

ABSTRACT

RIDDLE, JASON DALE. Maximizing the Impact of Field Borders for Quail and Early-succession Songbirds: What's the Best Design for Implementation? (Under the direction of Christopher E. Moorman.)

Northern bobwhite and many early-succession songbirds have experienced severe population declines in recent decades. Generally, these declines have been the result of habitat loss. Field borders can increase and enhance early-succession habitat for birds on farmland. Additionally, field border establishment and maintenance can be subsidized by a variety of government programs. However, field border characteristics, such as their shape, and the landscape context in which they occur may determine their effectiveness for bird conservation. We established linear and nonlinear field borders on farms in agriculture-dominated and forest-dominated landscapes in the Coastal Plain of North Carolina. Prior to field border establishment in 2004, we collected pre-treatment data on songbird density of focal species, nest success, brood parasitism frequency, summer bobwhite abundance, and fall bobwhite covey abundance. After field borders were established (2005 and 2006), we continued to collect data on the aforementioned variables as well as on artificial bobwhite nest success and field border vegetation characteristics. Summer bobwhite abundance increased on farms in agriculture-dominated landscapes from a mean of 0.54 (SE = 0.17) to 1.01 (SE = 0.12) bobwhite/count/farm from pre-treatment to post-treatment years, respectively ($P = 0.0188$). Summer abundance increased on farms with nonlinear habitats from 0.68 (SE = 0.17) to 1.07 (SE = 0.12) bobwhite/count/farm from pre-treatment to post-treatment years, respectively ($P = 0.0352$). However, summer abundance did not increase on farms with linear field borders in forest-dominated landscapes. There was a trend toward higher numbers of fall coveys/count on farms in agriculture-dominated landscapes by 0.27

(SE = 0.73) and lower on farms in forest-dominated landscapes by 0.50 (SE = 0.67), but these trends were not significant at the $\alpha = 0.05$ level. The proportion of depredated artificial bobwhite nests was similar across all treatments (mean = 0.375, SE = 0.042), as were the major vegetation characteristics of the field borders themselves.

Focal songbird species density, nest success probability, and brood parasitism frequency were unaffected by the establishment of field borders. Focal species density (males/7854 m²) was higher on farms in agriculture-dominated landscapes (mean = 1.15, SE = 0.11) than in forest-dominated landscapes (mean = 0.74, SE = 0.11; P = 0.0215). Indigo bunting/blue grosbeak nest success probability was higher on farms in agriculture-dominated landscapes (mean = 0.39, SE = 0.05) than in forest-dominated landscapes (mean = 0.17, SE = 0.05; P = 0.0243). Brood parasitism frequency was 0.33 (SE = 0.07), but did not differ between landscapes.

Our results suggest that linear and nonlinear field borders can be used to increase bobwhite populations on farms in agriculture-dominated landscapes. Nonlinear field borders can be used to increase bobwhite populations in forest-dominated landscapes. Early-succession songbirds did not respond to field borders in our study. However, the same landscapes that were most conducive to bobwhite management were also the highest quality landscapes for early-succession songbirds.

We compared the time-of-detection method for sampling coveys with an empirical logistic regression method. Both methods are unusual in that they account for some coveys not being available for detection. The time-of-detection method provided an estimate of detection probability (0.540, SE = 0.08) that was similar to the empirical method (0.585, SE = 0.13; P = 0.77). The time-of-detection method is less expensive to perform than the

empirical method. However, the empirical method may be more useful when the number of covey detections is low, and it can use information from a single count to calculate the detection probability for that count. Surveys conducted with the time-of-detection method and/or the empirical method may produce density estimates that are more comparable to estimates from line-transect methods where coveys are flushed (in environments where line-transect methods are appropriate).

Maximizing the Impact of Field Borders for Quail and Early-succession Songbirds:
What's the Best Design for Implementation?

by
JASON DALE RIDDLE

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Fisheries and Wildlife Sciences

Raleigh, North Carolina

2007

APPROVED BY:

Peter T. Bromley

David T. Cobb

Nicholas M. Haddad

Stacy A. C. Nelson

Kenneth H. Pollock

Christopher E. Moorman
Chair of Advisory Committee

DEDICATION

This work is lovingly dedicated to Jenny for her devotion and patience, Jackson and Sam for their inspiration, and Mom and Dad for their support.

BIOGRAPHY

I spent most of my childhood and early adult life living with my parents (Dale and Joye) and brother (Jonathan) in Buffalo Junction, Virginia. As you might imagine, Buffalo Junction isn't heavily populated. As such, my brother, a few friends, and I were able to roam around the woods, fields, and Kerr Lake all the time. I was surrounded by the green life of pine stands, pasture, and row crops. I think my desire to continue to be surrounded by life was a major factor that led me to the biological sciences. I decided to major in Biology at the College of William and Mary in Virginia. Ruth Beck and Daniel Cristol graciously took me in and allowed me to participate in a number of bird monitoring and research projects. I had begun to find my niche. As I was finishing up at William and Mary, I decided to pursue a Masters in Biology. Specifically, I wanted a rugged field experience that would allow me to see a scientific project through from beginning to end. Matthew Rowe at Appalachian State University agreed to take me on, and through a series of serendipitous events I ended up on an avian fire ecology project in beautiful Linville Gorge Wilderness. By this time I was becoming very interested in disturbance and early-succession birds. As I was finishing up my Masters, I was fortunate to gain some technical experience with the US Forest Service and some logging and forestry experience with family and friends. This opened up a major door for my career. In 2003, the Department of Forestry offered a Hofmann Forest Fellowship to me so I could pursue a Ph.D. at North Carolina State University. Chris Moorman agreed to take me on, and over time this project emerged. My interests in early-succession birds have continued to grow. One little critter, the bobwhite quail, has really found a place in my heart. Behaviorally, ecologically, and culturally, it is surely one of the greatest creatures in the world. Chris graciously allowed me the freedom to pursue other

developing interests as part of my project and graduate experience, namely detectability and statistics. As a result of Chris' flexibility and our integration of new sampling methods into this project, I will soon be starting a post-doctoral fellowship with Ken Pollock and Ted Simons in the Department of Zoology.

It truly has been a long, strange trip since I left Buffalo Junction. But, it's been a beautiful and deeply fulfilling journey.

ACKNOWLEDGEMENTS

It's been said that it takes a village to raise a child. I think the same thing applies to getting a Ph.D.! I could easily write a hundred pages of thanks to everyone who has made this possible. In the spirit of conserving a few trees and cutting my printing costs, I'll try to keep it a bit shorter than that.

First, I want to thank God for blessing us with the universe, senses to experience it, curiosity, and minds to pursue it. I'm thankful to live in this time and in this country, where we can conduct science and conservation with freedom.

My wife, Jenny, has been so supportive of this shared dream. I'm so thankful to have her. She's one of a kind, and I'm so lucky to be married to her. I couldn't have done any of this without her love and support. She knew when to give me a shoulder to cry on and when to give a swift kick in the pants to get me moving.

My boys, Jackson and Sam, have been such an inspiration. They have helped me to understand the importance of conservation in a new way. I hope this work makes your world better.

I want to thank my parents for their love and care. They encouraged my interest in science from a young age. Of equal importance, they set an example for me as conservationists by filling our neck of the woods with bluebird houses! They have continued to encourage my family and me with their prayers, advice, child care, and financial support. I couldn't have done it without you!

Tracy and Sherri Gold made important contributions to my spiritual growth and critical thinking in high school and early college. They did a wonderful job at the difficult

task of showing me how to question norms and authority, while still loving and respecting others.

Steve Webster also was a huge influence during my high school and early college years. He encouraged me to question authority and conventional wisdom. Steve embodies “thinking outside of the box” and I am forever grateful for his example in this as well as all the conversations we had while working.

The Wilderness Society, North Carolina Garden Club, Daniel Boone Native Gardens, Rolling Hills Land and Timber, Lee Bethea, USDA National Forests of North Carolina, and the Grandfather Mountain Ranger District provided a number of influential employment, contract, and scholarship opportunities during my Masters program in particular. In retrospect, it seems like each of these opportunities came along in just the right sequence, and they all contributed to me ending up in this place with this project.

I would like to thank the Fisheries and Wildlife Sciences Program, the Department of Forestry and Environmental Resources, and the College of Natural Resources at North Carolina State University for their tremendous financial and logistical support of myself and this project. I don’t think I’ve ever seen a staff so dedicated to facilitating graduate students and their research! I’ll never forget it, and I’ll try to do the same if given the opportunity.

This project would not have been possible without the generous financial and logistical support of Murphy-Brown, LLC and their staff. Specifically, Dawn Williamson, Kraig Westerbeak, and the many technicians and farm managers who helped us were wonderful. This project also would not have been possible without the generous financial and logistical support of the North Carolina Wildlife Resources Commission. Their professionalism, dedication, knowledge, and “sense of place” are unmatched. I would

especially like to thank Terry Sharpe, Chris Turner, Jeff Marcus, and Benjy Strobe for their technical advice, ideas, and camaraderie. These folks *do and live* conservation! I am so encouraged that private business, government agencies, and university researchers can come together and make a difference for wildlife in a way that benefits everyone.

I want to thank all the technicians that helped collect data for this project: Fern Perkins, Amelia Savage, Will Ricks, Caroline Reddy, Jeremy Remington, Josh McCormick, Chesley Ward, Krista Yantis, Stephen Long, Brad Herring, and Adam Sabatine. I want to give an extra special thanks to Fern for help at the beginning of the project and willingness to work all three summer field seasons! Many aspects of this work would not have been possible without her commitment and co-supervision of other field technicians and research activities.

To my committee, “The Agrinauts”, thank you for your commitment to these birds, this project, and me. Chris was very enthusiastic and always willing to get dirty in the field with the technicians and me. Chris took a chance with me because we had no project or funding other than my fellowship when I began. Chris was very open to various project ideas, and I think we settled on a great one. Chris encouraged me to co-author grants, co-teach Urban Wildlife Management, and participate in a variety of outlets for our research. I am particularly thankful for the landowner workshops with which we helped. Ken is one of the most encouraging professors with whom I’ve ever worked. His sound, yet practical, statistical advice was wonderful. Working with Ken has been one of the greatest academic honors of my career. Pete’s ability to bring everything back to the perspective of the landowner was very useful. He did a great job of reminding me that the benefits of research can only be realized fully when they are clearly communicated with other scientists, resource

professionals, and the public. Without Pete's labors, bobwhite conservation would not be where it is today, and we are all indebted to him for that. This project would not have been possible without David's support. Having him and the Commission behind us was critical to our success. Nick did a great job of encouraging me as an ecologist. I really appreciated his efforts to emphasize ecological principles and concepts. Stacy was a tremendous help with our landscape-level data and GIS efforts. His willingness to meet with me in the lab or look at our coverages on his own time was very much appreciated. I want to give special thanks to Terry again as he basically functioned as a non-voting committee member in addition to being a liaison between Chris and I, Murphy-Brown, LLC, and the Commission. Terry was always cool-headed and exceptionally insightful. His kind demeanor and intimate knowledge of the wildlife and plants of our area give him an almost mystical, and certainly saintly, presence in the field.

TABLE OF CONTENTS

List of Tables	xi
----------------------	----

List of Figures	xii
-----------------------	-----

The importance of habitat shape and landscape context to northern bobwhite populations: an experiment with field borders

Title page	1
Abstract	2
Study Area	6
Methods	7
Experimental Design	7
Data Collection	9
Summer Abundance	9
Artificial Nest Study	10
Fall Covey Abundance	12
Vegetation	12
Analysis	13
Summer Abundance	13
Artificial Nest Study	14
Fall Covey Abundance	14
Vegetation	15
Results	15
Summer Abundance	15
Artificial Nest Study	16
Fall Covey Abundance	16
Vegetation	17
Discussion	17
Management Implications	22
Acknowledgements	24
Literature Cited	25

The importance of agriculture-dominated landscapes and lack of field border effect for early-succession songbirds

Title page	39
Abstract	40
Study Areas	45
Methods	46
Experimental Design	46
Data Collection	48
Songbird Density	48
Nest Success and Brood Parasitism Frequency	49
Analysis	50

Songbird Density50
 Nest Success and Brood Parasitism Frequency50
 Results.....51
 Songbird Density51
 Nest Success and Brood Parasitism Frequency52
 Discussion.....52
 Management Implications.....56
 Acknowledgements.....58
 Literature Cited.....58

A comparison of the time-of-detection and an empirical logistic regression method
 for estimating northern bobwhite covey abundance

Title page73
 Abstract.....74
 Study Area79
 Methods.....79
 Empirical Method of Wellendorf et al. (2004)79
 Time-of-detection Method80
 Analysis.....80
 Results.....82
 Discussion.....82
 Recommendations.....85
 Acknowledgements.....88
 Literature Cited.....88

LIST OF TABLES

The importance of habitat shape and landscape context to northern bobwhite populations: an experiment with field borders

Table 1. Means (SE) of field border and row crop area (ha) per farm, North Carolina (2004-2006).	36
Table 2. Least squares means (SE) of summer abundance per count/per farm, North Carolina (2004-2006).....	37
Table 3. Means (SE) of the cone of vulnerability (degrees), zone of vulnerability (m), and cover (%) of open ground, herbaceous, and woody vegetation, North Carolina (2004-2006).	38

The importance of agriculture-dominated landscapes and lack of field border effect for early-succession songbirds

Table 1. Means (SE) of field border and row crop area (ha) per farm, North Carolina (2004-2006)	70
Table 1. Least-squares means (SE) of focal species densities (males/7854 m ²) with and without red-winged blackbirds on farms, North Carolina (2004-2006).	71
Table 2. Least-squares means (SE) of indigo bunting/ blue grosbeak nest survival probabilities and brood parasitism frequency on farms, North Carolina (2004-2006).	72

A comparison of the time-of-detection and an empirical logistic regression method for estimating northern bobwhite covey abundance

Table 1. AICc, Delta AICc, AICc weights, likelihoods, parameters, and deviance for closed-capture models used with the time-of-detection method in program MARK. All data were collected from commercial hog farms, North Carolina (2004-2006).	94
---	----

LIST OF FIGURES

The importance of habitat shape and landscape context to northern bobwhite populations: an experiment with field borders

- Figure 1. Farm locations and treatment assignments in Coastal Plain, North Carolina (2004-2006).32
- Figure 2. Overhead view of an artificial nest with lid closed (a). Overhead view of an artificial nest partially depredated (2 of 6 eggs missing) by a raccoon (prints indicated by black arrows) in the Coastal Plain, North Carolina, 2006 (b).33
- Figure 3. Least squares means and 95% confidence intervals for the average bobwhite count/farm during the summer on 24 farms in the Coastal Plain, North Carolina. “Before” data are from 2004. “After” data are the average of 2005 and 2006.34
- Figure 4. Means and 95% confidence intervals for the proportion of failed nests/farm on 24 farms (2005 and 2006 combined) in the Coastal Plain, North Carolina.35

The importance of agriculture-dominated landscapes and lack of field border effect for early-succession songbirds

- Figure 1. Farm locations and treatment assignments in Coastal Plain, North Carolina (2004-2006).66
- Figure 2. Least-squares means and 95% CIs of focal species density (males/7854 m²) with and without red-winged blackbirds (RWBL) on farms in agriculture- and forest-dominated landscapes, North Carolina (2004-2006).67
- Figure 3. Least-squares means and 95% CIs for indigo bunting density (males/7854 m²). Pre = before field borders, Post = after field borders, N = Nonlinear borders, L = Linear borders, Ag = Agriculture-dominated landscapes, For = Forest-dominated landscapes, North Carolina (2004-2006).68
- Figure 4. Least-squares means and 95% CI for indigo bunting/blue grosbeak nest success probabilities and brood parasitism frequencies on farms in agriculture- and forest-dominated landscapes, North Carolina (2004-2006).69

September 5, 2007
Jason D. Riddle
Department of Forestry and Environmental Resources
North Carolina State University
Campus Box 8008
Raleigh, NC 27695-8008
919-215-9517 (phone)
jdriddle@unity.ncsu.edu
919-515-6193 (FAX)

RH: Quail, habitat shape, and landscape context. Riddle et al.

**The importance of habitat shape and landscape context to northern bobwhite
populations: an experiment with field borders**

Jason D. Riddle, Department of Forestry and Environmental Resources, North Carolina State
University, Campus Box 8008, Raleigh, NC 27695-8008.

Christopher E. Moorman, Department of Forestry and Environmental Resources, North
Carolina State University, Campus Box 8008, Raleigh, NC 27695-8008.

Kenneth H. Pollock, Department of Zoology, North Carolina State University, Campus Box
7617, Raleigh, NC 27695-7617.

Abstract: Northern bobwhite (*Colinus virginianus*) populations have declined nationally for at least the last four decades. Field borders have been promoted as an important component of conservation plans to reverse this decline. Characteristics, such as shape and the landscapes in which field borders are established have the potential to influence their effectiveness for recovering northern bobwhite populations. We established narrow, linear (~3m wide) and nonlinear field borders on farms in agriculture-dominated and forest-dominated landscapes in the Coastal Plain of North Carolina after collecting pre-treatment data on summer bobwhite abundance and fall coveys. We measured the impact of field border establishment on summer abundance, artificial nest success, and fall covey abundance. After the establishment of field borders, summer bobwhite abundance nearly doubled on farms in agriculture-dominated landscapes and increased significantly on farms with nonlinear field borders. Summer bobwhite abundance did not increase on farms with linear field borders in forest-dominated landscapes. There was a trend towards an increase in fall coveys on farms in agriculture-dominated landscapes and a decrease on farms in forest-dominated landscapes. Artificial quail nest depredation rates were similar across all treatments indicating that bobwhite nests in narrow, linear habitats are no more likely to be depredated than nests in large nonlinear block habitats. Nonlinear and narrow, linear field borders can be used to increase bobwhite numbers on farms in landscapes dominated by agriculture. Less flexibility exists in forest-dominated landscapes, where only nonlinear field borders, or perhaps wide linear borders (e.g., > 10m), may result in an increase.

Key Words: artificial nests, *Colinus virginianus*, coveys, cropland, North Carolina, point counts

Northern bobwhite (*Colinus virginianus*) declined annually by 3% in the United States from 1966 to 2005 according to the Breeding Bird Survey (Sauer et al. 2005). Declines have been more intense in recent years and in some localized portions of the species' range. For example, bobwhite in North Carolina declined by 5.9%/year from 1980-2005 (Sauer et al. 2005). Bobwhite generally depend on early-succession habitats such as farm fields and grasslands, grass-brush rangelands, old fields and other recently fallow vegetation, cutovers, and open forests with a well developed herbaceous layer, especially when maintained by fire (see Brennan 1999 and references therein). Declines in northern bobwhite typically have been associated with the loss or degradation of these habitats, which has been a result of modern intensive agriculture, closed canopy pine plantations, urbanization, and fire suppression (Klimstra 1982, Brennan 1991, Askins 1993, Roseberry 1993, Brawn et al. 2001, Hunter et al. 2001).

Precipitous declines in northern bobwhite have generated much interest in developing practical conservation solutions, especially on private lands (e.g., Northern Bobwhite Conservation Initiative, hereafter NBCI). Dimmick et al. (2001) estimated that 78% of the NBCI's goal of increasing the bobwhite population by 2.7 million coveys can be met on private farmland. In particular, field borders have been emphasized as an important farmland conservation practice to slow or reverse quail declines (Dimmick et al. 2001). Field borders are field margins that are either allowed to go fallow or planted to some vegetation other than crops for erosion control, wildlife habitat, or crop benefits (e.g., Integrated Pest Management). A variety of field border practices for bobwhite and other early-succession birds currently are promoted and subsidized by federal and state programs, including the Conservation Reserve Program's (CRP) Upland Bird Habitat Buffer (CP-33; USDA 2004)

and the North Carolina Wildlife Resources Commission's (NCWRC) Cooperative Upland Habitat Restoration and Enhancement Program (CURE; Cobb et al. 2002). Field borders have the potential to provide nesting habitat, movement corridors, and cover for bobwhite (Burger et al. 1995, Puckett et al. 1995, Puckett et al. 2000) by providing usable space (Guthery 1997). Establishment of field borders nearly doubled the number of bobwhite coveys on farms in eastern North Carolina (Palmer et al. 2005). The subsidization of field border practices combined with their apparent high potential for increasing bobwhite populations makes them a cost effective conservation solution for private landowners. However, little is known about how particular field border characteristics and the surrounding landscape influence their effectiveness.

Traditionally, field borders have been linear habitats because this shape is considered more economical and conducive to other farming activities (Stoddard 1931, Morris 1998). However, the shape of a field border (linear or nonlinear) may have dramatic impacts on its value for northern bobwhite and other early-succession wildlife species. Linear field borders that are too narrow may promote negative edge effects and possibly act as population sinks for ground nesting birds via increased predator activity (Pedlar et al. 1997, Dijak and Thompson 2000) and nest depredation (Shalaway 1985, Camp and Best 1994, Clark and Bogenschutz 1999). For example, important nest predators such as raccoons (*Procyon lotor*) may be attracted to farm field edges and linear habitats with woody vegetation (e.g., fencelines) and use them for foraging and as travel lanes (Fritzell 1978, Pedlar et al. 1997, Dijak and Thompson 2000). Low nest success because of depredation has been suspected in at least one study of linear field borders (Puckett et al. 1995). Concentrating the same area of habitat into a nonlinear border may help reduce negative edge effects. However, dispersing

northern bobwhite may be less likely to encounter consolidated nonlinear field borders than highly interspersed linear borders of equal area. Similarly, linear borders may facilitate movements between other habitat patches.

The local abundance of northern bobwhite is greatly influenced by landscape-scale patterns (Roseberry and Sudkamp 1998). Thus, the effectiveness of local management efforts, such as field borders, may vary depending on the landscape matrix in which they occur. Roseberry and Sudkamp (1998) even advised that local-scale management efforts for bobwhite should be performed only within landscapes potentially suitable for this species. Similarly, Williams et al. (2004) suggested that conservation efforts should be focused on areas where populations already are present and where habitat improvements are possible. Presently, higher bobwhite densities are associated with landscapes that have a significant agricultural component. In particular, high percentages of row crops have been shown repeatedly to be associated with high bobwhite densities throughout much of their range (e.g., Brady et al. 1993, Roseberry and Sudkamp 1998, Sharpe et al. 2002). Heavily forested landscapes, especially those with closed canopy forests, typically do not provide suitable habitat for bobwhite (Bell et al. 1985) and can impede dispersal (e.g., via direct mortality, S.D. Wellendorf, unpublished data) and possibly also impede recolonization of habitat islands embedded in the forest matrix (Fies et al. 2002). Predator communities and their impacts also are likely to differ between forest- and agriculture-dominated landscapes (Thompson and Burhans 2003).

We examined the effect of establishing narrow, linear and nonlinear field borders on farms in landscapes dominated by either agriculture or forest on: summer northern bobwhite abundance; covey abundance; and depredation of artificial nests. Our primary goals were to

advance knowledge about bobwhite response to habitat manipulations and to provide agencies such as the Natural Resources Conservation Service (NRCS; which helps landowners by providing conservation plans for CP-33 and other CRP conservation practices) and NCWRC with practical recommendations for maximizing the impact of field borders for bobwhite and improving programs such as CRP and CURE, respectively. We hypothesized that field border establishment would increase summer bobwhite abundance and fall covey abundance. We also hypothesized that increases would be larger on farms in agriculture-dominated landscapes than in forest-dominated landscapes, and that bobwhite would respond differently to linear and nonlinear field borders. Finally, we hypothesized that artificial nest depredation rates and predator activity would differ in linear and nonlinear field borders, and in agriculture- and forest-dominated landscapes.

Study area

Our study was conducted on 24 commercial hog farms located in Bladen, Columbus, Duplin, Pender, Sampson, Scotland, and Robeson counties of the southern Coastal Plain of North Carolina (Figure 1). All farms were owned and operated by Murphy-Brown, LLC. Study sites were selected from a pool of over 200 company farms to minimize the potentially confounding differences among farms (e.g., crop rotations, recent timber activity, etc.). Each hog farm had one or more ‘hog houses’, which were confinement areas for hog production. Hog waste was collected into one or more lagoons adjacent to the hog house(s). This waste was applied to row crop and hay fields as a form of nutrient management. Most farms were on a crop rotation of corn, soybeans, and winter wheat, although some farms also grew cotton.

Methods

Experimental design

Treatments were arranged in a balanced 2 x 2 factorial with field border shape (linear or nonlinear) and landscape context (agriculture- or forest-dominated) as the two factors. There were six replicate farms for each of the four treatment combinations. We were not able to randomize field border shape on farms in either landscape due to logistical constraints. However, the pre- vs. post-treatment contrasts we were able to perform (see below) were robust to our lack of randomization due to the BACI-like nature of our design (Morrison et al. 2001). We were able to randomize aspects of vegetation sampling and artificial nest placement (see below) at the farm-level.

Field borders were established along the edges of row crop fields by allowing demarcated areas to go fallow following row crop harvest. Location of all field borders was based on patterns of waste application and advice given by farm managers and other Murphy-Brown, LLC personnel. Additionally, we located linear borders parallel to crop rows when possible to reduce the likelihood of encroachment by farm machinery. For nonlinear borders, we marked off nonlinear areas to go fallow in the corners or ends of fields. Individual linear field borders were ~3 m wide and varied by length (range = 66.40-1938.95 m; mean = 475.44; SE = 47.91) and therefore area (0.02-0.59 ha; mean = 0.14; SE = 0.01), whereas individual nonlinear field borders varied by shape and size (range = 0.05-2.48 ha; mean = 0.25; SE = 0.04). Because of the spray patterns, large size, and unusual shape of two fields on one farm in an agriculture-dominated landscape, two nonlinear field borders were much larger than the rest (2.48 and 1.32 ha, respectively). When these are excluded, the range in individual nonlinear field border area was (0.05-0.81 ha; mean = 0.20; SE = 0.02).

Field borders comprised ~2-3% of the total row cropped area on each farm. Total row crop area on each farm (and therefore total field border area) was higher on farms in agriculture-dominated landscapes and on farms with nonlinear borders (Table 1). However, when the aforementioned farm with very large fields and field borders is excluded, average row crop and field border areas (ha) were much more similar on farms in agriculture-dominated landscapes (row crop mean = 43.39, SE = 8.22; field border mean = 1.00, SE = 0.19) and on farms with nonlinear field borders (row crop mean = 50.4, SE = 8.04; field border mean = 1.26, SE = 0.19).

Farms were chosen from landscapes that were designated as either Focal Areas or Nonfocal Areas for northern bobwhite management by the NCWRC. A full description of the criteria and methodology used to differentiate these landscapes is available in Howell et al. (2002). For the purposes of this study, we emphasize that Focal Areas typically are agriculture-dominated landscapes (primarily row crops) whereas Nonfocal Areas typically are forest-dominated landscapes. To confirm that this was the case for our 24 study sites, we chose a central point on each farm and determined the amount of row crop and forest within a circular buffer with a radius of 2538 m (buffer area = 2023 ha). We used the same Landsat imagery and classification scheme as Howell et al. (2002) for this procedure. Farms in agriculture-dominated landscapes were surrounded by $49.0 \pm 1.8\%$ (mean \pm SE) row crops and $18.5 \pm 2.1\%$ forests. Farms in forest-dominated landscapes were surrounded by $20.1 \pm 2.3\%$ row crops and $44.9 \pm 3.8\%$ forests. The two landscapes were nearly perfect complements of each other with regards to the two parameters of interest.

Data collection

Summer abundance. Point count survey locations were established in 2004 in areas demarcated to become field borders. Each farm had 2-6 survey locations depending on farm characteristics and field border arrangement, but all survey locations were at least 250 m apart. All locations were sampled once in 2004 prior to the establishment of field borders, and once per year in 2005 and 2006 after field border establishment. Surveys were conducted from approximately 15 min after sunrise until approximately 1000 EST from May 15-June 30.

We used a novel combination of recently proposed point count methods, the dependent double-observer (Nichols et al. 2000) and the time-of-detection approach (Allredge et al. 2007), to allow estimation of detection probabilities. The time-of-detection approach is unusual in that it accounts for both components of the detection process: the probability that a bird sings and the probability that it is detected given that it sings. The common survey methods (e.g., double-observer and distance based methods) only account for the latter component and may lead to downward biased estimates of abundance or density when the probability that a bird sings is less than 1. Combining the time-of-detection approach with the double-observer approach can allow one to separate both components of the detection process and thereby evaluate the relative contribution of each (Pollock et al. *in review*).

To execute this novel method, two observers alternated roles as the primary and secondary observer from one point count to another on each farm. Each point count lasted 10 min and was divided into four equal time intervals of 2.5 min. Point counts had unlimited radii and the relative location of each detected bobwhite was recorded on a field sheet to help

avoid double counting. For the purposes of this paper, we combined observations from the primary and secondary observers within each time interval (i.e., only used the time-of-detection method) for analysis in MARK (White and Burnham 1999). The detection probability estimate provided by using only the time-of-detection method is the product of the probability that a bird sings and the probability that it is detected given that it sings (Allredge et al. 2007). Therefore, no information is lost by combining observations from both observers and using only the time-of-detection method.

We measured breeding season male abundance, however, we use the term “summer abundance” of northern bobwhite to facilitate comparisons in the Discussion section with other studies that have collected the data similarly and used the same terminology (e.g., Palmer et al. 2005). Additionally, bobwhite maintain remarkably stable sex ratios (Stoddard 1931, Leopold 1945, Rosene 1969, Brennan 1999), such that the number of males in a population should be proportional to the number of females.

Artificial nest study. On 12 farms (three in each treatment combination), we conducted an artificial bobwhite nest experiment in 2005 and 2006. On each farm, we established 6 nest sites each year within field borders. On the 6 farms with linear field borders, nests were placed directly in the middle of the fallow habitat (i.e., ~1.5 m from either edge). The approximate point of nest placement was determined by stratifying linear field borders into 6 segments of approximately equal length and then randomly selecting a point within that segment. Once the point had been located, we surveyed it and the immediate area to choose an exact location (~1.5 m from either edge) that would require the least amount of disturbance for nest establishment. In nonlinear field borders, nests also were placed in the middle except when there were fewer field borders than nests. When this

occurred, extra nests were placed at a random point 1.5 m from the edge of the largest field border(s). For example, if a farm had 5 nonlinear field borders, then five nests would be placed in the middle of each field border. In the largest field border, the 6th nest would be placed at a random bearing from the central nest at a distance of 1.5 m from the edge. In both linear and nonlinear field borders, nests were never closer than 20 m from one another.

We used the same artificial nests and a modified version of nest establishment and monitoring as Gillis (2000). Nest sites were established by removing all vegetation and debris from a circular area with a 60-cm diameter. Next, we tamped the ground with the sole of our boots until we had packed the soil into a hard surface. We then made a sand mixture by combining approximately 2 liters of sand box sand, 2 ounces of mineral oil, and various amounts of cement mix coloring to match the surrounding soil color. This mixture was sifted over the hard packed circle to create a sand ring to aid in predator identification. An artificial bobwhite nest was placed in the middle of the sand ring (Figure 2). The above-ground portion of the nest was approximately 7.5 cm tall with a diameter of approximately 15.25 cm. Each nest had metal pins on the bottom that were several cm long and helped anchor the nest to the ground. All nests had a metal frame construction with camouflage fabric woven around the exterior for disguise. Each nest had a lid, which could be opened to place eggs or to monitor nest contents at subsequent visits. Nests also had a small opening on one side to mimic the entrance of a real bobwhite nest. Six Japanese quail (*Coturnix coturnix*) eggs were placed in the middle of each nest for bait. Nests were then visited once per week for two weeks to check for depredation. A nest was removed if any of the eggs were missing, destroyed, or damaged by predators. When possible, predators were identified by their

tracks. We wore surgical latex gloves while establishing and checking nests to minimize scent contamination.

Fall covey abundance. We sampled fall coveys on all farms each year beginning in the first week of October and ending in the second week of November. In the southeastern United States, coveys are most likely to call and least likely to exhibit variation in call rates during this interval (Wellendorf et al. 2004). Each farm was sampled once per fall at a single location, which was approximately central to the field borders we established. We used a modified version of the sampling recommendations by Wellendorf et al. (2004). Each count began 45 min before sunrise and lasted one hour. Covey locations were recorded on digital orthogonal quarter-quadrangle (DOQQ) print-outs of each farm to help avoid double counting. At sunrise, we estimated cloud cover to the nearest 10% and recorded wind speed in km/hr with a hand held anemometer. Later, we obtained barometric pressure readings (in/Hg) for the 6-hr period prior to sunrise from local weather stations through the North Carolina State Climate Office. These readings were used to calculate any change in barometric pressure during the 6 hours prior to sunrise (Wellendorf et al. 2004). These environmental data along with the number of calling coveys were used to adjust call counts to obtain an abundance estimate using the equation provided in Wellendorf et al. (2004).

Vegetation. We sampled field border vegetation at each breeding season point count location in 2005 and 2006. Each point count location had three 1- x 1-m sub-plots. One sub-plot was located at the center of the point count. In linear field borders, the other two sub-plots were located opposite from each other 25 m from the center of the point count. One of the sub-plots was located within but adjacent to the interior side of the field border (the side adjacent to crops) and the other was located within but adjacent to the exterior side of the

field border. In nonlinear field borders, the location of the other two sub-plots was determined by randomly selecting a bearing and distance (within 50 m) for each sub-plot.

At each sub-plot, a 1- x 1-m sampling grid was placed on the ground. An angle locator attached to a 2-m PVC pole (5.1 cm diameter) was placed in the center of the grid. We tilted the pole towards each of the four corners of the sampling grid until it came in contact with vegetation to obtain four measures of the cone of vulnerability (Kopp et al. 1998). The bottom 15 cm of the PVC pole was covered with duct tape. We measured the zone of vulnerability by pacing out from each sub-plot in the four cardinal directions and recording the distance at which the lower 15-cm section of the PVC became totally visually obscured when viewed from a height of 1 m (Kopp et al. 1998). We visually estimated the percent cover of grass, woody vegetation, forbs, and open ground within the 1- x 1-m grid from 15 cm up to 2 m (sum of all four cover types = 100%).

In 2006, we noted which, if any, plant species comprised at least 33% of each sub-plot in an attempt to quantify the dominant plant species in field borders on each farm. Because most plots did not have $\geq 33\%$ coverage by any one species, we also determined the single plant species that most typified the field border within 50 m of the point count center regardless of the total coverage for that species.

Analysis

Summer abundance. For summer bobwhite abundance, we entered detection histories from each point count into the “Huggins Closed-capture with Heterogeneity” option in program MARK (White and Burnham 1999) to determine if detection probabilities differed between treatments and years. In some cases, we had multiple detection histories for a single bird (i.e., the same bobwhite was detected from multiple survey locations on each farm).

When this occurred, only the first detection was used in program MARK. The best model was M_{bh} (trap response and heterogeneity with a two point mixture) applied across treatments and years (AICc weight = 0.973). The detection probability was 0.49 and we were not able to detect a difference between years and treatments. Therefore the unadjusted counts could be used in our subsequent analyses because they were directly proportional to population size and detection probability did not vary substantially (Williams et al. 2002).

We analyzed the average count per farm (observations from both observers combined) using a 2 x 2 split-plot ANOVA (PROC GLM; SAS) with landscape context and habitat shape as the whole-plot factors. The split-plot factor was year (there were two levels: the pre-treatment year and the weighted average of the two post-treatment years). One-tailed pre-planned orthogonal contrasts were used (in the absence of a landscape context*habitat shape*year interaction) to test for an overall effect of field borders (i.e., summer abundance before field border establishment vs. after field border establishment). We also used one-tailed pre-planned orthogonal contrasts to compare summer abundance before and after field border establishment for both levels of each factor separately.

Artificial nest study. We averaged data from 2005 and 2006 for all artificial nest analyses. We used a 2 x 2 ANOVA (PROC GLM; SAS) with landscape context and habitat shape as the treatment factors to compare the mean proportion of failed nests/farm. Also as an adhoc test, we compared the proportion of failed nests in the center of blocks (i.e., edge nests excluded) to the proportion of failed nests in linear field borders to confirm that the inclusion of nonlinear field border edge nests did not bias the previous analysis.

Fall covey abundance. Fall covey data were sparse and not suitable for the same parametric procedures we used for the analyses on breeding season bobwhite abundance.

However, the difference between the average of the post-treatment years (2005 and 2006) and the pretreatment year (2004) was analyzed in a 2 x 2 ANOVA with landscape and habitat shape as treatment factors (PROC GLM, SAS). We only were able to use five farms from each of the four treatment combinations for this analysis because logistical issues rendered the 2004 data from one farm in each treatment combination unusable.

Vegetation. We averaged vegetation structure data (i.e., everything but plant species data) from 2005 and 2006 for analyses. We compared the cone of vulnerability, zone of vulnerability, and percent cover of woody, open ground, and herbaceous (grasses + forbs) layers using a 2 x 2 MANOVA (PROC GLM; SAS). We also considered each response variable separately in 2 x 2 ANOVAs (PROC GLM; SAS).

Results

Summer abundance

There was no interaction of landscape context, habitat shape, and year ($F_{1,20} = 0.06$, $P = 0.8036$). Therefore, we proceeded to test for an effect of field borders and for main effects between the pre and post-treatment years with contrasts (Table 2). Summer abundance increased from 0.65 (SE = 0.09) bobwhite/count/farm in the pre-treatment year to 0.94 (SE = 0.12) in the post-treatment years. Summer abundance nearly doubled in agriculture-dominated landscapes from a mean of 0.54 (SE = 0.17) to 1.01 (SE = 0.12) bobwhite/count/farm from pre-treatment to post-treatment years, respectively (Figure 3). However, summer abundance did not increase significantly on farms in forest-dominated landscapes from the pre-treatment to post-treatment years. Summer abundance increased on farms with non-linear field borders from 0.68 (SE = 0.17) to 1.07 (SE = 0.12) bobwhite/count/farm from pre-treatment to post-treatment years, respectively (Figure 3).

Summer abundance did not increase significantly on farms with linear field borders from the pre-treatment to post-treatment years. There was no interaction of landscape context and field border shape in the post-treatment years ($F_{1,20} = 0.74$, $P = 0.4007$).

Artificial nest study

The mean proportion of failed nests/farm did not differ between landscapes ($F_{1,8} = 0.39$, $P = 0.5496$) or field border shapes ($F_{1,8} = 0.39$, $P = 0.5496$; Figure 4), and there was no interaction between landscape and shape ($F_{1,8} = 0.88$, $P = 0.3762$). The average proportion of failed nests/farm was 0.375 (SE = 0.042). When edge nests from nonlinear border farms were removed from analysis, the results were similar. Our lengthy nest visitation interval of 1 week, coupled with rain events and relatively low levels of nest depredation resulted in too few identifiable nest predators for analysis. Of 144 nests (all treatments and both years combined), 54 failed. Of those nests that failed, 29 could not be attributed to any particular predator. Of the depredation events with identifiable predators, 14 were raccoons, seven were insects (usually ants), two were rodents, one was an opossum (*Didelphis virginiana*), and one nest was crushed by farm equipment.

Fall Covey Abundance

The number of coveys/count/farm increased by 0.27 (SE = 0.73) in agriculture-dominated landscapes and decreased by 0.50 (SE = 0.67) in forest-dominated landscapes, but there was no landscape effect ($F_{1,16} = 0.55$, $P = 0.4680$). Similarly, there was no main effect of habitat shape ($F_{1,16} = 0.02$, $P = 0.8906$), or interaction of landscape and habitat shape ($F_{1,16} = 0.75$, $P = 0.3986$). The overall mean change in covey abundance was -0.12 (SE = 0.49). Even though the overall average change in covey abundance was negative, the 95% CI (-0.12

± 1.04) contains “0” and therefore suggests that the change was not significant at the $\alpha = 0.05$ level.

Vegetation

Collectively, there was no difference in vegetation variables by landscape ($F_{5,16} = 0.25$, $P = 0.9327$), shape ($F_{5,16} = 2.43$, $P = 0.0804$), or interaction of landscape and shape ($F_{5,16} = 0.59$, $P = 0.7107$). The cone of vulnerability, zone of vulnerability, and coverage (%) of open ground and herbaceous vegetation did not differ between landscapes or habitat shapes, and there were no interactions of landscape and habitat shape (Table 3). There also was no effect of landscape or interaction of landscape and shape on the percent cover of woody vegetation. However, there was more woody vegetation in linear field borders than in nonlinear field borders. Field borders on 22 of 24 farms were dominated or co-dominated by dog fennel (*Eupatorium capillifolium*).

Discussion

Overall, field borders increased the summer abundance of northern bobwhite on the farms we sampled by about 45%. In a study of 12 farms in three eastern North Carolina counties, Palmer et al. (2005) documented 40% more bobwhite during summer months on farms with field borders than on farms without field borders. In Dare County, North Carolina, Puckett et al. (1995) recorded almost twice as many bobwhite on two farming areas with field borders than on two without field borders. Collectively, these results suggest that field borders are an effective means of substantially increasing summer bobwhite populations, at least in the Coastal Plain of North Carolina.

We found, however, that not all landscapes and field border shapes resulted in similar northern bobwhite responses. The impact of field borders was much more pronounced on

farms in agriculture-dominated landscapes. Specifically, there were nearly twice as many bobwhite on farms in agriculture-dominated landscapes after the establishment of field borders. Conversely, summer bobwhite abundance only increased by about 16% on farms in forest-dominated landscapes. This result supports assertions that local management should be concentrated in landscapes that have high potential for a positive response by bobwhites (Roseberry and Sudkamp 1998, Cobb et al. 2002, Williams et al. 2004). The study sites used by Puckett et al. (1995) and Palmer et al. (2005) were in landscapes that could be characterized as being locally dominated by agriculture.

The impact of field borders on summer northern bobwhite abundance was more pronounced on farms with nonlinear borders than on farms with linear borders. Bobwhite increased by about 57% on farms with nonlinear borders. Conversely, bobwhite only increased by about 29% on farms with linear field borders. The field borders in the Puckett et al. (1995) and Palmer et al. (2005) studies were all linear, and both studies recorded larger increases in summer abundance than we did on farms with linear borders in our study. However, Puckett et al. (1995) used field borders that were approximately 3.5 m wide and placed along both sides of drainage ditches with widths of approximately 2.5 m. Bobwhite also seemed to make heavy use of drainage ditches in areas without field borders, suggesting that the ditches themselves also provided cover and movement corridors (Puckett et al. 1995). Therefore the effective width of field borders in the Puckett et al. (1995) study may have been closer to 9 or 10 m. Field borders in the Palmer et al. (2005) study were 3-5 m wide. Our linear field borders only averaged about 3 m in width. Therefore, the width of linear field borders across our three studies is proportional to the magnitude of bobwhite

increase during summer months. In other words, linear field borders of 3, 3-5, and 9-10 m widths resulted in bobwhite populations that were about 29, 40, and 92% larger, respectively.

We were not able to detect differences in the abundance of fall northern bobwhite coveys associated with our treatments. The large amount of variation (proportional SEs of over 100%) associated with the estimates from these farms likely hindered our ability to detect what patterns, if any, existed with this response variable. The mean change in agriculture-dominated landscapes was positive, whereas the mean change in forest-dominated landscapes was negative. While this relationship was not statistically significant, it does reflect the pattern we observed in the summer abundance data, namely that bobwhite populations respond favorably in agriculture-dominated landscapes. Palmer et al. (2005) were able to detect an increase in covey abundance of nearly two-fold on farms with field borders. Their study sites had a much higher covey density. Covey calling behavior is density-dependent, and covey call adjustments are more stable as the average number of coveys heard per count increases (Wellendorf et al. 2004). The large amount of variation in our covey counts may have resulted from the low abundances we heard (~1 covey/farm, unpublished data) or from the fact that we only were able to perform one covey call count per farm per year. It also is possible that while our field borders appear to have been sufficient habitat for breeding season bobwhites in some treatments, they may not have been attractive over-wintering habitat for coveys (e.g., individual field borders or total field border area/farm were too small).

Artificial northern bobwhite nests were equally successful in all treatments. Sixty-three percent of our artificial nests were successful when combined across years and treatments. On the same study sites as Palmer et al. (2005), Gillis (2000) documented 74%

nest success, but with only a 3 d artificial nest exposure. The most common identifiable nest predators in our study were raccoons. Eight of 14 nests depredated by raccoons were in nonlinear field borders. Of these, half were in the center of the borders and half along the edges. Even though we were not able to make a statistical assessment, it appeared that raccoon nest predation pressures were not affected by field border shape or nest placement within nonlinear field borders. Gillis (2000) also documented relatively high levels of raccoon activity, along with gray fox (*Urocyon cinereoargenteus*) and small mammals. Gillis (2000) worked with linear field borders only and determined that predator visitation rates on artificial nests did not differ between nests that were located within the interior or exterior edge of field borders. To the extent that artificial nest depredation is an indicator of real nest depredation, our results along with those of Gillis (2000) suggest that field border shape alone is likely to have little effect on survival of northern bobwhite nests.

The field borders that we established had structural characteristics that were favorable for nesting and brood rearing habitat (i.e., the field borders were high quality habitats). Specifically, the average zone of vulnerability was less than 12-13 m for all treatments, which is favorable for concealment from terrestrial predators (Kopp et al. 1998). The average cone of vulnerability was very “narrow”, with average angles less than 13°, which is favorable for cover from aerial predators (Kopp et al. 1998). Finally, the average amount of herbaceous cover was >10%, which has been suggested as the minimum for bobwhite nesting and brood-rearing habitat (Schroeder 1985). The remarkable uniformity of structure and major species composition within the field borders between farms suggest that bobwhite increases on farms with nonlinear field borders and on farms in agriculture-dominated landscapes were because of the treatments rather than within patch differences. The

structural uniformity (i.e., homogeneity) of our field borders also may help to explain the similarity in artificial nest depredation rates in field borders with different shapes. Increased habitat heterogeneity can decrease predator efficiency (Bowman and Harris 1980). Under typical CP-33 and CURE contracts, one-third of all field borders (or sometimes one-third of each field border) are to be disked or burned each year to keep them in a perpetual state of early-succession. We did not disk or burn sections of our borders because our agreement with Murphy-Brown, LLC was for only 2 yrs of field border growth. Burning or disking one-third of all available field border habitats likely would result in increased habitat heterogeneity.

We were not able to identify with certainty the mechanisms by which field borders increased northern bobwhite populations. However, we suggest that spring dispersal may have played an important role, at least initially. We observed an increase in summer bobwhite abundance in 2005 immediately following field border establishment, but we did not see an increase from 2005 to 2006 (JDR, unpublished data). Because field borders did not exist in 2004, they could not have contributed to this initial increase by providing additional nesting opportunities and increased recruitment. Instead, the increase likely resulted from individuals dispersing from adjacent areas. While bobwhite traditionally have been considered to be relatively sedentary, recent studies determined that ~25-41% of individuals disperse > 1.8 km from their natal site or winter range to their breeding range (Fies et al. 2002, Townsend et al. 2003, Cook 2004).

Research on the dispersal of male and female bobwhite has shown mixed results. Many previous studies have demonstrated that males move greater distances than females (see Fies et al. 2002 for a review). However, other studies have not documented this trend

(e.g., Stoddard 1931). Fies et al. (2002), Townsend et al. (2003), and Cook (2004) are probably the most accurate dispersal studies of bobwhites to date because they did not have study area boundaries and did not suffer from the limitations of band recoveries (Cook 2004). Townsend et al. (2003) demonstrated that both sexes dispersed equal distances, but males were more likely to disperse than females. Cook (2004) reported that females moved slightly farther than males, but that males were somewhat more likely to disperse. Fies et al. (2002) demonstrated that male and female bobwhites both disperse in equal proportions. Nevertheless, one must use caution when extrapolating dispersal trends from one landscape to another (Åberg et al. 1995, Cook 2004).

Dispersing quail should be more successful at locating suitable habitat when inter-patch distances are relatively small (Fies et al. 2002) and hostile habitats (e.g., closed canopy woodlands) are a minor landscape component. This probably explains why summer bobwhite abundance nearly doubled on farms in agriculture-dominated landscapes, but did not increase as a whole in forest-dominated landscapes. Interestingly, Townsend et al. (2003) reported that dispersers had higher survival probabilities and initiated more nests than nondispersers. Given our highly variable covey estimates, it is unclear if the increase in summer bobwhite abundance resulted in an increase in fall recruitment. Palmer et al. (2005) were able to use data from other studies associated with their sites to make an argument that increased bobwhite populations on their field border farms likely resulted from increased recruitment.

Management Implications

Based on our study results, we encourage using a landscape-level approach to select farms for northern bobwhite management with field borders. There appears to be flexibility

in the shape of field borders which can be used to promote bobwhite in agriculture-dominated landscapes. Even relatively modest amounts (2-3% of row crop area) of nonlinear and extremely narrow, linear field borders increased bobwhite on farms in agriculture-dominated landscapes. Field borders still may increase bobwhite populations in forest-dominated landscapes, but less flexibility exists in the kinds of field borders which can be used. Nonlinear, or perhaps wide (>10 m), linear borders will be necessary to increase bobwhite on farms in these landscapes. However, field border management combined with forest management for bobwhite (e.g., thinning and burning) may be effective for increasing bobwhites in both landscapes.

CP-33 and CURE do not encourage or cost-share the establishment of field borders that average widths of less than 9.1 or 6.1 m, respectively. We were unable to meet these criteria on our farms because of constraints associated with the amount of row crop acres required for hog waste application. We recognize that linear field borders with widths greater than or equal to 10 m may have resulted in a similar response to that of the nonlinear field borders in our project. In other words, wide, linear borders may provide the same, or possibly greater, benefits as our nonlinear borders regardless of landscape context. Nevertheless, if narrow, linear borders can increase bobwhite in some landscapes, then agency administrators should consider their subsidization, or at least refrain from discouraging their use in situations when this may be the only way to increase usable space for bobwhite (Guthery 1997). Crop production can be so low at field edges that farmers may lose money by farming them (Morris 1998). Therefore, some landowners may be willing to use narrow field borders even without financial assistance. For example, the farmers with whom we worked were able to allow 3-m-wide borders without compromising primary farm

functions (hog and crop production) or receiving assistance from cost-share programs. We do not encourage an “as little as necessary” attitude towards bobwhite habitat establishment by recommending the consideration of narrow, linear field borders. Rather, we recommend that narrow, linear borders be considered for use when they are the only option. Even narrow field borders have the potential to benefit a variety of wildlife species other than bobwhite as well as protect water quality (Marcus et al. 2000, Smith et al. 2005).

Our results indicate that significant increases in bobwhite are possible in agriculture-dominated landscapes and when nonlinear field borders are used, even if only a small percentage of the landscape is converted to field borders. Again, we do not encourage an “as little as necessary” approach to bobwhite habitat restoration. However, land managers should not avoid attempting to establish nonlinear field borders or field borders in agriculture-dominated landscapes just because they are not able to convert large amounts of the landscape to field borders.

We recommend that future research focus on relationships between field border width, the relative and absolute amount of field border per farm or field (e.g., Smith 2004), and bobwhite response. We also strongly encourage researchers to conduct similar replicated studies with radio-marked birds. This will assist in location of nests and provide movement information which could add to a greater mechanistic knowledge of field border benefits. We also strongly encourage researchers to study the combined effects of field border and forest management for northern bobwhites.

Acknowledgements

We thank our field technicians F. Perkins, A. Savage, W. Ricks, C. Reddy, J. Remington, J. McCormick, C. Ward, K. Yantis, S. Long, B. Herring, and A. Sabatine for

many long hours in the field. F. Perkins also co-supervised several of the technicians and helped coordinate research activities. D. Williamson, K. Westerbeak, and all of the Murphy-Brown, LLC staff provided invaluable assistance in farm selection, farm access, field border location, and other study logistics. A. Oswald and family and Murphy Family Farms provided housing. T. Sharpe provided invaluable technical advice and encouragement. P. Bromley, D. Cobb, N. Haddad, and S. Nelson gave useful comments on this manuscript. This project was supported financially by the Department of Forestry and Environmental Resources at North Carolina State University, the North Carolina Wildlife Resources Commission, Murphy Brown, LLC, and a grant from the USDA-NRCS/MSU Bobwhite Restoration Project.

Literature Cited

- Åberg, J., G. Jansson, J. E. Swenson, and P. Angelstam. 1995. The effect of matrix on the occurrence of hazel grouse (*Bonasa bonasia*) in isolated habitat fragments. *Oecologia* 103:265-269.
- Allredge, M. W., K. H. Pollock, T. R. Simons, J. A. Collazo, and S. A. Shriner. 2007. The time of detection method for estimating abundance from point count surveys. *The Auk* 124:653-664.
- Askins, R. A. 1993. Population trends in grassland, shrubland, and forest birds in eastern North America. *Current Ornithology* 11:1-34.
- Bell, B., K. Dancak, and P. J. Zwank. 1985. Range, movements and habitat use by bobwhites in southeastern Louisiana pinelands. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 39:512-519.

- Bowman, G. G., and L. D. Harris. 1980. Effect of spatial heterogeneity on ground-nest depredation. *Journal of Wildlife Management* 44:806-813.
- Brady, S. J., C. H. Flather, K. E. Church, and E. W. Schenck. 1993. Correlates of northern bobwhite distribution and abundance with land-use characteristics in Kansas. *Proceedings of the National Quail Symposium* 3:115-125.
- Brawn, J. D., S. K. Robinson, and F. R. Thompson III. 2001. The role of disturbance in the ecology and conservation of birds. *Annual Review of Ecology and Systematics* 32:251-276.
- Brennan, L. A. 1991. How can we reverse the northern bobwhite population decline? *Wildlife Society Bulletin* 19:544-555.
- Brennan, L. A. 1999. Northern Bobwhite (*Colinus virginianus*). In *the Birds of North America*, No. 397. A. Poole and F. Gill, editors. The Birds of North America, Inc., Philadelphia, PA.
- Burger, L. W., Jr., M. R. Ryan, T. V. Dailey, and E. W. Kurzejeski. 1995. Reproductive strategies, success, and mating systems of northern bobwhite in Missouri. *Journal of Wildlife Management* 59:417-426.
- Camp, M. and L. B. Best. 1994. Nest density and nesting success of birds in roadsides adjacent to rowcrop fields. *American Midland Naturalist* 131:347-358.
- Clark, W. R., and T. R. Bogenschutz. 1999. Grassland habitat and reproductive success of ring-necked pheasants in northern Iowa. *Journal of Field Ornithology* 70:380-392.
- Cobb, D. T., T. L. Sharpe, D. Sawyer, and D. O. Baumbarger. 2002. Integrating early-successional wildlife and 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.
- Cook, M. P. 2004. Northern bobwhite breeding season dispersal, habitat use, and survival in a Southeastern agricultural landscape. Thesis, University of Georgia, Athens, Georgia, USA.
- Dijak, W. D., and F. R. Thompson III. 2000. Landscape and edge effects on the distribution of mammalian predators in Missouri. *Journal of Wildlife Management* 64:209-216.
- Dimmick, R. W., M. J. Gudlin, and D. F. McKenzie, editors. 2001. The northern bobwhite quail initiative. Southeast Quail Study Group Technical Committee, Knoxville, Tennessee, USA.
- 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.
- Fritzell, E. K. 1978. Habitat use by prairie raccoons during the waterfowl breeding season. *Journal of Wildlife Management* 42:118-127.
- Gillis, J. R. 2000. The effects of predator reduction and nesting habitat enhancement on activity of nest predators of northern bobwhite. Thesis, North Carolina State University, Raleigh, North Carolina, USA.
- Guthery, F. S. 1997. A philosophy of habitat management for northern bobwhites. *Journal of Wildlife Management* 61:291-301.
- Howell, D. L., D. T. Cobb, and T. L. Sharpe. 2002. Selection of focal areas for northern bobwhite enhancement on private lands in North Carolina. *Proceedings of the Annual*

- Conference of the Southeastern Association of Fish and Wildlife Agencies 56:159-170.
- Hunter, W. C., D. A. Buehler, R. A. Canterbury, J. L. Confer, and P. B. Hamel. 2001. Conservation of disturbance-dependent birds in eastern North America. *Wildlife Society Bulletin* 29:440-455.
- Klimstra, W. D. 1982. Bobwhite quail and changing land use. *Proceedings of the National Bobwhite Quail Symposium* 2:1-5.
- Kopp, S. D., F. S. Guthery, N. D. Forrester, and W. E. Cohen. 1998. Habitat selection modeling for northern bobwhites on subtropical rangeland. *Journal of Wildlife Management* 62:884-895.
- Leopold, A. S. 1945. Sex and age ratios among bobwhite quail in southern Missouri. *Journal of Wildlife Management* 9:30-34.
- Marcus, J. F., W. E. Palmer, and P. T. Bromley. 2000. The effects of farm field borders on overwintering sparrow densities. *Wilson Bulletin* 112:517-523.
- Morris, J. T. 1998. Conservation decisions of agricultural producers in eastern North Carolina. Dissertation, North Carolina State University, Raleigh, North Carolina, USA.
- Morrison, M. L., W. M. Block, M. D. Strickland, and W. L. Kendall. 2001. *Wildlife study design*. Springer, New York, New York, USA.
- Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. *The Auk* 117:393-408.

- 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.
- Pedlar, J. H., L. Fahrig, and H. G. Merriam. 1997. Raccoon habitat use at 2 spatial scales. *Journal of Wildlife Management* 61:102-112.
- Pollock, K. H., M. W. Alldredge, and T. R. Simons. Separation of availability and perception processes for aural detection in avian point counts: a combined multiple observer and time-of-detection approach. *Avian Conservation and Ecology in review*.
- 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 of the Southeastern Association of Fish and Wildlife Agencies* 49:505-515.
- Puckett, K. M., W. E. Palmer, P. T. Bromley, J. R. Anderson, Jr., and T. L. Sharpe. 2000. Effects of filter strips on habitat use and home range of northern bobwhites on Alligator River National Wildlife Refuge. *Proceedings of the National Bobwhite Quail Symposium* 4:26-31.
- Roseberry, J. L. 1993. Bobwhite and the "new" biology. *Proceedings of the National Bobwhite Quail Symposium* 3:16-20.
- Roseberry, J. L., and S. D. Sudkamp. 1998. Assessing the suitability of landscapes for northern bobwhite. *Journal of Wildlife Management* 62:895-902.
- Rosene, W. 1969. *The bobwhite quail: its life and management*. Rutgers University Press, New Brunswick, New Jersey, USA.
- SAS Institute 2006. Version 9.1.3. SAS Institute, Cary, North Carolina, USA.

- Sauer, J. R., J. E. Hines, and J. Fallon. 2005. The North American Breeding Bird Survey, Results and Analysis 1966 – 2005. Version 6.2.2006. USGS Patuxent Wildlife Research Center, Laurel, MD.
- Schroeder, R. L. 1985. Habitat suitability index models: Northern bobwhite. U.S. Fish and Wildlife Service Biological Report 82 (10.104).
- Shalaway, S. D. 1985. Fencerow management for nesting songbirds in Michigan. *Wildlife Society Bulletin* 13:302-306.
- Sharpe, T., D. Howell, and M. J. Gudlin. 2002. Habitat management practices for agricultural cropland. Pages 59-63 *in* Dimmick, R.W., M.J. Gudlin, and D.F. McKenzie, editors. The northern bobwhite conservation initiative. Miscellaneous publication of the Southeastern Association of Fish and Wildlife Agencies, South Carolina.
- Smith, M. D. 2004. Wildlife habitat benefits of field border management practices in Mississippi. Dissertation, Mississippi State University, Starkville, Mississippi, USA.
- Smith, M. D., P. J. Barbour, L. W. Burger, Jr., and S. T. Dinsmore. 2005. Density and diversity of overwintering birds in managed field borders in Mississippi. *Wilson Bulletin* 117:258-269.
- Stoddard, H. L. 1931. The bobwhite quail: its habits, preservation, and increase. Third edition. Charles Scribner's Sons, New York, New York, USA.
- Thompson, F. R., and D. E. Burhans. 2003. Predation of songbird nests differs by predator and between field and forest habitats. *Journal of Wildlife Management* 67:408-416.
- Townsend, D. E., II, D. M. Leslie, Jr., R. L. Lochmiller, S. J. DeMaso, S. A. Cox, and A. D. Peoples. 2003. Fitness costs and benefits associated with dispersal in northern bobwhites (*Colinus virginianus*). *American Midland Naturalist* 150:73-82.

- United States Department of Agriculture. 2004. Farm Service Agency Notice CRP-479. Farm Service Agency, Washington DC.
- Wellendorf, S. D., W. E. Palmer, and P. T. Bromley. 2004. Estimating calling rates of northern bobwhite coveys and measuring abundance. *Journal of Wildlife Management* 68: 672-682.
- White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. *Bird Study* 46:S120-S139.
- Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. Analysis and management of animal populations: modeling, estimation, and decision making. Academic Press, San Diego, California, USA.
- Williams, C. K., F. S. Guthery, R. D. Applegate, and M. J. Peterson. 2004. The northern bobwhite decline: scaling our management for the twenty-first century. *Wildlife Society Bulletin* 32:861-869.

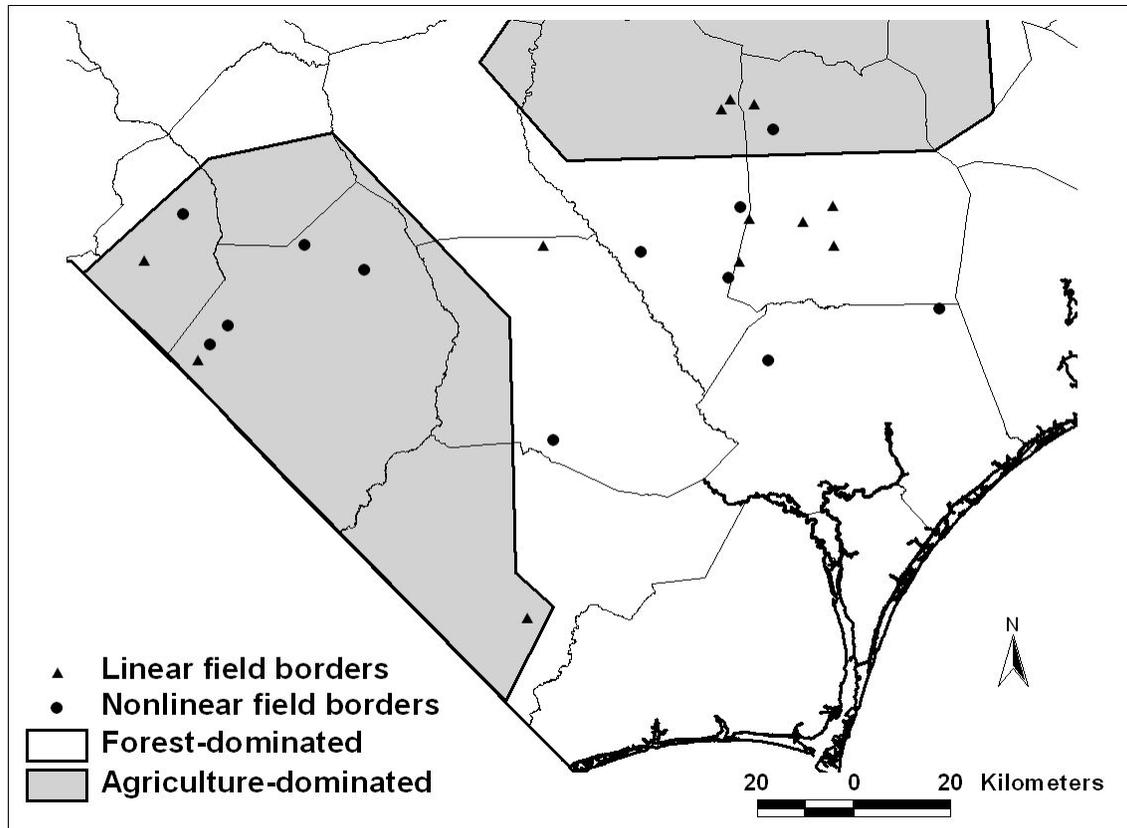


Figure 1. Farm locations and treatment assignments in Coastal Plain, North Carolina (2004-2006).



Figure 2. Overhead view of an artificial nest with lid closed (a). Overhead view of an artificial nest partially depredated (2 of 6 eggs missing) by a raccoon (prints indicated by black arrows) in the Coastal Plain, North Carolina, 2006 (b).

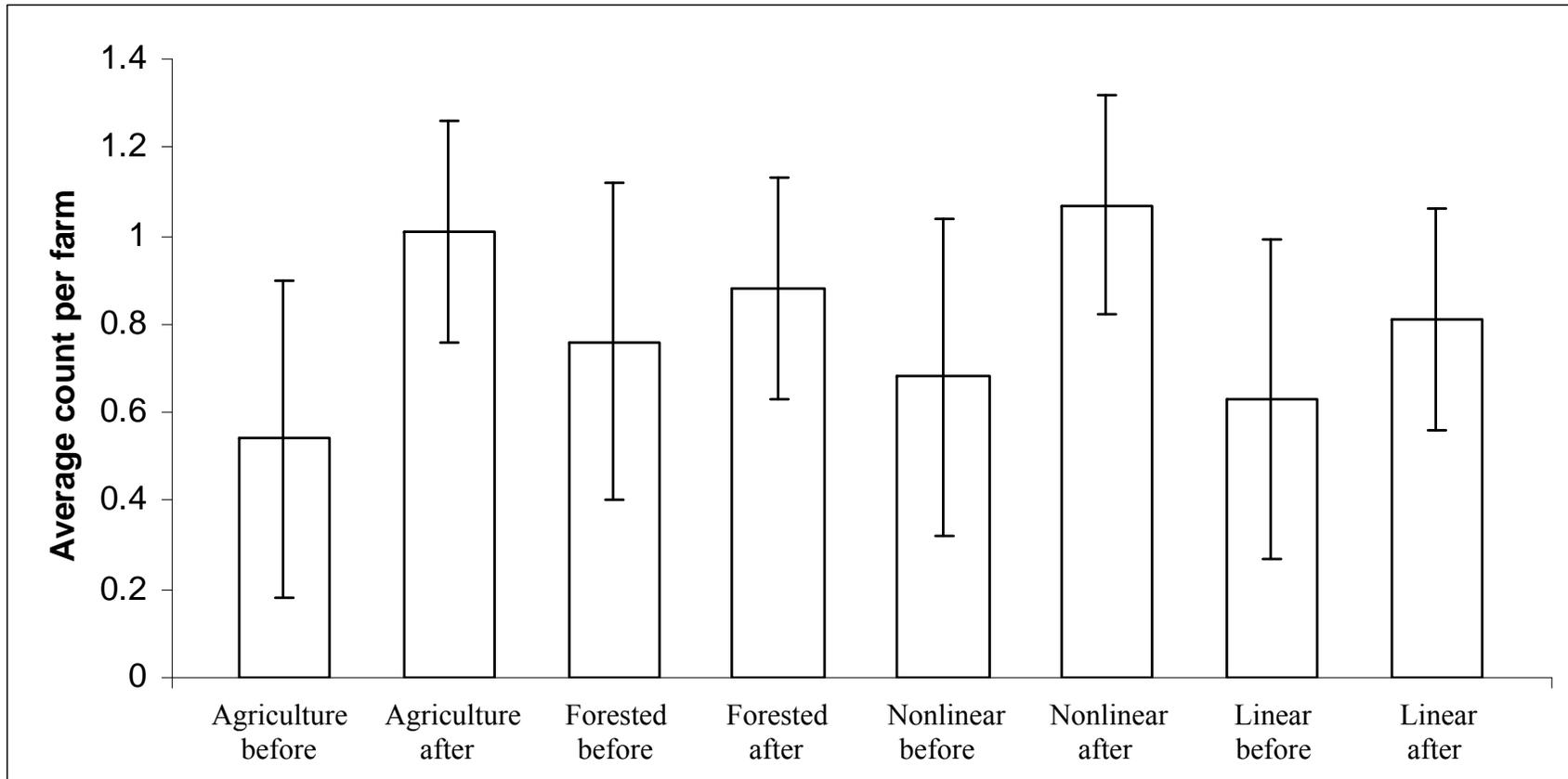


Figure 3. Least squares means and 95% confidence intervals for the average bobwhite count/farm during the summer on 24 farms in the Coastal Plain, North Carolina. "Before" data are from 2004. "After" data are the average of 2005 and 2006.

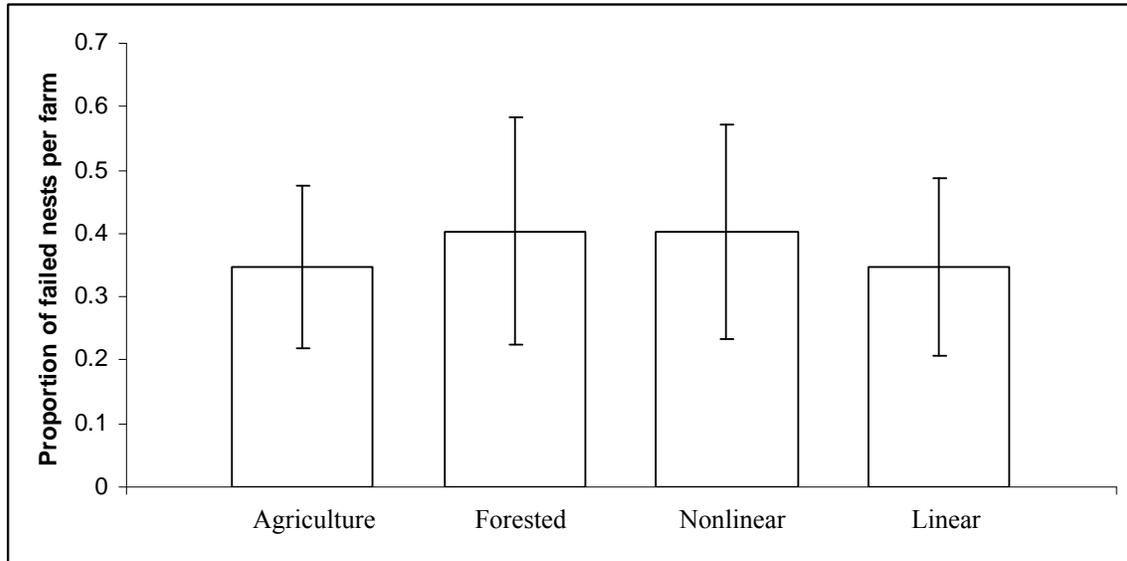


Figure 4. Means and 95% confidence intervals for the proportion of failed nests/farm on 24 farms (2005 and 2006 combined) in the Coastal Plain, North Carolina.

Table 1. Means (SE) of field border and row crop area (ha) per farm, North Carolina (2004-2006).

Treatments	Area (ha)	
	Field Border	Row Crop
Agriculture-dominated	1.24 (0.29)	50.37 (10.25)
Forest-dominated	1.08 (0.15)	42.63 (6.62)
Linear	0.85 (0.13)	36.20 (6.13)
Nonlinear	1.47 (0.27)	56.80 (9.73)

Table 2. Least squares means (SE) of summer abundance per count/per farm, North Carolina (2004-2006).

Treatment	Field Border Establishment		$t_{20}^{a,b}$	P ^c
	Pre-	Post-		
Agriculture-dominated	0.54 (0.17)	1.01 (0.12)	2.2220	0.0188
Forest-dominated	0.76 (0.17)	0.88 (0.12)	0.5791	0.2844
Nonlinear borders	0.68 (0.17)	1.07 (0.12)	1.9140	0.0352
Linear borders	0.63 (0.17)	0.81 (0.12)	0.8958	0.1905
Overall	0.65 (0.09)	0.94 (0.12)	1.985	0.0305

^a Absolute value of observed t statistic.

^b All tests are one-tailed.

^c Probability of observing the associated, or larger, t statistic.

Table 3. Means (SE) of the cone of vulnerability (degrees), zone of vulnerability (m), and cover (%) of open ground, herbaceous, and woody vegetation, North Carolina (2004-2006).

	Main effects								Interaction	
	Landscape context				Field border shape				Landscape context x field border shape	
	Agriculture	Forested	F _{1,20}	P	Nonlinear	Linear	F _{1,20}	P	F _{1,20}	P
Cone of vulnerability	12.92 (2.15)	12.27 (1.92)	0.05	0.8247	11.92 (1.58)	13.27 (2.39)	0.21	0.6535	0.93	0.3468
Zone of vulnerability	5.62 (0.66)	5.68 (0.67)	0.00	0.9447	5.50 (0.46)	5.80 (0.81)	0.10	0.7592	0.99	0.3324
Open ground (%)	66.92 (3.30)	63.71 (3.94)	0.40	0.5350	66.78 (2.78)	63.86 (4.34)	0.33	0.5723	2.13	0.1602
Herbaceous (%)	30.81 (3.28)	29.90 (2.19)	0.05	0.8220	31.85 (2.75)	28.85 (2.76)	0.57	0.4597	1.05	0.3173
Woody (%)	2.27 (0.70)	2.22 (0.37)	0.00	0.9497	1.37 (0.37)	3.12 (0.58)	6.23	0.0214	1.37	0.2560

Landscapes, field borders, and songbirds**The importance of agriculture-dominated landscapes and lack of field border effect for early-succession songbirds**

Jason D. Riddle¹

Department of Forestry and Environmental Resources
North Carolina State University
Campus Box 8008
Raleigh, NC 27695-8008

Christopher E. Moorman

Department of Forestry and Environmental Resources
North Carolina State University
Campus Box 8008
Raleigh, NC 27695-8008

¹ jdriddle@unity.ncsu.edu

Abstract

In recent decades, many early-succession songbird species have experienced severe and widespread declines. In most cases, these declines are related to habitat loss and degradation. Field borders create additional or enhance existing early-succession habitat on private farmland. However, field border shape and the landscape context surrounding farms may influence the effectiveness of field borders in contributing to the stabilization or increase of early-succession bird populations. We examined the influence of linear and nonlinear field borders on farms in landscapes dominated by either agriculture or forests on the density of focal species, including indigo bunting (*Passerina cyanea*), blue grosbeak (*Guiraca caerulea*), red-winged blackbird (*Agelaius phoeniceus*), common yellowthroat (*Geothlypis trichas*), grasshopper sparrow (*Ammodramus savannarum*), field sparrow (*Spizella pusilla*), and eastern meadowlark (*Sturnella magna*). We measured the effect of field border shape and landscape context on success and brown-headed cowbird (*Molothrus ater*) brood parasitism of indigo bunting and blue grosbeak nests combined. Field border establishment did not affect density of combined focal species or survival probability and brood parasitism frequency of indigo bunting and blue grosbeak nests. Combined focal species density was 55% higher in agriculture-dominated landscapes than forest-dominated landscapes ($P = 0.0215$), but this pattern disappeared when red-winged blackbirds were removed from the analysis. Indigo bunting/blue grosbeak nest success probability was more than twice as high in agriculture-dominated landscapes (39%) than in forested landscapes (17%), and brood parasitism frequency was high (33%) but did not differ between landscapes. Edges in agriculture-dominated landscapes are high-quality habitats for early-succession birds, but our field border treatments did not enhance habitat for these birds on farms in either landscape.

Key Words: Early-succession birds, field borders, habitat shape, landscape context, nest parasitism, nest success.

Many early-succession bird species are declining in North America. These declines often are related to habitat loss via intensive modern farming practices. Field borders can be used to create early-succession habitat on farmland which may help to reverse early-succession bird declines or stabilize populations. Factors such as field border shape and the landscape context in which they are established may determine the effectiveness of field borders for early-succession bird management on private farmland. We sought to determine the relative importance of these factors by measuring the density, nest success probability, and frequency of brood parasitism of several early-succession bird species on farms with either linear or nonlinear field borders in landscapes dominated by either agriculture or forests. Our goal was to provide federal and state resource agencies, such as the Natural Resources Conservation Service (NRCS) and the North Carolina Wildlife Resources Commission (NCWRC), with practical recommendations for maximizing the impact of field borders for songbirds and improving programs such as the Conservation Reserve Program (CRP) and the Cooperative Upland habitat Restoration and Enhancement program (CURE), respectively.

Many early-succession bird species have experienced significant and widespread declines over the past several decades (e.g., Askins 1993, Brawn et al. 2001, Hunter et al. 2001). Historically, early-succession birds (e.g., northern bobwhite (*Colinus virginianus*), grasshopper sparrow (*Ammodramus savannarum*), indigo bunting (*Passerina cyanea*),

Bachman's sparrow (*Aimophila aestivalis*), and red-winged blackbird (*Agelaius phoeniceus*) depended on naturally occurring disturbance in habitats such as grasslands, shrublands, and savannas (Brawn et al. 2001). Declines in early-succession birds have occurred because of destruction or alteration of early-succession habitats via intensive agriculture, closed-canopy pine plantations, urbanization, fire suppression, and disruption of flooding cycles and events (Klimstra 1982, Brennan 1991, Askins 1993, Roseberry 1993, Brawn et al. 2001, Hunter et al. 2001). Now, many of these birds primarily use human-created habitats like clearcuts, pasture, rangeland, and row crops.

Field borders may be used to create, supplement, or enhance early-succession habitat on private agricultural lands (Dimmick et al. 2002, Smith et al. 2005a). We use the term 'field border' to refer to areas of maintained herbaceous vegetation (grass and/or forbs, sometimes with a temporary shrub component) along field margins, established specifically for wildlife, but also providing other environmental benefits (Smith et al. 2005a). When field borders are managed for northern bobwhite and other early-succession bird species, they usually are disturbed with periodic selective herbicide application for woody vegetation control and/or with mowing, disking, or burning every 2-3 years to keep them in a perpetual state of early-succession. Field borders have the potential to benefit birds by creating nesting and brood-rearing habitat, escape cover, and foraging opportunities. For example, field borders have been shown to increase densities of wintering sparrows (Marcus et al. 2000, Smith et al. 2005a), early breeding season songbird nest density (Marcus 1998), breeding songbird abundance (Smith et al. 2005b), summer northern bobwhite abundance (Riddle et al. *in review*), and northern bobwhite covey abundance (Puckett et al. 1995, Marcus 1998, Puckett et al. 2000, Palmer et al. 2005). Field borders also may enhance existing edge

habitat. Linear strips of shrub habitat can soften hard forest edges (i.e., increase heterogeneity of edges by the addition or enhancement of an additional vegetation layer) and increase bird species richness and abundance (Morgan and Gates 1982, Fleming and Giuliano 1998), and herbaceous field borders with or without a shrub component may provide similar benefits. Field border establishment and maintenance can be subsidized by federal and state programs such as CRP's Upland Bird Habitat Buffer (CP-33; USDA 2004) and NCWRC's CURE (Cobb et al. 2002). Government subsidies and the apparent benefits field borders provide to a variety of bird species throughout the year make creation and maintenance of these habitats a potential cost effective conservation solution for private landowners. However, little is known about how particular field border characteristics, such as shape, or the surrounding landscape context may influence their use by breeding songbirds.

Traditionally, field borders have been linear-shaped habitats to avoid alteration of farm activities (Stoddard 1931) or to minimize reductions in crop production (Morris 1998). However, narrow, linear habitats, because of their high edge-to-area ratios and the forest edges they may juxtapose, have the potential to act as population sinks for some birds by concentrating nest depredation and brood parasitism (e.g., Gates and Gysel 1978, Besore et al. 1986, Johnson and Temple 1990, Yosef 1994). Several studies have demonstrated increased numbers of birds or nests in linear habitats in agricultural settings (Shalaway 1985, Besore et al. 1986, Bryan and Best 1991, Smith et al. 2005b). Nest predators such as raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), and snakes may actively search linear habitats and field edges because of high nest densities, or may use linear habitats or edges as travel lanes and find nests incidentally (Crabtree et al. 1989, Durner and Gates 1993,

Pedlar et al. 1997, Dijak and Thompson 2000). Therefore, birds that nest in linear habitats on farms may be especially vulnerable to nest depredation (but see Shalaway 1985). One potential solution to this problem is concentrating the same area of habitat into a nonlinear border, which may help reduce negative edge effects by decreasing edge-to-area ratios (Johnson and Temple 1990).

Habitat patches and edges can be influenced by landscape context (Andren 1995, Donovan et al. 1997). Thus, the effectiveness of local management efforts, such as field borders, may vary depending on the landscape context in which they occur. Bird abundance, nest survival, and brood parasitism rates in conservation buffers, strip vegetation, or grassland fragments can be influenced by landscape-level features such as the amount and proximity of woodlands (e.g., Arnold 1983, Johnson and Temple 1990). Similarly, nest depredation and brood parasite abundance along forest edges can be influenced by the amount of forest or agriculture in the surrounding landscape (Donovan et al. 1997).

Landscape context may become an increasingly important criterion for field border establishment for northern bobwhite (Roseberry and Sudkamp 1998, Riddle et al. *in review*). For example, Riddle et al. (*in review*) demonstrated that northern bobwhite populations increased more after the establishment of field borders on farms in agriculture-dominated landscapes than in forest-dominated landscapes. Indeed, NCWRC already limits enrollment in the CURE program to landowners in landscapes with high percentages of row crop agriculture. However, field borders often are established along field-forest edges, which many researchers view as potential ecological traps for songbirds, especially in agricultural settings (Gates and Gysel 1978, Heske et al. 1999). Land managers may not be as eager to

create early-succession habitat and enhance forest edges on farms for northern bobwhite if the landscapes in which these farms occur are deleterious for early-succession songbirds.

We examined the effect of linear and nonlinear field borders on farms in landscapes dominated by either agriculture or forests for a suite of early-succession songbirds with an emphasis on indigo buntings and blue grosbeaks (*Guiraca caerulea*). We hypothesized that establishing field borders would increase early-succession songbird density (i.e., a one-way response or one-tailed test). We also hypothesized that bird density, nest success, and brood parasitism frequency would be affected differently by the establishment of linear vs. nonlinear field borders and by the landscape context (agriculture-dominated vs. forest-dominated) surrounding farms. Two-way tests were used unless otherwise stated.

Study areas

We studied field borders on 24 commercial hog farms owned by Murphy-Brown, LLC. Farms were located throughout the southern Coastal Plain of North Carolina in the following counties: Bladen, Columbus, Duplin, Pender, Sampson, Scotland, and Robeson (Figure 1). The typical hog farm in eastern North Carolina consists of one or more hog houses (containment areas for hog production), lagoons for hog waste containment, and spray fields (row crop, hayfield, and/or pasture) for nutrient management. Our farms were selected from a pool of over 200 company farms to minimize potentially confounding differences among farms such as timber harvests and crop rotations. The farms in our study were all on a full or partial rotation of corn, soybeans, and wheat with some farms also growing cotton.

Methods

Experimental design.

We employed a balanced 2 x 2 factorial design with field border shape (linear or nonlinear) and landscape context (agriculture- or forest-dominated) as the two factors. Therefore, each treatment combination had 6 replicate farms. Field borders were established at the edges of row crop fields by allowing demarcated areas to go fallow after crop harvest. In 2004, field border locations were demarcated based on patterns of waste application, requirements for farm machinery operation, and advice given by farm technicians and other Murphy-Brown, LLC personnel. All field border habitats were out of crop production by the onset of the 2005 breeding season. Individual linear field borders were ~3 m wide and varied by length (range = 66.40-1938.95 m; mean = 475.44; SE = 47.91) and therefore area (0.02-0.59 ha; mean = 0.14; SE = 0.01), whereas individual non-linear field borders varied by shape and size (range = 0.05-2.48 ha; mean = 0.25; SE = 0.04). Most nonlinear borders were triangular, half-circle, or amoeboid in shape. Because of the spray patterns, large size, and unusual shape of two fields on one farm in an agriculture-dominated landscape, two nonlinear field borders were much larger than the rest (2.48 and 1.32 ha). When these are excluded, the range in individual nonlinear field border area was (0.05-0.81 ha; mean = 0.20; SE = 0.02). Field borders comprised ~2-3% of the total row cropped area on each farm. Total row crop area on each farm (and therefore total field border area) was higher on farms in agriculture-dominated landscapes and on farms with nonlinear borders (Table 1). However, when the aforementioned farm with very large fields and field borders is excluded, average row crop and field borders areas (ha) were much more similar on farms in agriculture-dominated landscapes (row crop mean = 43.39, SE = 8.22; field border mean =

1.00, SE = 0.19) and on farms with nonlinear field borders (row crop mean = 50.4, SE = 8.04; field border mean = 1.26, SE = 0.19).

Farms were selected from landscapes that were designated as either Focal Areas or Nonfocal Areas primarily for northern bobwhite, but also for early-succession songbird management, by the NCWRC for their CURE program (Cobb et al. 2002). Howell et al. (2002) provided a full description of the criteria and methodology used to identify and differentiate these landscapes for bobwhite management. For the purposes of this study, we emphasize that Focal Areas generally are agriculture-dominated landscapes (row crops in particular), whereas Nonfocal Areas generally are forest-dominated landscapes. To confirm that this was the case for our 24 farms, we located a central point on each farm and determined the amount of row crop and forest within a circular buffer with a radius of 2538 m (buffer area = 2023 ha). We used the same classification scheme with the same Landsat imagery as Howell et al. (2002) for this procedure. Farms in agriculture-dominated landscapes were surrounded by an average of $49.0 \pm 1.8\%$ (mean \pm SE) row crops and $18.5 \pm 2.1\%$ forests, whereas farms in forest-dominated landscapes were surrounded by an average of $20.1 \pm 2.3\%$ row crops and $44.9 \pm 3.8\%$ forests. Therefore, the two landscapes were nearly perfect complements of each other with regard to the two parameters of interest.

We were not able to randomize treatments due to logistical constraints. However, the pre- vs. post-treatment contrasts we were able to perform (see below) were robust to our lack of randomization due to the BACI-like nature of our design (Morrison et al. 2001). Comparisons of response variables between landscapes were not as robust to nonrandomization and inferences from these test results may not be as powerful as in our before and after comparisons.

Data collection.

Songbird density. Point count survey locations were established in 2004 in areas demarcated to become field borders. We established 2-6 survey locations on each farm. The number of survey locations varied because of individual farm characteristics and field border arrangement, but all survey locations within a farm were at least 250 m apart. All point count locations were sampled once in 2004 prior to the establishment of field borders, and once per year in 2005 and 2006 after field borders were established. Point counts were conducted from approximately 15 min after sunrise until approximately 1000 EST from May 15-June 30. All point counts had a fixed radius of 50 m.

We recorded all bird species present within plots and all flyovers. However, we were primarily interested in the following focal species for density estimates: indigo bunting, blue grosbeak, red-winged blackbird, common yellowthroat (*Geothlypis trichas*), grasshopper sparrow, field sparrow (*Spizella pusilla*), and eastern meadowlark (*Sturnella magna*). We chose these focal species because we believed they would be the songbirds most affected by the establishment of field borders. Based on the Breeding Bird Survey (BBS) from 1966-2005 (Sauer et al. 2005), these species have shown the following annual trends in the southeastern Coastal Plain: indigo bunting, -0.8% (P = 0.02); red-winged blackbird, -3.0% (P = 0.00); common yellowthroat, -1.0% (P = 0.01); eastern meadowlark, -3.7% (P = 0.00); and field sparrow -2.6% (P = 0.03). No data were available for blue grosbeak or grasshopper sparrow trends in the southeastern Coastal Plain. However, over the same time period in North Carolina, blue grosbeak and grasshopper sparrow did not show population changes at the $\alpha = 0.05$ level (Sauer et al. 2005).

We did not have enough detections of individual focal species to estimate detection probabilities for individual treatments and years for any species. Therefore, we had to assume that detection probabilities did not vary across treatments and years for focal bird species. This assumption may not be unreasonable in our case. For example, we previously demonstrated that northern bobwhite detection probabilities (estimated from data from the same two observers from the same point count locations but with unlimited radius) did not differ among treatment combinations or years (Riddle et al. *in review*). If site-level differences (e.g., field border shape) and landscape-level differences (e.g., amount of forest in surrounding areas) did not affect northern bobwhite detection probabilities for individuals heard up to ~1 km (Riddle, unpublished data), then our focal species' detection probabilities probably were not affected by vegetation differences associated with treatments within 50 m of the observers.

Nest success and brood parasitism frequency. We located and monitored bird nests on 12 of the 24 farms (3 farms in each treatment combination). All farms were monitored from early-May until the end of July in each year. In 2004, the pre-treatment year, all potential early-succession nesting habitat on each farm was searched multiple times. This mainly involved searching forest edges and ditches for nests. In 2005 and 2006, we expanded search efforts to include field border habitat as it became suitable for nesting. As in 2004, each farm was searched multiple times. In all years, we used a combination of systematic searches and behavioral cues to find nests. We monitored the nests of all species every 3-5 d.

We collected data on all nests found on each farm. However, we focused our attention on indigo bunting and blue grosbeaks because they were the most abundant focal species and have similar nesting ecology.

Analysis

Songbird density. We analyzed the average density per farm (observations from both observers combined) of all focal species combined, all focal species combined with red-winged blackbirds excluded, and indigo buntings alone using a 2 x 2 split-plot ANOVA (PROC GLM; SAS) with landscape context and habitat shape as whole-plot factors. The split-plot factor was year (the pretreatment year and the weighted average of the two post-treatment years). We performed analyses with and without red-winged blackbirds because they did not occur on every farm, but they often were very abundant when present on a farm. All densities are reported as males/7854 m² (the area of a circular plot with 50-m radius).

One-tailed pre-planned orthogonal contrasts were used, in the absence of a landscape context*habitat shape*year interaction, to test for an overall effect of field borders (i.e., density before field border establishment vs. after field border establishment). We also used one-tailed pre-planned orthogonal contrasts to compare density before and after field border establishment for both levels of each factor.

In the absence of a field border effect and landscape*year interaction, we tested for a main effect of landscape across all three years of the study.

Nest success and brood parasitism frequency. We combined indigo bunting and blue grosbeak nests for analysis because they often were difficult to distinguish in the field without visual identification of adults. Nest survival probabilities were calculated for each farm using the Mayfield method to calculate a daily nest survival rate and then raising that to the average number of days in the indigo bunting/blue grosbeak nesting cycle (Mayfield 1961, Mayfield 1975). Brood parasitism frequencies were calculated for each farm by dividing the number of parasitized bunting and grosbeak nests by the total number of bunting

and grosbeak nests on that farm. Nest survival probabilities and brood parasitism frequencies were analyzed with a similar 2 x 2 split-plot ANOVA and contrasts as described above.

Least-squares means are reported for all analyses.

Results

Songbird density. There was no interaction of landscape context, habitat shape, and year for focal species densities with ($F_{1,20} = 2.50$, $P = 0.1294$) and without red-winged blackbirds ($F_{1,20} = 1.90$, $P = 0.1837$). Focal species density with and without red-winged blackbirds did not increase as a result of field border establishment (Table 2). Focal species density with and without red-winged blackbirds did not increase following the establishment of linear field borders or nonlinear field borders. The establishment of field borders did not increase focal species density with or without red-winged blackbirds in agriculture-dominated or forest-dominated landscapes.

There was no year*landscape interaction on focal species density with ($F_{1,20} = 0.01$, $P = 0.9202$) or without red-winged blackbirds ($F_{1,20} = 0.00$, $P = 0.9937$). Focal species density with red-winged blackbirds was higher in agriculture-dominated landscapes (mean = 1.15, SE = 0.11) than in forest-dominated landscapes (mean = 0.74, SE = 0.11) ($F_{1,20} = 6.22$, $P = 0.0215$; Figure 2). However, focal species density without red-winged blackbirds was similar in agriculture-dominated landscapes (mean = 0.82, SE = 0.10) and forest-dominated landscapes (mean = 0.69, SE = 0.10) ($F_{1,20} = 0.78$, $P = 0.3862$; Figure 2).

When indigo buntings were considered alone, there was a 3-way interaction of landscape context, habitat shape, and year ($F_{1,20} = 4.56$, $P = 0.0453$). Buntings increased slightly after the establishment of field borders in every treatment ($P > 0.05$ in each case) except on farms in agriculture-dominated landscapes, where they decreased from 0.81 (SE =

0.15) to 0.35 (SE = 0.11) after the establishment of linear field borders ($t_{20} = 2.802$, $P = 0.0113$; Figure 3).

Nest Success and brood parasitism frequency. Over the course of the study, we located 166 indigo bunting/blue grosbeak nests. Sixty-three of these were parasitized by brown-headed cowbirds (*Molothrus ater*).

There was no evidence for an interaction of landscape context, habitat shape, and year for nest survival probability ($F_{1,8} = 0.02$, $P = 0.8810$) or brood parasitism frequency ($F_{1,8} = 0.36$, $P = 0.5661$). Overall, nest survival probability and brood parasitism frequency did not change after the establishment of field borders (Table 3).

There was no year*landscape interaction for nest survival probability ($F_{1,20} = 1.04$, $P = 0.3381$) or brood parasitism frequency ($F_{1,20} = 0.63$, $P = 0.4510$). Across all years, nest survival probabilities were more than twice as high in agriculture-dominated landscapes (mean = 0.39; SE = 0.05) than in forest-dominated landscapes (mean = 0.17; SE 0.05; $F_{1,8} = 7.67$, $P = 0.0243$; Figure 4). Overall brood parasitism frequency was 0.33 (SE = 0.07), but it did not differ between agriculture-dominated and forest-dominated landscapes.

Discussion

Field border establishment did not increase focal species density. However, other studies in agricultural settings reported higher concentrations of birds in linear and small, nonlinear patches (Shalaway 1985, Basore et al. 1986, Loman and Von Schantz 1991, Inglis et al. 1993, Smith et al. 2005b) and in softened woodland edges (Morgan and Gates 1982, Fleming and Giuliano 1998). We suspect that the lack of an overall response may have been a result of too little field border habitat. For example, species such as field sparrows were rarely detected on our farms. Yet, at nearby farms in Wilson County, NC, with ~13% of

tilled land in field borders, Marcus (1998) recorded field sparrows as one of the most abundant songbirds.

Indigo buntings showed trends of increasing densities after field border establishment in all treatments except for linear field borders in agriculture-dominated landscapes. Our finding of a decrease in indigo bunting density on farms in agriculture-dominated landscapes following field border establishment likely was driven in part by high densities (mean = two males/7854 m²) in the pre-treatment year on one farm in an agriculture-dominated landscape (which later received linear borders). We suspect that high densities on this farm in the pre-treatment year may have been due to late migrants passing through. Marcus (1998) also determined that indigo buntings decreased on farms in agriculture-dominated landscapes after linear field borders were established. While his finding may have resulted from small sample size and ours to a migration event, the fact that this trend was evident in both studies may warrant further study. However, Smith et al. (2005b) recorded 80% more indigo buntings on field edges with 6.1-m-wide field borders than on field edges without field borders.

Field border establishment did not affect indigo bunting/blue grosbeak nest survival probabilities or brood parasitism frequencies on our farms. Similarly, Marcus (1998) failed to detect differences in daily survival rates between nests on farms with field borders and on farms without. Few buntings and grosbeaks actually nested in field borders in our study area or in that of Marcus (1998). As such, the primary benefit of our borders to buntings and grosbeaks would have been softening of existing field-forest edges (i.e., increased heterogeneity of edges by the addition or enhancement of an herbaceous layer). Indigo buntings and blue grosbeaks will nest in herbaceous vegetation, shrubs, small trees, and low

branches on larger trees (Payne 1992, Ingold 1993). However, on farms in this study both species seemed to show a preference for one shrub in particular, salt myrtle (*Baccharis halimifolia*; JDR, unpublished data). While salt myrtle was abundant on many of our farms, it was only a minute fraction of the small woody component of our field borders. In general, field borders may have contained too little woody (2.25%; SE = 1.89) vegetation to provide additional nesting sites for buntings and grosbeaks. Also, our field borders were dominated by dog fennel (*Eupatorium capillifolium*), which very rarely was used by buntings or grosbeaks as a nesting substrate.

The nest success probability for indigo bunting/blue grosbeak was much higher on farms in agriculture-dominated landscapes (39%) than on farms in forest-dominated landscapes (17%). Our estimate of nest success for indigo bunting/blue grosbeak in agriculture-dominated landscapes was similar to that of Marcus (1998) for indigo bunting (39%) and blue grosbeak (41%). We are aware of no other studies that provide estimates of blue grosbeak nesting success in the southeastern US. However, Weldon (2004) reported an indigo bunting nest success probability of 31% (averaged across treatments) in shrubby patches in a heavily forested matrix at the Savannah River Site in South Carolina (Weldon 2004). Indigo bunting nest success was 21% in burned pine forests in the Georgia piedmont (White et al. 1999). Collectively, our results and those of Marcus (1998) suggest that agriculture-dominated landscapes provide high-quality habitats for birds such as indigo bunting and blue grosbeak when compared to nest success rates from forested landscapes in the southeastern US. However, more information is needed regarding individual female fecundity and fledgling survival in our study area.

We suggest that nest success in agriculture-dominated landscapes was high because lack of forest cover may have limited important nest predators. In particular, we believe snakes were the primary nest predator because most depredated nests were placed between 1 and 2 m from the ground in small salt myrtle branches (JDR, personal observation) where dexterous mesomammals such as raccoons could not reach them without climbing or manipulating the vegetation. In salt myrtle, this would have caused noticeable plant and nest damage, which was not observed in most cases. We observed snakes, such as the black rat snake (*Elaphe obsoleta*), along field edges and in shrubs. Black rat snakes may encounter nests in and around the forest margins they use for thermoregulation, foraging, and travel. Several studies suggest the ideal landscape for a black rat snake is likely a mosaic of small fields interspersed with forest (Weatherhead and Charland 1985, Durner and Gates 1993, Blouin-Demers and Weatherhead 2001). The numerous large fields and low amount of forest cover (18.5%) in agriculture-dominated landscapes may be insufficient to support black rat snakes to the same degree as forest-dominated landscapes. Durner and Gates (1993) suggested that high percentages of row crop decrease the suitability of landscapes for black rat snakes because they are not used for travel or foraging, and probably expose the snakes to greater risk of predation (see also Keller and Heske 2000). It is also possible that corvids depredated some nests, which could have been difficult to distinguish from snake depredation (Thompson and Burhans 2003). However, corvids may be less common nest predators than snakes in a shrubby environment (Thompson and Burhans 2003). Additionally, corvids were no more abundant on farms in forest-dominated landscapes than on farms in agriculture-dominated landscapes in our study (JDR, unpublished data).

Our overall estimate of brood parasitism (33%) did not differ between landscapes with markedly different amounts of forest cover, and was high when compared to other studies in the southeastern US. For example, Marcus (1998) reported only 3 of 51 nests parasitized by brown-headed cowbirds. In old-field habitat on James Island, South Carolina, bunting and grosbeak parasitism levels were 11.1% and 23.5%, respectively (Whitehead et al. 2002). Kilgo and Moorman (2003) reviewed parasitism rates for several known cowbird hosts in forested areas ($\geq 80\%$ forests) in the southeastern Coastal Plain, and reported average parasitism levels of 17.2% and 0% for indigo buntings and blue grosbeaks, respectively. However, they addressed the need for more work in areas of the Coastal Plain where agriculture was a more prevalent landscape feature (Kilgo and Moorman 2003). Our results suggest higher parasitism levels are possible in agricultural areas in the southeastern US than reported previously. We suggest farm operations specific to our study sites may have attracted brown-headed cowbirds. Hog farms usually have 1-2 covered grain bins for every hog house. Spillage as feed trucks fill these bins provides foraging opportunities for cowbirds and may indirectly increase parasitism rates nearby. Regardless, brood parasitism by brown-headed cowbirds in the southeastern US deserves more attention than previously thought (e.g., Wiedenfeld 2000), and could be especially harmful for single-brooded species, such as the yellow-breasted chat (*Icteria virens*) (Whitehead et al. 2002).

Management Implications

Multiple authors have addressed the need for a landscape-level approach to avian conservation (Freemark et al. 1995, Petit et al. 1995, Donovan et al. 1997, Heske et al. 2001). Landscape-level patterns in nest success, predator communities, and brood parasites can differ for individual bird species, guilds, and between and within regions (Donovan et al.

1997, Woodward et al. 2001). The need has been emphasized for manipulative and comparative studies within and between regions to identify areas where landscape-level patterns are favorable for target species and therefore most conducive to local management activities. This need is particularly great with regards to agriculturally fragmented landscapes and farmland habitat structures such as field borders (Freemark et al. 1995, Heske et al. 2001).

Our results suggest that agriculture-dominated landscapes support higher densities and higher nest success probabilities of early-succession birds than forest-dominated landscapes in the southeastern US. As such, we have identified a landscape in which local scale management may have high potential because of already elevated densities and relatively low nest depredation pressures. Similarly, agriculture-dominated landscapes are favorable for northern bobwhite management, and the establishment of field borders in these landscapes increases northern bobwhite populations (Puckett et al. 1995, Puckett et al. 2000, Palmer et al. 2005, Riddle et al. *in review*).

We were unable, however, to document any effects of field border establishment on early-succession songbirds, probably because too little field border habitat was created on individual farms. Additionally, the field borders we established likely contained too little of a woody component to be attractive nest sites for indigo buntings and blue grosbeaks. To improve early-succession songbird habitat, we recommend that more land be allotted for wider, linear and larger, nonlinear field borders than was used in this study. Additionally, longer rotations between disturbances (≥ 3 years depending on site conditions) should allow greater shrub composition in field borders and increased numbers of nest substrates. Using a 3-year rotation, a manager might disturb one-third of field border habitat each year, leaving

some older field borders with a more significant woody component for the songbirds, and more recently disturbed areas with more bare ground and a greater herbaceous component favorable for northern bobwhite.

Acknowledgements

We thank our field technicians F. Perkins, A. Savage, W. Ricks, C. Reddy, J. Remington, K. Yantis, S. Long, and A. Sabatine for many long hours in the field. F. Perkins also co-supervised several technicians and helped coordinate research activities. D. Williamson, K. Westerbeak, and all of the Murphy-Brown, LLC staff provided invaluable assistance in farm selection, farm access, field border location, and other study logistics. A. Oswald and family and Murphy Family Farms provided housing. T. Sharpe provided technical advice and encouragement. K. Pollock provided invaluable statistical advice and helpful comments on this manuscript. P. Bromley, D. Cobb, N. Haddad, and S. Nelson also provided helpful comments on this manuscript. This project was supported financially by the Department of Forestry and Environmental Resources at North Carolina State University, the North Carolina Wildlife Resources Commission, Murphy Brown, LLC, and a grant from the USDA-NRCS/Mississippi State University Bobwhite Restoration Project.

Literature Cited

- Andren, H. 1995. Effects of landscape composition on predation rates at habitat edges. Pages 225-255 in Hansson, L., L. Fahrig, and G. Merriam, Editors. *Mosaic Landscapes and Ecological Processes*. Chapman and Hall, London, UK.
- Arnold, G. W. 1983. The influence of ditch and hedgerow structure, length of hedgerows, and area of woodland and garden on bird numbers on farmland. *Journal of Applied Ecology* 20:731-750.

- Askins, R. A. 1993. Population trends in grassland, shrubland, and forest birds in eastern North America. *Current Ornithology* 11:1-34.
- Basore, N. S., L. B. Best, and J. B. Wooley, Jr. 1986. Bird nesting in Iowa no-tillage and tilled cropland. *Journal of Wildlife Management* 50:19-28.
- Blouin-Demers, G., and P. J. Weatherhead. 2001. Habitat use by black rat snakes (*Elaphe obsoleta obsoleta*) in fragmented forests. *Ecology* 82:2882-2896.
- Brawn, J. D., S. K. Robinson, and F. R. Thompson, III. 2001. The role of disturbance in the ecology and conservation of birds. *Annual Review of Ecology and Systematics* 32:251-276.
- Brennan, L. A. 1991. How can we reverse the northern bobwhite population decline? *Wildlife Society Bulletin* 19:544-555.
- Bryan, G. G., and L. B. Best. 1991. Bird abundance and species richness in grassed waterways in Iowa rowcrop fields. *American Midland Naturalist* 126:90-102.
- Cobb, D. T., T. L. Sharpe, D. Sawyer, and D. O. Baumbarger. 2002. Integrating early-successional wildlife and 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.
- Crabtree, R. L., L. S. Broome, and M. L. Wolfe. 1989. Effect of habitat characteristics on gadwall nest predation and nest-site selection. *Journal of Wildlife Management* 53:129-137.
- Dijak, W. D., and F. R. Thompson, III. 2000. Landscape and edge effects on the distribution of mammalian predators in Missouri. *Journal of Wildlife Management* 64:209-216.

- Dimmick, R. W., M. J. Gudlin, and D. F. McKenzie. 2002. The northern bobwhite quail initiative. Miscellaneous publication of the Southeastern Association of Fish and Wildlife Agencies, South Carolina, USA.
- Donovan, T. M., P. W. Jones, E. M. Annand, and F. R. Thompson, III. 1997. Variation in local-scale edge effects: mechanisms and landscape context. *Ecology* 78:2064-2075.
- Durner, G. M., and J. E. Gates. 1993. Spatial ecology of black rat snakes on Remington Farms, Maryland. *Journal of Wildlife Management* 57:812-826.
- Fleming, K. K., and W. M. Giulliano. 1998. Effect of border-edge cuts on birds at woodlot edges in southwestern Pennsylvania. *Journal of Wildlife Management* 62:1430-1437.
- Freemark, K. E., J. B. Dunning, S. J. Hejl, and J. R. Probst. 1995. A landscape ecology perspective for research, conservation, and management. Pages 381-427 in T. E. Martin and D. M. Finch, editors. *Ecology and management of neotropical migratory birds*. Oxford University Press, New York, New York, USA.
- Gates, J. E., and L. W. Gysel. 1978. Avian nest dispersion and fledging success in field-forest ecotones. *Ecology* 59:871-883.
- Heske, E. J., S. K. Robinson, and J. D. Brawn. 1999. Predator activity and predation on songbird nests on forest-field edges in east-central Illinois. *Landscape Ecology* 14:345-354.
- Heske, E. J., S. K. Robinson, and J. D. Brawn. 2001. Nest predation and neotropical migrant songbirds: piecing together the fragments. *Wildlife Society Bulletin* 29:52-61.
- Howell, D. L., D. T. Cobb, and T. L. Sharpe. 2002. Selection of focal areas for northern bobwhite enhancement on private lands in North Carolina. *Proceedings of the Annual*

- Conference of the Southeastern Association of Fish and Wildlife Agencies 56:159-170.
- Hunter, W. C., D. A. Buehler, R. A. Canterbury, J. L. Confer, and P. B. Hamel. 2001. Conservation of disturbance-dependent birds in eastern North America. *Wildlife Society Bulletin* 29:440-455.
- Inglis, I. R., E. Wright, and J. Lill. 1994. The impact of hedges and farm woodlands on woodpigeon (*Columba palumbus*) nest densities. *Agriculture, Ecosystems and Environment* 48:257-262.
- Ingold, J. L. 1993. Blue grosbeak. Number 79 in A. Poole, P. Stettenheim, and F. Gill, editors. *The Birds of North America: life histories for the 21st century*. Academy of Natural Sciences, Philadelphia, Pennsylvania, USA.
- Johnson, R. G, and S. A. Temple. 1990. Nest predation and brood parasitism of tallgrass prairie birds. *Journal of Wildlife Management* 54:106-111.
- Keller, W. L., and E. J. Heske. 2000. Habitat use by three species of snakes at the Middle Fork Fish and Wildlife Area, Illinois. *Journal of Herpetology* 34:558-564.
- Klimstra, W. D. 1982. Bobwhite quail and changing land use. *Proceedings of the National Bobwhite Quail Symposium* 2:1-5.
- Kilgo, J. C., and C. E. Moorman. 2003. Patterns of cowbird parasitism in the southern Atlantic coastal plain and piedmont. *Wilson Bulletin* 115: 277-284.
- Loman, J., and T. Von Schantz. 1991. Birds in a farmland-more species in small than in large habitat island. *Conservation Biology* 5:176-188.
- Marcus, J. F. 1998. The effects of predation and habitat improvement on farmland birds. Thesis. North Carolina State University, Raleigh, North Carolina, USA.

- Marcus, J. F., W. E. Palmer, and P. T. Bromley. 2000. The effects of farm field borders on overwintering sparrow densities. *Wilson Bulletin* 112:517-523.
- Mayfield, H. F. 1961. Nesting success calculated from exposure. *Wilson Bulletin* 73:255-261.
- Mayfield, H. F. 1975. Suggestions for calculating nest success. *Wilson Bulletin* 87:456-466.
- Morgan, K. A., and J. E. Gates. 1982. Bird population patterns in forest edge and strip vegetation at Remington Farms, Maryland. *Journal of Wildlife Management* 46:933-944.
- Morris, J. T. 1998. Conservation decisions of agricultural producers in eastern North Carolina. Dissertation, North Carolina State University, Raleigh, USA.
- Morrison, M. L., W. M. Block, M. D. Strickland, and W. L. Kendall. 2001. *Wildlife study design*. Springer, New York, New York, USA.
- 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.
- Payne, R. B. 1992. Indigo bunting. Number 4 in A. Poole, P. Stettenheim, and F. Gill, editors. *The Birds of North America: life histories for the 21st century*. Academy of Natural Sciences, Philadelphia, Pennsylvania, USA.
- Pedlar, J. H., L. Fahrig, and H. G. Merriam. 1997. Raccoon habitat use at 2 spatial scales. *Journal of Wildlife Management* 61:102-112.
- Petit, L. J., D. R. Petit, and T. E. Martin. 1995. Landscape-level management of migratory birds: looking past the trees to see the forest. *Wildlife Society Bulletin* 23:420-429.

- Pucket, 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 of the Southeastern Association of Fish and Wildlife Agencies* 49:505-515.
- Pucket, K. M., W. E. Palmer, P. T. Bromley, J. R. Anderson, Jr., and T. L. Sharpe. 2000. Effects of filter strips on habitat use and home range of northern bobwhites on Alligator River National Wildlife Refuge. *Proceedings of the National Bobwhite Quail Symposium* 4:26-31.
- Riddle, J. D., C. E. Moorman, and K. H. Pollock. The importance of habitat shape and landscape context for northern bobwhite populations: an experiment with field borders. *Journal of Wildlife Management in review*.
- Roseberry, J. L. 1993. Bobwhite and the "new" biology. *Proceedings of the National Bobwhite Quail Symposium* 3:16-20.
- Roseberry, J. L., and S. D. Sudkamp. 1998. Assessing the suitability of landscapes for northern bobwhite. *Journal of Wildlife Management* 62:895-902.
- SAS Institute 2006. Version 9.1.3. SAS Institute, Cary, North Carolina, USA.
- Shalaway, S. D. 1985. Fencerow management for nesting songbirds in Michigan. *Wildlife Society Bulletin* 13:302-306.
- Smith, M. D., P. J. Barbour, L. W. Burger, Jr., and S. T. Dinsmore. 2005a. Density and diversity of overwintering birds in managed field borders in Mississippi. *Wilson Bulletin* 117:258-269.
- Smith, M. D., P. J. Barbour, L. W. Burger, Jr., and S. T. Dinsmore. 2005b. Breeding bird abundance and diversity in agricultural field borders in the Black Belt Prairie of

- Mississippi. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 59:43-56.
- Stoddard, H. L. 1931. The bobwhite quail: its habits, preservation, and increase. Third edition. Charlars Scribner's Sons, New York, New York, USA.
- Thompson, F. R., and D. E. Burhans. 2003. Predation of songbird nests differs by predator and between field and forest habitats. *Journal of Wildlife Management* 67:408-416.
- United States Department of Agriculture. 2004. Farm Service Agency Notice CRP-479.
- Weatherhead, P. J., and M. B. Charland. Habitat selection in an Ontario population of the snake, *Elaphe obsoleta*. *Journal of Herpetology* 19:12-19.
- Weldon, A. J. 2004. The effects of patch shape and connectivity on nest site selection and reproductive success of the indigo bunting. Thesis, North Carolina State University, Raleigh, USA.
- White, D. H., B. R. Chapman, J. H. Brunjes, IV, R. V. Raftovich, Jr., and J. T. Seginak. 1999. Abundance and reproduction of songbirds in burned and unburned pine forests of the Georgia Piedmont. *Journal of Field Ornithology* 70:414-424.
- Whitehead, M. A., S. H. Schweitzer, and W. Post. 2002. Cowbird/host interactions in a southeastern old-field: a recent contact area? *Journal of Field Ornithology* 73:379-386.
- Wiedenfeld, D. A. 2000. Cowbird population changes and their relationship to changes in some host species. Pages 35-46 in J. N. M. Smith, T. L. Cook, S. I. Rothstein, S. K. Robinson, and S. G. Sealy, editors. *Ecology and management of cowbirds and their hosts*. University of Texas Press, Austin.

Woodward, A. A., A. D. Fink, and F. R. Thompson, III. 2001. Edge effects and ecological traps: effects on shrubland birds in Missouri. *Journal of Wildlife Management*

65:668-675.

Yosef, R. 1994. The effects of fencelines on the reproductive success of loggerhead shrikes.

Conservation Biology 8:281-285.

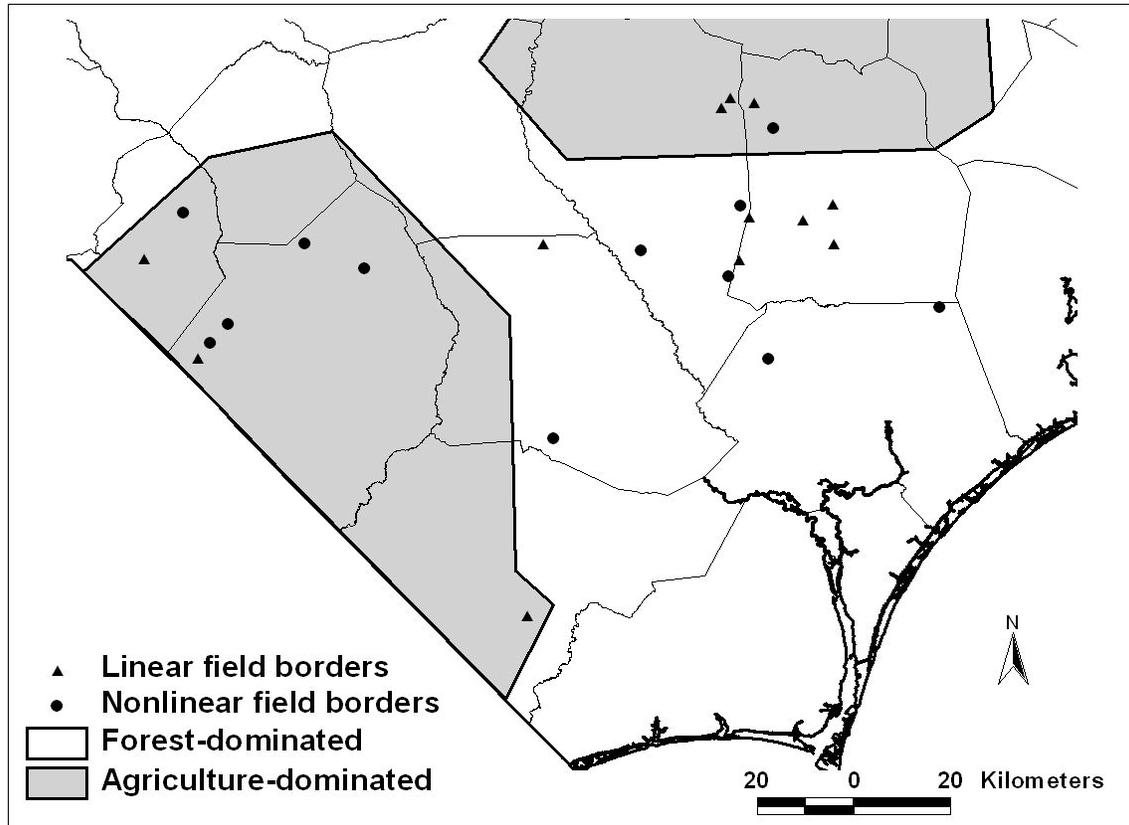


Figure 1. Farm locations and treatment assignments in Coastal Plain, North Carolina (2004-2006).

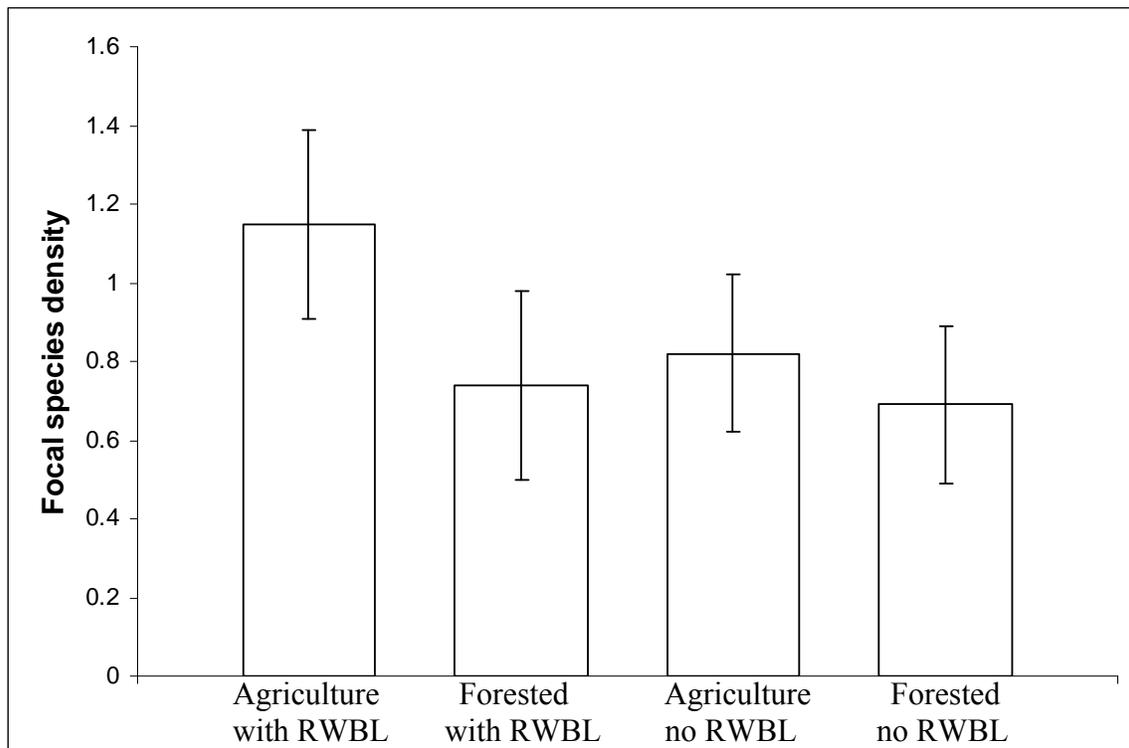


Figure 2. Least-squares means and 95% CIs of focal species density (males/7854 m²) with and without red-winged blackbirds (RWBL) on farms in agriculture- and forest-dominated landscapes, North Carolina (2004-2006).

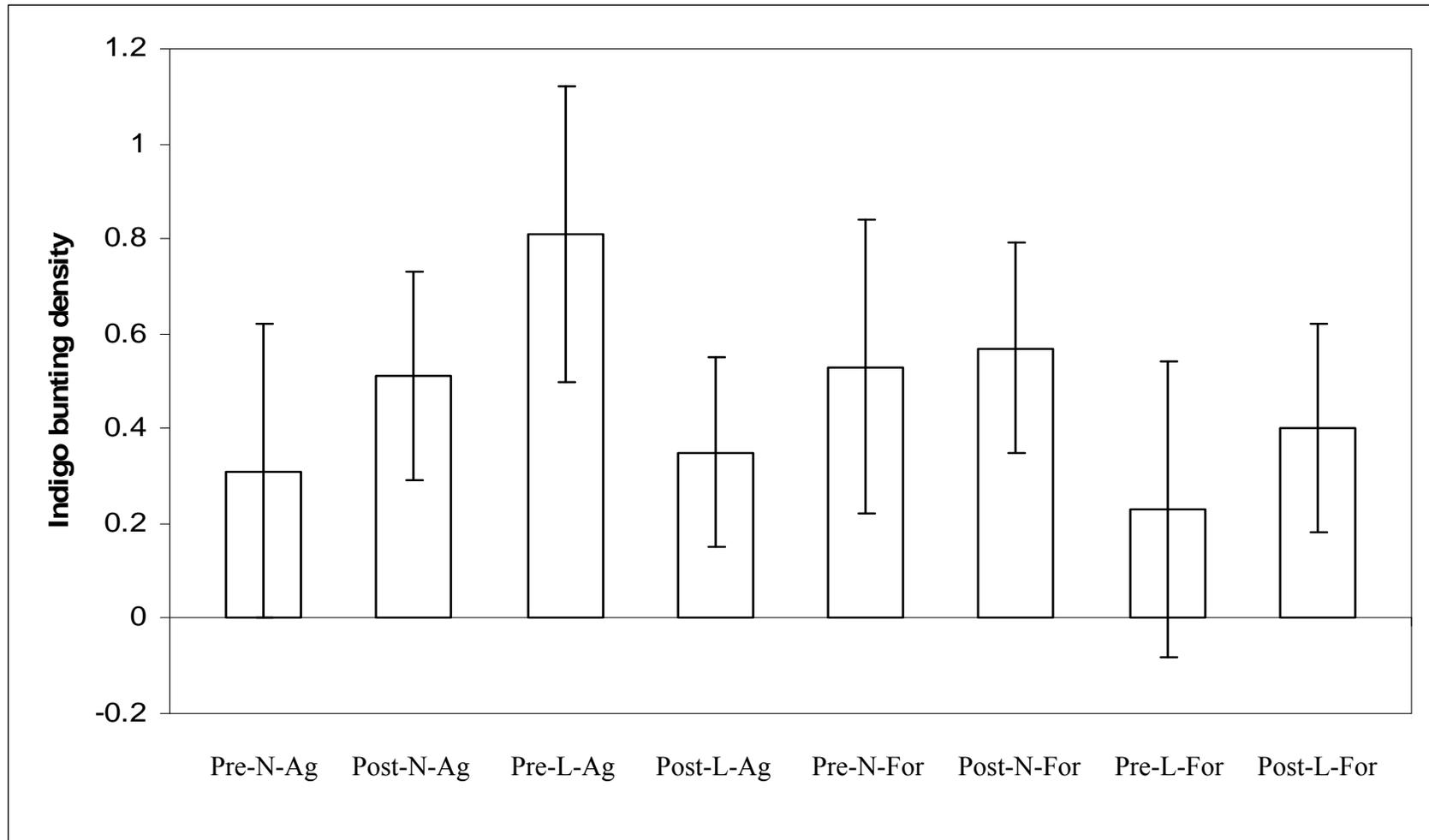


Figure 3. Least-squares means and 95% CIs for indigo bunting density (males/7854 m²), North Carolina (2004-2006). Pre = before field borders, Post = after field borders, N = Nonlinear borders, L = Linear borders, Ag = Agriculture-dominated landscapes, For = Forest-dominated landscapes.

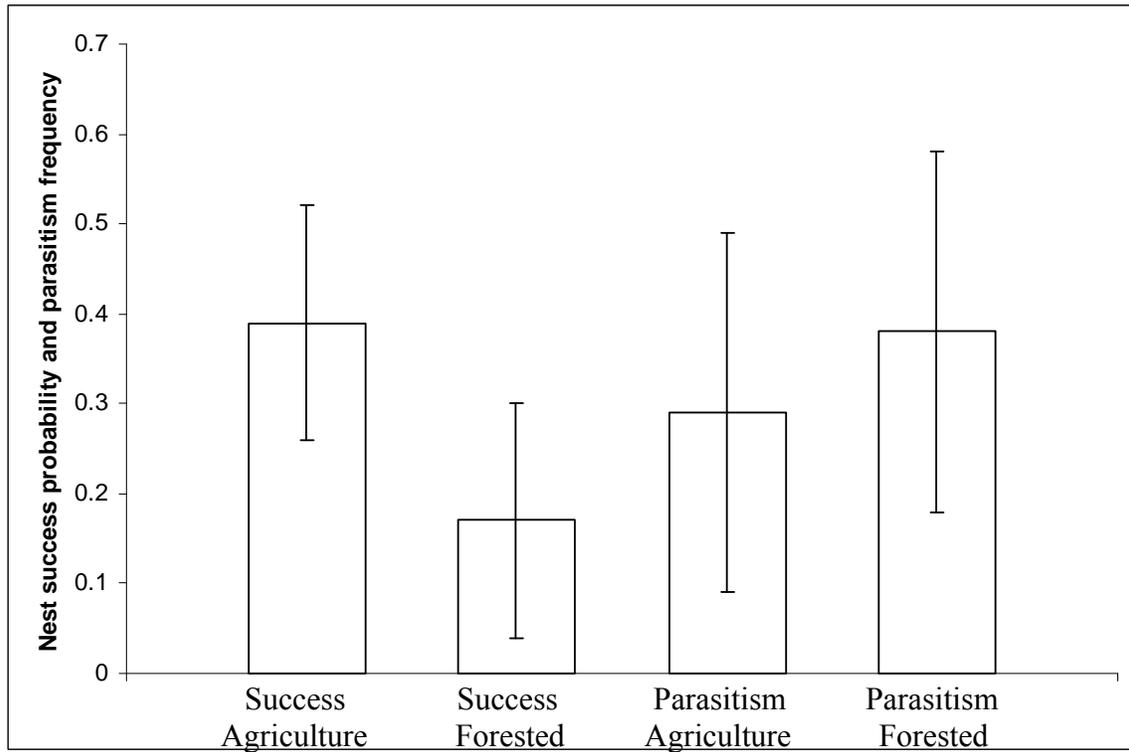


Figure 4. Least-squares means and 95% CI for indigo bunting/blue grosbeak nest success probabilities and brood parasitism frequencies on farms in agriculture- and forest-dominated landscapes, North Carolina (2004-2006).

Table 1. Means (SE) of field border and row crop area (ha) per farm, North Carolina (2004-2006).

Treatments	Area (ha)	
	Field Border	Row Crop
Agriculture-dominated	1.24 (0.29)	50.37 (10.25)
Forest-dominated	1.08 (0.15)	42.63 (6.62)
Linear	0.85 (0.13)	36.20 (6.13)
Nonlinear	1.47 (0.27)	56.80 (9.73)

Table 2. Least-squares means (SE) of focal species densities (males/7854 m²) with and without red-winged blackbirds on farms, North Carolina (2004-2006).

	Field Border Establishment		t ₂₀ ^{a,b}	P ^c
	Pre-	Post-		
<u>With red-winged blackbirds</u>				
Agriculture-dominated	1.17 (0.13)	1.13 (0.09)	0.2236	0.4143
Forest-dominated	0.75 (0.13)	0.74 (0.09)	0.1000	0.4701
Nonlinear borders	1.03 (0.13)	1.16 (0.09)	0.7937	0.2184
Linear borders	0.89 (0.13)	0.71 (0.09)	1.0909	0.1446
Overall	0.96 (0.09)	0.94 (0.07)	0.2000	0.4183
<u>Without red-winged blackbirds</u>				
Agriculture-dominated	0.83 (0.10)	0.80 (0.07)	0.2646	0.3992
Forest-dominated	0.71 (0.10)	0.68 (0.07)	0.2646	0.3949
Nonlinear borders	0.83 (0.10)	0.91 (0.07)	0.6403	0.2642
Linear borders	0.71 (0.10)	0.57 (0.07)	1.1705	0.1278
Overall	0.77 (0.07)	0.74 (0.05)	0.3742	0.3562

^aAbsolute value of observed t statistic.

^bAll tests are one-tailed.

^cProbability of observing the associated, or larger, t statistic.

Table 3. Least-squares means (SE) of indigo bunting/ blue grosbeak nest survival probabilities and brood parasitism frequency on farms, North Carolina (2004-2006).

	Field Border Establishment		$t_g^{a,b}$	P^c
	Pre-	Post-		
<u>Nest survival probabilities</u>				
Agriculture-dominated	0.44 (0.15)	0.33 (0.11)	0.5477	0.5960
Forest-dominated	0.09 (0.15)	0.26 (0.11)	0.8888	0.4000
Nonlinear borders	0.36 (0.15)	0.29 (0.11)	0.3873	0.7043
Linear borders	0.17 (0.15)	0.31 (0.11)	0.7280	0.4862
Overall	0.26 (0.11)	0.30 (0.08)	0.2449	0.8178
<u>Brood parasitism frequency</u>				
Agriculture-dominated	0.25 (0.16)	0.33 (0.11)	0.3873	0.7045
Forest-dominated	0.45 (0.16)	0.31 (0.11)	0.7280	0.4876
Nonlinear borders	0.54 (0.16)	0.37 (0.11)	0.8246	0.4345
Linear borders	0.17 (0.16)	0.26 (0.11)	0.4899	0.6385
Overall	0.35 (0.11)	0.32 (0.08)	0.2449	0.8190

^aAbsolute value of observed t statistic.

^bAll tests are two-tailed.

^cProbability of observing the associated, or larger, t statistic.

September 5, 2007
Jason D. Riddle
Department of Forestry and Environmental Resources
North Carolina State University
Campus Box 8008
Raleigh, NC 27695-8008
919-215-9517 (phone)
jdriddle@unity.ncsu.edu
919-515-6193 (FAX)

RH: Time-of-detection method for covey abundance. Riddle et al.

A comparison of the time-of-detection and an empirical logistic regression method for estimating northern bobwhite covey abundance

Jason D. Riddle, Department of Forestry and Environmental Resources, North Carolina State University, Campus Box 8008, Raleigh, NC 27695-8008.

Christopher E. Moorman, Department of Forestry and Environmental Resources, North Carolina State University, Campus Box 8008, Raleigh, NC 27695-8008.

Kenneth H. Pollock, Department of Zoology, North Carolina State University, Campus Box 7617, Raleigh, NC 27695-7617.

Abstract: The estimation of avian abundance or population density can require adjusting counts by the probability of detection. We compared two methods of estimating the probability of detection for northern bobwhite (*Colinus virginianus*) coveys. The first method is from Wellendorf et al. (2004) and is based on an empirical logistic regression model that includes the number of calling coveys, wind speed, cloud cover, and changes in barometric pressure as covariates. The second method, time-of-detection, is a relatively new point count technique. With the time-of-detection method, the point count is broken up into several subintervals, and for each subinterval a record is made of whether a covey is detected or not. The data then consists of a series of detection histories which can be used in closed capture-recapture models to estimate detection probability and population size or density (Allredge et al. 2007). It is different from other standard point count methods (distance sampling, multiple observers) in that it can provide estimates of the total probability of detection: the product of availability (i.e., that a bird sings) and detection given availability. The Wellendorf et al. (2004) method (hereafter empirical method) also estimates total probability of detection. We used the time-of-detection method and the empirical method to estimate abundance for a sample of coveys on farms in the Coastal Plain of North Carolina. The empirical method produced an average detection probability of 0.585 (SE = 0.13) and the time-of-detection method produced a detection probability estimate of 0.540 (SE = 0.08), and the two estimates were not significantly different. This is the first evaluation of the time-of-detection method with real field data. One major advantage of the empirical method is that it is based on a large sample of radio-marked animals and a robust empirical regression function. However, the empirical method is based on data from previous years and the model takes no account of this. The time-of-detection method is based on the data collected in a

current study and therefore does not suffer from this deficiency. Historically, density estimates from covey call surveys that do not account for detectability have corresponded poorly to estimates from coveys flushed along line-transects. Surveys conducted with the time-of-detection method and/or the empirical method may produce density estimates that are more comparable to estimates from line-transect methods in environments where line-transect methods are appropriate. However, line-transect methods, or other methods that rely on distance data alone, still will be biased by their lack of ability to account for both components of the detection process.

Key Words: *Colinus virginianus*, covey counts, detection probability, North Carolina, point counts, radio-telemetry

The Journal of Wildlife Management 00(0): 000-000, 20XX

Differences in bird detectability over space and time may bias abundance or density estimates that do not allow for the estimation of detection probabilities (Williams et al. 2002). Abundance estimates and detection probabilities are related by the equation:

$$\hat{N}_i = C_i / \hat{p}_i \quad (1)$$

where \hat{N} is the estimate of population abundance, C is the count statistic, \hat{p} is the estimate of detection probability, and i is time and/or location of the survey. Comparing abundance indices or counts from different times and/or locations may lead to biased population comparisons and poor management decisions if detection probability is not constant. Nevertheless, Rosenstock et al. (2002) indicated that index methods without corrections for detection probabilities were still used in 95% of the avian studies they reviewed.

Several point count methods have been proposed to allow for the estimation of detection probability. These include: distance sampling (Buckland et al. 2001); multiple

observers [independent (Allredge et al. 2006) and dependent (Nichols et al. 2000)]; time-of-detection (Farnsworth et al. 2002, Allredge et al. 2007); and repeated counts (Royle and Nichols 2003).

Detection probability can be viewed as the product of two components: availability and detection given availability (Marsh and Sinclair 1989, Farnsworth et al. 2002, Pollock et al. 2004, Allredge et al. 2006). The first component is the probability that an animal is available for detection. In the context of point counts, this is the probability that a bird sings or that it is not visually concealed from the observer. The second component is the probability that an animal is detected if it is available. For point counts, this is the probability that a singing bird is heard or that a visible bird is seen (see Allredge 2004, Pollock et al. 2004, Allredge et al. 2007). Therefore, the total probability of detection (p) can be written to show its components as:

$$p = p_a p_d \quad (2)$$

where p_a is the probability of a bird being available and p_d is the probability of a bird being detected given that it is available. Henceforth, we limit our discussion of detectability to that of bird call and song because much of the data collected during point count surveys are aural instead of visual (this is especially true for covey call surveys), and because most of the discussion about detectability in the literature has focused on aural detections. Distance sampling and multiple observer methods do not allow the estimation of total detection probability whereas the time-of-detection and repeated counts methods do (Allredge 2004, Pollock et al. *in review*).

The original time-of-detection method (also known as the time-of-removal method) uses information from the first interval in which a bird is detected (Farnsworth et al. 2002).

In this respect, it is closely related to classical removal methods (Zippin 1956, Zippin 1958, Seber 1982, Williams et al. 2002). The more recent time-of-detection method uses information about whether a bird is detected from every time interval in the point count. In other words, it allows for the creation of a detection history that can be viewed in a similar manner to a capture-recapture history in a closed-population model (Allredge 2004, Allredge et al. 2007). Using the full detection history is more efficient because capture-recapture methods generally are more efficient than removal methods (Seber 1982, Allredge et al. 2007). On the other hand it is possible that the first detection data may have fewer measurement errors than the detection information for all intervals.

The ability of the time-of-detection method to handle variation in bird singing rates is one of its hallmarks (Allredge et al. 2007). When four or more intervals are used and heterogeneity has a two point finite mixture (Norris and Pollock 1996, Pledger 2000, Allredge et al. 2007), then it is theoretically possible to model detection by maximum likelihood estimation using variations of the standard models presented by Otis et al. (1978) for closed-populations (see also Pollock et al. 1990, Williams et al. 2002). Moreover, this makes selecting the “best” model via information theoretic approaches possible (e.g., Akaike’s Information Criterion (AIC) in program MARK (White and Burnham 1999, Burnham and Anderson 2002)).

Allredge et al. (*in press*) recently evaluated the time-of-detection method with bird song in a realistic, but simulated field setting. The method performed reasonably well except under conditions of heterogeneity with very low detection probabilities. However, this shortcoming is not unique to the time-of-detection method (Allredge et al. *in press*). Allredge et al. (*in press*) encouraged other researchers to evaluate the method under various field

conditions. In particular, they suggest the time-of-detection method may be especially useful with birds that have large territories, high singing rates, and relatively low mobility in order to minimize localization errors. During the fall, northern bobwhite (*Colinus virginianus*) coveys have large territories, exhibit periods of high singing rates under favorable conditions, and do not move large distances during the time of day when they are most vocal. Therefore, northern bobwhite coveys may be particularly suited for sampling with the time-of-detection method.

Wellendorf et al. (2004) developed an empirical logistic regression model to estimate total detection probability for covey counts based on covariates, including the number of calling coveys, wind speed, cloud cover, and changes in barometric pressure prior to the count. Their model was created from 219 radiomarked coveys at 5 locations in the southeastern United States (farms in Tyrrell County, North Carolina; farms in Wilson County, North Carolina; Ames Plantation, Tennessee; a hunting plantation in Leon County, Florida; and Tall Timbers Research Station, Florida). The method does allow for some coveys to be unavailable.

We used the same sample of a northern bobwhite covey population to estimate detection probability using both the time-of-detection method and the empirical method. Thus, we were able to evaluate the time-of-detection method in comparison to the empirical method. In the discussion we will consider the advantages and disadvantages of both methods, when each is more appropriate for use, and then briefly discuss some relevant aspects of line-transect sampling in light of these two methods.

Study Area

Our study was conducted on 24 commercial hog farms in Bladen, Columbus, Duplin, Pender, Sampson, Scotland, and Robeson Counties in the Coastal Plain of North Carolina. These farms were part of a larger study of the effects of field border shape and landscape context on bobwhite and early-succession songbirds. See Riddle et al. (*in review*) for additional details regarding experimental design, farm descriptions, and overall project goals. It is worth noting that our study sites were relatively close to two of the locations (farms in Wilson and Tyrrell Counties) where Wellendorf et al. (2004) developed their method, which further strengthens our ability to compare the time-of-detection and empirical methods.

Methods

Empirical method of Wellendorf et al. (2004)

We sampled fall coveys on each farm in 2004, 2005, and 2006. Surveys were conducted from the first week of October until the second week of November. In general, covey calling behavior is less variable during these six weeks than the rest of the fall season in the southeastern United States (Wellendorf et al. 2004). Each farm was sampled once/year from a single fixed location, which was approximately central to the field borders that were established on each farm as part of our study. Point counts began at 45 min before sunrise and lasted 1 hr. When a covey sang, its location was recorded on a digital orthogonal quarter-quadrangle (DOQQ) print-out of the farm to help avoid double counting. In another attempt to avoid double counting, we considered calls from within 30 m of each other to be from the same covey (Wellendorf et al. 2004). At sunrise, we recorded wind speed in km/hr with a hand-held anemometer and estimated cloud cover to the nearest 10%. Later, we obtained hourly barometric pressure readings (in/Hg) for the 6 hrs prior to sunrise from the

nearest weather stations via the North Carolina State Climate Office. These readings were used to calculate the change in barometric pressure 6 hrs prior to sunrise. These environmental data were used along with the number of calling coveys from each count to calculate a covey call rate adjustment according to the following equation adapted from Wellendorf et al. (2004):

$$\text{Logit}(\hat{p}_w) = -0.228 + 0.348x_1 + 3.27x_2 - 0.002x_3 - 0.092x_4 \quad (3)$$

where x_1 is the number of coveys heard, x_2 is the change in barometric pressure for the 6 hrs prior to sunrise, x_3 is the percent of cloud cover, and x_4 is the wind speed. The covey call rate adjustment is an estimate of detection probability. To estimate the abundance of coveys in an area, the number of coveys heard is divided by the adjustment to correct for environmental variables and the number of calling coveys (Wellendorf et al. 2004)

Time-of-detection method

The time-of-detection method was performed simultaneously with the empirical method of Wellendorf et al. (2004) by the same observers. Each 1 hr point count was divided into four 15-min intervals. We recorded covey calling behavior in each interval separately by circling covey locations on the DOQQs with 4 different colors of ink, which corresponded to the 4 time intervals. Thus, a 4-digit detection history was created for each covey. For example, a covey that called in intervals 1 and 3, but not in 2 or 4, would have the following detection history: 1010.

Analysis

For the empirical method, we obtained an average covey call rate adjustment (all treatments) for the entire study by averaging all of the covey call rate adjustments from each farm from all years.

For the time-of-detection method, we entered detection histories from all farms and years into program MARK and compared the following models in a Huggins closed-capture framework (Huggins 1989, Huggins 1991): M_0 , M_t , M_b , M_{th} , M_{bh} , M_h . All heterogeneity models were two point mixtures (Pledger 2000). Models were evaluated using AICc (Burnham and Anderson 2002), and the model with the largest AICc weight was chosen to calculate a detection probability. Combining detection histories from all years and all treatments was necessary to perform this analysis because of small sample sizes (number of calling coveys in this case). However, our work with summer bobwhite calls indicated that detection probabilities did not differ substantially by year or by treatments, even though the surrounding landscapes were markedly different (Riddle et al. *in review*).

To make the two estimates comparable, we had to convert the probability of detection at least once in 15 mins to the probability of detection at least once in an hour for the time-of-detection method using the following equation:

$$\hat{p}_t = 1 - \prod_1^4 (1 - \hat{p}_i), \quad (4)$$

with

$$Var(\hat{p}_t) = \sum_1^4 [Var(\hat{p}_i) \prod_{j \neq i}^4 (1 - \hat{p}_j)], \quad (5)$$

based on the Delta or Taylor Series method (Williams et al. 2002).

We used the detection estimate from the empirical method (\hat{p}_w) and the time-of-detection method (\hat{p}_t) to test the following hypothesis:

$$H_0: p_w = p_t$$

$$H_a: p_w \neq p_t$$

We used the normal Z statistic (see for example Williams et al. 2002) for comparing two different estimates. A failure to reject H_0 means that the time-of-detection method produced a similar probability of detection to that of the empirical method.

Results

Data from four covey counts in 2004 could not be used because of logistical reasons. Of the other 68 covey count surveys performed, only 32 resulted in detections (i.e., only 32 could be used to estimate the average covey call rate adjustment for the empirical method). The average covey call rate adjustment was 0.585 (SE = 0.13).

Sixty-four coveys were detected over the course of the study. Therefore, 64 detection histories were entered into program MARK for use with the time-of-detection method. The “best” model was M_t (AICc = 0.73945, Table 1). The M_t model assumes that every covey has an equal probability of being detected within each sampling period, but detection probability can vary among the different sampling periods (Williams et al. 2002). M_{th} was the only other model with an AICc weight larger than zero. However, only 5 of 9 parameters were estimable for this model. If M_{th} was removed from the group of compared models because of poor performance, then M_t would have received all of the weight (i.e., AICc = 1). The detection estimates for each of the four time periods were $\hat{p}_1 = 0.236$ (SE = 0.060), $\hat{p}_2 = 0.371$ (SE = 0.084), $\hat{p}_3 = 0.008$ (SE = 0.009), $\hat{p}_4 = 0.034$ (SE = 0.018). Therefore, the average detection probability, calculated by Equation (4), was 0.540 (SE = 0.08). The two estimates were not statistically different ($P(|z_{0.05/2}| > 0.295) = 0.768$).

Discussion

The time-of-detection method provided an estimate of detection probability that was similar to that of the empirical method, but with a much smaller standard error. Moreover,

the selected model, M_i , is consistent with what is known about covey calling behavior.

Hamrick (2002) determined that coveys were most likely to give their first call at 27.36 (SE = 0.21) min before sunrise. Similarly, Wellendorf et al. (2004) reported coveys are most likely to give their first call at 23.4 (SE = 0.5) min before sunrise, with 87% of calls occurring prior to 15 min before sunrise. This corresponds with the higher detection probability estimates for time intervals 1 and 2, which were 0.236 and 0.371, respectively. The detection probabilities for periods 3 and 4 were only slightly greater than 0.0, which again is consistent with known covey calling behavior. The extremely low probabilities of detecting coveys during periods 3 and 4 limited our ability to detect heterogeneity, if it was present. If we had focused the first 30 min of sampling with multiple, short intervals, it is possible we could have fit model M_{th} . Nevertheless, the time-of-detection method allowed for the selection of a model that was able to identify and capitalize on a key aspect of covey behavior, as well as call rate variability, and produce a reliable detection estimate. This is the first evaluation of the time-of-detection method with real field data. The time-of-detection method appears to perform very well in the context of northern bobwhite covey sampling.

The time-of-detection method produced a similar detection estimate to the empirical method, but did not require the collection of additional data on wind speed, cloud cover, or barometric pressure. In this regard, the time-of-detection method is more convenient and less expensive. Hand-held anemometers can be costly and may range from 74 to 245 US dollars (JDR, *personal observation*). We were able to obtain barometric pressure readings from the North Carolina State Climate Office without charge because of our affiliation with North Carolina State University. However, if we had been required to pay for these data, the cost would have been 25 US dollars/request or 25 US dollars/hr of data retrieval. The time-of-

detection method also allows for site specific estimation of detection probability, which makes it sensitive to unidentified or unmeasured factors which could influence covey call variability. However, the time-of-detection method will not perform well when only a few coveys are detected in a study.

The primary advantage of the empirical method is that it allows for adjustments on a count-by-count basis. Therefore, it is especially useful for smaller scale studies with few replicates, or with larger scale studies on sites with few coveys and/or logistical constraints which prohibit repeated visits within a season to increase precision (e.g., Riddle et al. *in review*). The empirical method was developed on 5 study sites located across the southeastern United States and used similarities in covey call rates across sites (Wellendorf et al. 2004). The authors were interested in making sampling recommendations that most researchers could use, or improve upon, at most sites. Nevertheless, there are many site specific factors, such as landscape differences and the timing of recruitment and covey formation, which could be important and were not included in their model (Wellendorf et al. 2004).

The empirical method and the time-of-detection method share several assumptions. Both assume that the population of coveys within the sampled area is closed during the point count. This assumption is likely to hold in most cases. For example, it is possible that entire coveys (especially small ones) are depredated within the course of one hour at any particular site, but we believe this is unlikely to happen very often. Both methods assume that individual coveys are accurately identified (i.e., no double counting of single coveys and no mistaking multiple coveys as a single covey). Using DOQQs to map covey locations and the 30-m rule should help to avoid double counting. However, the ability of observers to

determine if birds giving covey calls are within 30 m of one another probably will decrease with increasing distance from the observer. This probably is not a major concern when covey densities are moderate to low (as in our study), but could be problematic in areas of high covey density (Roseberry 1982, DeMaso et al. 1992). The time-of-detection method has additional assumptions associated with the specific model(s) that best fits the data. M_1 was the best model for our data, and this adds the additional assumption that each covey has an equal detection probability within each sampling interval. This assumption might be violated if, for example, call rates of some coveys were elevated within a particular sampling interval because they had been disturbed and scattered during the night. However, Wellendorf et al. (2004) estimated that nocturnal disturbance had not occurred for more than 95% of the coveys they surveyed. In future studies, more intervals of shorter length (especially during the first 30 min of sampling) might allow one to account for this as a form of heterogeneity. The empirical method has the additional assumption that temperature, cloud cover, and barometric pressure changes are recorded accurately. The empirical method was developed at specific sites from a range of values for each of the betas used in Equation (3). Technically, use of the empirical method at sites and under conditions outside the range of those from which it was developed is a form of extrapolation. Similarly, another potential issue with the empirical method is that adjustments made to individual counts are not totally independent because the estimated betas in the logistic regression used to adjust each count are based on the same prior data set.

Recommendations

According to the Breeding Bird Survey, northern bobwhite have declined annually by 3% in the United States from 1966-2005 (Sauer et al. 2005). Recently, there has been

considerable interest in conservation solutions, such as field borders, to reverse bobwhite declines (Puckett et al. 1995, Puckett et al. 2000, Dimmick et al. 2001, Smith 2004, Palmer et al. 2005, Riddle et al. *in review*). Attempts to evaluate the effectiveness of these management activities only will be as reliable as the survey methods used in the evaluations. The time-of-detection and empirical methods both appear to be effective means of estimating detection probabilities for northern bobwhite coveys.

We recommend that researchers simultaneously use both methods when possible. The time-of-detection method adds little extra effort to the empirical method. It would be informative if other researchers were able to assess the performance of both methods for covey counts at other study sites to determine if our results are repeatable. When it is not possible to use both methods, we recommend the empirical method for smaller scale studies where replication and/or multiple independent counts may not be feasible, or in situations where the number of detections is likely to be low. We recommend the time-of-detection method for larger scale studies where the number of detections may be high and the cost of gathering wind speed and climatic data may be prohibitive because of logistics or costs. However, even in this case, it still may be informative to double sample (Bart and Earnst 2002) with the empirical method on a subset of points to allow for comparisons where possible.

We acknowledge that other studies have suggested covey call surveys provide poor density estimates when compared to line-transect methods that flush coveys (DeMaso et al. 1992, Rusk et al. 2007). Line-transect methods typically perform best when coveys are at high densities in relatively homogeneous habitat, such as some rangelands in Texas (Guthery 1998). However, these conditions are not typical for most bobwhite populations. Line-

transects may perform poorly when densities are low (Kuvlesky et al. 1989) and habitats are heterogeneous (e.g., interspersed fields and forests). Furthermore, on two sites with a variety of woodland, grassland, shrubland, and cropland habitats, Janvrin et al. (1991) determined that some northern bobwhite did not flush, even when observers stepped over them, and that 40% of coveys moved away from observers upon approach. Thus, two major assumptions of line-transect sampling were violated: 1) detection probability on the line is 1.0, and 2) birds do not move towards or away from an observer prior to detection (Guthery 1988). DeMaso et al. (1992) suggested that the poor performance of covey call methods as an index of covey density in their study may have resulted in part from violations of the assumptions that “the proportion of coveys calling is constant over space and time”. Indeed, Wellendorf et al. (2004) demonstrated that covey calling behavior is not constant over biweekly periods or over space (i.e., because covey calling behavior is density dependent and each survey location may have different densities). At a smaller temporal scale, our results indicate that detection probabilities changed significantly over a relatively short amount of time (i.e., over the course of an hour). Compared to traditional covey call surveys, surveys conducted with the time-of-detection method and/or the empirical method may produce density estimates that are more comparable to estimates from line-transect methods in environments where line-transect methods are appropriate. However, line-transect methods, or other methods that rely on distance data alone, will still be biased by their lack of ability to account for both components of the detection process.

Finally, we emphasize that our evaluation of the time-of-detection method would not have been possible without being able to make comparisons to the unique empirical model of Wellendorf et al. (2004). Similar Herculean efforts to develop empirical models based on

radio-tagged birds for other species may prove extremely useful for estimating detection probabilities directly and for validating detection estimates from other recently proposed point count methods.

Acknowledgments

Technicians B. Herring, W. Ricks, J. McCormick, and C. Ward provided assistance in the field. Thanks to D. Williamson, K. Westerbeak, and all of the Murphy-Brown, LLC staff who helped with farm selection, coordination with farm managers, and other logistical issues. T. Sharpe provided invaluable technical advice and encouragement. P. Bromley, D. Cobb, N. Haddad, S. Nelson, W. Palmer, and S. Wellendorf provided helpful reviews. The project was supported financially by the Department of Forestry and Environmental Resources at North Carolina State University, The North Carolina Wildlife Resources Commission, Murphy Brown, LLC, and a grant from the USDA-NRCS/Mississippi State University Bobwhite Restoration Project.

Literature Cited

- Allredge, M. W. 2004. Avian point count surveys: estimating components of the detection process. Dissertation. North Carolina State University, Raleigh, North Carolina, USA.
- Allredge, M. W., K. H. Pollock, and T. R. Simons. 2006. Estimating detection probabilities from multiple-observer point counts. *The Auk* 123:1172-1182.
- Allredge, M. W., K. H. Pollock, T. R. Simons, J. A. Collazo, and S.A. Shriner. 2007. Time-of-detection method for estimating abundance from point-count surveys. *The Auk* 124:653-664.

- Allredge, M. W., T. R. Simons, K. H. Pollock, and K. Pacifici. 2007. A field evaluation of the time-of-detection method to estimate population size and density for aural avian point counts. *In press*.
- Bart, J., and S. Earnst. 2002. Double sampling to estimate density and population trends in birds. *The Auk* 119:36-45.
- Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. Introduction to distance sampling. Oxford University Press, New York, New York, USA.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and inference: a practical information theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.
- DeMaso, S. J., F. S. Guthery, G. S. Spears, and S. M. Rice. 1992. Morning covey calls as an index of northern bobwhite density. *Wildlife Society Bulletin* 20:94-101.
- Dimmick, R. W., M. J. Gudlin, and D. F. McKenzie, editors. 2001. The northern bobwhite quail initiative. Southeast Quail Study Group Technical Committee, Knoxville, Tennessee, USA.
- Farnsworth, G. L., K. H. Pollock, J. D. Nichols, T. R. Simons, J. E. Hines, and J. R. Sauer. 2002. A removal model for estimating detection probabilities from point-count surveys. *The Auk* 119:414-425.
- Guthery, F. S. 1988. Line transect sampling of bobwhite density on rangeland: evaluation and recommendations. *Wildlife Society Bulletin* 16:193-203.

- Hamrick, R. G. 2002. Evaluation of northern bobwhite (*Colinus virginianus*) population monitoring methods and population trends in agricultural systems in the Upper Coastal Plain of Georgia. Thesis, University of Georgia, Athens, Georgia, USA.
- Huggins, R. M. 1989. On the statistical analysis of capture experiments. *Biometrika* 76:133-140.
- Huggins, R. M. 1991. Some practical aspects of a conditional likelihood approach to capture experiments. *Biometrics* 47:725-732.
- Janvrin, J. A., E. P. Wiggers, and T. V. Dailey. 1991. Evaluation of drive counts for estimating northern bobwhite densities. *Wildlife Society Bulletin* 19:475-481.
- Kuvlesky, W. P., Jr., B. H. Koerth, and N. J. Silvy. Problems of estimating northern bobwhite populations at low density. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 43:260-270.
- Marsh, H., and D. F. Sinclair. 1989. Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. *Journal of Wildlife Management* 53:1017-1024.
- Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. *The Auk* 117:393-408.
- Norris, J.L. III, and K. H. Pollock. 1996. Nonparametric MLE under two closed capture-recapture models with heterogeneity. *Biometrics* 52:639-649.
- Otis, D. L., K. P. Burnham, G. C. White, and D. L. Anderson. 1978. Statistical inference from capture data on closed animal populations. *Wildlife Monographs* 62:1-135.

- 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.
- Pledger, S. 2000. Unified maximum likelihood estimates for closed capture-recapture models using mixtures. *Biometrics* 56:434-442.
- Pollock, K. H., M. W. Alldredge, and T. R. Simons. Separation of availability and perception processes for aural detection in avian point counts: a combined multiple observer and time-of-detection approach. *Avian Conservation and Ecology in review*.
- Pollock, K. H., H. Marsh, L. L. Bailey, G. L. Farnsworth, T. R. Simons, and M. W. Alldredge. 2004. Separating components of detection probability in abundance estimation: An overview with diverse examples. Pages 43-58 in W. L. Thompson, editor. *Sampling rare and elusive species: concepts, designs and techniques for estimating population parameters*. Island Press, Washington D.C., USA.
- Pollock, K. H., J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical inference for capture-recapture experiments. *Wildlife Monographs* 107:1-97.
- 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 of the Southeastern Association of Fish and Wildlife Agencies* 49:505-515.
- Puckett, K. M., W. E. Palmer, P. T. Bromley, J. R. Anderson, Jr., and T. L. Sharpe. 2000. Effects of filter strips on habitat use and home range of northern bobwhites on Alligator River National Wildlife Refuge. *Proceedings of the National Bobwhite Quail Symposium* 4:26-31.

- Riddle, J. D., C. E. Moorman, and K. H. Pollock. The importance of habitat shape and landscape context for northern bobwhite populations: an experiment with field borders. *Journal of Wildlife Management in review*.
- Roseberry, J. 1982. Bobwhite. Pages 68-70 in D. E. Davis, editor. *Handbook of census methods for terrestrial vertebrates*. CRC Press, Boca Raton, Florida, USA.
- Rosenstock, S. S., D. R. Anderson, K. M. Giesen, T. Leukering, and M. F. Carter. 2002. Landbird counting techniques: current practices and an alternative. *The Auk* 119:46-53.
- Royle, J. A., and J. D. Nichols. 2003. Estimating abundance from repeated presence-absence data or point counts. *Ecology* 84:777-790.
- Rusk, J. P., F. Hernandez, J. A. Arredondo, F. Hernandez, F. C. Bryant, D. G. Hewitt, E. J. Redeker, L.A. Brennan, and R.L. Bingham. An evaluation of survey methods for estimating northern bobwhite abundance in southern Texas. *Journal of Wildlife Management* 71:1336-1343.
- Sauer, J. R., J. E. Hines, and J. Fallon. 2005. *The North American Breeding Bird Survey, Results and Analysis 1966 – 2005. Version 6.2.2006*. USGS Patuxent Wildlife Research Center, Laurel, MD.
- Seber, G. A. F. 1982. *The estimation of animal abundance and related parameters* (2nd edition), Macmillan Publishing Co., Inc., New York, New York, USA.
- Smith, M. D. 2004. *Wildlife habitat benefits of field border management practices in Mississippi*. Dissertation. Mississippi State University, Starksville, Mississippi, USA.

- Wellendorf, S. D., W. E. Palmer, and P. T. Bromley. 2004. Estimating calling rates of northern bobwhite coveys and measuring abundance. *Journal of Wildlife Management* 68: 672-682.
- White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. *Bird Study* 46:S120-S139.
- Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. *Analysis and management of animal populations: modeling, estimation, and decision making*. Academic Press, San Diego, California, USA.
- Zippin, C. 1956. An evaluation of the removal method of estimating animal populations. *Biometrics* 12:136-189.
- Zippin, C. 1958. The removal method of population estimation. *Journal of Wildlife Management* 22:82-90.

Table 1. AICc, Delta AICc, AICc weights, likelihoods, parameters, and deviance for closed-capture models used with the time-of-detection method in program MARK. All data were collected from commercial hog farms, North Carolina (2004-2006).

Model	AICc	Delta AICc	AICc weight	Model Likelihood	Model parameters	Estimable parameters	Deviance
Mt	163.391	0.00	0.73945	1.0000	4	4	381.613
Mth	165.478	2.09	0.26055	0.3524	9	5	381.613
Mb	210.692	47.30	0.00000	0.0000	2	2	433.033
Mbh	212.743	49.35	0.00000	0.0000	5	3	433.033
Mo	240.423	77.03	0.00000	0.0000	1	1	464.798
Mh	242.457	79.07	0.00000	0.0000	2	2	464.798