Original Article

Small Mammal Use of Field Borders Planted as Beneficial Insect Habitat

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ABSTRACT Field borders established for wildlife conservation have been recognized as a possible venue for also promoting beneficial insect populations, such as parasitic wasps and pollinators, on agricultural lands. However, traditional fallow field borders lack nectar sources required to sustain beneficial insect communities, and their value to small mammals is not well-understood. In October–November 2009, we trapped small mammals in four field-border treatments (planted native, warm-season grasses and prairie flowers, planted prairie flowers only, fallow vegetation, and frequently mowed vegetation) replicated around nine organic crop fields, and developed closed-population models in Program MARK to estimate abundance in each border. We also measured vegetation cover within each border treatment from June to August 2009. We captured 491 individuals of two species, the hispid cotton rat (*Sigmodon hispidus*) and house mouse (*Mus musculus*). Cotton rat abundance was ≥2 times greater in grass and flower borders and flowers-only borders than in fallow borders, likely because of greater vegetation density and availability of preferred foods in planted borders. No cotton rats were captured in mowed borders, and house mouse abundance was ≥5 times lower in mowed borders than in other border types. Lower abundance of cotton rats and house mice in mowed borders emphasizes the importance of structurally complex non-crop vegetation for supporting small-mammal communities in agricultural landscapes. Field borders planted to promote beneficial insects may be a useful tool for maximizing the ecological services provided by non-crop vegetation. © 2012 The Wildlife Society.

KEY WORDS agriculture, beneficial insects, field borders, *Mus musculus*, *Sigmodon hispidus*, small mammals.

Land area devoted to organic agriculture has increased dramatically in the United States; consequently, organic producers are demanding innovative methods for controlling both insect and herbaceous pest species without the use of insecticides or herbicides (Landis et al. 2000). One approach to pest management is to conserve biological control agents that naturally suppress pest populations within the farm landscape (Landis et al. 2005). Traditionally, arthropods that depredated (i.e., ladybugs, Family: Coccinellidae) or parasitized (i.e., parasitic wasps within Order: Hymenoptera) pest species were the focus of biological control. However, recent studies have demonstrated the contributions made by vertebrate species in controlling both insect and herbaceous pest species (Cardina et al. 2002, Borkhataria et al. 2006).

Small-mammal communities hold a number of important ecological roles and can have significant effects on the energetic dynamics within agricultural ecosystems (French et al. 1976). Because they account for a significant portion of the prey biomass consumed by vertebrate predators, small mammals serve as a foundation for many tropic interactions and can influence the abundance and diversity of avian and mammalian predator species within a landscape (Norrdahl and Korpimäki 1996, Meserve et al. 2003, Korpimäki et al. 2005). While they frequently act as seed dispersal agents, small mammals also consume large quantities of undesirable weed seeds and can impact vegetation composition within a landscape (Howe and Brown 1999, Cardina et al. 2002). Seed predation is recognized as an important weed population regulator and may be equally as effective at inhibiting weed emergence as current methods such as mulching with crop residue (Sharon et al. 2007). Therefore, landscapes that provide habitat for small-mammal populations may be rewarded with increased biodiversity along with the potential for reducing a wider variety of weed seeds throughout the year.

Allowing crop-field margins to return to fallow vegetation (hereafter, field borders) is a widely accepted conservation strategy within agricultural landscapes. Field borders are easily established and provide ecological benefits including

erosion control, improved water quality near riparian areas, and wildlife habitat (Osborne and Kovacic 1993, Daniels and Gilliam 1996, Riddle et al. 2008, Smith et al. 2008). In addition, field borders have minimal impact on crop productivity (Morris 1998).

Researchers have suggested that field borders may provide a venue through which biological control agents are conserved on the landscape (Griffiths et al. 2008). However, traditional fallow field borders are insufficient in supporting predator and parasitoid arthropod populations, largely because of the lack of nectar-producing vegetation found within the borders (Olson and Wäckers 2007). Predators and parasitoids of crop pests require diverse habitat conditions that provide abundant pollen and nectar sources and various microhabitats used as nesting and over-wintering sites throughout the year (Heimpel and Jervis 2005). Carbohydrates and amino acids from nectar and pollen are essential for reproduction and serve as alternate food source in times when prey species are less abundant (Wäckers and van Rijn 2005). In agricultural systems, habitat lacking in these components greatly reduces the ability of biological control agents to control pest species that are typically abundant in monoculture crops (Heimpel and Jervis 2005, Landis et al. 2005). However, habitat manipulation used to promote specific vegetation can increase beneficial insect communities (Landis et al. 2000, Forehand et al. 2006).

Field borders planted to promote beneficial arthropod populations also may provide the habitat conditions needed to sustain small-mammal communities. Although essential to many small-mammal species, access to early successional vegetation often is limited in intensive agricultural areas (Askins 2001, Harper 2007). Many small-mammal species require diverse stands of annual and perennial grasses and forbs for seed and herbaceous food sources, as well as protective cover from predators. The lower stratum of early successional vegetation is used as nesting sites and can provide thermal cover for individuals during the winter months (Foster and Gaines 1991). Borders also may function as travel corridors that facilitate safe movement among habitat patches (Butet et al. 2006). Whereas the benefits to small-mammal communities of non-crop areas, such as hedgerows, have been established (Yahner 1983, Silva and Prince 2008), no study has investigated use of field borders by small mammals.

The inherent differences in floral characteristics, such as relative proportion of grasses and forbs and structural characteristics of vegetation as protective escape cover, between planted and fallow borders may influence variability in small-mammal use of these habitat patches. Each small-mammal species requires specific habitat conditions related to their life history, and consequently responds to habitat differences that affect food and cover needs (Grant and Birney 1979, Osbourne et al. 2005). Accordingly, we investigated small-mammal responses to variability in field-border characters by comparing abundance of small mammals in four types of field borders replicated around each of nine organic farm fields.

STUDY AREA

We conducted our study in the upper coastal plain physiographical region at the Center for Environmental Farming System's Organic Research Unit outside of Goldsboro, North Carolina, USA. Within the Organic Research Unit, nine organic crop fields with areas ranging from 1.6 ha to 4 ha were planted in soybeans (*Glycine max*), corn (*Zea mays*), or hay crop (red clover [*Trifolium pretense*] and orchard grass [*Dactylis glomerata*]). Three fields were planted in each of the crop types, and crops followed an annual rotation pattern of hay to corn, corn to soybeans, and soybeans to hay. All agricultural practices followed U.S. Department of Agriculture organic crop production guidelines. We randomly assigned all four field-border treatments to each of the nine crop fields. All field borders were approximately 91.44 m × 9.14 m (0.08 ha), creating 0.33 ha of experimental habitat around each field. The field margin located between adjacent border treatments was mowed 2–3 times per month. The mean (±SD) distance between the edges of adjacent borders within a crop field was 30.0 ± 30.9 m.

The four border treatments were 1) planted native-warm season grasses and native prairie flowers (hereafter, native grasses–flowers), 2) planted native prairie flowers only (hereafter, flowers only), 3) fallow, unmanaged vegetation (hereafter, fallow), 4) unmanaged vegetation mowed 2–3 times per month (hereafter, mowed). The native grass species planted were indiangrass (*Sorghastrum nutans*) and little bluestem (*Schizachyrium scoparium*). Planted native prairie flower species were lance-leaved coreopsis (*Coreopsis lanceolata*), purple coneflower (*Echinacea purpurea*), black-eyed susan (*Rudbeckia hirta*), butterfly milkweed (*Asclepias tuberosa*), common milkweed (*Asclepias syriaca*), swamp sunflower (*Helianthus angustifolius*), heath aster (*Symphyotrichum pilosum*), and showy goldenrod (*Solidago speciosa*). Species of native prairie flowers were chosen because they are native to the United States, they are adaptable to North Carolina soils and climate, and their seeds are readily available for purchase. In addition, the various flower species bloomed at various times throughout the growing season, which provided a source of nectar throughout the growing season. The fallow border treatment mirrored field-border establishment practices used in government programs in the southeastern United States (e.g., CP-33 conservation practice), and we included the mowed treatment as a comparison with the management of cropland margins commonly implemented on farm landscapes.

We established planted field borders in the spring of 2008. Treatment areas were disked, smooth seedbeds were prepared using a field cultivator, and then seed mixes were broadcast using a manually powered seed spreader. After sowing seeds, a culti-packer was run over the treatment area to ensure good seed-to-soil contact. Once vegetation in the planted borders reached approximately 30 cm in height, it was mowed to a height of approximately 15 cm. Throughout the 2008 growing season, planted borders were mowed 5–6 times to reduce weed competition and to promote

stand establishment. Following the 2008 growing season, no further management was performed on planted border treatments.

Following tillage in the autumn of 2007, vegetation was permitted to grow undisturbed in all fallow border treatments for the duration of the study. Fallow field-border vegetation consisted of a mix of commonly occurring annual and perennial grasses and herbaceous species. Prevalent grasses included non-native bermudagrass (*Cynodon dactylon*) and non-native crabgrass (*Digitaria ciliaris*), and commonly occurring herbaceous species were horseweed (*Conyza canadensis*), dogfennel (*Eupatorium capillifolium*), heath aster (*Symphyotrichum ericoides*), pigweed (*Amaranthus* spp.), and non-native sicklepod (*Senna obtusifolia*). Mowed borders were cut to a height of 16 cm every 2–3 weeks throughout the growing season.

METHODS

From June to August 2009, we estimated vegetation parameters within each field border at eight random sampling points using a 1-m × 1-m frame. At each sampling point, we estimated visually the percent cover of forbs, grass, woody vegetation, and bare ground in the frame. In planted field borders, we also counted the number of each prairie flower and native grass species present within the sampling frame. To estimate vegetation density and height, we used a Robel pole to record five visual obstruction readings in each field border following protocols outlined in Robel et al. (1970). Although vegetation characteristics changed between when we measured vegetation in the summer and when we trapped small mammals several months later, most grasses and forbs held their structure through the trapping sessions. Accordingly, we reported the vegetation measures only as an index of relative differences among border treatments and not as a predictor of small-mammal response.

We trapped small mammals for three consecutive weeks in October and November 2009. We chose this period to best match the peak of seed shedding from grasses and forbs in borders, which allowed us to quantify small-mammal activity for an associated study of weed–seed predation. In addition, the risk of predation of trapped individuals by fire ants (*Solenopsis invicta*) was lower during the cooler autumn months than in the spring and summer (C.J. Plush, personal observation). Each week, we sampled all four field borders surrounding each of three crop fields (one each of hay, soybeans, and corn) continuously for 6 days. We set 10 Sherman (H.B. Sherman Traps, Tallahassee, FL) live traps along a transect running lengthwise through the middle of each field border, with 9-m spacing between traps. During each 6-day trapping session, 120 traps were used to sample the 12 field borders. We used peanut butter balls rolled in oatmeal as bait, and we placed cotton balls in each trap to provide bedding for small mammals on cold nights. We opened traps approximately 2 hr before sunset each night, and checked after sunrise the following morning. We marked captured individuals with an individually numbered ear tag and released individuals at the point of capture. We sexed each capture but were not able to accurately assign age. Traps

were kept closed during the day between morning checks and evening openings. All research was conducted under North Carolina State University Institutional Care and Use protocol 09-052-O.

We used Program MARK to estimate the abundance of small-mammal species within each field border (White and Burnham 1999). We created individual capture histories for each species of small mammal and ran closed-population capture–mark–recapture abundance models in Program MARK. Closed-population capture–mark–recapture models assume no emigration or immigration within the sampling area as well as no births or deaths within the population. Movement between borders within a trapping session was limited, and only three individuals were captured in multiple field borders within a trapping session. Because of model assumptions, we excluded these three individuals from analysis. We fitted model M_0, M_t, and M_b (Otis et al. 1978) to account for potential differences in detection and then compared the Akaike Information Criterion values to determine the best-fit model (Burnham and Anderson 2002). Other models, such as M_{tb}, which include even more parameters, were not considered because of the limited number of captures and recaptures within each of our field borders. We included individual field border as a group in the capture–mark–recapture analysis and estimated N for each group, thus yielding an abundance estimate for each species within each individual field border (i.e., 36 abundance estimates for each species). For field borders with no captures, we assumed an abundance of 0. To compare estimated abundance among border treatments, we conducted an analysis of variance (ANOVA) using Proc MIXED (SAS Institute Inc., Cary, NC). We ran separate ANOVAs for each small-mammal species, and in each model we included border treatment and adjacent crop type as fixed effects, and field as a random effect. We used a Tukey–Kramer adjustment for pair-wise comparisons to compare differences in small-mammal species abundance among the different field-border treatments. To determine differences in percentage of forbs, grass, woody vegetation and bare ground and visual obstruction reading among field-border treatments, we performed ANOVAs using Proc MIXED. In all MIXED models, we included border treatment as a fixed effect and field as a random effect. Significance was accepted at $P \leq 0.05$ for statistical tests.

RESULTS

Over all trapping periods and field-border treatments, we captured 177 individual hispid cotton rat (*Sigmodon hispidus*) 267 times and 314 individual house mouse (*Mus musculus*) 446 times. However, 3 cotton rats and 36 house mice that died during capture sessions were censored from statistical analyses. In native grasses–flowers borders, we captured 78 cotton rats (36 M and 42 F) and 85 house mice (50 M, 33 F, and 2 unknown). In flowers-only borders, we captured 68 cotton rats (34 M, 32 F, and 2 unknown), and 99 house mice (52 M, 45 F, and 2 unknown). We captured 28 cotton rats (11 M, 16 F, and 1 unknown) and 78 house mice (43 M, 33 F, and 2 unknown) in the fallow border treatment. We
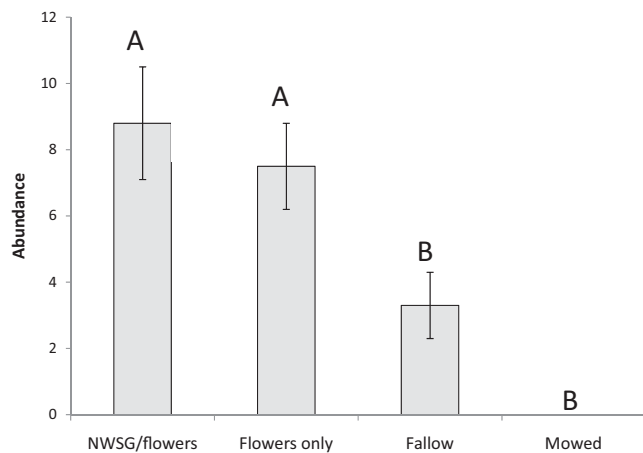
Figure 1. Estimated least-squares mean (±SE) abundance of hispid cotton rat (*Sigmodon hispidus*) in four field-border treatments replicated around nine crop fields in North Carolina, USA (Oct–Nov 2009). Values with different corresponding letters were statistically different ($P < 0.05$).

Figure 2. Estimated least-squares mean (±SE) abundance of house mouse (*Mus musculus*) in four field-border treatments replicated around nine crop fields in North Carolina, USA (Oct–Nov) 2009. Values with different corresponding letters were statistically different ($P < 0.05$).

captured 0 cotton rats and 16 house mice (9 M and 7 F) in the mowed borders.

The best-fit model for estimating hispid cotton rat abundance based on the Akaike Information Criterion was the behavioral model, M_b, which assumes the probability of initial capture (P) is greater than the probability of recapture (C); here, the mean P was 0.33 and C was 0.09. The mean (±SE) abundance of cotton rats was 8.8 ± 1.7 in the native grasses–flowers border treatment, 7.5 ± 1.3 in the flowers-only border treatment, 3.3 ± 1.0 in the fallow border treatment, and 0.0 in the mowed border treatment (Fig. 1). Cotton rat abundance differed among the field-border treatments ($F_{3,24} = 15.8$, $P < 0.0001$), but adjacent crop type did not influence cotton rat abundance ($F_{2,24} = 2.09$, $P = 0.15$). Cotton rat abundance estimates were over 2 times greater in native grasses–flowers and flowers-only borders compared with fallow borders and mowed borders. Abundance estimates for fallow border and mowed borders
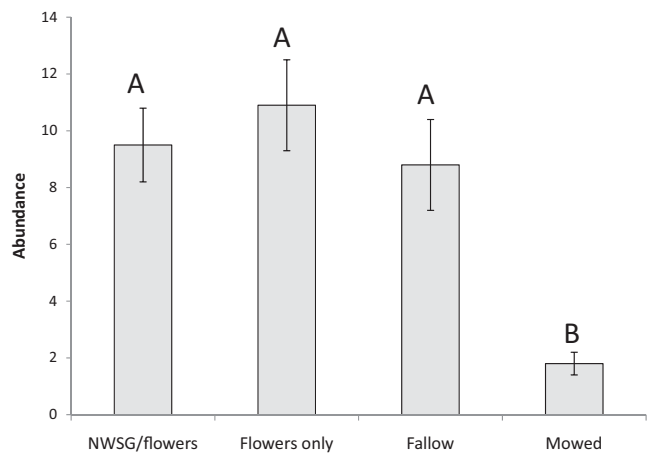
were statistically similar, but no cotton rats were captured in mowed borders (Fig. 1).

The best-fit model for estimating house mouse abundance was again model M_b, which assumes P is not equal to C; we found $P = 0.36$ and $C = 0.08$. Mean (±SE) house mouse abundance was 9.5 ± 1.3 in native grasses–flowers borders, 10.9 ± 1.6 in flowers-only borders, 8.8 ± 1.6 in fallow borders, and 1.8 ± 0.36 in mowed borders (Fig. 2). House mouse abundance differed among field-border treatments ($F_{3,24} = 10.97$, $P < 0.0001$), but adjacent crop type did not affect house mouse abundance ($F_{3,24} = 0.63$, $P = 0.54$). House mouse abundance was ≥5 times lower in mowed borders than in all other border treatments, but abundance did not differ among the three other border treatments (Fig. 2).

Percent cover of forbs was greater in native grasses–flowers, flowers-only, and fallow borders than in mowed borders (Table 1). Percent grass cover was greater in native grasses–flowers and mowed borders, but variation among

Table 1. Mean and standard error for vegetation parameters within four field-border treatments replicated around nine crop fields in North Carolina, USA (Jun–Aug 2009).

Plant species (no. of plants/m²) or vegetation variable	Native grasses–flowers[a]		Flowers only		Fallow		Mowed	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Indiangrass (*Sorghastrum nutans*)	1.2	0.6						
Little bluestem (*Schizachyrium scoparium*)	3.3	1.5						
Butterfly milkweed (*Asclepias tuberosa*)	1.4	1.1	1.6	0.8				
Common milkweed (*Asclepias syriaca*)	1.0	0.5	1.1	0.7				
Black-eyed susan (*Rudbeckia hirta*)	4.6	2.1	5.1	3.2				
Purple coneflower (*Echinacea purpurea*)	1.9	1.1	2.1	1.0				
Lance-leaved coreopsis (*Coreopsis lanceolata*)	1.5	0.8	1.7	0.4				
Swamp sunflower (*Helianthus angustifolius*)	1.4	1.1	1.3	0.7				
Heath aster (*Symphyotrichum pilosum*)	2.1	0.7	1.8	0.7				
Showy goldenrod (*Solidago speciosa*)	1.6	0.9	1.3	0.4				
Cover forbs (%)	50.9[A]	15.9	61.5[A]	12.9	47.9[A]	22.3	29.2[B]	11.0
Cover grass (%)	35.2	20.0	23.9	5.9	24.1	15.2	45.0	23.8
Cover woody (%)	0.0	0.0	0.0	0.0	4.4	8.1	0.0	0.0
Bare ground (%)	64.7	7.5	67.4	7.5	48.5	15.1	53.3	23.4
Visual obstruction reading	4.5[A]	0.5	3.7[AB]	0.5	3.1[B]	0.7	0.6[C]	0.1

[a] Means within rows followed by different letters were statistically different ($P < 0.05$).

replicates within the same treatment made statistical relationships difficult to detect (Table 1). Planted indiangrass was most abundant in native grasses–flowers borders, whereas crabgrass and bermudagrass was most abundant in all other border treatments. Black-eyed susan, heath aster, and purple coneflower were the most abundant flower species in planted field borders (Table 1). Bare ground cover did not differ among border treatments. Mean visual obstruction reading was approximately 45% greater in native grasses–flowers borders than in fallow borders, but did not differ between flowers-only and fallow borders (Table 1). Visual obstruction reading was over 5 times lower in mowed borders than in all other border types (Table 1).

DISCUSSION

Our results suggest that establishing areas of unmowed, non-crop vegetation along field margins is an effective strategy for providing habitat to farmland small-mammal populations. However, maximizing the ecological value of set-aside lands is increasingly important as demand for commodity foods and limited funding for conservation programs constrains efforts to promote biodiversity in agricultural landscapes. Therefore, field borders planted as beneficial insect habitats may be especially useful, because they provide habit for small mammals and beneficial insects.

Mowed field borders demonstrated little value to small mammals in our study. Predation risk is likely the greatest factor in determining small mammal use of an area, and because frequent mowing inherently eliminates ground and overhead vegetation cover needed to hide individuals from predators, small mammals avoided these areas (Brown 1988, Manson and Stiles 1998). We recorded only one recaptured individual in mowed borders, which suggests that the few individuals captured in mowed borders were simply dispersing to or from more suitable habitat. In addition, constant mowing likely diminished food availability, because vegetation was not permitted to flower and bear seed. Given that mowing field margins and other similar habitat types is a common practice among agricultural producers, we suspect the lack of available habitat limits small-mammal populations on farmlands, especially following crop harvest. Farming practices that eliminate cover for small mammals may also negatively influence predator populations because of reductions in amount of small-mammal prey biomass (Butet and Leroux 2001).

Greater cotton rat abundance in beneficial insect habitats than in fallow borders may have been because planted borders contained denser vegetation and more food sources for cotton rats. Because of their larger size, cotton rats require dense vegetation to hide from predators and for suitable nesting sites (Cameron and Spencer 1981). The bunch-forming morphology of native grasses and native prairie flowers in planted borders created open spaces at the ground level that facilitated movement within habitat patches, while retaining an overhead canopy structure. Native warm-season grasses are a preferred food source for cotton rats (Schweiger et al. 2000), and we frequently noted areas within native grasses–flowers borders where small sections of native grasses had been chewed and scattered along the ground, but did not witness signs of cotton rat foraging activity in the other field-border treatments (C.J. Plush, personal observation). Although their preference for feeding on native prairie flower species is unknown, cotton rats typically select foraging areas that contain a diverse mix of monocot and dicot food sources necessary for meeting nutritional needs (Randolph and Cameron 2001). Therefore, the addition of prairie flowers in the flowers-only borders, coupled with fallow vegetation that also established, may have provided a greater diversity of food sources to cotton rats than in fallow borders.

Both planted and fallow field borders supported great numbers of house mice, which suggests that house mice are less sensitive to variation in vegetation composition and are abundant in crop-field margins wherever adequate food and cover resources are available. Originating in the agricultural areas of the Middle East, house mice have long been associated with areas of human habitation, and frequently establish feral populations on lands disturbed by human activities (Brown et al. 2007). Our study site had an extensive history of agricultural use, and the land adjacent to crop fields contained numerous machine sheds, pole-barns, and grain storage facilities where house mice populations are known to thrive (Pocock et al. 2004). The proximity of the field borders to anthropogenic areas likely allowed house mice to rapidly disperse into these habitat patches and exploit the food and cover resources that were available. In the autumn, house mice feed primarily on agricultural weed seeds and waste grain leftover in crop fields following harvest (Whitaker 1966). Although seed abundance can limit feral house mice populations and their preference for prairie flower seeds is unknown, the large number of mice captured in our study suggests seed food sources were readily available (Twigg and Kay 1994).

The establishment of both planted and fallow field borders is likely a useful management strategy for promoting small-mammal weed-seed predators. Although weed seeds make up a small percentage of cotton rats' diet, mice are highly effective weed-seed predators, and may reduce the number of weed seeds in crop fields (Inouye et al. 1980, Cardina et al. 2002, Westerman et al. 2003). The intensity of weed-seed predation by small mammals is related directly to the availability of vegetative cover, and continues to increase if cover is maintained perpetually (Meiss et al. 2010). Granivorous rodents typically forage at night to minimize predation risk, and uncultivated field margins likely provide a safe, day-time resting site that is close to foraging areas within crop fields. In addition, perennial borders serve as important overwintering refuges, especially after crop harvest minimizes the availability of vegetative cover. Although increases in house mice may be beneficial because of reductions in weed seeds, it may also be detrimental to crop production. Large house mouse populations can cause declines in crop yields, and often damage farm equipment such as irrigation lines and electrical devices (Conover et al. 1995, Brown et al. 2007). Therefore, landowners should consider site-specific conditions, needs, and objectives when developing field-border management strategies for the added benefit of weed-seed reduction alone.

MANAGEMENT IMPLICATIONS

Our results indicate that field borders planted as beneficial insect habitats promote greater densities of small mammals compared with traditional fallow field borders. Coupled with the fact that these habitat patches likely support more diverse arthropod communities, planted field borders may be a useful management strategy for maximizing the biodiversity potential of set-aside lands. However, planted field borders are expensive to establish. In our study, establishment costs for native grasses–flowers and flowers-only borders were approximately US$1,928/ha and US$1,773/ha, respectively. Although estimates for planting borders in non-experimental settings are substantially less than the costs for establishing our borders, planting field borders to provide small-mammal habitat alone is likely not cost-effective. Rather, the increase in small-mammal populations is an additional ecological bonus for landowners whose primary objectives are to promote beneficial insects. Conversely, fallow borders are relatively inexpensive to establish and provided habitat for individuals of both rodent species, especially house mice. Therefore, fallow borders could be created to provide habitat for a variety of wildlife species if beneficial insects were not a focus (Riddle et al. 2008, Plush et al. In press). Finally, we estimated that mowing borders in our study 2–3 times per month during the growing season cost approximately US$1,000/ha/year, which should be considered in decisions about long-term field border management.

ACKNOWLEDGMENTS

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Associate Editor: Gervais.