Management and Conservation Article

The Importance of Habitat Shape and Landscape Context to Northern Bobwhite Populations

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ABSTRACT Northern bobwhite (*Colinus virginianus*) populations have declined nationally for at least the past 4 decades. Field borders have been promoted as an important component of conservation plans to reverse this decline. Field border characteristics, such as shape and the landscapes in which the borders are established, have the potential to influence their effectiveness for recovering northern bobwhite populations. We established narrow linear (approx. 3-m-wide) and nonlinear field borders on farms in agriculture-dominated and forest-dominated landscapes in the Coastal Plain of North Carolina, USA, after collecting pretreatment data on summer bobwhite abundance. After establishment of field borders, summer bobwhite abundance nearly doubled on farms in agriculture-dominated landscapes and increased approximately 57% on farms with nonlinear field borders. Summer bobwhite abundance did not increase on farms with linear field borders in forest-dominated landscapes. 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 we found only nonlinear field borders resulted in an increase. (JOURNAL OF WILDLIFE MANAGEMENT 72(6):1376–1382; 2008)

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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, USA, declined annually by 5.9% from 1980 to 2005 (Sauer et al. 2005). Bobwhite generally depend on 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 forests, urbanization, and fire suppression (Klimstra 1982, Brennan 1991, Askins 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 [NBCI]). Dimmick et al. (2002) 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 bobwhite declines (Dimmick et al. 2002). 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 early-succession songbirds currently are promoted and subsidized by federal and state programs, including the Conservation Reserve Program's (CRP) Upland Bird Habitat Buffer (CP-33; United States Department of Agriculture 2004) and the North Carolina Wildlife Resources Commission's (NCWRC) Cooperative Upland Habitat Restoration and Enhancement Program (CURE; Cobb et al. 2002). Field borders can provide nesting habitat, movement corridors, and cover for bobwhite by providing usable space (Burger et al. 1995; Puckett et al. 1995, 2000; Guthery 1997). Establishment of field borders nearly doubled the number of bobwhite coveys on farms in eastern North Carolina (Palmer et al. 2005). Field borders can provide benefits to songbirds as well (Marcus 1998; Marcus et al. 2000; Smith et al. 2005*a*, *b*). 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 (i.e., linear or nonlinear) may have dramatic impacts on its value for northern bobwhite and other 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 and nest depredation (Shalaway 1985, Camp and Best 1994, Pedlar et al. 1997, Clark and Bogenschutz 1999, Dijak and

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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, 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 often are associated with landscapes that have a substantial 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 bobwhites (Bell et al. 1985) and may impede dispersal and recolonization of habitat islands embedded in a closed canopy forest matrix (Fies et al. 2002).

We examined the effect of establishing nonlinear and narrow linear field borders on farms in landscapes dominated by either agriculture or forest on summer northern bobwhite abundance. Our primary goals were to advance knowledge about bobwhite response to habitat manipulations and to provide agencies such as the Natural Resources Conservation Service and NCWRC with practical recommendations for maximizing the impact of field borders for bobwhite and improving programs such as CRP and CURE. We hypothesized that field border establishment would increase summer bobwhite 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.

STUDY AREA

We conducted our study on 24 commercial hog farms located in Bladen, Columbus, Duplin, Pender, Sampson, Scotland, and Robeson counties of the southern Coastal Plain of North Carolina (Fig. 1). All farms were owned and operated by Murphy-Brown, LLC (Warsaw, NC). We selected study sites from a pool of >200 company farms to minimize the potentially confounding differences among farms (e.g., crop rotations, recent timber activity). Each hog farm had ≥1 hog house, which was a confinement area for hog production.

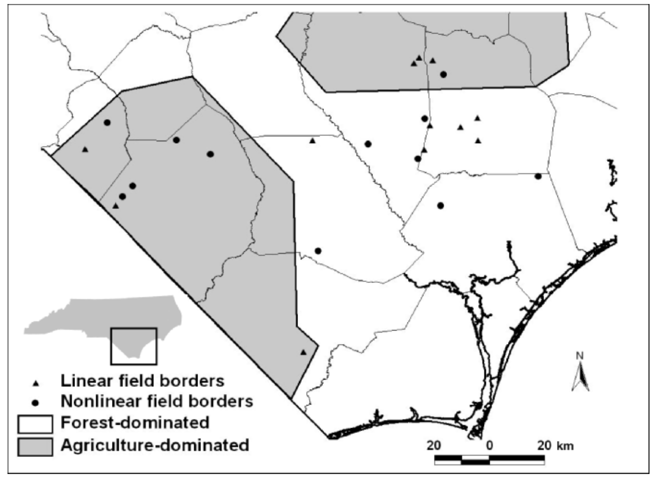

Figure 1. Farm locations and treatment assignments in Coastal Plain, North Carolina, USA, 2004–2006, studied for potential effects on summer northern bobwhite abundance.

Hog waste was collected into ≥1 lagoon adjacent to the hog house(s). This waste was applied to row crop, pasture, and hay fields as a form of nutrient management. Most farms were on a crop rotation of corn, soybean, and winter wheat, although a few farms occasionally grew cotton on some fields.

METHODS

Experimental Design

We arranged treatments in a balanced 2×2 factorial with field border shape (linear or nonlinear) and landscape context (agriculture- or forest-dominated) as the 2 factors. There were 6 replicate farms for each of the 4 treatment combinations ($n = 24$). We were not able to randomize field border shape on farms in either landscape because of hog waste application patterns and regulatory requirements. However, the pre- vs. posttreatment contrasts we were able to perform (see below) were robust to our lack of randomization due to the before-after, control-impact-like nature of our design (Morrison et al. 2001). We were able to randomize aspects of vegetation sampling at the farm level.

Field borders were established along the edges of row crop fields by allowing demarcated areas to go fallow after 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 approximately 3 m wide and varied by length (range = 66.40–1,938.95 m; $\bar{x} = 475.44$; SE = 47.91) and therefore area (0.02–0.59 ha; $\bar{x} = 0.14$; SE = 0.01), whereas individual nonlinear field borders varied by shape and size (range = 0.05–2.48 ha; $\bar{x} = 0.25$; SE = 0.04). Total field border area per farm and total row crop area per farm ranged from 0.43 ha to 3.81 ha ($\bar{x} = 1.16$; SE = 0.16) and from 17.00 ha to 127.13 ha ($\bar{x} = 46.5$; SE = 6.02), respectively, and did not influence results. Field borders made up an average of 2.50% (SE = 0.06) of total row cropped area on each farm and did not differ by treatment.

We chose farms from landscapes that were designated as either focal areas or nonfocal areas for northern bobwhite management by the NCWRC (Howell et al. 2002). For our purposes, 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 2,538 m (buffer area = 2,023 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% ($\bar{x} \pm$ SE) row crops and 18.5 $\pm$ 2.1% forests. Farms in forest-dominated landscapes were surrounded by 21.0 $\pm$ 2.3% row crops and 44.9 $\pm$ 3.8% forests.

Data Collection

We established point count survey locations 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 $\geq$250 m apart. We sampled all locations once in 2004 before establishment of field borders and once per year in 2005 and 2006 after field border establishment. We conducted surveys from approximately 15 minutes after sunrise until approximately 1000 hours from 15 May to 30 June.

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 (Alldredge 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 $<$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 (K. H. Pollock, North Carolina State University, unpublished report).

To execute this combined method, 2 observers alternated roles as primary and secondary observer from one point count to another on each farm. Each point count lasted 10 min and was divided into 4 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. We combined observations from the primary and secondary observers within each time interval for analysis in MARK (White and Burnham 1999) and used Akaike's Information Criterion corrected for small sample size (AIC_c) to select the best model (Burnham and Anderson 2002).

Although we measured breeding season male abundance, we use the term "summer abundance" of northern bobwhite to facilitate comparisons 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 such that the number of males in a population should be proportional to the number of females (Stoddard 1931, Leopold 1945, Rosene 1969, Brennan 1999).

We sampled field border vegetation at each point count location in 2005 and 2006. Each point count location had 3 1×1-m subplots. One subplot was located at the center of the point count. In linear field borders, the other 2 subplots were located opposite from each other 25 m from the center of the point count. One of the subplots was located within but adjacent to the interior side of the field border (the side adjacent to crops), and the other subplot was located within but adjacent to the exterior side of the field border. In nonlinear field borders, we determined the location of the other 2 subplots by randomly selecting a bearing and distance (within 50 m) for each subplot.

At each subplot, we placed a 1×1-m sampling grid on the ground. We placed an angle locator attached to a 2-m polyvinyl chloride (PVC) pole (5.1 cm diam) in the center of the grid. We tilted the pole towards each of the 4 corners of the sampling grid until it came in contact with vegetation to obtain 4 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 disc of vulnerability by pacing out from each subplot in the 4 cardinal directions and recording the distance at which the lower 15-cm section of the PVC pole became totally visually obscured when viewed from a height of 1 m (Kopp et al. 1998). We visually estimated percent cover of grass, woody vegetation, forbs, and open ground within the 1×1-m grid from 15 cm up to 2 m (sum of all 4 cover types = 100%). In 2006, we visually determined the single plant species that most typified the field border within 50 m of the point count center.

Analysis

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 whether detection probabilities differed among treatments and years. In some cases, we had multiple detection histories for one bird (i.e., the same bobwhite was detected from multiple survey locations on each farm). When this occurred, we used only the first detection in Program MARK. The best model was M_{bh} (trap response and heterogeneity with a 2-point mixture) with no treatment or year effect (AIC_c wt = 0.973). Detection probability was 0.49 and because there was no difference between years or treatments, the unadjusted counts were directly proportional to population size and could be used in our subsequent analyses (Williams et al. 2002).

We analyzed the average count per farm (observations from both observers combined) using a 2×2 split-plot

Table 1. Least-squares means of summer bobwhite abundance per count per farm, North Carolina, USA (2004–2006).

Treatment	Field border establishment					
	Pre		Post			
	$\bar{x}$	SE	$\bar{x}$	SE	t_{20}[a,b]	P[c]
Agriculture-dominated	0.54	0.17	1.01	0.12	2.235	0.019
Forest-dominated	0.76	0.17	0.88	0.12	0.5791	0.284
Nonlinear borders	0.68	0.17	1.07	0.12	1.9140	0.035
Linear borders	0.63	0.17	0.81	0.12	0.8958	0.191
Overall	0.65	0.12	0.94	0.09	2.336	0.031

[a] Absolute value of observed t statistic.
[b] All tests are 1-tailed.
[c] Probability of observing the associated, or larger, t statistic.

analysis of variance (ANOVA) with PROC GLM in SAS (SAS Institute, Cary, NC) with landscape context and habitat shape as the whole-plot factors. The split-plot factor was year (there were 2 levels: the pretreatment yr and the weighted average of the 2 posttreatment yr). We used 1-tailed preplanned orthogonal contrasts (in the absence of a landscape context × habitat shape × yr interaction) to test for an overall effect of field borders (i.e., summer abundance before vs. after field border establishment). We also used 1-tailed preplanned orthogonal contrasts to compare summer abundance before and after field border establishment for both levels of each factor separately.

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

RESULTS

There was no interaction of landscape context, habitat shape, and year ($F_{1,20} = 0.06$, $P = 0.804$). Therefore, we proceeded to test for an effect of field borders and for main effects between pre- and posttreatment years with contrasts (Table 1). Summer abundance increased from 0.65 (SE = 0.12) bobwhite per count per farm in the pretreatment year to 0.94 (SE = 0.09) in posttreatment 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 per count per farm from pretreatment to posttreatment years, respectively. However, summer abundance did not increase significantly on farms in forest-dominated landscapes from the pretreatment to posttreatment years. Summer abundance increased on farms with nonlinear field borders from 0.68 (SE = 0.17) to 1.07 (SE = 0.12) bobwhite per count per farm from pretreatment to posttreatment years, respectively. Summer abundance did not increase significantly on farms with linear field borders from the pretreatment to posttreatment years. There was no interaction of landscape context and field border shape in the posttreatment years ($F_{1,20} = 0.74$, $P = 0.401$).

Collectively, there was no difference in vegetation variables by landscape ($F_{5,16} = 0.25$, $P = 0.933$), shape ($F_{5,16} = 2.43$, $P = 0.080$), or interaction of landscape and shape ($F_{5,16} = 0.59$, $P = 0.711$). The cone of vulnerability, disc 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 2). There also was no effect of landscape or interaction of landscape and shape on woody vegetation cover. 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 summer abundance of northern bobwhite on the farms we sampled by about 45%. In a study of 12 farms in 3 eastern North Carolina counties, Palmer et al. (2005) documented 40% more bobwhite during summer 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 bobwhites on 2 farming areas with field borders than on 2 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

Table 2. Means of the cone of vulnerability (degrees from vertical), disc of vulnerability (m), and cover (%) of open ground, herbaceous, and woody vegetation, North Carolina, USA (2004–2006).

	Main effects												Interaction of landscape context × field border shape	
	Landscape context						Field border shape							
	Agriculture		Forested				Nonlinear		Linear					
	$\bar{x}$	SE	$\bar{x}$	SE	$F_{1,20}$	P	$\bar{x}$	SE	$\bar{x}$	SE	$F_{1,20}$	P	$F_{1,20}$	P
Cone of vulnerability	12.93	2.15	12.27	1.92	0.05	0.825	11.93	1.58	13.27	2.39	0.21	0.654	0.93	0.347
Disc of vulnerability	5.62	0.66	5.68	0.67	0.00	0.945	5.50	0.46	5.80	0.81	0.10	0.759	0.99	0.332
Open ground (%)	66.92	3.30	63.71	3.94	0.40	0.535	66.78	2.78	63.86	4.34	0.33	0.572	2.13	0.160
Herbaceous (%)	30.81	3.28	29.90	2.19	0.05	0.822	31.85	2.75	28.85	2.76	0.57	0.460	1.05	0.317
Woody (%)	2.27	0.70	2.22	0.37	0.00	0.950	1.37	0.37	3.12	0.58	6.23	0.021	1.37	0.256

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, which 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. 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 m or 10 m. Field borders in the Palmer et al. (2005) study were 3–5 m in width. Our linear field borders only averaged about 3 m in width. Therefore, the width of linear field borders across our 3 studies is proportional to the magnitude of bobwhite increase during summer. In other words, linear field borders of 3-m, 3–5-m, and 9–10-m widths resulted in bobwhite populations that were about 29%, 40%, and 91% larger, respectively.

We established field borders with structural characteristics favorable for nesting and brood rearing habitat (i.e., the field borders were high quality habitats). Specifically, the average disc of vulnerability was <12–13 m for all treatments, which is favorable for concealment from terrestrial predators (Kopp et al. 1998). The average cone of vulnerability was narrow, with average angles <13° from vertical, 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 among 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.

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 after field border establishment, but we did not see an increase from 2005 to 2006 (J. D. Riddle, North Carolina State University, 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. Although bobwhite traditionally have been considered to be relatively sedentary, recent studies determined that approximately 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).

Dispersing quail should be more successful at locating suitable habitat when interpatch distances are relatively small (Fies et al. 2002) and hostile habitats (e.g., closed canopy forests) are a minor landscape component, which 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. Townsend et al. (2003) reported that dispersers had higher survival probabilities and initiated more nests than did nondispersers. Although we did not address recruitment, Riddle (2007) documented a slight trend toward increasing covey abundance after the establishment of field borders on farms in agriculture-dominated landscapes.

MANAGEMENT IMPLICATIONS

We encourage using a landscape-level approach to select farms for northern bobwhite management with field borders. There seems 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 that 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.

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 landscape-level, replicated studies with radiomarked birds, which will assist in location of nests and estimation of productivity as well as provide movement information that 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.

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