ABSTRACT

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Strips of fallow vegetation along cropland borders (hereafter, field borders) are an effective strategy for providing wildlife habitat. However, traditional fallow borders lack the nectar-producing vegetation needed to sustain many beneficial insect populations (e.g. crop pest predators, parasitoids, and pollinator species). Planted borders that contain mixes of prairie flowers and grasses may harbor more diverse arthropod communities, but the relative value of these borders as wildlife habitat compared to fallow borders is unknown. We compared the wildlife value of 4 different field border treatments (planted native grass and prairie flowers, planted prairie flowers only, fallow vegetation, or mowed vegetation) by conducting northern bobwhite foraging trials, arthropod sampling, overwintering sparrow surveys, and small mammal trapping. In spring 2008, field border treatments were established randomly around 9 organic crop fields, and all borders were approximately 0.084 hectares.

Groups of 6 human-imprinted bobwhite chicks were led through 30-minute foraging trials in all border treatments from June-August 2009 and 2010. Following trials, chicks were immediately euthanized, and their crops and gizzards were later dissected. Eaten arthropods were identified to family, measured with digital calipers, and counted. Allometric equations were used to calculate a mean foraging rate for each border treatment (grams of arthropods consumed/ chick/ 30 min). Arthropod prey availability was determined within each border treatment using a modified blower-vac to sample arthropods at the vegetation strata where chicks foraged. Foraging rate did not differ among treatments in 2009 or 2010.

Total arthropod prey densities calculated from blower-vac samples did not differ among border treatments in 2009 or 2010.

From November-March 2009-2010 and 2010-2011, single-observer transect surveys were conducted to determine overwintering sparrow use in the different field border treatments. During surveys, the total number of sparrows was counted in each field border, and individual species were identified only if easily visible with binoculars. A majority of birds observed were sparrows (96.4%), of which we were able to positively indentify 1424 (51%) to species. The most common sparrow species observed within field borders were savannah sparrow (*Passerculus sandwichensis*) (61.5%), song sparrow (*Melospiza melodia*) (22.8%), and swamp sparrow (*Melospiza georgiana*) (6.8%). Total sparrow densities were 5-10 times lower in mowed borders than in other border treatments in 2009-2010 and 2010-2011, but did not differ among planted and fallow borders in either year.

In October-November 2009, small mammals were trapped over a 6-day period in each field border using Sherman live-traps. Captured individuals were marked with individually numbered ear tags, and released. Over all trapping periods, 512 individuals of only two species, the hispid cotton rat (*Sigmodon hispidus*) and house mouse (*Mus musculus*), were captured. Using the mark-recapture data, closed population models were created in Program MARK to estimate the density (number of individuals/hectare) of each species in each border. Cotton rat density was higher in borders planted for beneficial insect habitat, which likely was influenced by greater vegetation density and availability of preferred foods in these border types. Total small mammal density was lower in mowed borders, emphasizing the importance of available non-crop vegetation for supporting small mammal communities within intensive agricultural areas.

Overall, the results of this study suggest that field borders planted as beneficial insect habitats provide quality wildlife habitat comparable to traditional fallow field borders. Additionally, planted borders may maximize the biodiversity potential of field border establishment by providing suitable habitat for both wildlife and beneficial insect populations

Wildlife Use of Field Borders Planted as Beneficial Insect Habitat

by
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DEDICATION

I would like to dedicate this thesis to all of the men and women who have influenced my decision to choose a career dedicated to the conservation and care of our natural world. To my father, J Plush, who at a young age kindled my love and respect for the great outdoors through countless hunting and fishing trips, and surrounded me with great men who shared in his passion. To all of my mentors and teachers, who spent the time and effort to shape my knowledge and understanding of the intricacies of ecology.

BIOGRAPHY

Charles Plush was born in Wichita, Kansas, and grew up in three different states including Oklahoma and Georgia. Charlie received a bachelor’s degree in Wildlife at the University of Georgia in 2008, where he graduated Magna Cum Laude. He and his wife moved to Clayton, North Carolina in 2009, where he began working on his Master’s degree in Fisheries, Wildlife, and Conservation Biology at North Carolina State University. When time permits, Charlie enjoys hunting, fishing, vegetable gardening, backpacking with his wife, and training his two beloved hunting dogs, Bea and Maple.

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Beneficial Insect Habitats Provide Quality Northern Bobwhite Brood Habitat

Abstract

Strips of fallow vegetation along cropland borders are an effective strategy for providing northern bobwhite (*Colinus virginianus)* brooding habitat. However, fallow borders lack nectar-producing vegetation needed to sustain many beneficial insect populations (e.g. crop pest predators, parasitoids, and pollinator species). Planted borders that contain mixes of prairie flowers and grasses may harbor more diverse arthropod communities, but the relative value of these borders as brood habitat compared to fallow borders is unknown. We used groups of 6 human-imprinted bobwhite chicks as a bioassay for comparing 4 different border treatments (planted native grass and prairie flowers, planted prairie flowers only, fallow vegetation, or mowed vegetation) as bobwhite brood habitat from June-August 2009 and 2010. All field border treatments (0.33 ha each) were established around 9 organic crop fields. Groups of chicks were led through borders for 30-minute foraging trials and immediately euthanized, and their crops and gizzards were later dissected and eaten arthropods were identified, measured, and counted. We used allometric equations to calculate a mean foraging rate for each border treatment (g of arthropods consumed/ chick/ 30 min). We determined arthropod prey availability within each border treatment using a modified blower-vac to sample arthropods at the vegetation strata where chicks foraged. Foraging rate did not differ among treatments in 2009, but was higher in fallow borders compared to other treatments in 2010. Total arthropod prey densities calculated from blower-vac samples did not differ among border treatments in 2009 or 2010. Our results suggest

beneficial insect habitats may maximize the biodiversity potential of field border establishment by providing suitable habitat for beneficial insects and bobwhite young.

Introduction

Uncultivated field margins (hereafter, field borders) are an effective practice for providing multiple ecological services within agricultural landscapes. Field borders aid in erosion control (Daniels and Gilliam 1996), improve water quality near riparian areas (Osborne and Kovacic 1993), and provide useable habitat for numerous wildlife species (Morgan and Gates 1983, Mineau and McLaughlin 1996, Palmer et al. 2005). For landowners, the establishment of field borders is both simple and cost-effective, requiring only that natural vegetation be allowed to grow along the interface of crop and field edge where crop productivity is inherently poor (Morris 1998). Borders also are effective in straightening oddly shaped fields, making it easier for producers to efficiently operate machinery during agricultural activities.

In the United States, land area devoted to organic agriculture increased by 15 percent annually from 2002-2007, totaling just under 4.3 million acres (United States Department of Agriculture Economic Research Service, 2008). Consequently, demand for pest management strategies other than conventional pesticide use has increased. Many producers now employ a myriad of practices to meet pest suppression needs, collectively referred to as Integrated Pest Management (IPM) (Zehnder et al. 2007). A primary component of IPM is biological control, where natural enemies of pest species replace chemical suppressants. Commonly used biological control agents include parasitoid wasp (i.e. Families: Eulophidae, Braconidae, Eurytomidae) and fly (i.e. Family: Syrphidae) species along with predator species such as ladybugs (Family: Coccinellidae) and lacewings (Family: Chrysopidae). Typically, biological control involved the rearing and augmentation of the control agent, where it was released in mass quantities into areas where pest control was needed (Caltagirone and Huffaker 1980). However, there is a growing interest in conserving natural enemies within the landscape, thus eliminating the costs incurred with rearing and augmenting control agents on a regular basis (Landis et al. 2005).

Demand for conservation of habitats needed to promote and sustain biological control agents is high. Some organic producers even cited the need for developing habitat to attract natural crop pest enemies as their top priority in insect pest and weed management (Creamer and Kleese 2000). Additionally, the global decline of insect pollinators, such as bees and butterflies, has raised concern from growers who depend on these insects for adequate crop production and from conservation biologists who recognize the important ecological roles these insect groups play (Allen-Wardell 1998, Gallai et al. 2008).

Although field borders have been recognized as a possible venue for promoting natural crop pest enemies and pollinator species (collectively referred to as beneficial insects), traditional field borders composed of fallow vegetation are incapable of supporting beneficial insect populations, largely because of the lack of nectar-producing plants within the borders. Predators and parasitoids of crop pests require diverse habitats that provide abundant pollen and nectar sources and differential microhabitats used as nesting and over-wintering sites throughout the year (Heimpel and Jervis 2005). Sugar obtained from pollen and nectar is essential for beneficial insect reproduction, and serves as alternate food source for predator species in times when prey species are less abundant (Wäckers and van Rijn

2005). While the young of parasitoid wasps feed on their host, adults of these species often rely exclusively on nectar and pollen to meet caloric demands. In agricultural systems, habitat lacking in these components greatly reduces predator and parasitoid species ability to control pest species that are inherently abundant in monoculture crops (Heimpel and Jervis 2005, Landis et al. 2005). In Georgia, USA, Olson and Wäckers (2007) showed that fallow field borders established as northern bobwhite (*Colinus virginianus)* habitat where unsuitable for increasing beneficial insect populations. However, increases in desired arthropod communities are possible through habitat manipulation that promotes specific vegetation (Landis et al. 2000, Forehand et al. 2006).

Populations of upland game birds (Order: Galliformes) are declining globally, largely due to the loss or degradation of usable early-successional habitat essential to life cycle functioning (Rands 1992, Guthery 1997, Vickery and Herkert 1999). In the United States, the northern bobwhite (hereafter bobwhite) is an economically and culturally important game bird species that once was abundant throughout its range, but over the last two decades has declined precipitously (Sauer et al. 2003). In an effort to increase upland game bird populations, government agencies have initiated programs that subsidize the establishment of fallow field borders on private agricultural lands (Sotherton 1998, Gray and Teels 2006). Vegetation structure in field borders can provide the closed overhead canopy and bare ground microhabitat preferred by bobwhite for brood-rearing, foraging, and movement (Kopp et al. 1998, Taylor et al. 1999). Annual and perennial weeds attract insects vital to bobwhite chick development (Handley 1931, Jackson et al. 1987), and produce seeds eaten throughout the year by bobwhite and songbird species alike (Jon et al. 1995, Marcus et al.

2000). Field borders have been a widely accepted practice because landowners suffer minimal losses in agricultural productivity (Outward et al. 2000), and local bobwhite populations have been shown to increase where field borders have been established (Puckett et al. 1995, Palmer et al. 2005, Riddle et al. 2008). In Europe, establishing strips of non-crop vegetation through the center of agricultural fields to promote beneficial insects, primarily predaceous spider (Order: Aranae) and beetle (Order: Coleoptera) species, has been a long-standing practice amongst cereal producers (Ovenden et al. 1998) that has also benefited gray partridge (*Perdix perdix*) (Aebischer and Ewald 2010). However, in the United States, less is known about whether field borders planted specifically for promoting beneficial insects also might benefit bobwhite populations.

Maximizing the number of ecological benefits provided by borders is crucial in gaining widespread acceptance and implementation (Allen and Vedever 2005). While landowners cite wildlife conservation as their primary reason for establishing borders, the possibility of added crop production benefits resulting from increased numbers of beneficial insects may provide additional incentive for landowner participation (Allen and Vedever 2005, Morandin and Winston 2006). This may be especially true for the increasing number of organic growers who rely on integrated pest management in controlling insect pest populations. Establishment of beneficial insect habitat also can increase the competitive score for landowners attempting to enroll in government subsidy programs.

We compared the value of field borders planted for promoting beneficial insects to traditional fallow field borders as brood habitat for bobwhites. Invertebrates account for nearly 90% of young game bird chicks' diet, and proteins acquired from these foods are essential for adequate feather and muscle growth (Nestler et al. 1942). Lack of available habitats that provide chick access to arthropod food sources can limit game bird population growth, and the need for greater understanding of upland game bird brood ecology has been recognized (Potts 1986, Burger 2001). Understanding how beneficial insect habitats may benefit bobwhite populations will aid land managers in developing field border management strategies that provide the greatest ecological benefit. To assess brood-habitat value, we: 1) used human-imprinted bobwhite chicks to investigate the use and availability of arthropods as food for bobwhite chicks in different field border habitats, and 2) determined the abundance and diversity of available arthropod food sources in various border habitats.

Study Area and Field Border Establishment

Our study was conducted at the Center for Environmental Farming System's (CEFS) Organic Research Unit (ORU) located in the upper coastal-plain physiographical region of North Carolina from 2009-2010. The ORU consisted of 9 organic crop fields with areas ranging from 1.6-4 ha. Each year, 3 fields each were planted in soybeans (*Glycine max*), corn (*Zea mays*), or hay crop (red clover (*Trifolium pretense*) and orchard grass (*Dactylis glomerata*)). Year to year crop rotation was performed as follows: hay followed corn, corn followed beans, and beans followed hay. All agricultural activities followed United States Department of Agriculture (USDA) organic crop production guidelines. In the spring 2008, 4 randomly assigned border habitat treatments were established around each of the 9 crop fields. Each habitat treatment was approximately 91.44 m long by 9.14 m wide, for a total of 0.33 ha of experimental habitat in each field. The 4 border habitat treatments were as follows: 1) planted native-warm season grasses (NWSG) and native prairie flowers (hereafter NWSG/Flowers); 2) planted native prairie flowers only (hereafter Flowers Only); 3) fallow, unmanaged vegetation (hereafter Fallow); 4) volunteer grasses and herbaceous vegetation mowed 2-3 times per month (hereafter Mowed). The NWSG species planted were indiangrass (*Sorghastrum nutans*) and little bluestem (*Schizachyrium scoparium).* Native prairie flower species planted in NWSG/Flowers and Flowers Only borders 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*). We selected species planted in the NWSG/Flowers and Flowers Only borders because their seeds are readily available for purchase, they were native to the United States, and they were adaptable to local soils and climate. Additionally, the mix of flower species bloom at various dates, providing nectar sources throughout the growing season. The fallow border represented traditional field borders established for wildlife habitat, and the mowed border served as a reference.

Planted field borders were established by disking the treatment area and broadcasting the seed mix over the tilled soil using a manually powered seed spreader. Following broadcasting, a culti-packer was run over the treatment area to ensure good seed-to-soil contact. In planted field borders, once vegetation reached approximately 0.3 m high, it was mowed at a height of 15 cm, 5-6 times throughout the 2008 growing season to reduce weed competition and to promote sound stand establishment. Following the 2008 growing season, we preformed no further management activities on any of the planted field border treatments. Fallow field borders were tilled in the fall of 2007, and left to return to natural vegetation for the duration of the study. Fallow field border vegetation consisted of a mix of grasses, primarily bermudagrass (*Cynodon dactylon)* and crabgrass (*Digitaria ciliaris)*, and commonly occurring herbaceous species, such as horseweed (*Conyza canadensis*), dogfennel (*Eupatorium capillifolium)*, heath aster (*Symphyotrichum pilosum)*, pigweed *(Amaranthus spp.)*, and coffeeweed (*Senna obtusifolia*). Baccharis (*Baccharis halimifolia*) also became prevalent within fallow borders two years following border establishment.

Methods

Northern Bobwhite Foraging Trials

The use of human-imprinted chicks in studying food preferences and foraging habits is well documented for bobwhite and other game bird species (Kimmel and Healy 1987, Palmer et al. 2001, Smith and Burger 2005, Huwer et al. 2008). We used 10-12 day old human-imprinted bobwhite chicks to conduct 3 foraging trials each year from June-August in 2009 and 2010. We scheduled foraging trials to coincide with the primary brooding periods of wild bobwhites in the southeastern United States.

Prior to each trial, we purchased 100-150 pen-strain bobwhite eggs from a local breeder and upon delivery placed them in a commercial incubator (Jamesway Incubator Model 252, Butler Manufacturing, Fort Atkinson, WI). We assumed pen-strain chicks would forage equally to genetically wild bobwhite (Smith and Burger 2005). We incubated eggs at temperature and humidity levels necessary for proper chick development, and eggs were rotated automatically 4 times daily. After 21 days of incubation, we placed eggs in hatching trays and transported them to a commercial hatcher. Inside the hatcher, a tape recorder played a recording of a three note whistle call and the researcher’s voice continuously at 1-

minute intervals. At 21 days of incubation, chicks are able to hear within the egg, thus playing of the recordings began the human imprinting process (Kimmel and Healy 1987). Upon hatching, we placed chicks in a towel held by a researcher, and transported each to the rearing facility. During transport, we constantly touched chicks being held in the towel while also speaking softly and making the three note whistle call.

At the rearing facility, chicks were held next to the researchers for at least one hour and later placed into an imprinting ring. The imprinting ring consisted of a cardboard barrier (approximately 3 m in diameter, and 0.3 m high) placed on cedar-chip bedding with a brooder lamp provided as a heat source. Following hatching, we spent at least 24 consecutive hours in contact with the chicks to ensure successful imprinting. During this initial 24-hour period (hereafter Day 0), we constantly talked to the birds, whistled to them, congregated them under our hands, and held them next to our bodies. On Day 1, we fed chicks wild arthropods captured nearby, and on Day 2, groups of 30-40 chicks were designated by painting different colors of nail polish on their heads. Beginning on Day 3, we exercised chicks for at least 1 hour, twice daily in designated groups in nearby lawns, a field, or “weedy” areas. The exercise sessions were meant to expose the chicks to habitats similar to ones used in the foraging trials and to familiarize chicks with arthropod foraging. Chicks that did not respond to the observers when called or frequently produced “lost calls” were considered unsuccessfully imprinted and were immediately removed from the study. Immediate removal of unsuccessfully imprinted chicks was essential, because failure to do so would diminish the likelihood of other chicks becoming fully imprinted. Between exercise sessions, we kept chicks in the imprinting ring and provided them with commercial game bird starter food (Game Bird Startena, Purina ®) and water *ad libitum.* During any period when researchers were not with the chicks, a recording of the three note whistle and the researchers' voice was left playing to provide assurance to the chicks. Exercise sessions continued daily until the chicks were 10-12 days old when they were transported to the site of foraging trials.

We transported chicks via automobile to CEFS the morning prior to foraging trials. Chicks were restricted of any arthropod foods 18 hours prior to the trials, and restricted of all foods 4 hours before trials to ensure that crops and gizzards were flushed completely of any arthropod fragments and to encourage foraging. We performed foraging trials over a two-day period during which all borders around 3 of the crop fields (hay, soy, corn) were sampled, for a total of 12 borders sampled per trial. Each year, all borders around each of the 9 fields were sampled once. We conducted trials only on dry days between 0900 and 1200 hours to ensure all vegetation was dry and insect movement was not impeded by moisture. At least 4 observers were present on the day of each trial. To begin a trial, a pair of observers released a group of 6 chicks at the end of a specified border. One observer stood behind the brood of chicks while the other stood in the middle of the border 15 m in front of the brood. The trailing observer kept a constant count of the brood and ensured that chicks did not forage outside of the border. The distant observer would whistle at 1-min intervals to ensure the brood would continue foraging on the correct path. Whenever the brood reached the distant observer, the observer roles would reverse, and the distant observer would begin trailing the brood while the original trailer would walk outside the border and reestablish a position 15-20 m away from the brood further down the border. During trials, we allowed chicks to forage freely within the border boundaries, with no contact or interference from observers. We conducted trials for exactly 30 min, and immediately at the end of each trial, we collected and euthanized chicks. Although 6 chicks were used in each trial, a small number of chicks were excluded from analysis, either because they were not captured immediately after the 30 min time limit, or their digestive organs were damaged during extraction. We placed chicks in plastic bags and stored them in portable coolers containing ice. Later in the day, we stored chicks in a freezer at 17.8° C. All research was conducted under North Carolina State University Institutional Care and Use protocol #09-052-O.

Crop and Gizzard Analysis

We placed frozen chicks in a refrigerator to thaw for at least 12 hours. After thawing, we extracted the crop, esophagus, and gizzard from each chick, and stored the digestive organs in a 70% ethyl alcohol solution. Prior to analysis, we opened the digestive organs with a scalpel, and rinsed their contents with an ethyl alcohol solution into a petri dish. Using a 30x dissecting microscope, we indentified whole arthropods to family, and we measured the length and width of each arthropod to the nearest 0.01 mm using digital calipers. We also searched the crop and gizzard contents for diagnostic arthropod fragments (i.e. mandibles, tibias, wings, etc). Counting and identification of arthropods observed as diagnostic fragments followed protocols outlined in Rosenberg and Cooper (1990) and Palmer et al. (2001). When possible, we indentified fragments to family; order was recorded otherwise. We recorded lengths and widths of diagnostic fragments as well.

Arthropod Sampling

A number of sampling methodologies have been developed for assessing arthropod abundance and diversity including sweep nets, pitfall traps, and drift fences. Yet, relative abundance values obtained using these methods likely are biased, because the methods may fail to sample from the arthropod communities most readily available to bobwhite chicks (Hutto 1990, Palmer et al. 2001). For example, sweep netting may only capture insects occupying the upper half of the vegetation strata, and pitfall traps may not capture insects that have a limited movement range. To minimize these biases, we employed an arthropod sampling technique that is indiscriminate of vegetation structure or species characteristics. Also, our technique sampled arthropods from the vegetation strata where bobwhite chicks forage (Cooper and Whitmore 1990).

To sample arthropods in the different border habitats, we used a modified, gas-powered blower-vacuum similar to one described in Harper and Guynn (1998). We conducted arthropod sampling during the day between 0900 and 1200 hours within 3 days following a foraging trial to capture arthropod communities representative of the time when foraging trials were conducted. In each field border, we sampled arthropods along 3, 3.05-m transects that ran perpendicular to the length of the border habitat. Transect lines were distributed randomly across the length of each border, and were marked 2 days prior to arthropod sampling. We calculated arthropod density by multiplying the length of the transect line (3.05 m) by the width of the blower-vacuum tube (0.13 m) (Density= # arthropods/ 0.38 m^2). During sampling, we attempted to hold the blower-vacuum suction nozzle at a fair distance ahead of us to capture insects before they flushed. We also positioned the suction nozzle so that it would collect arthropods from the ground and lower levels of the vegetation strata. Following each sample, we removed the bag, tied it closed, and stored it in a cooler with ice. Later in the day, we stored all samples in a freezer at 17.8° C.

We dried bag contents at least 1 week prior to analysis. Contents were emptied on a white sorting tray, and arthropods were sorted with tweezers and a hand lends. From each sample, we counted all arthropods and indentified them to family.

Vegetation Sampling

We sampled vegetative composition in each field border within 5 days of a foraging trial in that respective border. We sampled at 8 randomly distributed points within each field border using a 1-m x 1-m frame. In each frame, we visually estimated the percent cover of forbs, grasses, woody vegetation, bare ground, and canopy cover, because previous research has suggested their importance in predicting habitat suitability for game bird chicks (Greenfield et al. 2002). Within NWSG/Flowers and the Flowers Only borders, we also estimated the abundance of each planted NWSG and flower species. In 2009, we counted the number of each NWSG and flower species within each sample. In 2010, we estimated the percent cover of all planted NWSGs and planted flowers, as well as the percent cover of each individual NWSG and flower species. Because vegetation parameters were estimated independently, the total sum of estimated percentages often exceeded 100%.

To estimate relative vegetation density and height, we used a Robel pole to obtain visual obstruction readings (VOR) at five random points within each field border (Robel et al. 1970). A horizontal black line was drawn in the center of each interval so that observers could determine half-decimeters. The pole was placed in the center of the sampling point so that it stood upright. While kneeling 2 meters away from the pole, we determined the highest visible half-decimeter to obtain a VOR score from each of the 4 cardinal directions. We averaged the 4 VOR scores to determine an overall VOR score for each sampling point.

Statistical Analysis

Because vegetation structure and composition changed drastically over the two years following establishment, we analyzed differences in northern bobwhite foraging rates, arthropod availability, and vegetation characteristics among border treatments separately for each year. We used allometric equations to calculate the estimated live weight of each arthropod consumed by each chick during foraging trials (Palmer 1995). We summed the estimated live weights of each arthropod consumed by each chick to calculate a foraging rate (g of arthropods consumed/chick/ 30 min). To test for differences in foraging rates among year and field border treatment, we performed an analysis of variance (ANOVA) using Proc MIXED (SAS Institute Inc. Cary, NC). We also performed ANOVAs using Proc MIXED to test for differences in the mass of each taxonomic order and family consumed by chicks among border treatments. In all models, we treated border treatment as a fixed effect, and field as a random effect. We also included chick nested within the interaction between field and border treatment as a random repeated measures effect to account for variability among individual chicks. We used Tukey-Kramer adjustments in pairwise comparisons to evaluate differences in foraging rates, weight of taxonomic order consumed, and weight of taxonomic family consumed relative to border treatment. We only reported the mean mass of arthropods consumed per chick to taxonomic orders and families that made up a significant portion of bobwhite chicks' diet. We excluded certain taxonomic orders and families, such as Diptera and Neuroptera, from individual comparisons among field border treatments because the amount of mass consumed within those taxonomic groups was too small to make statistical comparisons.

To compare overall arthropod prey abundance and abundance of arthropods in each taxonomic order and family among field border treatments, we performed individual ANOVAs using Proc MIXED. In all models, we included border treatment as a fixed effect, and field as a random effect. We used Tukey-Kramer adjustments in pairwise comparisons to compare the total number of arthropods and the number of arthropods within each taxonomic order and family among border treatments. To assess arthropod diversity among border treatments, we also calculated a Shannon-Weiner diversity index value (H') for each border treatment in each year. The index is scored on a 0-4 scale, with higher values suggesting greater arthropod diversity.

We compared percent cover of forbs, grass, woody vegetation, bare ground, canopy cover and VOR among border treatments by performing ANOVAs using Proc MIXED. In all models, we included border treatment as a fixed effect, and field as a random effect. We used a Tukey-Kramer adjustment in pairwise comparisons to evaluate differences in vegetation parameters among border treatments. Significance was accepted at $P \leq 0.05$ for all statistical tests.

Results

Northern Bobwhite Foraging Trials

We led a total of 432 bobwhite chicks through foraging trials from 2009-2010. We excluded 1 chick from analysis in 2009, and 14 chicks in 2010. We indentified 2656 arthropods consumed by chicks in 2009, and a 2267 arthropods consumed in 2010. In 2009, chicks consumed 30 families of arthropods in NWSG/Flowers borders, 35 families in Flowers Only borders, 39 families in Fallow borders, and 32 families in Mowed borders. In 2010, chicks consumed 23 arthropod families in NWSG/Flowers borders, 25 families in Flowers Only borders, 23 families in Fallow borders, and 24 families in Mowed borders.

Arthropods in the taxonomic orders Coleoptera, Hemiptera, and Hymenoptera made up the largest percentage of chicks' diet in all border treatments. Carabid beetles (Family: Carabidae) and darkling beetles (Family: Tenebrionidae) comprised the largest percentage of Coleopteran families consumed by chicks in both years. Among Hemipteran families, stinkbug nymphs (Family: Pentatomidae) and damselbugs (Family: Nabidae) were consumed in the greatest proportions. The majority of Hymenopterans consumed by chicks in all border treatments were ants (Family: Formicidae) (Table 1).

We failed to detect a difference in foraging rate among border treatments in 2009 ($F_{3, 201,=}$ 0.63, P=0.60), and in 2010 ($F_{3,188}$ =2.17, P=0.60) (Figure 1). In 2010, foraging rate was higher in Fallow borders than in Mowed borders. Foraging rate did not differ among NWSG/Flowers, Flowers Only, and Mowed borders in both 2009 and 2010 (Figure 1). In 2010, we excluded 1 Fallow border replicate from analysis. The replicate was exclude because in early 2010, the border was treated with methyl bromide to eradicate tropical spiderwort (*Commelina benghalensis)*, a federally listed noxious weed. Because of the chemical treatment, the successional age and species composition of the vegetation within this border was not comparable to other Fallow border replicates in 2010.

Lepidoptera larvae (caterpillars), Orthoptera, and Coleopteran species contributed the highest mean mass of arthropods consumed per chick among taxonomic orders in all field border treatments. Although they comprised a large percentage of the prey items in chicks' diets, ants (Family: Formicidae) and Hemipteran species contributed little to the total amount of biomass consumed by each chick. Grasshoppers (Family: Acrididae) had the highest mean weight within Orthoptera, and Carabid beetles had the highest mean weight within Coleoptera (Table 2).

In 2009, chicks foraging in NWSG/Flowers borders consumed over 41% greater mass of Coleoptera than in all other border treatments. Mean mass of Carabid beetles consumed was approximately 52% lower in Mowed borders compared to NWSG/Flowers borders, but did not differ among NWSG/Flowers, Flowers Only, and Fallow borders. Mass of Hemiptera consumed per chick did not differ among border treatments in 2009, but was over 34% lower in Mowed borders in 2010 compared to all other border treatments. In 2009, chicks foraging in Mowed borders consumed over 75% greater mass of grasshoppers compared to NWSG/Flowers and Flowers Only borders. Mass of spiders (Order:Aranae) consumed was over 42% greater in Fallow borders than in NWSG/Flowers and Flowers Only borders in 2009 (Table 2).

In 2010, mean mass of Aranae, Coleoptera, and Hymenoptera consumed did not differ among border treatments. However, mass of Carabid beetles consumed was approximately 3 times higher in Fallow borders compared to Mowed borders. In 2010, chicks consumed a greater mass of Pentatomidae in NWSG/Flowers and Flowers Only borders compared to Fallow and Mowed borders. In 2010, chicks ate 84% greater mass of Lepidoptera larvae in Fallow borders than in NWSG/Flowers borders (Table 2).

Arthropod Sampling

We collected 212 blower-vacuum samples from 2009-2010. Within all border treatments, total arthropod densities ranged from 33.67-42.26 arthropods/ 0.38 m^2 in 2009, and 36.07-43.63 arthropods/0.38 m^2 in 2010. Total arthropod density was not different among border treatments in 2009 or 2010. In 2009, Aranae density was over 41% higher in NWSG/Flowers and Flowers Only border than in Mowed borders, and Hemiptera density was over 38% less in NWSG/Flowers borders than in Fallow and Mowed borders. Cicadellidae density was approximately 2 times greater in Fallow and Mowed borders compared to NWSG/Flowers and Flowers Only borders ($P<0.05$). Mean density of Coleoptera, Hymenoptera, and Lepidoptera larvae was not different among border treatments in 2009. Orthoptera density was nearly 2 times higher in Flowers Only border compared to NWSG/Flowers and Mowed borders in 2009 (Table 3).

In 2010, Aranae density was over 27% higher in NWSG/Flowers borders than all other border treatments, and Coleoptera density was approximately 2 times greater in NWSG/Flowers borders than in Mowed borders. Weevil (Family: Curculionidae) density was over 65% higher in NWSG/Flowers and Flowers Only borders than in Mowed borders. Mean density of Hemiptera was approximately 2 times greater in Mowed borders than in NWSG/Flowers and Flowers Only borders. Density of leafhoppers (Family: Cicadellidae) was over 56% higher in Mowed borders than in all other border treatments. In 2010, there were over 2 times less Hymenoptera in Mowed borders than in all other border treatments, but there was no difference in the density of Orthoptera among border treatments. Density of Lepidoptera larvae was over 75% lower in NWSG/Flowers borders compared to Mowed borders in 2010 (Table 3.).

Based on Shannon-Weiner diversity index (H’), in both 2009 and 2010, arthropod diversity was highest in Fallow borders and lowest in Mowed borders (Table 3).

Vegetation Sampling

Percent cover of forbs was over 39% less in Mowed borders compared to all other border treatments in 2009. In 2010, percent forb cover was 29% higher in Flowers Only borders compared to all other border treatments. Grasses dominated the vegetation composition of Mowed borders, while herbaceous species comprised the majority of the other border treatments. The grasses found in Flowers Only, Fallow, and Mowed borders consisted primarily of bermudagrass and crabgrass, and indiangrass was the dominant species in NWSG/Flowers borders. In both years, black-eyed susan and heath aster comprised the majority of planted flowers species within NWSG/Flowers and Flowers Only borders. However, Flowers Only borders contained a greater abundance of additional planted flower species compared to NWSG/Flowers borders. Within NWSG/Flowers borders, forbs made up the largest percentage of vegetation in 2009, while in 2010, planted NWSGs were the predominant vegetation type (50.51%). The percentage of woody vegetation was highest in Fallow field borders in both 2009 and 2010, and consisted primarily of *Baccharis halimifolia*. In both years, percentage of bare ground did not differ among border treatments, although the mean bare ground estimate in Mowed borders was over 50% less than in other border types in 2010. In 2009, average VOR was higher in NWSG/Flowers compared to Fallow and Mowed borders, but did not differ from Flowers Only borders in 2009. In 2010, average VOR was highest in Fallow borders, and lowest in Mowed borders (Table 4).

Discussion

Our results suggest beneficial insect habitats provide quality brood habitat for bobwhite chicks comparable to traditional fallow field borders. We observed higher foraging rates compared to similar studies using human-imprinted bobwhite chicks (Maidens 2001, Smith and Burger 2005, Doxon and Carroll 2010), indicating that the field border habitats in our study provided the habitat conditions and abundance of available arthropods needed for chicks to consume large quantities of invertebrate prey. Although fallow borders are an inexpensive, relatively simple means of providing brood habitat within farmlands, beneficial insect habitats may be of greater value to landowners, because they may provide suitable habitat for both game bird young and beneficial insect populations. With increasing concern for declining biodiversity within agricultural landscapes, beneficial insect habitats appear to be a viable option for maximizing the value of set-aside lands for native arthropod, avian (Plush 2011), and plant communities.

Although chicks foraging in mowed borders consumed large amounts of arthropods, these results do not suggest that mowed borders provide sufficient brood habitat for precocial game bird young. Quality brood habitat typically consists of diverse stands of vegetation with well-developed canopy structure and large areas of bare ground (Burger et al. 1994, Taylor et al. 1999). Chicks foraging in habitats with little over-head cover are highly susceptible to predation, and because of their small stature, dense vegetation at the ground level limits their ability to indentify and capture arthropod prey (Potts 1986, Doxon and Carroll 2010). We propose three possible explanations for why foraging rates were high within mowed borders even though they provided poor structural conditions: 1) arthropod prey were abundant within mowed habitats, 2) chicks had been "trained" frequently in mowed areas prior to foraging trials, and 3) chicks consumed large, dead arthropods that had been killed by mowers on previous days. Mowed borders contained similar abundance of preferred arthropod foods, and combined with the benefit of previous "training" in mowed habitats, may have been able to consume large quantities of prey despite vegetative qualities that typically hinder foraging efficiency. Observers witnessed on multiple occasions chicks consuming dead, adult grasshoppers during trials in mowed borders (C. Plush, pers. observation). Therefore, foraging rates observed in mowed borders may have been inflated because of the large amount of biomass contributed by adult grasshoppers.

Bare ground is an important component of quality bobwhite brood habitat (Greenfield et al. 2002). Brooding hens typically select foraging areas that contain 25-50% bare ground cover, largely because ample areas of bare ground facilitates the unrestricted movement necessary for chicks to efficiently capture arthropod prey (Taylor and Burger 2000). Additionally, a large percentage of chicks' diet consists of ground-dwelling arthropods, such as spiders and Carabid beetles, and bare ground allows chicks to easily identify such food sources, which otherwise may not be visible in habitats with a heavy thatch layer. In our study, the importance of bare ground was demonstrated in the 2010 Fallow border replicate treated with methyl bromide. When used as a soil fumigant, methyl bromide severely reduces the seed bank, and thus, a large percentage of the border consisted of bare ground the following growing season. Although the replicate was removed from analysis, mean foraging rate was 0.54 grams/chick/30 minutes compared to 0.12 grams/chick/30 minutes among all other fallow border replicates in that year. We suspect the substantially higher foraging rate was related directly to amount of bare ground cover, which was 6 times higher than in other fallow border replicates.

Arthropod abundance does not necessarily correlate with bobwhite foraging efficiency and is likely not a limiting factor for bobwhite chicks in field border habitats. Arthropod prey was abundant throughout all border treatment types, despite dramatic differences in vegetation composition and structure. These findings emphasize similar research suggesting that arthropod prey abundance is a less important determinant of foraging habitat quality than vegetation structure (Palmer et al. 2001, Doxon and Carroll 2010). Similarly, insectivorous songbirds continue to use foraging habitats that provide higher quality vegetative structure, even after arthropods have been severely reduced in these areas (Champlin et al. 2009). Although insufficient arthropod prey abundance can limit game bird young survival rates (Potts 1986), such instances are typically restricted to lands where invertebrate populations are substantially suppressed via widespread insecticide application (Palmer 1995). However, in uncultivated field margins, arthropod prey is abundant, and therefore, focus should be directed toward promoting vegetation that facilitates chick mobility and provides protection from predators.

Our results suggest that bobwhite chicks meet invertebrate biomass demands through flexibility in arthropod food selection, and have the ability to adapt accordingly to temporal and spatial variation in arthropod abundance. Although chicks consumed different quantities of specific arthropod taxa, the total mass of arthropods consumed was often similar because chicks ate either few numbers of large arthropods (i.e. Lepidoptera larve, grasshoppers) or high numbers of small arthropods (Hemipterans, spiders, ants). Although small arthropods are typically more abundant, the availability of large arthropod foods may be more important because chicks spend considerably less energy searching for, capturing, and consuming their prey. Additional time spent foraging increases the risk of predation for young game bird chicks (Potts 1997), and may limit the time available for loafing and resting, which is essential to feather growth and muscle development. However, many large arthropod food sources are difficult for young bobwhite to capture under normal circumstances (i.e. adult grasshoppers), and may be available only during brief time periods. For example, almost all of the Lepidopteran larvae biomass consumed by chicks in Fallow field borders in 2010 was in August, and the species of Lepidoptera larvae consumed was the same in each chick (C. Plush, unpublished data). Apparently chicks were able to capitalize on a mass emergence of one species of caterpillar during this time. Large concentrations of caterpillars are highly ephemeral, and based on the low densities of caterpillars captured during arthropod sampling; they are likely not a reliable food source throughout much of the brooding season.

Also, not all arthropod foods have equal nutritional value. Both beetles and ants are highly sclerotized, and consequently have lower digestibility compared to softer bodied arthropods such as spiders, Hemipterans, and Lepidoptera larvae (Evans and Sanson 2005). Therefore, the nutritional value of certain arthropods may be overestimated, because a large portion of their mass is indigestible. In habitats where chicks consumed high quantities of highly sclerotized invertebrates, they may be wasting considerable energy digesting poor quality foods.

Although prior research has indicated the importance of forb abundance to game bird young (Hill 1985, Hagen et al. 2002), we failed to detect an influence of forb cover on bobwhite foraging rates or arthropod densities. Despite dramatic differences in the abundance and species composition of herbaceous vegetation in the various border types, chicks consumed relatively similar quantities of invertebrates and total arthropod prey biomass did not vary. Similarly, Doxon and Carroll (2007) noted that the addition of forb plantings in Conservation Reserve Program grass fields did not increase arthropod prey abundance, and Barnes et al. (1995) observed an equal number of invertebrates in fescue (*Festuca arundinacea)*-dominated hay fields compared to fields with significantly greater forb abundance. We suggest that the value of forb cover to game bird young is likely not in its ability to attract greater arthropod prey; rather, the structure of herbaceous plants increases foraging efficiency. Leaf growth on most herbaceous plants is focused on areas above the height of young bobwhite, while a large portion of monocot biomass is near the ground level. The leaf morphology of many forbs likely allows for easier movement within foraging habitats, and additionally provides the well-developed canopy structure needed for protection from aerial predators.

The high percentage of exotic grasses, particularly crabgrass and bermudagrass, within traditional fallow field borders and borders planted in a mix of flowers likely decreased their value to bobwhite young because of the greater risk of heat stress within these habitats. Adequate shade and thermal microclimate is an often over-looked, but important aspect of quality bobwhite brood habitat (Taylor and Guthery 1994). Bobwhite chicks are unable to thermoregulate adequately until 30 days of age (Borchelt and Ringer 1973), and consequently suffer high mortality rates if exposed to high temperatures even within short periods of time (Forester et al. 1998). Because both bermudagrass and crabgrass form dense stands along the ground level, habitats inundated by these plant species may maintain temperatures that exceed the heat-tolerance threshold for bobwhite young (Burkhart 2004), and consequently, brooding hens typically avoid these areas in the wild (Forester et al. 1998). We frequently observed chicks displaying signs of heat stress in habitats where bermudagrass and crabgrass were prevalent. However these observations were restricted to the final minutes of foraging trials, and therefore did not appear to impact foraging efficiency during the majority of the trials (C. Plush, personal obs.).

Even within border habitats that would typically be considered poor quality, chicks were able to capitalize on high quantities of available foods. Because of the short duration of the foraging trials, chicks did not suffer from poor vegetative qualities that likely would reduce foraging efficiency over time. Although 30-minute foraging trials are highly effective in assessing feeding preferences and arthropod availability, trials conducted over longer time periods may be necessary for assessing how vegetation composition impacts upland game bird young in the wild.

Implications for Conservation and Management

As biodiversity within arable farmlands continues to diminish because of increasingly homogenous cropping systems and highly efficient practices, set-aside habitats should be managed to maximize their biodiversity potential. Accordingly, field borders planted as beneficial insect habitats may be a useful management tool for providing habitat to upland game bird young while also promoting important arthropod communities. We recommend beneficial insect habitat seed mixes include NWSGs, because they often out-compete exotic grass species that are otherwise prevalent within border habitats and diminish the borders' value to bobwhite young and other wildlife. On larger habitat plots, NWSGs also may provide desirable nesting sites for game birds and other ground-nesting bird species (George et al. 1979, Giuliano and Daves 2002). Additionally, inclusion of NWSGs within beneficial insect habitats increases their value to local small mammal populations and overwintering sparrow species (Plush 2011). Regardless of field border type, frequent disturbance is essential for maintaining bare ground cover and prohibiting woody and grass species dominance over natural forbs and/or planted flowers. In beneficial insect habitats, NWSGs can dominate stands within 2-3 years, thus minimizing the number of nectar-producing flowers.

Beneficial insect habitats likely have greater aesthetic appeal compared to traditional fallow field borders. Landowners rate the appearance of their property and the image it portrays to neighbors higher than the wildlife and financial value of their land (Daley et al. 2004). Therefore, landowners may be hesitant to participate in fallow field border establishment programs because these habitats look "weedy" and may portray poor land stewardship. However, borders containing flower mixes that bloom throughout the year are aesthetically pleasing and likely more acceptable to many producers. Finding new ways to integrate habitat into arable lands is essential for conserving biodiversity within these landscapes, and with the growing interest in agro-tourism in the United States and Europe

(McKelvie 2004, Carpio et al. 2008), habitats that are both aesthetically pleasing and ecologically beneficial might be a win-win solution for improving rural economies while also meeting conservation objectives.

However, landowner willingness to accept the additional monetary and time costs necessary in establishing beneficial insect habitats will be a key factor in their wide-spread implementation. In our study, the cost of establishing NWSG/Flowers and Flowers Only borders was approximately $1928/ha and $1773/ha, respectively. Therefore, fallow borders may be the best option for landowners whose sole objective is upland game bird conservation, because these habitats are easier to establish and less expensive.

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Table 1. Percentage of the total number of arthropods consumed by northern bobwhite chicks in 4 field border treatments by taxonomic order and most frequently consumed taxonomic family (June-Aug 2009 and 2010).

	NWSG/Flowers	Flowers Only	Fallow	Mowed
Aranae	13.43	15.46	11.33	11.84
Chilopoda	1.48	0.52	0.16	0.29
Coleoptera	37.24	33.36	30.42	27.89
Carabidae	14.13	12.59	9.06	8.12
Curculionidae	5.39	6.63	6.07	4.30
Tenebrionidae	10.77	5.38	5.42	8.21
Dermaptera	0.00	0.07	0.00	0.00
Diptera	0.31	0.15	0.16	0.48
Gastropoda	0.00	0.00	0.16	0.29
Hemiptera	20.45	22.90	27.51	31.61
Cicadellidae	3.51	2.28	1.86	3.72
Nabidae	4.29	2.36	4.94	3.63
Pentatomidae	4.37	5.52	7.85	4.87
Hymenoptera	21.55	19.44	19.58	19.48
Formicidae	20.37	17.89	18.28	18.43
Lepidoptera Larvae	1.80	3.24	6.31	5.73
Orthoptera	3.75	4.12	3.56	2.10
Acrididae	3.75	3.90	3.48	2.01
	n=1282	n=1359	n=1236	n=1046

Note: n= The total # of arthropods consumed by all chicks in each field border treatment in 2009 and 2010.

Table 2. Estimated least-square mean (±SE) mass (mg) of most important taxonomic orders and families of arthropods consumed per northern bobwhite chick over 30-minute foraging trials in 4 field border treatments (Jun-Aug 2009 and 2010).

	NWSG/Flowers	Flowers Only	Fallow	Mowed
2009				
Aranae	7.5^{b} (2.1)	8.5^{b}(2.1)	14.7^{a}(2.1)	11.8^{ab} (2.1)
Total Coleoptera	29.3^{a}(5.0)	16.6^{b}(4.8)	17.2^{b}(4.7)	14.1^{b}(4.7)
Carabidae	84.5^{a}(11.8)	63.7^{ab}(11.8)	54.2^{ab}(11.8)	40.3^{b}(12.5)
Curculionidae	5.6(2.0)	4.8(1.6)	5.8 (1.4)	4.8 (1.5)
Tenebrionidae	23.5^{a}(3.6)	11.6^{b}(3.8)	17.8^{ab}(4.9)	16.0^{ab}(3.8)
Total Hemiptera	8.4 (1.7)	8.0 (1.7)	9.5 (1.6)	7.5 (1.7)
Cicadellidae	8.0 (3.6)	10.1(3.8)	6.2 (4.5)	12.2 (3.6)
Nabidae	8.8^{ab}(1.3)	8.7^{ab}(1.4)	10.3^{a}(1.3)	5.9^{b}(1.4)
Pentatomidae	9.2(8.5)	9.1(5.4)	17.7(4.0)	11.0 (6.0)
Total Hymenoptera	2.7(1.4)	1.5(1.4)	1.5(1.5)	2.1(1.4)
Formicidae	2.8 (1.4)	1.4(1.4)	1.4(1.5)	2.4(1.5)
Lepidoptera Larvae	65.4(43.2)	60.2(38.7)	55.0(29.0)	82.1(43.1)
Total Orthoptera	53.3^{b}(44.4)	85.4^{ab}(44.6)	65.0^{ab}(44.5)	195.0^{a}(47.2)
Acrididae	53.3^{b}(44.0)	117.9^{ab}(49.8)	42.9^{b}(46.6)	218.0^{a}(49.8)
2010				
Aranae	5.0 (2.1)	4.9 (2.1)	4.9 (2.1)	3.1 (2.2)
Total Coleoptera	12.0 (5.1)	10.4(5.0)	14.4(5.0)	6.4(5.2)
Carabidae	30.5^{ab}(14.4)	29.6^{ab}(11.8)	53.7^{a}(12.5)	15.9^{b}(12.5)
Curculionidae	9.5^{a}(1.5)	8.1^{ab}(1.4)	6.2 ^{ab}(1.4)	4.7 ^{b}(1.6)
Tenebrionidae	16.8(4.9)	14.4 (4.1)	12.2 (6.3)	16.0 (4.9)
Total Hemiptera	11.2^{a}(1.9)	11.2^{a}(1.8)	10.3^{a}(1.8)	6.7^{b}(1.8)
Cicadellidae	5.3(4.1)	6.4(5.0)	5.6(5.8)	4.6(3.8)
Nabidae	6.6(1.5)	4.5(1.6)	5.8(1.8)	5.6(1.6)
Pentatomidae	27.7^{a}(4.2)	23.2^{a}(4.0)	18.7^{b}(4.0)	10.0^{b}(4.2)
Total Hymenoptera	9.8(1.4)	8.1(1.5)	8.9(1.5)	7.6(1.5)
Formicidae	9.1(1.5)	9.5(1.4)	9.9(1.4)	7.9(1.4)
Lepidoptera Larvae	19.9^{b}(30.7)	45.0^{ab}(30.7)	121.0^{a}(38.7)	116.7^{a}(49.7)
Total Orthoptera	55.6(50.4)	48.0(47.2)	102.9(54.5)	44.3(66.7)
Acrididae	55.2(49.8)	47.7(46.7)	102.5(53.8)	43.7(65.8)

Note: Within rows, means followed by different letters were different ($P<0.05$).

Table 3. Estimated least-square mean (±SE) number of arthropods per 0.38 m^2 of most important taxonomic orders and families in 4 field border treatments (Jun-Aug 2009 and 2010).

	NWSG/Flowers	Flowers Only	Fallow	Mowed
2009				
Aranae	8.85^{a} (1.38)	9.00^{a} (1.38)	7.39^{ab} (1.38)	5.22^{b} (1.38)
Total Coleoptera	5.19(0.95)	5.74(0.95)	5.35(0.95)	4.26(0.95)
Carabidae	1.70(0.73)	2.70(0.73)	1.30(0.73)	1.52(0.73)
Curculionidae	0.52(0.16)	0.59(0.16)	0.50(0.16)	0.15(0.16)
Tenebrionidae	0.30(0.13)	0.30(0.13)	0.43(0.13)	0.26(0.13)
Total Hemiptera	8.11^{b}(2.35)	12.37^{ab}(2.35)	17.41^{a}(2.35)	13.26^{a}(2.35)
Cicadellidae	2.41^{a}(1.49)	3.85^{a}(1.49)	6.63^{b}(1.49)	6.81^{b}(1.49)
Nabidae	0.52(0.34)	0.44(0.34)	1.20(0.34)	0.52(0.34)
Pentatomidae	0.04(0.05)	0.07(0.05)	0.07(0.05)	0.07(0.05)
Total Hymenoptera	3.26(0.90)	4.15(0.90)	5.11(0.90)	2.89(0.90)
Formicidae	1.81(0.86)	2.56(0.86)	2.07(0.86)	1.56(0.86)
Lepidoptera Larvae	0.07(0.05)	0.04(0.05)	0.07(0.05)	0.07(0.05)
Total Orthoptera	2.63^{bc}(0.75)	4.26^{a}(0.75)	3.39^{ab}(0.75)	1.67^{c}(0.75)
Acrididae	0.93^{b}(0.37)	1.04^{b}(0.37)	2.30^{a}(0.37)	1.37^{b}(0.37)
Total Arthropods	33.85(4.85)	38.59(4.85)	42.26(4.85)	33.67(4.85)
H’	2.88	2.98	3.12	2.83
	n=27	n=27	n=25	n=27
2010				
Aranae	11.11^{a}(1.16)	8.04^{b}(1.16)	7.98^{b}(1.16)	6.96^{b}(1.16)
Total Coleoptera	7.33^{a}(1.47)	5.19^{ab}(1.47)	5.31^{ab}(1.47)	3.96^{b}(1.47)
Carabidae	2.89(0.76)	1.48(0.76)	1.96(0.76)	1.48(0.76)
Curculionidae	1.26^{a}(0.31)	1.44^{a}(0.31)	0.87^{ab}(0.31)	0.44^{b}(0.31)
Tenebrionidae	0.00(0.08)	0.15(0.08)	0.04(0.08)	0.04(0.08)
Total Hemiptera	5.63^{a}(1.52)	5.33^{a}(1.52)	7.19^{ab}(1.52)	10.70^{b}(1.52)
Cicadellidae	2.22^{b}(0.97)	2.44^{b}(0.97)	2.59^{b}(0.97)	5.93^{a}(0.97)
Nabidae	0.63(0.21)	0.11(0.21)	0.11(0.21)	0.15(0.21)
Pentatomidae	0.07(0.06)	0.07(0.06)	0.07(0.06)	0.15(0.06)
Total Hymenoptera	6.89^{a}(1.53)	7.19^{a}(1.53)	9.15^{a}(1.53)	3.59^{b}(1.53)
Formicidae	3.22^{ab}(1.27)	3.19^{ab}(1.27)	5.57^{a}(1.27)	1.81^{b}(1.27)
Lepidoptera Larvae	0.15^{b}(0.18)	0.33^{ab}(0.18)	0.48^{ab}(0.18)	0.70^{a}(0.18)
Total Orthoptera	1.41(0.30)	1.33(0.30)	1.39(0.30)	1.30(0.30)
Acrididae	1.04(0.30)	0.96(0.30)	0.83(0.30)	0.96(0.30)
Total Arthropods	40.19(5.38)	36.07(5.38)	42.15(5.38)	43.63(5.38)
H’	2.47	2.54	2.59	2.15
	n=27	n=27	n=25	n=27

Note: Means within rows followed by different letters were different ($P<0.05$). n= The number of samples collected in each border treatment. H’=Shannon-Weiner Diversity Index.

Table 4. Mean (±SE) for vegetation parameters within 4 field border treatments in North Carolina (Jun-Aug 2009-2010).

	NWSG/Flowers	Flowers Only	Fallow	Mowed
2009				
Planted NWSG				
Sorghastrum nutans	1.17 (0.56)	N/A	N/A	N/A
Schizachyrium scoparium	3.28 (1.47)	N/A	N/A	N/A
Planted Forbs			N/A	N/A
Asclepias tuberose	1.43 (1.12)	1.57 (0.80)	N/A	N/A
Asclepias syriaca	1.00 (0.5)	1.06 (0.73)	N/A	N/A
Rudbeckia hirta	4.62 (2.11)	5.09 (3.20)	N/A	N/A
Echinacea purpurea	1.85 (1.06)	2.08 (0.99)	N/A	N/A
Coreopsis lanceolata	1.54 (0.77)	1.68 (0.37)	N/A	N/A
Helianthus angustifolius	1.41 (1.1)	1.26 (0.71)	N/A	N/A
Symphyotrichum pilosum	2.08 (0.7)	1.84 (0.65)	N/A	N/A
Solidago speciosa	1.56 (0.93)	1.30 (0.41)	N/A	N/A
% Total Forbs	50.91^{a} (15.89)	61.47^{a} (12.87)	47.88^{a} (22.27)	29.19^{b} (10.99)
% Total Grass	35.18 (20.01)	23.86 (5.89)	24.11 (15.17)	45.0 (23.75)
% Woody	0.00 (0.00)	0.00 (0.00)	4.44 (8.08)	0.00
% Bare ground	64.72 (7.50)	67.43 (7.52)	48.47 (15.05)	53.27 (23.36)
VOR	4.49^{a} (0.49)	3.73^{ab}(0.45)	3.08^{b} (0.67)	0.58^{c} (0.11)
2010				
Planted NWSG	50.51 (16.70)	N/A	N/A	N/A
Sorghastrum nutans	12.64 (6.01)	N/A	N/A	N/A
Schizachyrium scoparium	70.28 (9.81)	N/A	N/A	N/A
Planted Forbs	38.72 (16.14)	71.57(19.14)	N/A	N/A
Asclepias tuberosa	0.00 (0.00)	1.39(1.42)	N/A	N/A
Asclepias syriaca	0.28 (0.83)	1.42(2.60)	N/A	N/A
Rudbeckia hirta	46.11 (21.50)	29.03(14.43)	N/A	N/A
Echinacea purpurea	4.22 (3.84)	7.28(7.82)	N/A	N/A
Coreopsis lanceolata	1.67 (2.07)	3.22(3.27)	N/A	N/A
Helianthus angustifolius	0.44 (0.87)	7.04(6.94)	N/A	N/A
Symphyotrichum pilosum	34.67 (26.06)	36.15(17.65)	N/A	N/A
Solidago speciosa	0.00 (0.00)	0.00 (0.00)	N/A	N/A
% Total Forbs	40.60^{b}(15.00)	74.79^{a}(19.21)	53.08^{b} (22.82)	1.83^{c}(2.64)
% Total Grass	55.63^{b}(15.55)	23.64^{c}(21.32)	38.18^{bc}(23.11)	98.25^{a} (2.95)
% Woody	0.93^{b}(2.70)	0.72^{b}(1.01)	6.51^{a}(6.19)	0.00^{b} (0.00)
% Bare ground	13.65(12.18)	15.13 (11.37)	14.67 (18.52)	6.18 (16.23)
VOR	4.56^{b} (0.37)	3.35^{c} (0.32)	5.93^{a} (1.26)	0.44^{d} (0.20)

Table 4 Continued

Note: VOR samples, n=45; all other samples n=72. In 2009, estimates for individual species of planted NWSG and planted forbs are based on the no. individual plants/ m^2. In 2010, estimates for individual species of planted NWSG and planted forbs are based on the percent cover/ m^2. Means within rows followed by different letters were different ($P<0.05$).

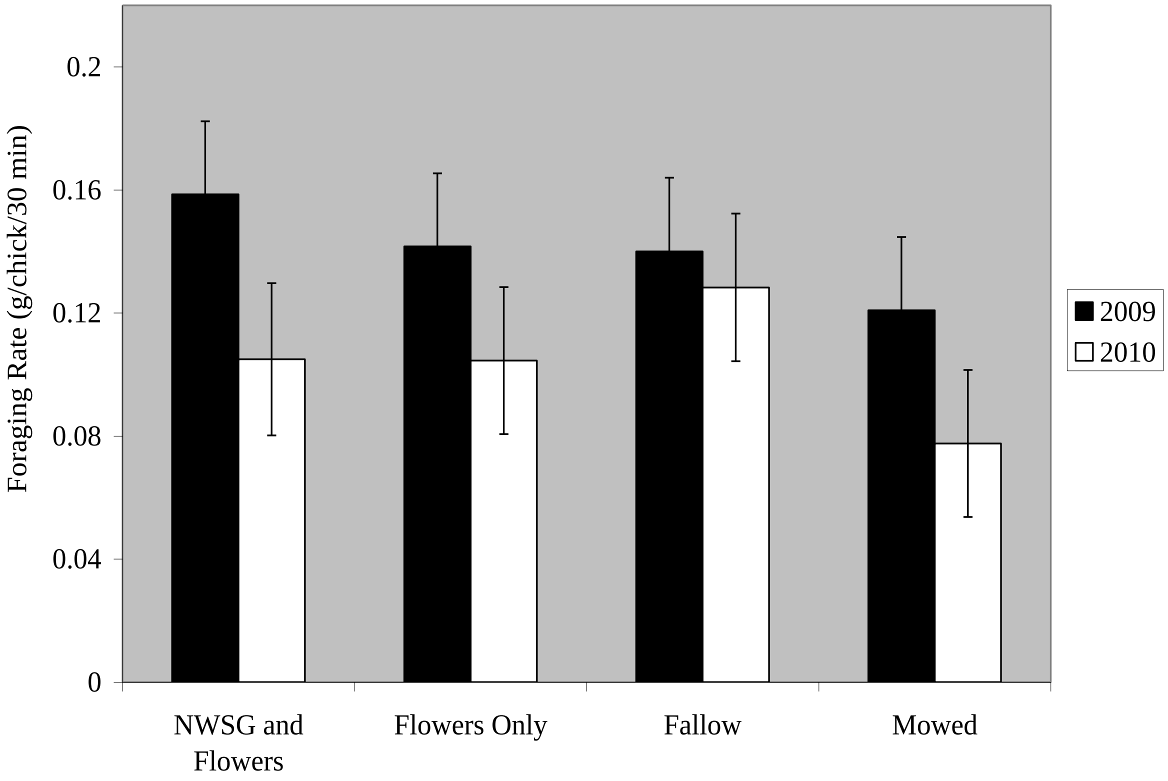

Figure 1. Estimated least-square mean foraging rates (g of arthropods consumed/chick/30 min) for northern bobwhite chicks within 4 field border habitats in North Carolina (2009-2010). Least-square mean estimates and SE derived from MIXED models.

Overwintering Sparrow Use of Field Borders Planted as Beneficial Insect Habitat

Abstract

Field borders are an effective conservation strategy for providing habitat to overwintering sparrows, and also may be a venue through which beneficial insect populations are promoted. However, traditional fallow field borders lack sufficient pollen and nectar sources required to sustain beneficial insect populations, and therefore, borders planted to a mix of native prairie flowers and grasses may be needed if increases in beneficial insect populations are desired. Although the value of fallow borders to birds has been established, little is known about bird use of beneficial insect habitats. Using single-observer transect surveys, we compared overwintering sparrow densities among 4 field border treatments (planted native warm season grasses and prairie flowers, planted prairie flowers only, fallow, and mowed) replicated around 9 organic crop fields from November-March 2009-2010 and 2010-2011. Sparrow densities were 5-10 times lower in mowed borders than in other border treatments in 2009-2010 and 2010-2011, but did not differ among planted and fallow borders in either year. Planted field borders may be a useful conservation practice for providing habitat for both overwintering sparrows and beneficial insects.

Introduction

Grass and shrubland songbirds have declined steadily in North America over the last half-century (Sauer et al. 2005). Populations in the southeastern United States have suffered in particular, experiencing annual declines between 1.1 and 2.3% (Sauer et al. 2003). Species declines are attributed primarily to the loss or degradation of usable early-successional habitat (Vickery and Herkert 1999). Historically, such habitats included farm grasslands and pastures, timber harvests, fallow fields, and fire-adapted forests with well-developed grass and herbaceous understories (Hunter et al. 2001). Yet, over the past half-century, most native grasslands have been converted for other uses, and remaining habitat has been altered or fragmented by urbanization, agricultural intensification, fire suppression, and forest maturation (Brennan and Kuvlesky 2005). Consequently, most grassland birds primarily use agricultural production areas that often lack essential habitat requirements as a result of modern farming practices (Hunter et al. 2001, Murphy 2003).

Declines in grassland songbird populations have prompted efforts to conserve and enhance early-successional habitat. Federal and state agencies have initiated programs to develop practical land-management strategies that will provide adequate habitat for songbirds without diminishing agricultural productivity on private lands (Best 2000). A widely accepted practice is to leave areas along crop field margins (hereafter field borders) fallow so they return to natural vegetation (Marcus et al. 2000, Smith et al. 2005, Smith et al. 2008). This interface between crop and adjacent areas has lower crop productivity (Morris 1998), and a number of programs offer subsidization to compensate for financial losses incurred as a result of establishing the field borders (e.g. Conservation Reserve Program's Upland Bird Habitat Buffer (CP-33), Bobwhite Quail Initiative in Georgia, and North Carolina Wildlife Resource Commission Cooperative Upland Habitat Restoration and Enhancement Program). Field borders are simple and relatively inexpensive to establish, and aside from wildlife habitat, provide erosion control and improved water quality near riparian areas (Osborne and Kovacic 1993, Daniels and Gilliam 1996).

Most research investigating the use of field borders by songbirds has focused on the breeding season, but less is known about use of borders by wintering sparrows (Vickery and Herkert 1999). Although narrow field borders increase the density of some avian species, their value as nesting habitat is typically low (Bryan and Best 1994, Moorman and Riddle 2010). Songbirds nesting within narrow habitat strips suffer high rates of nest predation, largely because of increased predator activity and efficiency (Camp and Best 1994, Dijak and Thompson 2000). Because the breeding season benefits of field borders to grassland songbirds are variable, borders may be of greater value to songbird populations during the winter, particularly resident and short-distance migrant sparrows. Marcus et al. (2000) and Smith et al. (2005) observed increases in overwintering sparrow densities on farms where field borders were established in North Carolina and Mississippi, respectively. Additionally, Blank et al. (2011) reported an increase in overwintering songbird density and species richness on Maryland farmlands following establishment of strip habitats.

However, fallow field borders typically lack the flowering plants required by arthropod species that either prey upon or parasitize insect crop pests (hereafter, beneficial insects) (Olsen and Wäckers 2007). Traditionally, biological control of pest insects involved the augmentation and release of control species; however, there is a growing interest in developing land management practices that promote and maintain beneficial insect populations, especially on organic farms (Landis et al. 2005). To meet caloric demands, most adult beneficial insects require habitats with abundant pollen and nectar sources, and without them, are unable to maintain population sizes large enough to control pest populations that are inherently large within monoculture crop fields (Heimpel and Jervis

2005, Landis et al. 2005). Therefore, field borders planted in a mix of flowering species may better conserve beneficial insect populations, including ecologically and economically important pollinator species (Allen-Wardell et al. 1999).

The inherent differences in floral characteristics between planted and fallow borders may influence variability in sparrow use of these habitats. Granivorous sparrow species rely heavily on seed food sources during the winter, and seed abundance can influence bird densities within an area, especially after waste grains have been depleted (Robinson and Sutherland 1999). Seed availability also can be a major factor in winter mortality rates for many sparrow species (Watts 1990). Overwintering habitats must contain sufficient percentages of bare ground for seeds to be accessible to sparrows, which otherwise have difficulty scratching through a thick thatch layer. Variability in vegetation structure also can influence differential use of field margin habitats, depending on individual bird species' foraging strategy and reliance on protective cover (Beck and Watts 1997, Douglas et al. 2009).

Field border management strategies that provide habitat for both beneficial insects and songbirds may be a useful tool for maximizing the ecological benefits of conservation practices focused on agricultural lands. We measured overwintering sparrow densities within field borders planted as beneficial insect habitat to determine whether their value as overwintering songbird habitat is comparable to traditional fallow field borders.

Study Area

We conducted the study in the upper coastal-plain physiographic region at the Center for Environmental Farming System's Organic Research Unit (ORU) near Goldsboro, North

Carolina. Within the ORU, 9 organic crop fields ranging from 1.6-4.0 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 United States Department of Agriculture (USDA) organic crop production guidelines. In 2008, 4 field border treatments were established randomly around each of the 9 crop fields. All field borders were approximately 91.44 m by 9.14 m (0.08 ha), creating a total of 0.33 ha of experimental habitat around each field.

The 4 border treatments were: 1) planted native-warm season grasses (NWSG) and native prairie flowers (hereafter NWSG/Flowers); 2) planted native prairie flowers only (hereafter Flowers Only); 3) fallow, unmanaged vegetation (hereafter Fallow); 4) volunteer grasses and herbaceous vegetation mowed 2-3 times per month (hereafter Mowed). The NWSG 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*). We chose the mix of native prairie flowers because they are native to the United States, they are adaptable to North Carolina soils and climate, and the seeds were readily available for purchase. Additionally, individual species bloomed at various times during the growing season, which provided a continuous source of nectar. The fallow treatment was intended to represent traditional field borders established for wildlife habitat, and the mowed treatment acted as a reference.

We established planted field borders in the spring of 2008. Treatment areas were disked, and the corresponding seed mix was broadcast over the tilled soil using a manually powered seed spreader. After the seeds were sewn, we ran a culti-packer over the treatment area to ensure good seed-to-soil contact. Once vegetation in the planted borders reached approximately 0.3 m in height, we mowed the area at a height of approximately 16 cm. During the 2008 growing season, planted borders were mowed 5-6 times to reduce weed competition. No further management was performed on planted border treatments. Following tillage in the fall of 2007, natural vegetation was permitted to grow in all fallow border treatments for the duration of the study. Fallow field border vegetation consisted of a mix of grasses, such as bermudagrass (*Cynodon dactylon)* and crabgrass (*Digitaria ciliaris),* and commonly occurring herbaceous species, such as horseweed (*Conyza canadensis*), dogfennel (*Eupatorium capillifolium)*, heath aster, pigweed *(Amaranthus spp.)*, and coffeeweed (*Senna obtusifolia*). *Baccharis halimifolia* also became prevalent within fallow borders two years following border establishment.

Methods

We estimated overwintering songbird densities using single observer transect surveys from November-March 2009-2010 (hereafter, 2009) and 2010-2011 (hereafter, 2010). In 2009 and 2010, the same observer walked the edge of each field border treatment and counted the number of birds within each border. Because many overwintering sparrows move in large flocks, share subtle field markings, and tend to fly into dense cover shortly after flushing, it is difficult to identify individuals to species. Therefore, we counted sparrow species collectively, and indentified individuals only when easily visible with binoculars. We were careful to note the location of where flushed birds landed so that individuals were not counted more than once. Also, to ensure that all individuals present were counted, the observer frequently clapped and talked loudly while conducting surveys. Surveys were between sunrise and 1000 EST on mornings with no precipitation and winds not exceeding 25 kmph. The observer surveyed all field borders over the course of the morning, and the order borders were sampled differed on each subsequent survey. In each year, borders were sampled 9 times by a single observer.

We estimated vegetation composition within each field border at 8 randomly distributed points using a 1- x 1- m sampling frame from June-August 2009 and 2010. At each sampling point, we estimated the percent cover of forbs, grass, woody species, and bare ground. Within NWSG/Flowers and Flowers Only borders, we also estimated the abundance of each planted NWSG and flower species. In 2009, we counted the number of each NWSG and flower species within each sample. In 2010, we estimated the percent cover of all planted NWSGs and planted flowers, as well as the percent cover of each individual NWSG and flower species. We estimated vegetation height and density using a Robel pole to calculate visual obstruction readings (VOR) at 5 random points within each field border (Robel et al. 1970). We classified land adjacent to each field border treatment as crop field, shrubland, forest, or man-made structures.

Statistical Analysis

To quantify overwintering sparrow response to border habitat type, we performed an analysis of variance (ANOVA) using repeated measures models in Proc MIXED (SAS Institute, Inc., Cary, NC). Number of sparrows counted was the dependent variable and border treatment, adjacent habitat, and year were the independent variables. Year, adjacent habitat type, and border treatment were treated as fixed effects, and field was included as a random effect. We also included the interaction between field and border treatment within year as a repeated measures effect in the model, because individual borders were surveyed multiple times within the same year. We reported sparrow densities as the number of sparrows per 0.08 ha. We used a Tukey-Kramer adjustment to compare sparrow density among border treatments.

Because field borders were 10 m wide and consisted primarily of herbaceous vegetation, we assumed detection probability was near 100% (Diefenbach et al. 2003). Additionally, during our initial surveys in 2009, we walked through the middle of border treatments making noise and beating vegetation immediately following a survey to determine if individuals had not been detected. Few birds were undetected (C. Plush, unpublished data).

We conducted ANOVAs using Proc MIXED to test for differences in percent cover of forbs, grass, bare ground, and woody vegetation, and mean VOR among border treatments. Because structure of the vegetation in planted and fallow borders changed drastically during the two years of the study, we analyzed differences in vegetation structure and composition among border treatments separately for each year. In all models, we treated border treatment as a fixed effect, and included field as a random effect. We used Tukey-Kramer adjustments to compare vegetation parameters among border treatments.

Results

We observed 2881 birds in the winters of 2009 and 2010. Most birds were sparrows (96.4%), of which we were able to positively indentify 1424 (51%) to species. Sparrow species observed within field borders were savannah sparrow (*Passerculus sandwichensis*) (61.5%), song sparrow (*Melospiza melodia*) (22.8%), swamp sparrow (*Melospiza georgiana*) (6.8%), field sparrow (*Spizella pusilla*) (3.8%), dark-eyed junco (*Junco hyemalis*) (2.9%), white-crowned sparrow (*Zonotrichia leucophrys*) (0.8%), grasshopper sparrow (*Ammodramus savannarum*) (0.7%), and chipping sparrow (*Spizella passerina*) (0.4%). Other birds observed within borders included northern bobwhite (*Colinus virginianus*), eastern bluebird (*Sialia sialis*), and eastern meadowlark (*Sturnella magna*).

We detected no difference in total sparrow density between 2009 and 2010 or an interaction between year and field border treatment. Adjacent habitat type did not affect sparrow density, but sparrow density differed among field border treatments (Table 1). In 2009, sparrow density was similar among NWSG/Flowers, Flowers Only, and Fallow borders, but sparrow density was over 5 times lower in mowed borders than in other border types (Figure 1). In 2010, sparrow density again was similar between planted and fallow borders, although density was 42% higher in Fallow borders than in Flowers Only borders and 35% higher in Fallow borders than in NWSG/Flowers borders. In 2010, Mowed borders had 6-10 times lower sparrow abundance than all other border treatments (Figure 1).

Percentage of forb cover was not different between planted and fallow borders in 2009, but was at least 29% higher in Flowers Only borders than in other treatments in 2010 (Table 2). Black-eyed susan and heath aster comprised over 50% of the planted flower species present in NWSG/Flowers and Flowers Only borders. Percentage of grass cover was similar in all treatments in 2009. In 2010, grass cover did not differ between Fallow and NWSG/Flowers borders, but was nearly 50% lower in Flowers Only borders than in NWSG/Flowers borders. The majority of grass species within NWSG/Flowers borders were planted NWSGs, whereas bermudagrass and crabgrass were the dominant species in other treatments. Percent bare ground cover was similar among border treatments in both years. Mean VOR was greatest in NWSG/Flowers Only borders in 2009, but in 2010, VOR was over 23% higher in fallow borders than in other treatments. In 2010, percentage of woody vegetation was nearly 7 times greater in Fallow borders than in other border treatments (Table 2).

Discussion

Beneficial insect habitats provided winter habitat for sparrows equal to that of fallow field borders. Rising demand for food production coupled with increasing economic constraints on conservation programs make it essential that conservation strategies focused on agricultural lands yield the greatest amount of ecological services possible. Therefore, field borders planted as beneficial insect habitat may be a useful tool for maximizing biodiversity on arable lands by providing habitat to both beneficial insects and declining populations of grassland sparrows.

Mowed field margins demonstrated little value to overwintering sparrows, because they provided no cover and limited access to food sources. Mowed borders lacked the structural diversity needed for protection from predators, and frequent mowing prohibited vegetation from flowering and producing seed. Also, thatch typically accumulates in frequently mowed areas, and grasses begin to dominate stands over short time periods (McCoy et al. 2001). Because sparrows are weak scratchers, the combination of a thick litter layer and dense stands of mat-forming grasses reduces their ability to identify and access food sources on the ground. Low sparrow densities observed in mowed borders in our study implies that wide-spread agricultural practices that leave cultivated lands void of residual cover during the winter may be a factor in the decline of many grassland bird species (Murphy 2003). In fact, in Europe, the long-term decline of many granivorous bird species has been linked to increased winter mortality due to the loss of food and cover resources on farmlands (Peach et al. 1999, Robinson and Sutherland 1999). We suspect similar detrimental effects on overwintering sparrows in the U.S., given that most crop fields have been cultivated prior to the winter months, and the mowing of field edges, hedgerows, and ditches are commonplace practices.

Although vegetation structure may be of greatest importance, differences in plant species composition may impact sparrow abundance indirectly through food availability. Sparrows are primarily granivourous during the winter months, and the abundance of seeds can affect overwintering bird densities and survival (Robinson and Sutherland 1999, Moorcroft et al. 2006). Seed production within field borders may be especially important during later winter months, particularly when waste grain food sources are quickly depleted in crop fields due to efficient harvest. In fallow borders, commonly occurring annual and perennial grasses and forbs, such as crabgrass, heath aster, and pigweed produce seeds readily eaten by sparrows (Pulliam and Enders 1971); however, no research has been conducted on songbird preference for seeds produced by flower species planted in beneficial insect habitats. More research is needed to determine whether seed availability and vegetation species influence sparrow abundance in beneficial insect habitats.

We observed higher sparrow densities in both planted and fallow field borders than in other studies of sparrow use of field borders (Marcus et al. 2000, Smith et al. 2005, Conover et al. 2007), which may be related to organic farming practices used in adjacent crop fields. Organic farms support higher species richness and abundance of breeding songbirds compared to conventionally managed crop fields (Vickery et al. 2001, Beecher et al. 2005, Belfrage et al. 2006). However, less is known about winter bird use of organic versus conventionally managed agricultural fields. Organically managed fields typically are smaller in size, and contain greater amounts of non-crop vegetation because of restrictions on herbicide use (Beecher et al. 2005). Most sparrow species are less likely to use expansive areas of clean farming, where access to immediate escape cover is not available (Watts 1991). In our study, the smaller fields may have allowed sparrows to exploit greater areas of the crop fields because access to escape cover was maximized by surrounding field borders. Also, residual weed seeds produced by non-crop vegetation may have been more abundant within crop fields, thus providing a larger food source to sparrows. Although we recognize that comparisons between studies can be misleading because of differences in methodology and the species of birds encountered, the high densities of sparrows detected during our study suggests a need for additional research investigating the benefits of organic farming practices to overwintering birds.

The increase in woody cover likely contributed to the increase in sparrow use of fallow borders in 2010. Song and swamp sparrows, two of the most commonly detected species in our study, typically select wintering habitats with substantial shrub and woody cover (Beck and Watts 1997, Baldwin et al. 2007), and savannah sparrows frequently used woody vegetation as perches while feeding in adjacent edge habitats (C. Plush, pers. observation). Early successional habitats containing modest levels of woody vegetation often support more diverse breeding (Riddle and Moorman 2010) and wintering bird communities (Baldwin et al. 2007), likely because the greater amount of structural diversity satisfies the habitat requirements of multiple bird species. Additionally, tall, woody vegetation acts as natural deterrent to aerial predators because it provides a greater over-head screening effect, and increases the distance of vulnerability between the ground and where predators can capture prey efficiently (Watts 1990).

However, expansive woody cover can limit the value of border habitats to many grassland-obligate species (Graves et al. 2010). Whereas song and swamp sparrows generally thrive in areas with substantial shrub or woody cover, savannah sparrows typically are restricted to grassland habitats, and likely would respond negatively if woody vegetation became the dominate vegetation type within border habitats (Arcese et al. 2002, Wheelwright and Rising 2008). Because the management practices used to establish beneficial insect habitats inherently deter woody vegetation encroachment, planted borders may provide suitable habitat over longer time periods for sparrow species strongly associated with strictly herbaceous cover, such as grasshopper sparrows and savannah sparrows.

We failed to detect an effect of adjacent habitat type on total sparrow abundance, but we suspect that adjacent cover type likely influenced species-specific distributions among field borders (Smith et al. 2005, Conover et al. 2007). Edge-adverse species (e.g. savannah sparrow) may have selected borders established between agricultural fields, while other species (e. g. song sparrow and swamp sparrow) used borders adjacent to shrub or forest habitats. Additional research is needed on individual species use of beneficial insect habitats, especially within areas where borders have been planted over larger areas and independent of fallow field borders.

Management Implications

Although planted borders can be created to provide habitat for beneficial insects and overwintering birds, structurally complex borders containing a mix of grasses, forbs, and woody shrubs likely provide the highest quality year-round bird habitat (Riddle and Moorman 2010). Managers or landowners with a primary interest in bird conservation should include NWSGs in seed mixes to improve the vertical structure of planted borders. Additionally, if beneficial insect habitat is not an objective, the use of fallow borders likely is the best option, because they are easier and less expensive to establish than borders planted in a mix of grasses and flowers. In our study, the cost of establishing NWSG/Flowers and Flowers Only borders was approximately $1928/ha and $1773/ha, respectively. Regardless of the border type, frequent disturbance is required to limit woody plant and grass dominance over forbs in the borders. Frequent disturbance is especially important in planted mixes containing NWSGs because these grasses can quickly form monocultures that diminish the border’s value to both beneficial insects and overwintering birds (Dively 2008).

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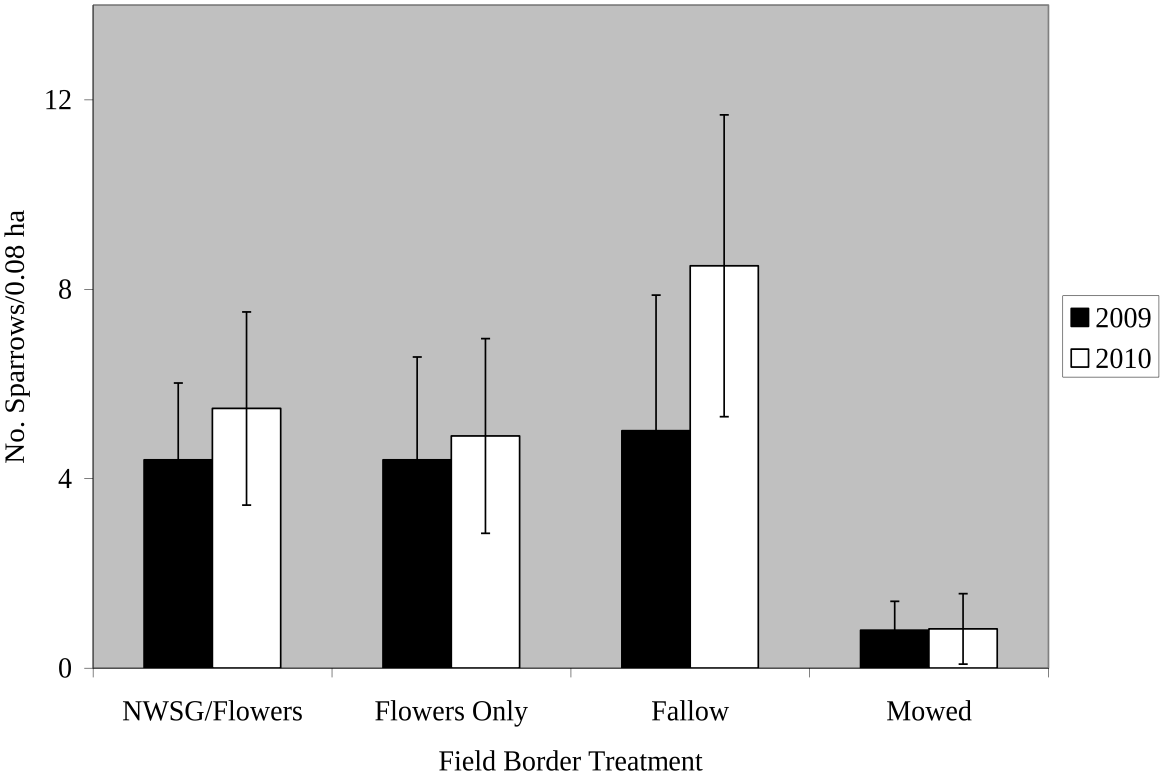

Figure 1. Mean (±SE) sparrow density (no. sparrows/ 0.08 ha) in 4 four field border treatments in North Carolina (Nov-Mar 2009-2010 and 2010-2011).

Table 1. Results of an analysis of variance test of the effects of year, treatment, and adjacent habitat on overwintering sparrow density in 4 field border treatments in North Carolina (Nov-Mar 2009-2010 and 2010-2011).

Variable	*F*	*Num df*	*Den df*	*P*
Year	1.93	1	16	0.18
Treatment	6.64	3	46	<0.001
Year x Treatment	0.76	3	46	0.52
Adjacent Habitat	0.21	3	46	0.89

Table 2. Mean and SE for vegetation parameters within 4 field border treatments in North Carolina (Jun-Aug 2009 -2010).

	Field Border Treatment							
	NWSG/Flowers		Flowers Only		Fallow		Mowed	
Variable	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
2009								
Sorghastrum nutans (no./ m²)	1.17	0.56	N/A		N/A		N/A	
Schizachyrium scoparium (no./ m²)	3.28	1.47	N/A		N/A		N/A	
Asclepias tuberosa (no./ m²)	1.43	1.12	1.57	0.80	N/A		N/A	
Asclepias syriaca (no./ m²)	1.00	0.50	1.06	0.73	N/A		N/A	
Rudbeckia hirta (no./ m²)	4.62	2.11	5.09	3.20	N/A		N/A	
Echinacea purpurea (no./ m²)	1.85	1.06	2.08	0.99	N/A		N/A	
Coreopsis lanceolata (no./ m²)	1.54	0.77	1.68	0.37	N/A		N/A	
Helianthus angustifolius (no./ m²)	1.41	1.10	1.26	0.71	N/A		N/A	
Symphyotrichum pilosum (no./m²)	2.08	0.70	1.84	0.65	N/A		N/A	
Solidago speciosa (no./m²)	1.56	0.93	1.30	0.41	N/A		N/A	
% Total Forbs	50.91^{a}	15.89	61.47^{a}	12.87	47.88^{a}	22.27	29.19^{b}	10.99
% Total Grass	35.18	20.01	23.86	5.89	24.11	15.17	45.00	23.75
% Woody	0.00	0.00	0.00	0.00	4.44	8.08	0.00	0.00
% Bare ground	64.72	7.50	67.43	7.52	48.47	15.05	53.27	23.36
VOR	4.49^{a}	0.49	3.73^{ab}	0.45	3.08^{b}	0.67	0.58^{c}	0.11

Table 2. Continued

2010

Total Planted NWSG (% cover)	50.51	16.70	N/A		N/A		N/A	
Sorghastrum nutans	12.64	6.01	N/A		N/A		N/A	
Schizachyrium scoparium	70.28	9.81	N/A		N/A		N/A	
Total Planted Flowers (% cover)	38.72	16.14	71.57	19.14				
Asclepias tuberose	0.00	0.00	1.39	1.42	N/A		N/A	
Asclepias syriaca	0.28	0.83	1.42	2.60	N/A		N/A	
Rudbeckia hirta	46.11	21.50	29.03	14.43	N/A		N/A	
Echinacea purpurea	4.22	3.84	7.28	7.82	N/A		N/A	
Coreopsis lanceolata	1.67	2.07	3.22	3.27	N/A		N/A	
Helianthus angustifolius	0.44	0.87	7.04	6.94	N/A		N/A	
Symphyotrichum pilosum	34.67	26.06	36.15	17.65	N/A		N/A	
Solidago speciosa	0.00	0.00	0.00	0.00	N/A		N/A	
% Total Forbs	40.6^{b}	15.0	74.8^{a}	19.2	53.1^{b}	22.8	1.83^{c}	2.64
% Total Grass	55.6^{b}	15.6	23.6^{c}	21.3	38.2^{bc}	23.1	98.3^{a}	2.95
% Woody	0.93^{b}	2.70	0.72^{b}	1.01	6.51^{a}	6.19	0.00^{b}	0.00
% Bare ground	13.7	12.2	15.1	11.4	14.7	18.5	6.18	16.2
VOR	4.56^{b}	0.37	3.37^{c}	0.32	5.93^{a}	1.26	0.44^{d}	0.20

Note: Means within rows followed by different letters are different ($P<0.05$). Mean ($\bar{X}$) of planted species within NWSG/Flowers and Flowers Only treatments is the mean no. / m^2 in 2009, and in 2010, it is the % coverage/ m^2. VOR= visual obstruction reading.

Small Mammal Use of Field Borders Planted as Beneficial Insect Habitat

Abstract

Field borders established for wildlife conservation have been recognized as a possible venue for also promoting beneficial insect populations (i.e. parasitic wasps, pollinators) on agricultural lands. However, traditional fallow field borders lack nectar sources needed to sustain beneficial insect communities, and their value to small mammals is not well understood. In October-November 2009, we trapped small mammals in 4 field border treatments (planted native-warm season grasses and prairie flowers, planted prairie flowers only, fallow vegetation, and frequently mowed vegetation) replicated around 9 organic crop fields, and developed closed population models in Program MARK to estimate density in each border. We also measured vegetation cover within each border treatment from June-August 2009. We captured 512 individuals of only two species, the hispid cotton rat (*Sigmodon hispidus*) and house mouse (*Mus musculus*). Cotton rat density was higher in borders planted for beneficial insect habitat, which likely was influenced by greater vegetation density and availability of preferred foods in these border types. Total small mammal density was lower in mowed borders, emphasizing the importance of available non-crop vegetation for supporting small mammal communities within intensive agricultural areas. Field borders planted to promote beneficial insects may be a useful tool for maximizing the ecological services provided by non-crop vegetation.

Introduction

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 (Creamer and Kleese 2000). One approach to pest management is to conserve biological control agents that naturally suppress pest populations within the farm landscape (Landis et al. 2000). 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 (Brust 1994, Borkhataria et al. 2006).

Small mammal communities hold a number of important ecological roles, and can have significant impacts 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 trophic interactions, and can influence the abundance and diversity of avian and mammalian predator species within a landscape (Norrdahl and Korpimaki 1996, Meserve et al. 2003, Korpimaki 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). 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 (Brust 1994, 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 natural 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, Palmer et al. 2005). Field borders have minimal impact on crop productivity, and numerous government subsidy programs exist to compensate for any financial losses to the landowner (Barbour 2006).

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 habitats that provide abundant pollen and nectar sources and differential microhabitats used as nesting and over-wintering sites throughout the year (Heimpel and Jarvis 2005). Sugar obtained through pollen and nectar is essential for reproduction, and serves 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 inherently abundant in monoculture crops (Heimpel and Jarvis 2005, Landis et al. 2005). However, habitat manipulation used to promote specific vegetation can increase beneficial insect communities (Landis et al. 2000, Jones and Gillet 2005, Forehand et al. 2006).

Field borders intended 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 habitats often is limited in intensive agricultural areas. 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). While the benefits to small mammal communities of non-crop areas such as hedgerows have been established (Yahner 1983, Silva and Prince 2008), less is known about the use of field borders by small mammals.

We investigated difference in small mammal densities in 4 types of field borders replicated around 9 organic farm fields. Individual small mammal species require specific habitat conditions related to their life-history, and consequently respond to habitat differences that impact food and cover needs (Grant and Birney 1979, Osbourne et al. 2005). Therefore, we predicted that small mammal response among the field border treatments would vary due to the inherent differences in floral characteristics between borders planted as beneficial insect habitat and traditional fallow borders.

Study Area

We conducted our study in the upper coastal plain physiographical region at the Center for Environmental Farming System's Organic Research Unit (ORU) outside of Goldsboro, North Carolina. Within the ORU, 9 organic crop fields with areas ranging from

1.6-4 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 USDA organic crop production guidelines. We randomly assigned field border habitat treatments to each of the 9 crop fields. All field borders were approximately 91.44 m by 9.14 m (0.08 ha), creating a total of 0.33 ha of experimental habitat around each field.

The 4 border habitat treatments were: 1) planted native-warm season grasses (NWSG) and native prairie flowers (hereafter, NWSG/Flowers); 2) planted native prairie flowers only (hereafter, Flowers Only); 3) fallow, unmanaged vegetation (hereafter, Fallow); 4) volunteer grasses and herbaceous vegetation mowed 2-3 times per month (hereafter, Mowed). The NWSG 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 ericoides),* 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. Additionally, 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

Southeast (e.g., CP-33 conservation practice), and the mowed border treatment acted as a reference.

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 0.3 m 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 fall of 2007, natural 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 bermudagrass (*Cynodon dactylon)* and crabgrass (*Digitaria ciliaris),* and commonly occurring herbaceous species were horseweed (*Conyza canadensis*), dogfennel (*Eupatorium capillifolium)*, heath aster (*Symphyotrichum ericoides)*, pigweed (*Amaranthus spp.),* and coffeeweed (*Senna obtusifolia*).

Methods

We trapped small mammals for 3 consecutive weeks in October 2009. Each week, we sampled all 4 field borders surrounding each of 3 crop fields (one each of hay, soybeans, corn) continuously for 6 days. We set 10 Sherman live traps along a parallel transect running lengthwise through the middle of each field border, with 9 m spacing between each trap.

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 hours 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. 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.

From June-August 2009, we estimated vegetation parameters within each field border at 8 random sampling points using a 1- x 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 NWSG species present within the sampling frame. To estimate vegetation density and height, we used a Robel pole to record five visual obstruction readings (VOR) in each field border following protocols outlined in Robel et al. (1970).

Statistical Analysis

We used Program MARK to estimate the density 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 mark-recapture population density models in Program MARK assuming a closed population. In our density estimation models, we assumed no emigration or immigration within the sampling area as well as no births or death within the population. Movement among borders was limited; however 20 individuals were captured in multiple field borders. Because of model assumptions, we excluded these 20 individuals from analysis. We selected the best-fit model for predicting small mammal density based on the lowest Akaike information criterion (AIC) value. Results from the best-fit model yielded a density estimate for each species within each individual field border (i.e., 36 density estimates for each species). To compare estimated densities 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 included border treatment and adjacent crop type as fixed effects, and field as a random effect. We used a Tukey-Kramer adjustment for pairwise comparisons to compare differences in small mammal species density among the different field border treatments. To determine differences in percentage of forbs, grass, woody vegetation, bare ground, and VOR 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 512 individuals of only hispid cotton rat (*Sigmodon hispidus*) and house mouse (*Mus musculus*). In NWSG/Flowers borders, we captured 92 cotton rats and 102 house mice. In Flowers Only borders, we captured 70 cotton rat individuals, and 110 house mouse individuals. We captured 33 cotton rats and 88 house mice in the Fallow border treatment. We captured 0 cotton rats and 17 house mice in the Mowed borders. The best-fit model for estimating hispid cotton rat densities assumed that the probability of initial capture (C) was equal to the probability of recapture (P), and that initial population size (N) was different among field borders (Table 1). Based on the best-fit model, the mean (± SE) density (individuals/ ha) of cotton rats was 141.49 ± 25.07 in the NWSG/Flowers border treatment, 119.12 ± 30.59 in the Flowers Only border treatment, 31.89 ± 17.29 in the Fallow border treatment, and 0 ± 0 in the Mowed border treatment (Figure 1). Cotton rat density differed among the field border treatments ($F_{3, 24}$= 17.83, P<0.0001), but adjacent crop type did not influence cotton rat densities ($F_{2, 24}$ = 0.67, P=0.67). Cotton rat densities were over 3 times higher in NWSG/Flowers and Flowers Only borders compared to Fallow borders and Mowed borders, and densities in Fallow border and Mowed borders were similar (Figure 1).

The best-fit model for estimating house mouse densities assumed C=P, and N was the same for all field borders (Table 2). Mean (± SE) house mouse density (individuals/ ha) was 186.00 ± 23.28 in NWSG/Flowers borders, 215.99 ± 30.19 in Flowers Only borders, 165.89 ± 30.78 in Fallow borders, and 28.32 ± 5.83 in Mowed borders (Figure 2). House mouse density differed among field border treatments ($F_{3,24}$ =14.21, P<0.0001), and adjacent crop type did not affect house mouse densities ($F_{3,24}$ =1.05, P=0.37). House mouse density was over 5 times lower in Mowed borders than in all other border treatments, but did not differ among the 3 other border treatments (Figure 2).

Percent cover of forbs was higher in NWSG/Flowers, Flowers Only, and Fallow borders than in Mowed borders (Table 3). Percent grass cover was greater in NWSG/Flowers and Mowed borders, but variation among replicates within the same treatment made statistical relationships difficult to detect (Table 3). Planted indiangrass was most abundant in NWSG/Flowers borders, while 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 3). Bare ground cover did not differ among border treatments. Mean VOR was approximately 45% higher in NWSG/Flowers borders than in Fallow borders, but did not differ between Flowers Only and Fallow borders (Table 3). VOR was over 5 times lower in Mowed borders than in all other border types (Table 3).

Discussion

Our results suggest that establishing areas of 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 suitable habit for both 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 (Plush, unpublished data), suggesting that the few individuals captured in mowed borders were simply dispersing to or from more suitable habitat. Additionally, constant mowing likely diminished food availability, because vegetation was not permitted to flower and bear seed. Given that mowing field margins and other similar habitats is a common practice among agricultural producers, we suspect that 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).

Higher cotton rat densities in beneficial insect habitats compared to fallow borders may have been because planted borders contained denser vegetation as well as a greater abundance of food sources for cotton rats. Because of their larger size, cotton rats require dense vegetation to hide them from predators and for suitable nesting sites (Cameron and Spencer 1981). Additionally the bunch-forming morphology of NWSGs and native prairie flowers creates open spaces at the ground level that facilitates easier movement within habitat patches, while retaining an over-head canopy structure. NWSGs are a preferred food source for cotton rats (Schweiger et al. 2000), and we frequently noted areas within NWSG/Flowers borders where small sections of NWSGs had been chewed and scattered along the ground, but did not witness signs of cotton rat foraging activity in the other field border treatments. 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). The addition of prairie flowers, coupled with natural vegetation that also established in planted borders, may have provided a greater diversity of food sources to cotton rats compared to fallow borders that contained only fallow vegetation.

Both planted and fallow field borders supported high densities of house mice, suggesting 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 habitats and exploit the food and cover resources that were available. In the fall, 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 high mouse densities observed in our study suggest that 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, house mice are highly effective weed seed predators, and can significantly reduce the number of weed seeds in crop fields. 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). Granivourous rodents typically forage at night to minimize predation risk, and uncultivated field margins likely provide a safe, day-time resting site that is minimal distance to foraging areas within crop fields. Additionally, 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 mice 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 to traditional fallow field borders. Coupled with the fact that these habitats 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 NWSG/Flowers and Flowers Only borders were approximately $1928/ha and $1773/ha, respectively. Therefore, 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.

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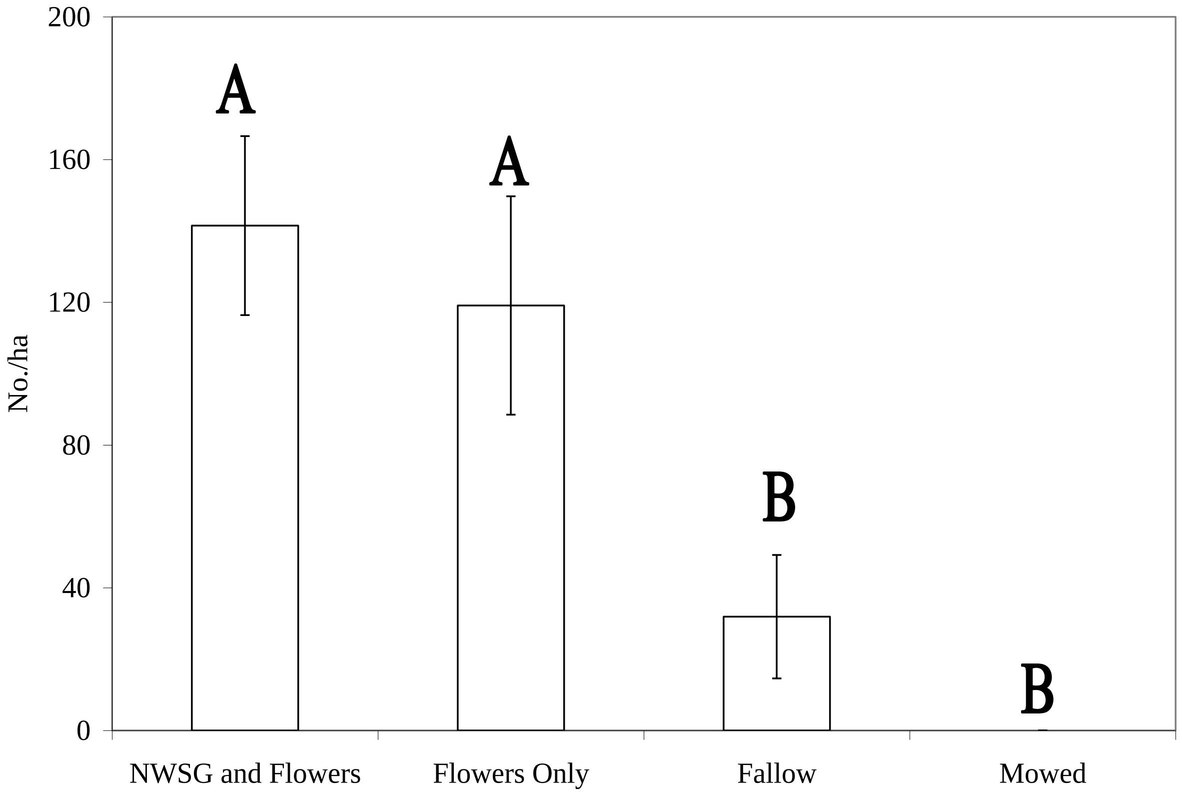

Figure 1. Estimated least-square mean density (individuals/ ha) of hispid cotton rat (*Sigmodon hispidus*) in 4 field border treatments in North Carolina (Oct-Nov 2009). Values with different corresponding letters were statistically different (*P*<0.05).

Figure 2. Estimated least-square mean density (individuals/ ha) of house mouse (*Mus musculus*) in 4 field border treatments in North Carolina (Oct-Nov) 2009. Values with different corresponding letters were statistically different (P<0.05).

Table 1. Candidate models for estimating density of hispid cotton rat (*Sigmodon hispidus*) and house mouse (*Mus musculus)* in 4 field border treatments in North Carolina (Oct-Nov 2009). All models assumed the probability of initial capture (C) was equal to the probability of recapture (P), but initial population size (N) varied. We considered the model with the lowest Akaike Information Criteria (AIC) value as the model that best fit the data. All models were derived using Program MARK.

Model	AIC	ΔAIC	Parameters	Deviance
Sigmodon hispidus				
C=P, N different	704.03	0.00	28	509.95
C=P, N same	718.03	13.18	25	529.44
C=P	729.87	25.02	45	498.47
Mus musculus				
C=P, N same	885.56	0.00	39	753.16
C=P, N different	991.79	106.23	44	783.69
C=P	1017.03	131.47	59	766.70

Table 2. Mean and SE for vegetation parameters within 4 field border treatments in North Carolina (Jun-Aug 2009).

	Field Border Treatment							
Variable	NWSG/Flowers		Flowers Only		Fallow		Mowed	
Species (no. plants/m²)	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Sorghastrum nutans	1.17	0.56	N/A		N/A		N/A	
Schizachyrium scoparium	3.28	1.47	N/A		N/A		N/A	
Asclepias tuberosa	1.43	1.12	1.57	0.80	N/A		N/A	
Asclepias syriaca	1.00	0.50	1.06	0.73	N/A		N/A	
Rudbeckia hirta	4.62	2.11	5.09	3.20	N/A		N/A	
Echinacea purpurea	1.85	1.06	2.08	0.99	N/A		N/A	
Coreopsis lanceolata	1.54	0.77	1.68	0.37	N/A		N/A	
Helianthus angustifolius	1.41	1.10	1.26	0.71	N/A		N/A	
Symphyotrichum ericoides	2.08	0.70	1.84	0.65	N/A		N/A	
Solidago speciosa	1.56	0.93	1.30	0.41	N/A		N/A	
% Cover Forbs	50.91^{a}	15.89	61.47^{a}	12.87	47.88^{a}	22.27	29.19^{b}	10.99
% Cover Grass	35.18	20.01	23.86	5.89	24.11	15.17	45.00	23.75
% Cover Woody	0.00	0.00	0.00	0.00	4.44	8.08	0.00	0.00
% Bare ground	64.72	7.50	67.43	7.52	48.47	15.05	53.27	23.36
VOR	4.49^{a}	0.49	3.73^{ab}	0.45	3.08^{b}	0.67	0.58^{c}	0.11

Note: Means within rows followed by different letters were statistically different ($P<0.05$). VOR= visual obstruction reading.