACT** **1**
- **INTRODUCTION** **3**
- **METHODS** **6**
  - *Study Area* *6*
  - *Capture* *8*
  - *Radio-telemetry* *9*
  - *Nest Monitoring* *10*
  - *Vegetation Surveys* *11*
  - *Nest-Site Selection* *12*
  - *Nest Survival* *12*
  - *Habitat Selection Analysis* *13*
  - *Movement Analysis* *14*
  - *Survival Analysis* *15*
- **RESULTS** **16**
  - *Capture and Radio-telemetry* *16*
  - *Nesting* *17*
  - *Nest-Site Selection* *18*
  - *Nest Survival* *18*
  - *Habitat Selection* *18*
  - *Movement* *19*
  - *Survival* *20*
- **DISCUSSION** **21**
- **MANAGEMENT IMPLICATIONS** **26**
- **LITERATURE CITED** **28**

LIST OF TABLES

Table 1. Covariates used to describe northern bobwhite nest-site selection (SS), nest survival (NS), and habitat selection (HS) in southeastern North Carolina, USA (2014-2015). 34

Table 2. Covariates collected to describe influence of time, home range, farm, and individual characteristics on northern bobwhite survival rate in southeastern North Carolina, USA (1 June – 15 September 2014 and 2015). 35

Table 3. Mean percentage (standard error) of ground cover and vegetation cover measured at nest sites on managed and unmanaged farms in southeastern North Carolina (2014 – 2015). 36

Table 4. The AIC_c, ΔAIC_c, and model weight (ω) for the assessment of influence of vegetation characteristics on northern bobwhite nest-site selection in southeastern North Carolina (2014 – 2015). 37

Table 5. The AIC_c, ΔAIC_c, and model weight (ω) for the assessment of influence of time and habitat management characteristics on northern bobwhite daily nest survival in southeastern North Carolina (2014 – 2015). 38

Table 6. The AIC_c, ΔAIC_c, and model weight (ω) for the assessment of habitat covariates on northern bobwhite daily nest survival in southeastern North Carolina (2014-2015). 39

Table 7. The AIC_c, ΔAIC_c, and model weight (ω) for the assessment of bobwhite summer habitat selection on a farm with habitat management in southeastern North Carolina, USA (15 Apr – 31 July, 2014 and 2015). 40

Table 8. The AIC_c, ΔAIC_c, and model weight (ω) for the assessment bobwhite summer habitat selection on farms without habitat management in southeastern North Carolina, USA (15 Apr – 31 July, 2014 and 2015). 41

Table 9. Causes of mortalities (1 June – 15 September) on farms with and without bobwhite habitat management in southeastern North Carolina, USA (2014 – 2015). 42

Table 10. The AIC_c, ΔAIC_c, and model weight (ω) for the assessment of summer bobwhite survival in southeastern North Carolina, USA (1 Jun – 15 Sep, 2014 and 2015). 43

LIST OF FIGURES

Figure 1. Map of managed (Holmes Complex) and unmanaged (Delway and Livingston) farm sites, Bladen and Duplin Counties, North Carolina, USA, 1 February 2014 – 30 September 2015. 44

Figure 2. Layout of plot for 10-m x 10-m vegetation surveys conducted at occupied and reference plots on working farms in southeastern North Carolina (2014 – 2015). 45

Figure 3. Number of monitored active nests per day for 2014 nesting season on Holmes Complex (managed) and Delway Farm (unmanaged), Bladen and Duplin Counties, North Carolina, USA. 46

Figure 4. Number of monitored active nests per day for 2015 nesting season on Holmes Complex (managed) and Livingston Farm (unmanaged), Bladen County, North Carolina, USA........ 47

SUMMER VITAL RATES AND MOVEMENT OF NORTHERN BOBWHITE IN RESPONSE TO HABITAT MANAGEMENT ON WORKING FARMS

ABSTRACT

Working farms offer great potential to contribute to northern bobwhite (*Colinus virginianus*) habitat restoration across much of the species' range, but the demographic response to habitat management is relatively unknown. We investigated northern bobwhite summer survival, habitat selection, and movements, as well as nesting ecology on working farms with and without bobwhite habitat management. We radio-collared wild northern bobwhite (n= 239) on commercial hog farms with and without bobwhite habitat management in southeastern North Carolina. A 1,740-ha farm with 9% of the property maintained as early successional vegetation served as the singular farm to have significant bobwhite habitat management. A 170-ha farm with 2% of the property in early successional field borders and a 395-ha farm with no previous early successional management served as farms without habitat management in 2014 and 2015, respectively. We recorded locations of marked birds 3 times/week and located nests (n = 71). We measured vegetation cover at telemetry locations and nest sites and at paired reference locations within 250 m of each nest or telemetry location. Nest sites had greater coverage of forbs (β = 1.075, SE = 0.2139) than reference locations. The bobwhite on managed farms (1 nest/2 marked individuals) initiated nests at twice the rate of those on the unmanaged farms (1 nest/4 marked individuals). We observed some individuals nesting in sites with minimal ground cover (e.g., corn field, dense forest, harvested pine stand without herbaceous cover) on unmanaged farms, leading to lower nest success (28.6%) than on managed farms (46.9%). Individuals on managed farms used

sites with greater forb (β = 0.631, *SE* = 0.069, *P*= < 0.001) cover, and individuals on unmanaged farms used sites with greater forb (β = 0.623, *SE* = 0.179, *P*= < 0.001) and bramble (β = 0.614, *SE* = 0.176, *P*= < 0.001) cover compared to nearby reference sites. Individuals on the managed farm moved a greater distance between winter and summer home ranges (μ= 778 m) than those on unmanaged farms (μ= 524 m, *P*= 0.02), which indicated a greater separation of winter and summer cover unique to the managed farm. The survival rate from 1 June – 15 September was 0.497 (*SE*= 0.052) on the managed farm, and 0.714 (*SE*= 0.113) on unmanaged farms. When managing for nesting cover on working farms, an emphasis should be placed on establishing areas of fallow, herbaceous cover in close proximity to row crops and shrub cover. Creating herbaceous vegetation near the shrub cover needed for winter, escape, and thermal cover may reduce the need for individuals to make long daily and seasonal movements.

INTRODUCTION

Land-use changes in the eastern United States have resulted in a steady loss of early successional plant communities. Fallow agricultural land and unmanaged woodlands have been allowed to succeed into closed-canopy forest (Brennan 1991, Burger 2001). Additionally, fire suppression has reduced the impact of a primary natural disturbance to delaying succession (Engstrom et al. 1984). These changes have resulted in the decline of many wildlife species reliant on early successional vegetation for food and cover (Samson and Knopf 1994, Best et al. 1997). In fact, the northern bobwhite (*Colinus virginianus*, hereafter bobwhite) has declined by 82% since the mid-twentieth century (Sauer et al. 2014). As a result of its popularity as a game bird, the bobwhite has become a flagship species to support the conservation of early successional communities (Palmer et al. 2011, Riffell et al. 2008).

Although forests are a predominant land cover type within the eastern United States, restoring forested landscapes to early successional cover poses substantial challenges for bobwhite habitat conservation. Manageable forestland comprises roughly 141 million ha in the eastern United States, yet only about 4% of private forestland has any form of timber management plan in place (Butler and Leatherberry 2004, Nickerson et al. 2011). Additionally, landowners often are reluctant to manage their forests for bobwhite because the low basal area required to develop suitable understory vegetation contradicts with economical timber management practices by reducing forestland to woodland or savanna (Oehler 2003). Hence, extensive areas of closed canopy forest can be a hindrance to bobwhite conservation (Bowling et al. 2014). The optimal basal area to produce bobwhite habitat within a wooded landscape ranges from 9 m^2/ha to 14 m^2/ha, whereas income potential from even-aged pine stands declines below 14 m^2/ha (Masters et al. 2003). In turn, this disparity has relegated most bobwhite habitat management to public wildlife management areas or private quail hunting plantations.

Cropland comprises 198 million hectares, 26.8% of the land area within the eastern United States, providing ample opportunities for early successional conservation on private land (Nickerson et al. 2011). In fact, the Northern Bobwhite Conservation Initiative estimated 78% of their target increase of 2.7 million coveys could be attained through conservation on private farmland (Palmer et al. 2011). Creating bobwhite habitat on working farms may reduce the cost and effort of habitat management because unused or underproductive areas can be converted more readily to early successional vegetation than areas with a high proportion of woody vegetation (Brennan 1991, Greenfield et al. 2003). Importantly, partnering land conservation efforts with agricultural practices on working farms has the potential to provide habitat for bobwhite while maintaining economically critical land use (Burger et al. 1990, King and Savidge 1995, Bowling et al. 2014). Converting as little as 2-3% of total row crop area into early successional vegetation can increase bobwhite abundance on working farms (Riddle et al. 2008). Additionally, agricultural land can be kept in early successional vegetation more easily than forested lands because the former lacks a substantial woody component (Greenfield et al. 2003, Gill et al. 2006).

Despite the potential for working farms to provide bobwhite habitat, little research has focused on how habitat management impacts the movement and vital rates of individuals inhabiting working farms. Additional understanding about conservation opportunities on working farms is needed to aid bobwhite population recovery in areas of the eastern US (Brennan 1991, Best et al. 1997, Burger 2001, Riddle et al. 2008). Although considerable research has been conducted on bobwhite movement and survival in forested systems managed for bobwhite (DeVos and Mueller 1993, Dixon 1996, Hughes et al. 2005, Terhune et al. 2006, Terhune et al. 2010), populations within these systems likely respond differently to habitat management than those residing in areas dominated by agricultural practices. Information on characteristics of productive nesting sites is essential to maximizing benefits from restoration efforts on working farms.

Determining existing locations acting as population sources can provide insight into where resources have the greatest impact within agricultural landscapes. Moreover, identifying predictors of low nest survival could ensure management on private farmland is conducted most appropriately (Riddle et al. 2008). Field borders, linear strips of early-successional vegetation either left fallow or planted adjacent to agricultural fields, often are used to restore early-successional vegetation on working farms (Palmer et al. 2005, Smith et al. 2005, Riddle et al. 2008). Bobwhite abundance has increased following implementation of field borders (Puckett et al. 1995, Palmer et al. 2005, Riddle et al. 2008). Borders containing a mix of warm-season grasses and forbs provide a combination of cover and arthropod prey for broods (Moorman et al. 2013). However, there is concern that the added recruitment potential following the establishment of small areas of habitat may be outweighed if predator density also is increased (Puckett et al. 1995).

We compared bobwhite summer movement, habitat selection, survival, nest-site selection, and nest survival between a farm with habitat management and two farms without management (i.e., one unmanaged farm in each year of the study). Our objectives were to use radio-marked bobwhite residing on managed and unmanaged farms to 1) characterize vegetation composition of nest sites on working farms, 2) determine the metrics of vegetation composition that are the best predictors of daily nest survival rates, 3) compare spring movement distances and summer home range sizes between the 2 farm types, 4) compare summer habitat selection between the 2 farm types and, 5) determine if habitat management or spring movement distances impacted summer survival. We hypothesized that individuals residing on a farm with habitat management would experience greater nest survival rates because of the nesting cover provided by managed early succession vegetation. The bobwhite on farms with habitat management would also move less and therefore hold smaller home ranges because these individuals would be able to locate necessary food and cover more readily. Additionally, the added ease in locating necessary resources provided by habitat management would decrease the potential of an individual exposing itself to predation, resulting in higher survival rates on the managed farm.

METHODS

Study Area

We conducted our study on 3 hog farms: Holmes (2014, 2015) and Livingston (2015) in Bladen County, North Carolina, and Delway (2014) in Duplin County, North Carolina (Figure 1). Farms were in the southeastern coastal plain physiographic region, which is characterized by low topography and sandy, nutrient-poor soils mottled with Carolina bays.

Carolina bays are elliptical depressions, often with standing water and rich organic soils (Sharitz 2003). However, a majority of Carolina bays have been ditched and drained for loblolly pine (*Pinus taeda*) silviculture and row crop agriculture.

The Holmes complex was the sole farm to receive substantial bobwhite habitat management. At the time of our study, the 1,740-ha commercially-owned farm had participated for 8 years in the North Carolina Wildlife Resources Commission's (NCWRC) Corporate Cooperative Upland habitat Restoration and Enhancement (CURE) Program, which created early successional vegetation on corporate farmland (Cobb et al. 2002). Holmes had 56 ha of fallow field borders between 3 m and 18 m in width on 790 ha of row crops and 21 ha of fallow non-linear vegetation areas largely composed of broomsedge (*Andropogon virginicus*), dogfennel (*Eupatorium capillifolium*), horseweed (*Conyza canadensis*), goldenrod (*Solidago* spp.), pokeweed (*Phytolacca americana*), native smartweeds (*Polygonum* spp.), and blackberry (*Rubus* spp.). Additionally, 19 ha of native warm-season grasses and forbs and 49 ha of longleaf pine (*Pinus palustris*) were planted. Little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardi*), indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*) comprised the grasses planted within the native vegetation areas, whereas the planted forbs consisted of a mix of perennial species to benefit pollinators.

The commercially-owned Delway farm, located approximately 40 km east of Holmes, was a 170-ha farm consisting of 33 ha of row crops, 29 ha of pasture, 64 ha of unmanaged hardwood forest, 13 ha of loblolly pine forest managed for timber, and 3 ha of unplanted field borders. The Delway farm was categorized as an unmanaged farm for the 2014 season because it participated minimally in the CURE program for 3 years prior to our study and had a very small portion of its property maintained by CURE as narrow strips along the edge of row crops and drainage ditches. The 395-ha privately-owned Livingston farm, located 10 km south of the Holmes complex, acted as the unmanaged farm for the 2015 season. Livingston land cover included 83 ha of row crops, 11 ha of pasture, 180 ha of pine forest managed for timber, 101 ha of unmanaged mixed forest, and 20 ha of shrubland. The Livingston farm had not been previously managed to restore early successional cover, but prior logging events created widely dispersed patches of shrub cover. We made the decision to change unmanaged farm sites between 2014 and 2015 because the size and land cover of the Livingston farm better represented other unmanaged farms in the area, and its proximity to the managed farm simplified research logistics.

All 3 farms irrigated row crops with effluent from lagoons using overhead sprayers. Row crops on Delway and Livingston farms consisted of corn (*Zea mays indentata*). Additionally, both farms also planted spray-fields of bermudagrass (*Cynodon dactylon*) as a means of warm-season effluent disposal. The Holmes complex cultivated corn, winter wheat (*Triticum aestivum*), and soybeans (*Glycine max*). The Holmes complex over-seeded bermudagrass with cereal rye (*Secale cereal*) in pastures, which were used as year-round spray fields and leased for hay or grazing during the summer.

Capture

We captured bobwhite from 1 February to 4 April 2014 and 2015 using modified funnel entrance cage traps (Stoddard 1931). Traps measured 40-cm wide x 70-cm long x 26-cm high and were baited with soybeans or cracked corn. We placed traps in cleared areas within shrub cover near shrub/grassland interfaces and covered the tops of traps with leafy vegetation to hide captured individuals. We checked trap arrays 3 hours after sunrise and 1 hour before sunset each day to minimize the likelihood of stress and mortalities. We divided captured birds into two age cohorts, juvenile and adult, distinguished by the presence of buffy tips on primary coverts of juveniles. To weigh birds, we placed individuals in cotton handling bags hung from a 300-g spring scale. Individuals greater than 130-g were affixed with transmitters to ensure the entire radio package did not exceed 5% of any individual's weight. We affixed 320-day pendant VHF radio transmitters (model# AWE-Q, American Wildlife Enterprises) with Dacron string. Transmitters weighed approximately 6.2 g, and contained a 12-hour mortality sensor (Fies et al. 2002). We used sequentially numbered size #7 (5.56mm) aluminum butt-end leg bands (National Band & Tag Company) to identify individuals. We released captured groups near their original capture site in the direction of cover to reduce possibility of mortality by allowing for normal coveying behavior post-capture. We kept daily records of captures per 100 trap nights as an index of bobwhite density for each year on managed and unmanaged farms.

Radio-telemetry

We obtained 3 locations per individual each week from 1 April until 31 July. After 31 July, we reduced the number of collected locations to 1 per week on remaining birds until 15 September. We located birds using R4000 VHF receivers fixed with 3-element Yagi-style antennas (Advanced Telemetry Systems, Isanti, MN) by homing toward the individual to within 50-m while taking care to not interfere with their normal behavior (White and Garrott 1990). While maintaining a consistent distance, we walked an arc around the individual to decrease estimated location error. We used handheld Oregon 450 Global Positioning System [GPS] navigator (Garmin International, Inc., Olathe, KS) to collect UTM locations in the estimated direction and distance each individual or group was observed. We ensured all locations were collected when GPS accuracy was ≤ 5 m. We homed directly into each mortality site immediately upon observing a mortality signal to reduce the likelihood of any scavenging. We used the individual's remains and condition of the transmitter to best identify the cause of each mortality (i.e., mammalian predator, avian predator, snake, unknown predator, non-predation). If we could not locate an individual with Yagi antennas, we searched from the last known location expanding outward to ~5 km using a truck mounted omnidirectional antenna. We continued searches in this manner on each tracking day for 2 weeks until the individual was either located or declared lost.

Nest Monitoring

We located nests by approaching individuals recorded in the same location for 2 consecutive monitoring days. If that individual was attending a nest, we marked the specific location using the GPS unit, discretely flagged a nearby location, and recorded the nest status (i.e., nest building, egg laying, incubating). We conducted an egg count on all nests during the incubation stage. After the initial encounter, we monitored the presence of the incubating adult from beyond 50-m to minimize disturbance. Once the incubating adult left the nesting site, we approached the nest to determine the outcome (i.e., successful, depredated, abandoned). We categorized nests as successful if any eggs exhibited the presence of pipping. We categorized nests as depredated if broken eggshells were present or all eggs or eggshells were absent. We considered nests to be abandoned if they were left unattended for ≥ 3 consecutive monitoring days.

Vegetation Surveys

We documented vegetative cover at all nest sites and a subset of locations, where we previously observed the presence of at least 1 marked individual. We collected vegetation measurements ≤ 10 days of observing the outcome of a nest or collecting a telemetry location. Vegetation plots consisted of 2 10-m transects with midpoints intersecting perpendicularly at the nest or observed location. We measured vegetation at each meter along both transects, totaling 21 points at each location (Figure 2). We collected measurements using a 3.18-cm (1.25-in) x 2-m PVC pole subdivided lengthwise into 10 2-dm bands. At each sample point within a plot, we passed the pole vertically through the vegetation until it made contact with the ground to ensure an accurate measurement of vegetation cover. At each of these points, we recorded the ground cover (i.e., bare ground, thatch, leaf litter) below the pole and the vegetative species in contact with each band of the pole (Moorman and Guynn 2001). We conducted the same vegetation measurements at a reference point paired to each nest-site. We chose reference points from a list of random distance (20 – 250 m) and azimuth (0 – 359 degrees) combinations. We selected the maximum distance between nest and reference points based on the average home range of individuals residing in an area with similar land cover (Terhune et al. 2006). We allowed reference points to fall within any vegetation type in the specified random distance range. For any reference point not falling within a vegetated area (i.e., hog lagoon, body of water, barn, road), we decreased the random distance measurement until the entire plot to be measured was outside of these obstructions.

Nest-Site Selection

We compared vegetation composition and structure between each paired nest and reference point using the “lme4” package to create a generalized linear mixed-effect model with a binomial outcome to identify nest/reference point (Bates et al. 2015, R Version 3.2, www.r-project.org, accessed 31 Aug 2015). We paired individual nest and reference point sets in analysis by assigning a unique identifier to each set and establishing the identifier covariate as the sole random-effect variable in our model. We created vegetation cover covariates by grouping related or structurally similar plant species (Table 1). We tested for collinearity between predictor variables using Pearson’s correlation coefficient with a maximum threshold of 0.5. If the correlation between two covariates exceeded this level, we removed the covariate that would be more difficult to alter through habitat management efforts (Table 1). We included standardized vegetation composition covariates as fixed-effects in the mixed model to determine the best individual predictors of nest-site selection (Table 1). We built candidate models from vegetation covariates using forward selection with 2 ΔAIC_c per model covariate as the minimum threshold for inclusion.

Nest Survival

We estimated the effects of habitat covariates on daily nest survival rates using the nest survival package from Dinsmore et al. (2002) in Program MARK (White and Burnham 1999). The distance from the nest to the nearest edge of mature forest and presence of habitat management were included in the nest survival analysis (Table 1). Additionally, we measured the distance from the nest to the edge of the vegetation type containing the nest (e.g., field border) and the shape index of the vegetation type (Table 1). We used an open-reel fiberglass tape to measure all vegetation type and landscape-scale covariate distances ≤ 100 m and ArcGIS Desktop for all distances > 100 m (ArcGIS Desktop: Version 10.2.2. Redlands, CA: Environmental Systems Research Institute). We collected all vegetation cover covariates during vegetation surveys (Table 1). We tested for collinearity between covariates using Pearson's correlation coefficient with a maximum threshold of 0.5 (Table 1). If the correlation between two covariates exceeded this level, we removed the covariate believed to be less informative for management recommendations. We standardized all continuous covariates to have a mean of 0 and a variance of 1 for the modeling process. We used a two-stage modeling process to first evaluate effects of year, date incubation was initiated, and presence of habitat management (Table 1). Using the best initial model, we added distance to nearest edge of mature forest, distance to edge of the vegetation type containing the nest, and vegetation cover covariates to create candidate models for selection of best overall model (Table 1). We used forward selection to add individual second stage covariates to create the best overall model. The minimum threshold for inclusion in the model during forward selection was 2 ΔAIC_c per covariate.

Habitat Selection Analysis

We analyzed vegetation data for individuals located on managed and unmanaged farms separately to determine how habitat management altered habitat selection. We compared paired vegetation plots (used and reference) using the "lme4" package to create a generalized linear mixed-effect model with a binomial outcome to determine vegetative characteristics of sites used by individuals during the summer period (Bates et al. 2015, R Version 3.2, www.r-project.org, accessed 31 Aug 2015). We used vegetation cover covariates identical to the nest-site selection analysis, and 2 additional covariates measuring the number of trees within 10 m and percentage of canopy cover above the point (Table 1). We tested for collinearity among predictor variables using Pearson's correlation coefficient with a maximum threshold of 0.5. If two variables exceeded this level of correlation, we removed the variable that would be more difficult to alter through habitat management efforts. We included vegetation composition covariates in the mixed model to determine the top individual predictors of habitat selection. Using individual covariate performance, we created a top model using forward selection with 2 ΔAIC_c per model covariate as the minimum threshold for inclusion in model (Anderson and Burnham 2002).

Movement Analysis

We established summer movement to be that which occurred between covey breakup and the end of nesting (i.e., 15 April – 15 September). We focused movement and home range analysis on all individuals with ≥20 recorded locations during the summer to ensure a more accurate representation of summer home range. Requiring ≥20 recorded locations effectively censored any individual from movement analysis that was lost or died between 15 April and 1 June. We used locations of individuals to create 50% and 95% kernel density home range shapefiles for ArcGIS Desktop using the "adehabitatHR" package (Calenge 2006, R Version 3.2, www.r-project.org, accessed 31 Aug 2015). We calculated the area and distance from capture site to the centroid of the core range using ArcGIS Desktop (ArcGIS Desktop: Version 10.2.2. Redlands, CA: Environmental Systems Research Institute). The distance from an individual's winter capture site to the centroid of the summer core range signified the straight-line spring movement distance. We used Student's t-tests to compare mean core and home range areas and spring movement distances between juveniles and adults, males and females, and individuals on managed and unmanaged farms.

Survival Analysis

We condensed survival data into weekly encounter histories to standardize the period of time between encounter occasions within and between years. We analyzed survival by creating a 16-week (1 June – 15 September) model using the known fates package in Program MARK (White and Burnham 1999). Because the creation of summer home ranges required ≥ 20 locations after 15 April on each analyzed individual, we could only create a 16-week survival model to facilitate the inclusion of movement covariates (Table 2). We tested for collinearity between covariates using Pearson's correlation coefficient with a maximum threshold of 0.5. If variables exceeded this level of correlation, we removed the variable believed to be less informative to management. We selected the model with the lowest AIC as the best model (Anderson and Burnham 2002). The minimum threshold for establishing a difference between models was 2 ΔAIC_c. We censored all lost individuals following their last known fate when building survival models. We accounted for uncertainty in the fate of lost individuals in final survival estimates by creating 2 variations for each model. The upper limit of this model was created by assuming all lost individuals survived until the end of the summer period and the lower limit was created by assuming all lost individuals died after the date of their last known fate (Pollock et al. 1989).

RESULTS

Capture and Radio-telemetry

We captured 118 individuals (104 on the managed farm, 14 on the unmanaged farm) in 2014, and 123 (108 on the managed farm, 15 on the unmanaged farm) in 2015. Captures per 100 traps night were greater on the managed than the unmanaged farms in 2014 (managed= 9.0, unmanaged= 5.7) and 2015 (managed= 7.0, unmanaged= 4.2), suggesting greater bobwhite density on the managed farm. All but 2 individuals, which exhibited non-capture related injuries in 2014, received transmitters. Additionally, we censored mortalities (n= 13) that occurred within 7 days of capture (Tsai et al. 1999). We recaptured 5 individuals in 2015 that originally were captured as juveniles in 2014. We collected 4989 (4241 managed and 748 unmanaged) locations on 160 (133 managed and 27 unmanaged) individuals during the summer periods in 2014 and 2015. During the entire monitoring period, we lost track of 21 individuals (16 managed and 5 unmanaged). We lost 4 individuals prior to the beginning of the summer period, whereas all others occurred from late-April to early-May or from late-July to early-August. The 5 individuals recaptured in 2015 exhibited summer movements ranging from 954 m to 2191 m from their 2014 capture site. Of the 5 individuals recaptured in 2015, only the individual we observed moving 2191 m was captured in an explicitly different part of the farm the following year. In 2015, we captured this individual in an isolated area of winter cover 2184 m from its 2014 capture site. The other 4 individuals were recaptured an average of 564 m from their 2014 capture site within the same vegetation area or a directly adjacent vegetation type. Emigration rates beyond 5-km of the farm property boundaries may have been as high as 11.0% on the managed farm and 18.5% on the unmanaged farms assuming all losses were caused by emigration, but losses likely can be attributed to a combination of depredation, transmitter failure, and emigration from the study areas.

Nesting

The nesting season spanned from 21 May to 15 September in 2014, and 19 May to 21 September in 2015. We located 40 (39 managed and 1 unmanaged) and 31 nests (25 managed and 6 unmanaged) during the 2014 and 2015 seasons, respectively (Figures 3 and 4). We located 6 nests (8.5%) during the egg laying stage and 65 nests (91.5%) during the incubation stage. Pooling both years, we observed 1 incubated nest per 2 marked individuals alive at the start of the nesting season on the managed farm, and 1 incubated nest per 4 marked individuals alive at the start of the nesting season on unmanaged farms. Clutch sizes ranged from 8 to 23 eggs on the managed farm and from 11 to 14 eggs on the unmanaged farm. The mean clutch size did not differ between the managed farm (μ=13.5) and unmanaged farms (μ= 12.1, t=-1.501, df= 8.83, P= 0.16). Males incubated 36% (n = 24) and females 64% (n = 43) of nests. Egg hatchability, the percentage of eggs to hatch within a successful nest, did not differ between the managed farm (μ= 0.95) and unmanaged farms (μ= 0.937, t= 0.254, df= 1.2, P=0.83). Naïve nest success was 44% over both years, with 19 and 12 nests hatching in 2014 and 2015, respectively. Naïve nest success on the farm with habitat management was 46.9%, whereas nest success on farms without habitat management was 28.6%. Successful nests on the managed farm produced 312 hatchlings (2014= 202, 2015= 110), whereas the nests we monitored on the unmanaged farms produced 23 hatchlings (2014= 0, 2015= 23).

Nest-Site Selection

We censored 2 nests from site selection analysis because the nest-site vegetation was altered prior to data collection, which left 69 nests in the final analyses. Percent forb cover (P= < 0.001) was the only vegetation covariate that differed between nest sites on managed (μ= 53.61, SE= 4.32) and unmanaged (μ= 17.01, SE= 2.49) farms (Table 3). Additionally, the best model for characterizing nest sites on all farms included only percentage of forb cover as a covariate; nest-sites were characterized by a greater percentage of forb cover (β = 1.08, SE = 0.21) than reference sites (Table 4).

Nest Survival

We censored 4 nests from survival analysis because of possible research induced abandonment and removed 2 nests from model analysis because of alteration of vegetation prior to data collection; this left 65 nests in the final analyses. The daily nest survival rate did not differ between years, and was 0.964 (SE = 0.008) in 2014 and 0.952 (SE = 0.011) in 2015. Daily nest survival rate pooled over the 2 years was 0.962 (SE = 0.007). Pooled nest survival for the incubation period (23 days) was 0.410. We were unable to statistically differentiate between the daily nest survival rates on managed, 0.964 (SE = 0.007), and unmanaged, 0.927 (SE = 0.041), farms, possibly because of the low number of nests located on unmanaged farms. The null was the top nest survival model, which indicated no covariates affected daily nest survival rates (Table 5, Table 6).

Habitat Selection

Bobwhite used areas on the managed farm (n= 517 locations) with greater forb cover (β= 0.631, SE= 0.069, Z= 9.09, P= < 0.001), and bobwhite on the unmanaged farms (n= 88 locations) used areas with greater forb (β= 0.623, *SE*= 0.179, *Z*= 3.51, *P*= < 0.001) and bramble cover (β= 0.614, *SE*= 0.176, *Z*= 3.48, *P*= < 0.001) than observed at reference sites (Table 7, Table 8).

Movement

Individuals on the managed farm (*n*= 94) had longer spring movement distances than those on the unmanaged farms (*n*= 16) (*t*= -2.092, df= 30.50, *P*= 0.04). This indicated that nesting cover was further separated from winter cover on the managed farm. The mean spring movement distance of individuals on the managed farm was 778 m (*range*= 55 – 2654 m), but only 524 m (*range*= 81 – 1744 m) on the unmanaged farms. Also, mean summer home range (*t*= -2.520, df= 40.79, *P*= 0.02) and summer core range (*t*= -2.079, df= 36.43, *P*= 0.04) sizes were larger amongst bobwhite on the managed farm than on the unmanaged farms. The mean summer home range size of individuals on the managed farm was 274 ha (*range*= 9 – 1565 ha) compared to 157 ha (*range*= 45 – 604 ha) on the unmanaged farms. The mean summer core range size of individuals on the managed farm was 58 ha (*range*= 2 – 334 ha) compared to 36 ha (*range*= 8 – 140 ha) on the unmanaged farms. We were unable to analyze possible differences in movement between age and sex within each farm type because of the low number of individuals captured on the unmanaged farms; therefore, the following observations were pooled across farms. The spring movement distance (*t*= 1.475, df= 105.35, *P*= 0.14) and summer home range sizes (*t*= 1.342, df=102.48, *P*= 0.18) did not differ between males (*n*= 47) and females (*n*= 63). Juveniles (*n*= 63) held larger home ranges than adults (*n*= 47), (*t*= 2.108, df= 101.14, *P*= 0.04), whereas spring movement distances did not differ between the 2 ages classes (*t*= 1.073, df= 107.35, *P*= 0.29). The mean summer home range for juveniles was 301.4 ha (*range*= 9.3 – 1565.2 ha), whereas adults held a mean home range of 198.2 ha (*range*= 10.4 – 1092.0 ha).

Survival

We observed 53 mortalities during the 16-week summer period, 28 in 2014 and 25 in 2015. The predominant assigned causes of mortality were mammalian predator (15), avian predator (13), unknown predator (21), snake (3), and ran over by mower (1) (Table 9). Two survival models were within 2 ΔAIC_c of the top model, but the top model was >2 ΔAIC_c from the null model indicating weak support for this model (Table 10) (Anderson and Burnham 2002). We averaged the top 3 models to derive more accurate survival estimates. The averaged 16-week survival model showed that age class and farm type best described the variation in survival rates; the survival rate was slightly greater for adults than juveniles (β= 0.199, *SE*= 0.139) and for bobwhite on unmanaged farms than on the managed farm (β= -0.290, *SE*= 0.168). Survival for the 16-week period was 0.497 (*SE*= 0.052) on the managed farm and 0.873 (*SE*= 0.063) on the unmanaged farms. During the 16-week period, we lost 8 individuals combined between the 2014 and 2015 seasons. All losses occurred on the managed farm. When accounting for these lost individuals as either live the entire summer season or dead after their last known fate, 16-week summer survival adjusted to between 0.438 (*SE*= 0.050) and 0.519 (*SE*= 0.051) on the managed farm, and no adjustments were needed to unmanaged survival estimates because no individuals were lost on the unmanaged farm.

DISCUSSION

Our results indicate that populations on the unmanaged farms were limited by the low availability of sufficient herbaceous nesting cover. The similar clutch sizes and hatching rate of nests on the managed and unmanaged farms suggest that individuals on the unmanaged farm were equally fit and food availability was not limiting reproduction. Alternatively, we observed multiple indications that sparse nesting cover resulted in low reproduction on the unmanaged farms. On the managed farm, early successional vegetation in the CURE program accounted for only 9% of the farm property, but 64.1% of located nests were within these areas. An additional 9.4% of nests were located in unmaintained farm road ditch banks directly adjacent to maintained early successional field borders. Conversely, individuals on the unmanaged farms either made no known attempt to nest or nested in notably poorer sites such as a cornfield void of ground cover, a densely forested pine stand, logging slash within a pine stand clearcut during the previous year, or a hay field. Additionally, when individuals on the unmanaged farms did nest, they experienced low nest survival rates. The recurring positive relationships between forb cover and nest-site selection and summer habitat selection on the managed farm also suggest unmanaged farms lacked adequate herbaceous cover needed for bobwhite nesting.

Bobwhite may have selected nesting sites with greater proportions of forbs because of the multiple benefits afforded to both the incubating adult and the post-hatching brood (Harper et al. 2007). Additionally, senescent material from herbaceous cover provided important nest building material (Stoddard 1931, Klimstra and Roseberry 1975). An abundance of forbs provided food in the form of seeds as well as high abundances of arthropod prey, which are crucial for brood development and egg-laying females (Brennan and Hurst 1995, Moorman et al. 2013). The combination of adequate overhead cover from predators, open space at ground level to facilitate movement, sufficient nesting material, and abundant food resources for adults and broods likely are why nesting locations with greater forb cover were selected.

Within the managed farm, herbaceous vegetation sufficient for nesting cover readily occurred in the field borders and planted areas, but the highest densities of this vegetation type occurred only narrowly along forest edges and ditch banks on the unmanaged farms. Field borders of naturally occurring grasses and forbs were used more frequently for nesting than planted native grasses. We found 1 nest per 3 ha in fallow field borders and non-linear areas, whereas we located 1 nest per 5 ha in planted native grasses and forbs suggesting planting was not required to provide nesting cover. Furthermore, not all areas of planted grasses were used equally. More specifically, a 2-ha planted native vegetation area containing switchgrass grew dense and unsuitable for bobwhite nesting cover. We did not observe any nesting attempts within planted switchgrass. Conversely, we observed bobwhite nesting in 3 of the 4 other planted areas, which contained little bluestem and big bluestem at far lower densities than the switchgrass. Our observations were consistent with those from other landscapes that found bobwhite avoided areas with dense-growing grass species, which did not provide proper nesting structure and impeded movement (Barnes et al. 1995, Unger et al. 2015).

Although we observed greater nest initiation rates than Puckett et al. (1995), both studies showed individuals initiated more per capita nests on managed farms. However, Puckett et al. (1995) observed nest survival rates increase as the nesting season progressed, which was attributed to a seasonal increase in nesting cover as soybeans matured and, hence, provided continuous nesting cover. However, individuals in our study avoided the sparse, narrow nesting cover provided in early-season field borders, and instead nested in non-linear areas, which possibly decreased early-season exposure to nest predators.

The observed differences in survival rates and movement distances between bobwhite on the farms with and without habitat management were not those originally hypothesized. The unexpectedly higher mortality rates observed on the managed compared to the unmanaged farms likely resulted from reduced access to escape cover for individuals on the managed farm as well as the small sample sizes on unmanaged farms, which did not allow for a full observation of the true survival rates within that system. We believe a variation in predator densities amongst study farms had little impact on the difference in observed mortality rates, considering all farms were located within similar landscapes in the same region of North Carolina. Even though summer survival was lower on the managed farm compared to the unmanaged farm, the summer survival rates on the managed farm were similar to those observed in other stable populations and hence are not cause for concern (DeVos and Mueller 1993, Puckett et al. 1995, Burger et al. 1995).

Although efforts on the managed farm improved one component of habitat (i.e., nesting cover), the sites of these improvements were isolated from other necessary cover types, which effectively created a fragmented habitat. Our observation that farms with bobwhite habitat management experienced greater spring movement further supports previous research suggesting fragmented habitats cause greater seasonal movements

(Loveless 1958, Smith et al. 1982, Fies et al. 2002, and Terhune et al. 2010). In fact, bobwhite on the managed farm exhibited spring movement distances and home range areas markedly larger than those observed during prior studies in landscapes with more contiguous seasonal cover (Terhune et al. 2006, Janke and Gates 2013). The large distance between winter cover and herbaceous nesting cover on the managed farm required individuals to make long spring movements to meet their seasonal cover requirements. Winter cover predominantly existed around the outer edges of the farm, whereas the interior consisted of large row crop fields with field borders. Field borders often lacked woody vegetation, a critical component of winter and escape cover (Williams et al. 2000, Unger et al. 2015). Additionally, standing dead vegetation along ditches without field borders was regularly mowed during winter to create a "clean" landscape, which produced roughly 775 ha void of winter cover. This action caused a stark disparity between vegetation conditions at the interior and margins of the farm, requiring individuals to move longer distances to travel from winter to summer cover. Also, Brooke et al. (2015) reported bobwhite within an open landscape selected areas closer to shrub cover throughout the breeding season, which suggests these areas provided cover for bobwhite throughout the year. It is possible the extensive and contiguous herbaceous cover found on the managed farm during the summer reduced barriers to movement, but also required individuals to hold large home ranges to find all of the cover types they required (Williams et al. 2000, Bowling et al. 2014).

Despite bobwhite on the managed farm exhibiting longer seasonal movement distances and greater densities than those on the unmanaged farms, our observations suggest these populations do not inherently act as a source for surrounding low-quality habitat.

During both years, a large proportion (89%) of bobwhite captured on the managed farm held summer home ranges centered within the property boundaries of the managed farm, indicating an unwillingness by most individuals to use unmanaged areas surrounding the farm property. Our observations indicate bobwhite on managed farms have the possibility to become a population source only when low-quality habitat in areas surrounding managed farms is improved. During the 2015 study season, a 325-ha farm adjacent to the managed farm property allowed all row crop fields to lay fallow throughout the growing season in preparation for the construction of a solar energy project. The bare fields on this farm quickly succeeded into large areas dominated by herbaceous forbs. Consequently, half of all observations (5) of individuals holding summer home ranges off the managed farm property occurred during this time period and on this adjacent farm. The individuals that moved to the adjacent farm were responsible for 16% of the nests found at the managed farm site during 2015 and exhibited a 50% naïve nest success rate. The willingness of individuals to reside on this farm and the ensuing reproductive success of these individuals indicate nearby habitat improvements can facilitate successful immigration from a currently managed farm.

We believe the apparent greater bobwhite density on the managed farm compared to the unmanaged farm was a result of greater nest initiation and nest survival rates despite exhibiting comparatively lower adult survival. Although adult survival was identified by Sandercock et al. (2008) to generally be the most impactful vital rate to bobwhite population growth across its entire range, our findings suggest bobwhite abundances can also be suppressed by low nest initiation and nest survival rates in row crop landscapes that lack nesting cover. We indicated that both nest initiation and nest survival rates were greater on the managed farm as a result of greater herbaceous cover that provided adequate nest concealment; naïve nest success was 46.9% and 28.6% on the farms with and without habitat management, respectfully. Nest survival on the farm with habitat management was comparable to the highest nest survival rates observed in previous studies that monitored the effects of habitat management (Burger et al. 1995, Hughes et al. 2005, Staller et al. 2005, Potter et al. 2011, Peters et al. 2015). As a species that typically exhibits high reproductive output and low annual survival, we suggest bobwhite populations can persist on working farms so long as these sites are managed to provide and maintain nesting cover through the creation of early successional vegetation in close proximity to the shrub cover needed for winter, escape, and thermal cover.

MANAGEMENT IMPLICATIONS

Working farms have the potential to be a favorable medium for creating and maintaining areas of early successional vegetation for bobwhite in an economical and efficient manner. Sparse herbaceous cover in most row crop agriculture likely is responsible for poor recruitment. Conversely, areas of grasses and forbs, interspersed with sparse shrubs, provide desirable summer cover. Field borders and other areas of herbaceous vegetation provide opportunity for bobwhite population growth on working farms and could be the key link to maintaining high densities of bobwhite on private farmland. Managers should be aware that the farmland chosen for management can dictate patterns in survival and movement just as much as the management efforts. Fallow borders of early successional cover on working farms do not reduce spring movement or increase summer survival on their own; instead, increasing early successional vegetation on working farms drives population persistence or growth through increased nest initiation and nest survival rates. Therefore, managers should ensure that cover created to increase recruitment is placed within close proximity to shrub cover to also provide winter, thermal, and escape cover. If northern bobwhite is a management concern on working farms, some shrub cover should be retained in ditches, field borders, and areas of low crop production to create a mosaic of cover. Although habitat management can be effective in increasing bobwhite abundances on working farms, farms with habitat management cannot act as a population source to surrounding areas unless habitat management efforts are also extended to those areas.

LITERATURE CITED

Anderson, D. R., and Burnham, K. P. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer-Verlag, New York, New York, USA.

Barnes, T. G., L. A. Madison, J. D. Sole, and M. J. Lacki. 1995. An assessment of habitat quality for northern bobwhite in tall fescue-dominated fields. Wildlife Society Bulletin 23:231-237.

Bates, D., M. Maechler, B. Bolker, S. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67(1): 1-48.

Best, L. B., H. Campa III, K. E. Kemp, R. J. Robel, M. R. Ryan. J. A. Savidge, H. P. Weeks Jr., and S. R. Winterstein. 1997. Bird abundance and nesting in CRP fields and cropland in the Midwest: a regional approach. Wildlife Society Bulletin 25(4):864-877.

Bowling, S. A., C. E. Moorman, C. S. Deperno, and B. Gardner. 2014. Influence of Landscape Composition on Northern Bobwhite Population Response to Field Border Establishment. Journal of Wildlife Management 78:93–100.

Brennan, L. A. 1991. How can we reverse that northern bobwhite population decline? Wildlife Society Bulletin 19(4):544-555.

Brennan, L. A. and G. A. Hurst. 1995. Summer diet of northern bobwhite in eastern Mississippi: implications for habitat management. Proceedings of the Annual Conference of the Association of Fish and Wildlife Agencies 49:516-524.

Brooke, J. M., D. C. Peters, A. M. Unger, E. P. Tanner, C. A. Harper, P. D. Keyser, J. D. Clark, and J. J. Morgan. 2015. Habitat manipulation influences northern bobwhite resource selection on a reclaimed surface mine. The Journal of Wildlife Management 79: 1264-1276.

Burger Jr., L. W. 2001. Quail management: issues, concerns, and solutions for public and private lands—a southeastern perspective. Quail V: Proceedings of the fifth nation quail symposium, Texas Parks and Wildlife Department, Austin, TX. S. J. DeMaso, W. P. Kuvlesky, Jr., F. Hernández, and M. E. Berger, eds: 20-34.

Burger Jr., L. W., E. W. Kurzejeski, T. V. Dailey, and M. R. Ryan. 1990. Structural characteristics of vegetation in CRP fields in northern Missouri and their suitability as bobwhite habitat. Transactions of the North American Wildlife and Natural Resources Conference 55:74-83.

Burger Jr., L. W., T. V. Dailey, E. W. Kurzejeski, and M. R. Ryan. 1995. Survival and cause-specific mortality of northern bobwhite in Missouri. Journal of Wildlife Management 59:401–410.

Butler, B. J., and E. C. Leatherberry. 2004. America's family forest owners. Journal of Forestry 102:4-14.

Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197: 516-519.

Cobb, D. T., T. L. Sharpe, D. Sawyer, and D. O. Baumbarger. 2002. Integrating early-successional wildlife habitats into North Carolina's 21st century landscape. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 56:124-135.

DeVos, T. A., Jr., and B. S. Mueller. 1993. Reproductive ecology of northern bobwhite in north Florida. Proceedings of the National Quail Symposium 3:83-90.

Dinsmore, S.J., G.C. White, and F.L. Knopf. 2002. Advanced techniques for modeling avian nest survival. Ecology 83:3476-3488.

Dixon, K. R., M. A. Horner, S. R. Anderson, W. D. Henriques, D. Durham, and R. J. Kendall. 1996. Northern bobwhite habitat use and survival on a South Carolina plantation during winter. Wildlife Society Bulletin 24:627-635.

Engstrom, R. T., R. L. Crawford, and W. W. Baker. 1984. Breeding bird populations in relation to changing forest structure following fire exclusion: A 15-year study. Wilson Bulletin 96: 437–450.

Fies, M. L., K. M. Puckett, and B. Larson-Brogdon. 2002. Breeding season movements and dispersal of northern bobwhites in fragmented habitats of Virginia. Proceedings of the National Quail Symposium 5:173-179.

Gill, D. E., P. Blank, J. Parks, J. B. Guerard, B. Lohr, E. Schwartzman, J. G. Gruber, G. Dodge, C. A. Rewa, and H. F. Sears. 2006. Plants and breeding bird response on a managed Conservation Reserve Program grassland in Maryland. Wildlife Society Bulletin 34:944-956.

Greenfield, K. C., M. J. Chamberlain, L. W. Burger Jr., and E. W. Kurzejeski. 2003. Effects of burning and discing Conservation Reserve Program fields to improve habitat quality for northern bobwhite (*Colinus virginianus*). The American midland naturalist 149:344-353.

Harper, C.A. 2007. Native warm-season grasses: identification establishment and management for wildlife and forage production in the mid-south: a manual for natural resource professionals and other land managers. University of Tennessee, Extension Service.

Hughes, D. W., T. M. Terhune, D. C. Sisson, and H. L. Stribling. 2005. Demographics of northern bobwhite on agricultural and intensively managed bobwhite plantation landscapes. Proceedings of Annual conference of the Southeast Association of Fish and Wildlife Agencies 59:30-42.

Janke, A. K., and R. J. Gates. 2013. Home range and habitat selection of northern bobwhite coveys in an agricultural landscape. The Journal of Wildlife Management 77:405-413.

King, J. W., and J. A. Savidge. 1995. Effects of the Conservation Reserve Program on wildlife in southeast Nebraska. Wildlife Society Bulletin 23:377-385.

Klimstra, W. D. and J. L. Roseberry. 1975. Nesting ecology of the bobwhite quail in southern Illinois. Wildlife Monographs 41:3-37.

Loveless, C. M. 1958. The mobility and composition of bobwhite quail populations in south Florida. Florida Game and Fresh Water Fish Commission Technical Bulletin 4, Tallahassee.

Masters, R. E., K. Robertson, B. Palmer, J. Cox, K. McGorty, L. Green, C. Ambrose. 2003. Red Hills Forest Stewardship Guide. Miscellaneous Publication # 12, Tall Timbers Research Station, Tallahassee, Florida, USA.

Moorman, C. E. and D. C. Guynn Jr. 2001. Effects of group-selection opening size on breeding bird habitat use in a bottomland forest. Ecological Applications 11:1680-1691.

Moorman, C. E., C.J. Plush, D.B. Orr, and C. Reberg-Horton. 2013. Beneficial insect borders provide northern bobwhite brood habitat. PloS one, 8:e83815.

Nickerson, C., R. Ebel, A. Borchers, and F. Carriazo. 2011. Major uses of land in the United States, 2007. U.S. Department of Agriculture, Economic Research Service EIB-89, Washington D.C., USA.

Oehler, J. D. 2003. State efforts to promote early-successional habitats on public and private lands in the northeastern United States. Forest Ecology and Management, 185:169-177.

Palmer, W.E., S.D. Wellendorf, J.R. Gillis, and P.T. Bromley. 2005. Effect of field borders and nest-predator reduction on abundance of northern bobwhites. Wildlife Society Bulletin, 33:1398-1405.

Palmer, W. E., T. M. Terhune, and D. F. McKenzie (eds). 2011. The national bobwhite conservation initiative. A range-wide plan for recovering bobwhite. National Bobwhite Technical Committee Technical Publication, ver. 2.0, Knoxville, TN.

Peters, D. C., J. M. Brooke, E. P. Tanner, A. M. Unger, P. D. Keyser, C. A. Harper, J. D. Clark, and J. J. Morgan. 2015. Impact of experimental habiat manipulation on northern bobwhite survival. Journal of Wildlife Management 79:605-617.

Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7–14.

Potter, L. M., D. L. Otis, and T. R. Bogenschutz. 2011. Nest success of northern bobwhite on managed and unmanaged landscapes in southeast Iowa. The Journal of Wildlife Management 75(1):46-51.

Puckett, K.M., W.E. Palmer, P.T Bromley, J.R. Anderson, Jr., and T.L. Sharpe. 1995. Bobwhite nesting ecology and modern agriculture: a management experiment. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 49:503-517.

Riddle, J. D., C. E. Moorman, and K. H. Pollock. 2008. The importance of habitat shape and landscape context to northern bobwhite populations. Journal of Wildlife Management 72:1376-1382.

Riffell, S., D. Scognamillo, and L.W. Burger. 2008. Effects of the Conservation Reserve Program on northern bobwhite and grassland birds. Environmental Monitoring and Assessment 146:309-323.

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link. 2014. *The North American Breeding Bird Survey, Results and Analysis 1966 - 2013.* Version 01.30.2015. USGS Patuxent Wildlife Research Center, Laurel, MD.

Samson, F. and F. Knopf. 1994. Prairie conservation in North America. BioScience, 418-421.

Sandercock, B. K., W. E. Jensen, C. K. Williams, and R. D. Applegate. 2008. Demographic sensitivity of population change in northern bobwhite. Journal of Wildlife Management 72:970–982.

Sharitz, R. R. 2003. Carolina bay wetlands: unique habitats of the southeastern United States. *Wetlands* 23:550-562.

Smith, G. F., F. E. Kellogg, D. L. Doster, and E. E. Provost. 1982. A 10-year study of bobwhite quail movement patterns. Proceedings of the National Quail Symposium 2:35– 44.

Smith, M. D., P. J. Barbour, L. W. Burger, Jr., and S. J. Dinsmore. 2005. Density and diversity of overwintering birds in managed field borders in Mississippi. Wilson Bulletin 117:258-269.

Staller, E. L., W. E. Palmer, J. P. Carroll, R. P. Thornton, and D. C. Sisson. 2005. Identifying predators at northern bobwhite nests. Journal of Wildlife Management 69:124-132.

Stoddard, H. L. 1931. The bobwhite quail: its habits, preservation and increase. Charles Scribner's Sons, New York, New York, USA.

Terhune, T. M., D. C. Sisson, H.L. Sribling, and J. P. Carroll. 2006. Home range, movement, and site fidelity of translocated northern bobwhite (*Colinus virginianus*) in southwest Georgia, USA. European Journal of Wildlife Research 52:119-124.

Terhune T. M., D. C. Sisson, W. E. Palmer, B. C. Faircloth, H. L. Stribling, and J. P. Carroll. 2010. Translocation to a fragmented landscape: survival, movement, and site fidelity of Northern Bobwhites. Ecological Applications 20:1040–1052.

Tsai, K., K. H. Pollock, and C. Brownie. 1999. Effects of violation of assumptions for survival analysis methods in radiotelemetry studies. Journal of Wildlife Management 63:1369-1375.

Unger, A. M., E. P. Tanner, C. A. Harper, P. D. Keyser, F. T. Van Manen, J. J. Morgan, and D. L. Baxley. 2015. Northern bobwhite season habitat selection on a reclaimed surface coal mine in Kentucky. Journal of Widlife Management 2:235-246.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46:S120-S139.

White, G. C., and R. A. Garrott. 1990. Analysis of wildlife radio-tracking data. Academic Press, San Diego, California, USA.

Williams, C. K., R. S. Lutz, R. D. Applegate, and D. H. Rusch. 2000. Habitat use and survival of northern bobwhite (*Colinus virginianus*) in cropland and rangeland ecosystems during the hunting season. Canadian Journal of Zoology 78:1562–1566.

Table 1. Covariates used to describe northern bobwhite nest-site selection (SS), nest survival (NS), and habitat selection (HS) in southeastern North Carolina, USA (2014-2015).

Abbreviation	Description	Analysis
DATE	Date of first presence of incubating adult at nest site (± 2 day accuracy)	NS
YEAR	Year of study	NS
MAN	Presence of bobwhite habitat management on farm where nest is located	NS
W.DIST	Distance from nest to nearest mature forest stand ≥ 1 ha	NS
E.DIST	Distance from nest to nearest edge of vegetation patch	NS
S.INDEX [A]	Numerical index describing shape of vegetation patch containing nest	NS
BG [B]	Percentage of sample points with bare ground present	SS, NS, HS
BR	Percentage of sample points with in contact with all *Smilax* and *Rubus* species	SS, NS, HS
CO	Percentage of sample points with corn present	SS, NS, HS
LI [C,D]	Percentage of sample points with non-graminoid leaf litter present	SS, NS, HS
NWSG	Percentage of sample points with native warm-season grasses present	SS, NS, HS
OG [C]	Percentage of sample points with any other grass species present	SS, NS, HS
FORB	Percentage of sample points with forbs present	SS, NS, HS
SO	Percentage of sample points with soybean plants present	SS, NS, HS
TH	Percentage of sample points with graminoid leaf litter present	SS, NS, HS
TR	Percentage of sample points with trees present	SS, NS, HS
WD	Percentage of sample points with woody debris present	SS, NS, HS
WO	Percentage of sample points with woody shrubs present	SS, NS, HS
STEM	Count of all woody stems ≥ 10-cm dbh within 10-m of quail location	HS
CANOPY [E]	Categorical variable ranking canopy level cover within 5 - 20% divisions	HS

[A] Patch Shape Index $= P/(2\sqrt{\pi A})$, where P= patch perimeter (m) and A= patch area (m^2).
[B] Removed from habitat and nest-site selection analysis because of collinearity with CO
[C] Removed from habitat and nest-site selection analysis because of collinearity with TH
[D] Removed from habitat selection analysis because of collinearity with WO, TR, and BR
[E] Removed from habitat selection analysis because of collinearity with TR

Table 2. Covariates collected to describe influence of time, home range, farm, and individual characteristics on northern bobwhite survival rate in southeastern North Carolina, USA (1 June – 15 September 2014 and 2015).

Covariate	Description
Age	Age of individual upon time of capture
Habitat Management	Presence of bobwhite habitat management on farm where individual resided
Home Range[A]	Area of 95% summer home range
Movement Distance	Distance from capture site to centroid of 50% summer home range
Sex	Sex of individual
Time	Week of summer period
Year	Year of study

[A] Removed from analysis because of collinearity with Movement Distance

Table 3. Mean percentage (standard error) of ground cover and vegetation cover measured at nest sites on managed and unmanaged farms in southeastern North Carolina (2014 – 2015).

Cover Type	Covariate	Managed	Unmanaged	T-stat	P-value
Ground Cover	Bare Ground	2.46 (0.69)	5.44 (5.03)	0.544	0.61
	Leaf Litter	43.55 (4.37)	41.50 (12.57)	-0.144	0.90
	Thatch	40.86 (4.07)	40.82 (13.12)	-0.003	1.00
Vegetative Cover	**Forbs**	**53.61 (4.32)**	**17.01 (2.49)**	**-4.041**	**0.00**
	Brambles	11.90 (2.64)	11.56 (7.19)	-0.042	0.97
	Native Warm-season Grasses	19.20 (3.07)	18.37 (10.43)	-0.072	0.95
	Other Grasses	16.44 (2.94)	20.41 (12.53)	0.287	0.79
	Corn	0.77 (0.38)	11.56 (9.99)	0.999	0.36
	Soybeans	0.92 (0.51)	0.00 (0.00)	-1.801	0.08
	Trees	5.99 (1.37)	25.17 (8.54)	2.058	0.08
	Woody Debris	3.61 (1.16)	12.24 (7.32)	1.081	0.32
	Woody Vegetation	8.45 (2.30)	10.88 (9.36)	0.235	0.82

Table 4. The AIC_c, ΔAIC_c, and model weight (ω) for the assessment of influence of vegetation characteristics on northern bobwhite nest-site selection in southeastern North Carolina (2014 – 2015).

Model	AIC_c	ΔAIC_c	ω
Forb Cover	168.4	0.00	0.999
Native Warm-season Grass Cover	182.8	14.44	0.001
Soybean Cover	186.5	18.17	0.000
Bramble Cover	190.8	22.47	0.000
Corn Cover	194.6	26.25	0.000
NULL	198.2	29.79	0.000
Shrub Cover	199.4	31.02	0.000
Tree Cover	199.8	31.45	0.000
Woody Debris Cover	200.1	31.68	0.000

Table 5. The AIC_c, ΔAIC_c, and model weight (ω) for the assessment of influence of time and habitat management characteristics on northern bobwhite daily nest survival in southeastern North Carolina (2014 – 2015).

Description	AIC_c	ΔAIC_c	ω
NULL	217.513	0.00	0.346
Habitat Management	218.363	0.85	0.226
Incubation Initiation Date	218.662	1.15	0.195
Year	219.499	1.99	0.128
Incubation Initiation Date + Habitat Management	221.134	3.62	0.057
Habitat Management + Year	221.473	3.96	0.048
Incubation Initiation Date + Year	251.814	34.30	0.000
Habitat Management + Year + Incubation Initiation Date	277.831	60.32	0.000

Table 6. The AIC_c, ΔAIC_c, and model weight (ω) for the assessment of habitat covariates on northern bobwhite daily nest survival in southeastern North Carolina (2014-2015).

Model	AIC_c	ΔAIC_c	ω
NULL	217.513	0.00	0.152
Shrub Cover	217.572	0.06	0.148
Bramble Cover	217.621	0.11	0.144
Shape Index	218.925	1.41	0.075
Other Grass Cover	219.213	1.70	0.065
Distance to Vegetation Type Edge	219.230	1.72	0.065
Distance to Forest Edge	219.382	1.87	0.060
Native Warm-season Grass Cover	219.394	1.88	0.059
Tree Cover	219.415	1.90	0.058
Woody Debris Cover	219.441	1.93	0.057
Forb Cover	219.483	1.97	0.056

Table 7. The AIC_c, ΔAIC_c, and model weight (ω) for the assessment of bobwhite summer habitat selection on a farm with habitat management in southeastern North Carolina, USA (15 Apr – 31 July, 2014 and 2015).

Model	AIC_c	ΔAIC_c	Ω
Forb Cover	1347.2	0.00	1.0
Bramble Cover	1375.7	28.50	0.0
Corn Cover	1420.5	73.26	0.0
Tree Cover	1422.5	75.40	0.0
Native Warm-season Grass Cover	1425.3	78.06	0.0
Soybean Cover	1434.3	87.07	0.0
Shrub Cover	1434.6	87.39	0.0
Stem Count	1436.4	89.16	0.0
NULL	1437.4	90.22	0.0
Other Grass Cover	1438.8	91.61	0.0
Woody Debris Cover	1438.8	91.61	0.0

Table 8. The AIC_c, ΔAIC_c, and model weight (ω) for the assessment bobwhite summer habitat selection on farms without habitat management in southeastern North Carolina, USA (15 Apr – 31 July, 2014 and 2015).

Model	AIC_c	ΔAIC_c	ω
Forb Cover + Bramble Cover	226.7	0.00	0.995
Forb Cover	238.5	11.83	0.003
Bramble Cover	239.0	12.32	0.002
Tree Cover	244.4	17.74	0.000
Soybean Cover	244.5	17.83	0.000
Shrub Cover	245.0	18.39	0.000
Stem Count	245.3	18.67	0.000
NULL	248.1	21.40	0.000
Corn Cover	248.9	22.27	0.000
Woody Debris Cover	249.7	23.02	0.000
Other Grass Cover	249.9	23.29	0.000
Native Warm-season Grass Cover	250.1	23.47	0.000

Table 9. Causes of mortalities (1 June – 15 September) on farms with and without bobwhite habitat management in southeastern North Carolina, USA (2014 – 2015).

Year	Farm	Mammalian	Avian	Unknown Predator	Snake	Non-Predatory	Total
2014	Managed	6	11	9	0		26
	Unmanaged	1	0	1	0		2
2015	Managed	6	1	11	3	1	22
	Unmanaged	2	1	0	0	0	3
	Total	15	13	21	3	1	53

Table 10. The AIC_c, ΔAIC_c, and model weight (ω) for the assessment of summer bobwhite survival in southeastern North Carolina, USA (1 Jun – 15 Sep, 2014 and 2015).

Model	AIC_c	ΔAIC_c	ω
S(Age + Farm Type)	472.031	0.000	0.3195
S(Farm Type)	472.126	0.095	0.3046
S(Age)	473.681	1.651	0.1399
S(NULL)	474.258	2.227	0.1049
S(Movement Distance)	476.178	4.147	0.0402
S(Year)	476.205	4.174	0.0396
S(sex)	476.214	4.183	0.0395
S(Time)	478.654	6.623	0.0117

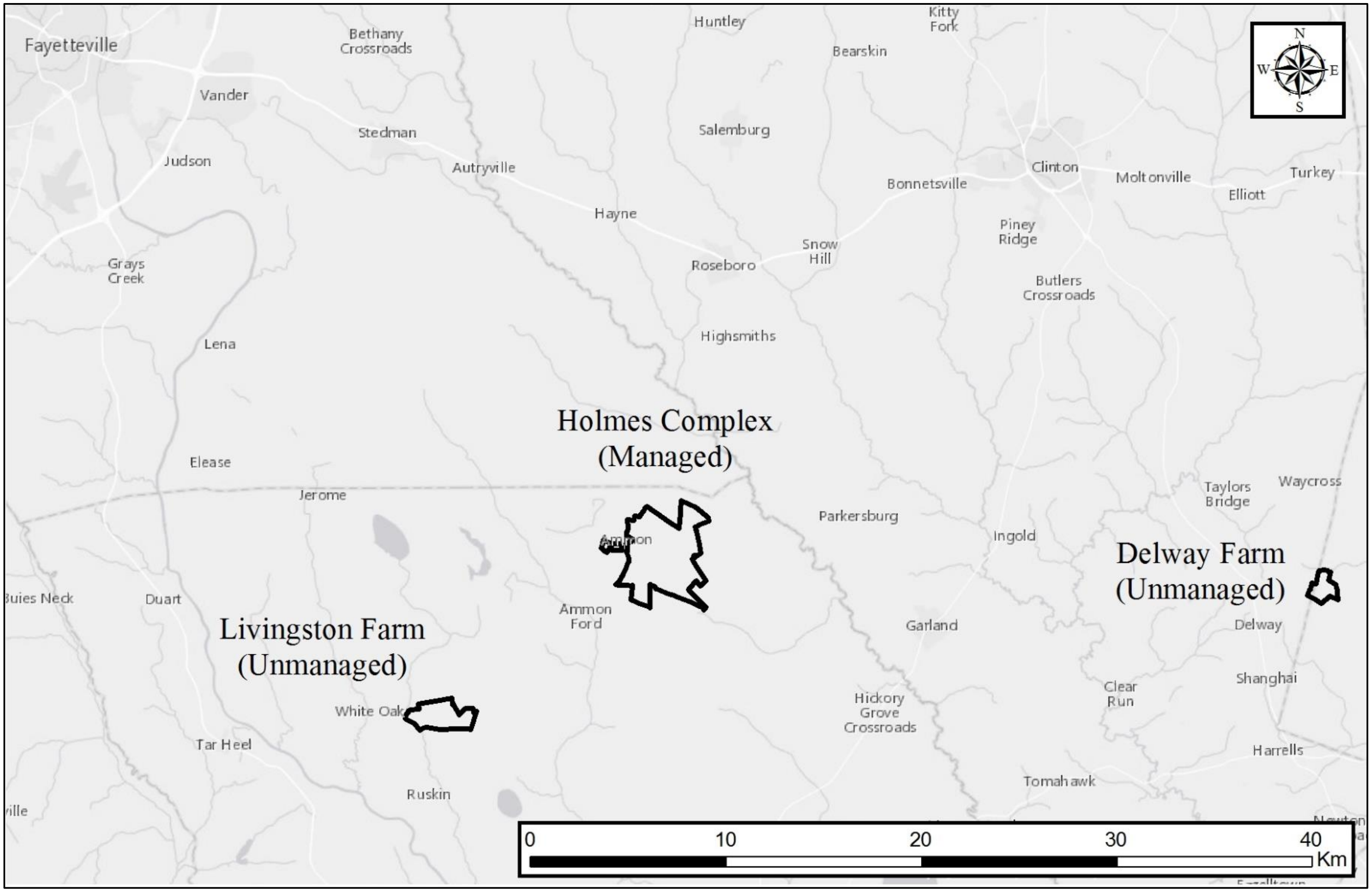

Figure 1. Map of managed (Holmes Complex) and unmanaged (Delway and Livingston) farm sites, Bladen and Duplin Counties, North Carolina, USA, 1 February 2014 – 30 September 2015.

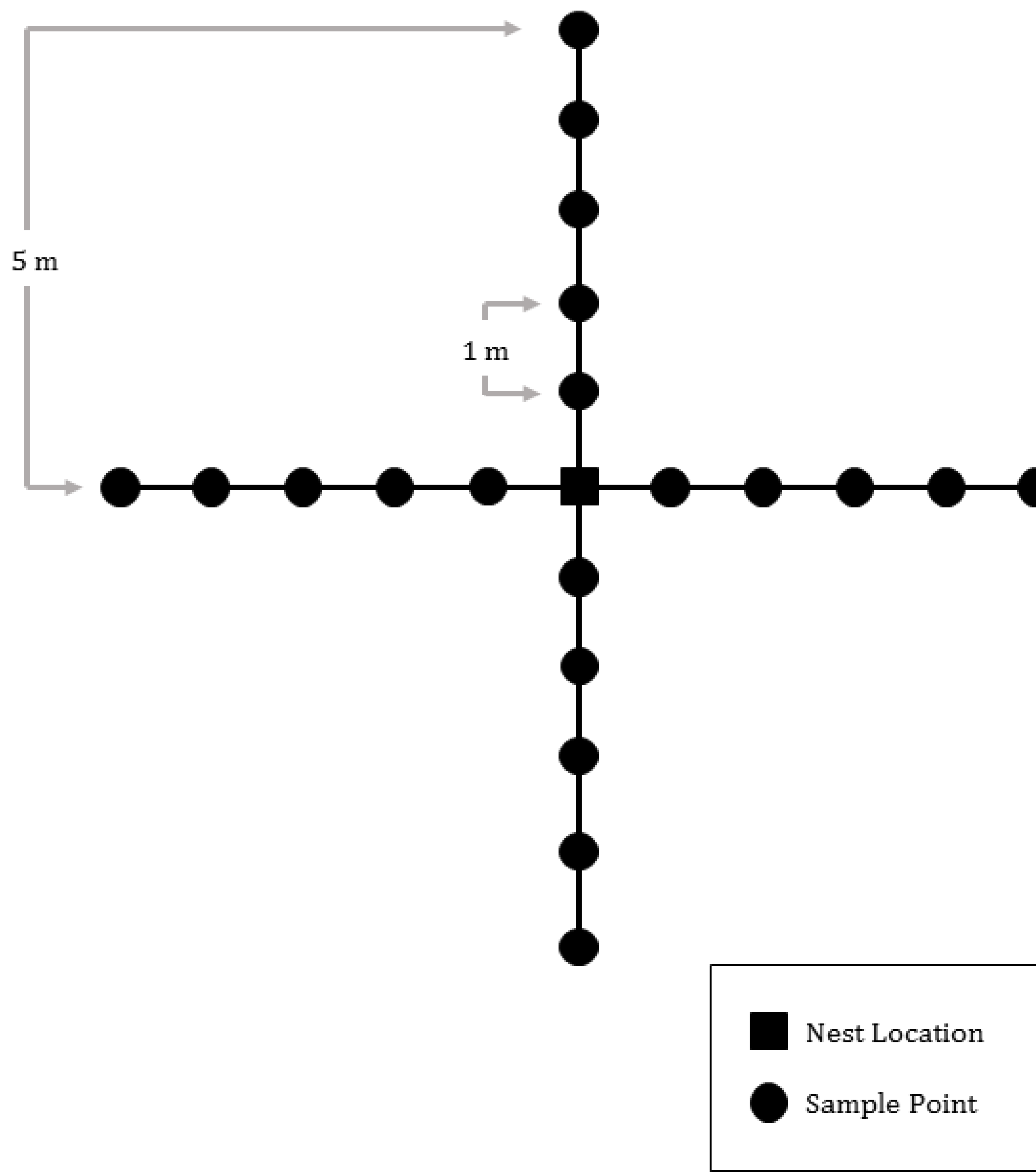

Figure 2. Layout of plot for 10-m x 10-m vegetation surveys conducted at occupied and reference plots on working farms in southeastern North Carolina (2014 – 2015).

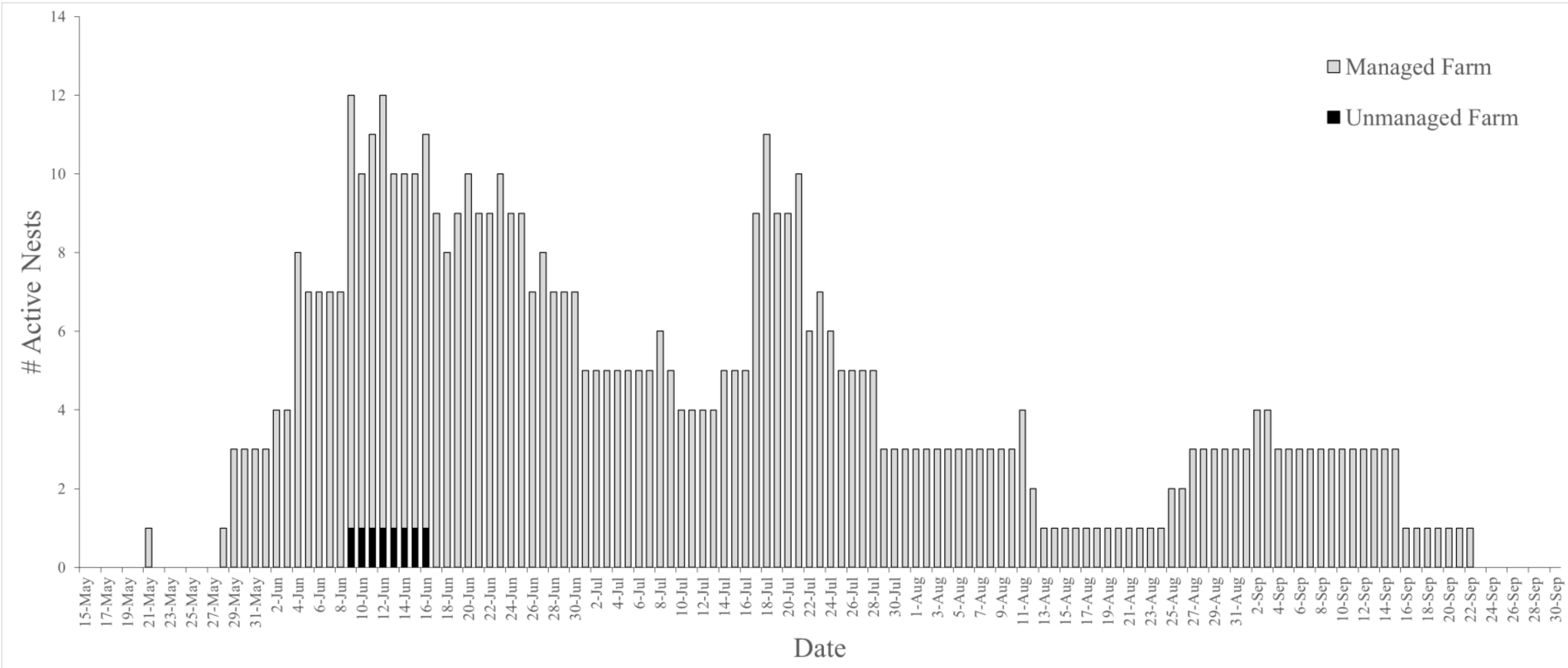

Figure 3. Number of monitored active nests per day for 2014 nesting season on Holmes Complex (managed) and Delway Farm (unmanaged), Bladen and Duplin Counties, North Carolina, USA.

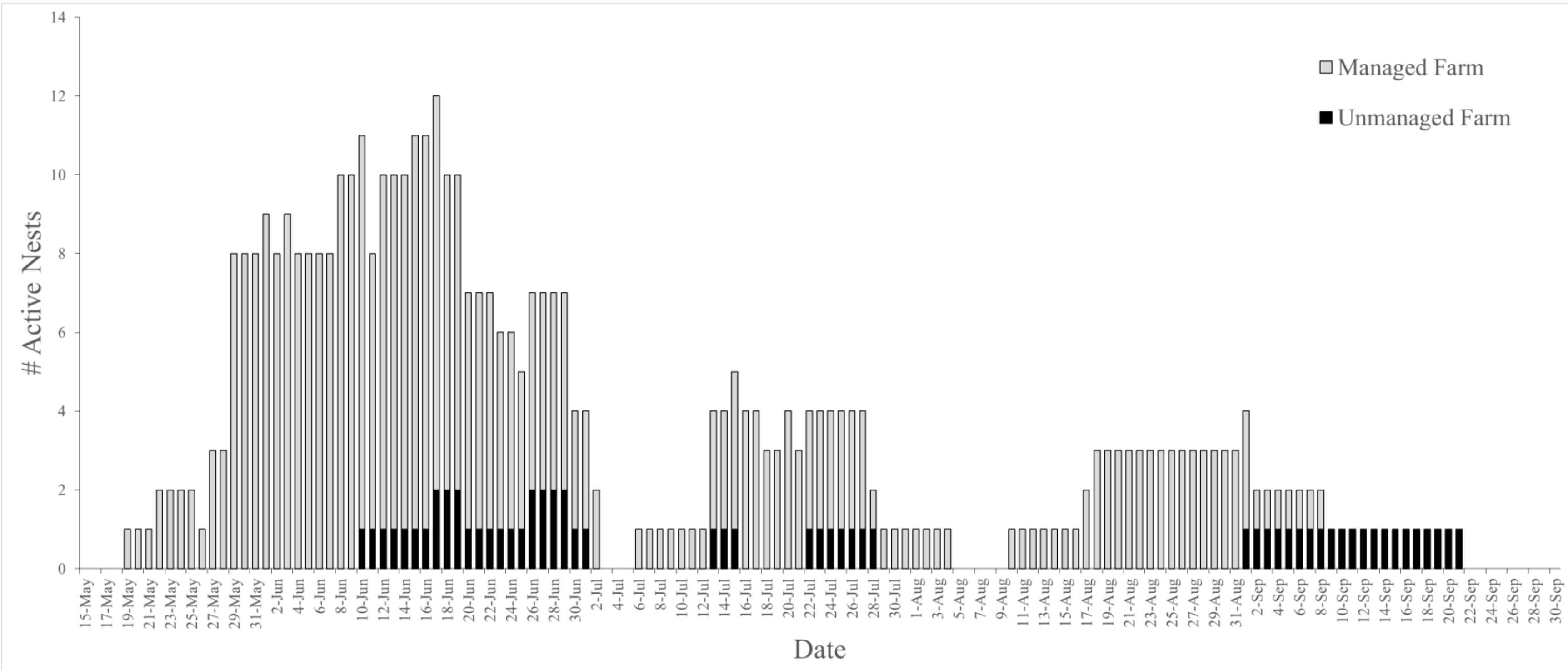

Figure 4. Number of monitored active nests per day for 2015 nesting season on Holmes Complex (managed) and Livingston Farm (unmanaged), Bladen County, North Carolina, USA.