Management implications for invertebrate assemblages in the Midwest American agricultural landscape

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Chapter 7

Enhancement of Linear Agricultural Areas for Invertebrates and Breeding Birds

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Abstract

Birds are an important part of the agricultural landscape, as having nature value, but also as pest control agents and bio-indicators for the health of the environment. Here we look at linear non-crop elements in agricultural areas as an opportunity to provide food for nestlings of avian species. We measured invertebrate availability as it relates to structural complexity at the local and landscape levels in three counties in central Illinois. Invertebrate availability was measured with taxonomic diversity and estimated biomass during spring of 2012 and 2013. Our study shows that field edge characteristics have the greatest impact on invertebrate diversity and abundance, as compared to field and landscape features. This finding shows that the availability of bird food, both in diversity and biomass, may be easily enhanced without changes to agricultural practices.

Keywords: agricultural landscape, birds, nestlings, taxonomic diversity, biomass, invertebrates

Introduction

In Illinois, as elsewhere, bird populations are changing with an overall decline in many species (Walk and Warwick, 2010), which has been related to loss of habitat due to agricultural intensification and increased urbanization of the landscape (Walk and Warwick, 2010). The use of pesticides may also play a role in avian declines (Geiger *et al.*, 2010). Agricultural intensification has the admirable goal of increasing production of food, feed, and fuel which is necessary to human life. At the same time, the loss of biodiversity and ecosystem services is a concern. In the United States, management for biodiversity has been with a focus on land sparing" (Phalan *et al.*, 2011; Grau *et al.*, 2013). This leaves isolated tracts to be managed for biodiversity and other areas focused on housing or agriculture. Many countries in Europe use a land sharing approach. This tactic uses a combination of landscape complexity and agricultural practices with a conservation approach to maximize biodiversity and ecosystem services and subsidize farmers for the subsequent loss in yield (Vickery *et al.*, 2004; Donald and Evans, 2006; Carvell *et al.*, 2007).

The landscape of Illinois has altered dramatically since initial settlement over two centuries ago. The General Land Office Survey (~1820) reported about two thirds of the landcover as prairie with the remainder forested (Anderson, 1970). Very little of the land was developed or cultivated. Settlement occurred moving from the south to the north with settlers coming from Tennessee and Kentucky. By 1920, 90% of Illinois was farmed with much of the population living in rural areas (Walk and Warwick, 2010). Cultivated ground was dominated by corn, and the remaining farmland a diverse mixture of hay, pasture and small grains (mostly oats). Most farms were small by today's standards, averaging 52 ha in size and most (> 90%) had both cattle and horses. Today farms have grown in size to an average of 149 ha (Walk and Warwick, 2010) with the fastest growing landuse type as developed (areas used for industrial, commercial, and residential purposes) (Walk and Warwick, 2010). The number of cattle and horses have dropped and with it the need for hay, pasture, and small grains. Row crops are dominated by corn and soy in a two to three-year rotation. Field size increased > 80% while the number of fields was about halved. Landuse will continue to shift in response to human needs and climate change.

Avian populations shifted along with the landuse. Idle grasslands, defined as not having been grazed, hayed or mowed in the year of the survey, declined from 1.8

million acres in the early 1900s to 1.2 million acres in the 2000s. Surprisingly the absolute abundance and species richness of birds in grasslands have increased during this time period (Walk and Warwick, 2010). What is less surprising is that the relative abundance of the species has undergone a major shift since the surveys conducted in the early 1900's with some species dropping from dominance while other species prospered with changing habitat availability. As field size increased and the amount of edge decreased, surveys of linear grasslands taken in the 2000s show a decline in both the absolute abundance and the number of species from surveys taken in the 1950s (Walk and Warwick, 2010).

Edges, i.e. the area between habitat patches, and their role as habitat for birds have been studied for decades (Ries *et al.*, 2004). Birds inhabiting this habitat are often generalists that can use the heavily disturbed areas (Walk and Warwick, 2010). Little is known about the distribution of invertebrates in agricultural field margins in the Midwest. The neglect of this ecologically important group is somewhat surprising considering the importance of invertebrates as food items for breeding birds and their nestlings. During the breeding season, the diet of many avian species shifts to include insects as a protein source (Bell, 1990; Cavitt and Thompson, 1997) and later to feed rapidly developing nestlings.

We looked at linear, non-crop elements in agricultural areas early in the avian breeding season to provide invertebrates to feed nestlings. We examined edge and field features and landscape characteristics to determine which had the greatest impact on invertebrate diversity and estimated biomass with the goal of providing guidance to improving invertebrate biodiversity and food availability for bird nestlings within the agricultural landscape. Studies have shown that invertebrate richness and abundance are influenced by complexity at the landscape scale (Steffan-Dewenter and Tscharntke, 2002; Batáry *et al.*, 2007), field characteristics (Westerman *et al.*, 2003; Marvier *et al.*, 2007) and edge characteristics (Stinner and House, 1990; Wilson *et al.*, 1999). We examined the hypotheses that invertebrates were dependent on these features independently or in combination or not dependent on any of these characteristics.

Methods

Study Area. The study was conducted in central Illinois in Cass, Christian and Sangamon Counties (Fig. 1). This is part of the Grand Prairie Natural Division, a vast plain of formerly tallgrass prairie (Schwegman, 1973). Soils are fertile and well drained with the use of tile lines and ditches. The topography is generally level to rolling. Illinois climate is typically continental with cold winter temperatures (mean -3.8°C), warm summers (24.6°C) and frequently fluctuating temperature, humidity, cloudiness and wind conditions. Precipitation averages 895 mm per year and the growing season is ~185 days (Midwestern Regional Climate Center 2009; Springfield, Illinois http:/mcc.sws.uiuc.edu). During both years of the study period, precipitation was much below normal. Due to the reduced precipitation and high ambient temperatures, the region was considered to be in an extreme drought (National Oceanic and Atmospheric Administration 2012).

Figure 1. Location of Cass, Sangamon and Christian counties in Illinois, USA.

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We selected 30 agricultural fields, ten in each of three Illinois counties, mostly seeded in a two to three-year corn (*Zea mays*) and soybean (*Glycine max*) rotation. The average field size was 28 ha varying between 1 and 117 ha. Structural complexity in the areas around the fields ranged from simple landscapes with a relatively high percentage of arable land, to complex landscapes with a relatively low percentage of arable land and a large proportion of semi-natural land cover and other land use types. We selected fields with varying degrees of edge structure ranging from closely mown monoculture through shrubby vegetation several m in height. Roadsides were managed with a variety of mowing regimes and some areas were impacted by drift of herbicides. We obtained permission to access the fields from either the land managers or landowners. Landowners or managers seeded field interiors with genetically modified corn or soybeans, prior to the start of the study.

Sampling Methods. From late May 26 to June 13 in 2011 and 2012, invertebrates were sampled with sticky boards, sweep netting, and pitfall trapping (Eymann, 2010). We selected this time period early in the breeding season to be comparable to other studies (Graber and Graber, 1963; Hendron, 2010) Sampling methods were chosen to sample varied invertebrate feeding styles (flying, gleaning, and epigeic). Sticky boards and pitfall traps were placed at six locations per field, grouped equidistant from the ends of the field and adjacent to the road or field edge; three in the cultivated field interior (FI) and three on the edge (FE) outside the tilled area and spaced at 10 m intervals. Sampling sites in the FI were 10-15 m from the edge in the second equipment row and not in the field head. Sites on the FE were 1-2 m from the FI and within the vegetated edge. Sweep netting was conducted only in the FE to avoid damage to the crops.

Pitfall traps were 150 ml plastic cups with an aperture of 70 mm placed into the ground so that the mouths were flush with the ground and was level with the ground surface. Each trap was filled to ~ 2.5 cm with a solution of water and vinegar and a few drops of dish soap added to break the surface tension of the water. Ethylene glycol was not used because it attracted mammals to the traps during a pilot study. Pitfall traps were retrieved seven days after placement and contents placed in a labeled clear Ziploc bag containing 70% isopropyl alcohol and kept for future identification.

One sticky board (Sensor ~ 8 cm x 13 cm Yellow Monitoring Cards, GrowSmart), attached to a flag (~ 6 cm X 9 cm X 76 cm LimeGlo, Forestry Suppliers) was placed adjacent to each pitfall trap. Boards were placed with a minimum of half the board above the vegetation. Boards were retrieved after two days and placed in a clear plastic cover and saved for future identification.

A sweep net sample consisted of 30 strokes, 360° around the sweep netter in the field edge near each of the pitfall traps for three samples total per field. The net was 15" in diameter with muslin netting (Forestry Suppliers). All sweep net samples were collected on sunny days between 10:00 am and 14:00 pm with wind 0-19 km/

hr as measured on the Beaufort scale. Invertebrates were placed in a "knockdown" jar containing chloroform soaked cotton for several minutes and then placed in a labeled clear plastic Ziploc bag containing 70% isopropyl alcohol and kept for future identification.

ArcView GIS 3.2 (Environmental Systems Research Institute, Inc., Redlands, CA, USA) was used on The Illinois Critical Trends Assessment landcover database (Luman *et al.*, 2009) to determine field area (ha), field edge length (m), average depth of edge (m), distance to nearest large non-agricultural area >1 ha (m), proportion of non-agricultural area at three different scales, and soil type. Field edge length was the length of the field edge adjacent to the sampling area. Complexity, i.e., proportion of non-agricultural area, was determined within a 1000 m circular plot around each sampling location. Arable land included corn, soybeans, other miscellaneous row crops, and winter wheat (*Triticum aestivum*). Non-arable land was defined as upland forest, savannah, coniferous forest, wet meadow, marsh, seasonally flooded, floodplain forest, swamp and shallow water.

Field locations were determined using a global positioning system (Garmin Oregon 450t). Each field was assigned a number designating specific sample location. Dates of trap placement, sample retrieval and sweep netting were recorded. Vegetation of the edge, field, and nearest neighboring field was also recorded. The height of vegetative edge was measured at 30 points along a transect between pitfall traps using a measuring stick.

Characteristics of the edges included the height and variability of the vegetation within the edge; the treatment of the edge: whether it had been mown since the start of the growing season or effected by herbicide drift; the depth and length of the edge; and the amount of bare ground (Kennedy *et al.*, 2009) around the sample location. Field characteristics included the crop in both the study field and adjacent field not separated by a hard surface, field size and length, and crop height and variation. Landscape features included soil type, the distance to the nearest non-arable space > than 1 ha; and the proportion of non-arable land to arable land within a 1000 m circle.

Identifications. A general overview of the bird species present was generated by noting species seen or heard during the period of time the investigators were in the field either preparing or retrieving invertebrate samples, around 20 minutes per location May 26 to June 13 in 2011 and 2012.

Invertebrates were examined using a binocular microscope. Ten percent of the samples were examined a second time as quality control. An independent investigator adjudicated any conflicting identifications. Numbers of invertebrates smaller than 2 mm were estimated. Invertebrates larger than 2 mm were identified to lowest operational taxonomic unit (OTU) which in most cases was family, using taxonomic keys (Triplehorn and Johnson, 2005) and reference collections housed at the Illinois State Museum Research and Collections Center (ISM RCC). Some invertebrates were identified to orders rather than family due to rarity, dominance of one family, or difficulty of identification. We used the reference collections to measure a random sample of ten invertebrates in each family, of the mostly commonly collected taxa in Illinois, to determine average length.

Data Analysis. All statistical analyses were performed using the package 'lme4' in R (version 3.0.2; The R Foundation for Statistical Computing 2013). We applied a generalized linear mixed models (GLMM) assuming a Poisson distribution. Response variables were taxonomic diversity (TD), and estimated biomass (WT). TD was the exponentially transformed Shannon Wiener H' ($e^{H'}$), making it Hill numbers of order 1 (Hill, 1973; Jost, 2007). This transformation was made to ensure TD had the correct statistical characteristics for analysis (Jost, 2007). WT was an estimate of dry weight (mg) based on average length (mm) (Rogers *et al.*, 1976).

Mathematical models were used to represent the various hypotheses of response variables and model fit used as a method of choosing the best hypothesis (or best working model) (Burnham and Anderson, 1998). The model-selection approach can help select among the numerous hypothesis that could not be tested using a single model approach. For the purpose of developing the models, we classified the predictor variables into three groups: 1) *edge*: edge vegetation height and variation, edge length and depth, amount of bare ground, and whether vegetation had been recently mown or exposed to herbicide drift; 2) *field*: crop in the field and adjacent field, area and length of the field, and height and variation of the crop; and 3) *landscape*: soil type, distance to the nearest non-arable land > 1 ha, and percent of non-arable land within a 1000 m circle around the sampling site.

We developed eight hypotheses regarding the response variable X, either TD or WT, being dependent on a combination of these three groups of predictor variables. The eight hypotheses are as follows: $H_{1:}$ X dependent on edges; H_2: X dependent on fields; H_3: X dependent on landscape; H_4: X dependent on edges and fields; H_5: X dependent on edges and landscape; H_6: X dependent on fields and landscape; H_7: Global Model: X dependent on edges, fields and landscape; and H_8: Null Model: X not dependent on either edges, fields or landscape.

Akaike's information criterion corrected for sample size (AICc) was used to compare models (Burnham *et al.*, 2011). Burnham and Anderson (1998) suggest that models having ΔAICc (difference in AICc scores) within 1–2 of the best model have substantial support. Models within about 4–7 of the best model have considerably less support, while models with ΔAICc > 10 have essentially no support.

Random factors were method of collection (sticky board, pitfall trap, and sweep net), and field within county within year of sampling. TD was rounded to be able to apply a Poisson family GLMM. In case of fitting the models of TD, we needed to add the identity of the sample (ID) as a random factor to the model in order to get a solution for the models. Although the variance component of ID was small, this could indicate that the error of the models was not completely Poisson distributed without the ID (Elston *et al.*, 2001). In these cases the actual distribution can be assumed to be a quasi-Poisson distribution. Data is reported as $\bar{x} \pm$ SE.

Results

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There were 890 samples collected by pitfall trap, sticky boards or sweep netting. We identified 155,460 specimens to 138 operational taxonomic units (OTUs). General invertebrate sampling results have been reported elsewhere (Evans *et al.*, 2016). Taxonomic diversity averaged 2.2 (1.0-15.3) ± 0.09. Biomass averaged 1155.0 mg (0.9-35720) ± 74.30.

For both TD and WT, our first hypothesis had the best fit: TD and WT dependent on edge features which included edge vegetation height and variation, edge length and depth, amount of bare ground, and whether vegetation had been recently mown or exposed to herbicide drift (Table 1). In edges, diversity remains almost constant as edge height increases. It increases as vegetation height variability, edge depth and percent of bare ground increases. It decreases as field length increases. In fields, as edge height and variability and percent of bare ground increase, diversity increases. As field length increases, diversity in the field increases. As edge depth increases, diversity in the fields decreases. In both fields and edges, as edge height and variability and percent of bare ground increased, biomass increased. As field length increased, biomass in the edges showed a slight decline and an increase in fields. As edge depth increased, biomass in the fields declined and in the edges increased. TD was slightly greater in the edges where there was no mowing or evident herbicide drift and treatment of the edges had no impact on the fields. WT was greatest in edges impacted by herbicide drift and least in areas that had been mown (Tables 2 and S1, Figures 2 and 3).

There were 19 bird species identified during sampling (Table 3). All birds were seen or heard at least five times in each of the counties in each year of sampling. We also report population trends, residence status, nest placement, number of broods per year, feeding habits and habitat preferences based on literature (Ehrlich *et al.*, 1988; Kleen *et al.*, 2004; Walk and Warwick, 2010).

Table 1. Comparison of the models for (a) taxonomic diversity (TD) and (b) estimated biomass (WT). $H_{1:}$ X dependent on local edges; H_2: X dependent on local agriculture; H_3: X dependent on landscape complexity; H_4: X dependent on local edge and local; agriculture; H_5: X dependent on local edge and landscape complexity; H_6: X dependent on local agriculture and landscape complexity; H_7: Global Model; H_8: Null Model. Df: degrees of freedom of the model; AICc: corrected AIC; Delta AICc: difference in AICc between the model and the model with the smallest AICc; AICcWt: model weight according to delta AICc; Cum. Wt: cumulative model weights; LL: Log Likelihood.

(a) TD

TD	Df	AICc	Delta AICc	AICcWt	Cum.Wt	LL
H_1	19	3571.09	0.00	0.98	0.98	-1766.11
H_3	31	3580.65	9.56	0.01	0.99	-1758.17
H_2	23	3581.28	10.19	0.01	1.00	-1767.00
H_5	45	3583.73	12.64	0.00	1.00	-1744.41
H_4	34	3586.77	15.68	0.00	1.00	-1757.99
H_6	49	3589.04	17.95	0.00	1.00	-1742.60
H_7	60	3598.09	27.00	0.00	1.00	-1734.63
H_8	4	3602.48	31.39	0.00	1.00	-1797.22

(b) WT

WT	Df	AICc	Delta AICc	AICcWt	Cum.Wt	LL
H_1	19	2928.34	0.00	1	1	-1444.73
H_3	31	2947.35	19.01	0	1	-1441.52
H_4	34	2948.13	19.79	0	1	-1438.67
H_8	4	2950.93	22.59	0	1	-1471.44
H_5	45	2956.96	28.62	0	1	-1431.03
H_2	23	2957.24	28.91	0	1	-1454.98
H_6	49	2976.58	48.24	0	1	-1436.37
H_7	60	2980.81	52.47	0	1	-1425.99

Table 2. Impact of individual variables in the fields and edges. Taxonomic diversity = (TD) and biomass = (WT).

Variable Increase	TD Edge	TD Field	WT Edge	WT Field
Edge Height	Decreased	Increased	Increased	Increased
Edge Variation	Increased	Increased	Increased	Increased
Edge Length	Decreased	Increased	Decreased	Increased
Edge Depth	Increased	Decreased	Increased	Decreased
Bare ground %	Increased	Increased	Increased	Increased
Treatment	Mown (least)	No Impact	Mown (least)	No Impact

Table 3. Birds seen or heard during sampling; population trends and life history compiled from literature. P/M: permanent or migratory; ag: agriculture. Nest location, number of broods, feeding habits, diet, and habitat (Ehrlich 1988), residence status and trend per year over the past 50 years (Kleen 2004); trends, diet and habitat (Walk 2011).

Species	*Latin name*	Trend per year	P/M	Nest location	Broods	Feeding habits	Diet	Habitat
Ring-necked pheasant	*Phasianus colchicus*	-2.0%	P	ground nest	1	ground glean	terrestrial and aquatic invertebrates, small vertebrates, seeds, grain, fruit	edge, ag, open country, woodlands
Northern bobwhite	*Colinus virginianus*	-1.9%	P	ground nest	1	ground glean	leaves, fruit, buds, tubers, spiders, snails, small vertebrates 85%veg 15% animals more insects in summer	hedgerows, tall grassland, old fields, woodlands, ag
Killdeer	*Charadrius vociferus*	8.1%	M	ground nest	1	ground glean	75% insects, remainder wide variety of invertebrates 2% weed seeds	gravel
Mourning dove	*Zenaida macroura*	0.5%	M	usually tree 0'-40'	multiple (2-6)	ground, foliage glean	seeds, including waste grain from cultivated fields > 99% of diet.	edge, ag
House wren	*Troglodytes aedon*	1.6%	M	cavity (snag) 0'-20'	2-3	ground, foliage glean	insects, including millipedes, spiders, snails	open woodland, shrubland, ag
American robin	*Turdus migratorius*	2.9%	M	tree or shrub 10-20'	2	ground, foliage, glean	insects, fruit	forest, woodland, gardens parks
Gray catbird	*Dumetella carolinensis*	0.7%	M	dense brush shrubland, edge 2'-10'	2	ground, foliage glean	insects, fruit, spiders, berries	dense brush
Brown thrasher	*Toxostoma rufum*	-0.9%	M	low shrub 0'-10'	2-3	ground, foliage glean	omnivore: insects invertebrates, small vertebrates, berries, fruit	dense brush, shrubland, edge
White-eyed vireo	*Vireo griseus*	-1.8%	M	dense brush 1'-8'	1-2	Foliage glean	insects during breeding season, 20-30% berries in winter	edge, ag, brushy moist areas near streams, old fields, scrub
Field sparrow	*Spizella pusilla*	-3.0%	M	sapling, shrub 0-2.5'	2-3	ground, foliage	insects, seeds, incl few spiders, seeds of forbs and grass	old fields, brush, edge, thorn scrub
Northern cardinal	*Cardinalis cardinalis*	0.6%	P	dense brush, sapling 1'-15'	multiple 2-4	ground glean	insects, seeds, fruit	dense shrubs, brush, thickets, riparian thickets
Blue grosbeak	*Guiraca caerulea*	1.7%	M	shrub 3'-12'	2	ground, foliage glean	insects, seeds, including snails, grain occasional fruit	dense brush
Indigo bunting	*Passerina cyanea*	-1.0%	M	tree, tangle 1.5-4'	2-3	foliage, ground glean	insects, seeds, fruit, including grain, berries	forest edge, woodland, old fields, shrub, orchards

American goldfinch	*Carduelis tristis*	-0.5%	M	shrub, forb 2'-40'	1-2	foliage, ground glean	seeds, insects, including seeds of deciduous trees, forbs, grass, floral buds, berries	weedy and cultivated fields, woodland, riparian edge
Song sparrow	*Melospiza melodia*	0.1%	M	shrub 0-3'	2-4	ground, foliage glean	insects, seeds, including grass and forb seeds, some berries, crustaceans and mollusks	early succession, dense veg riparian, forest edge
Red-winged blackbird	*Agelaius phoeniceus*	-0.3%	M	brush (wet), reeds	2-3	ground, foliage glean, hawks	insects, seeds, spiders, grass and forb seeds, rarely fruit	fresh water marshes, riparian edge, fields
Eastern meadowlark	*Sturnella magna*	-2.3%	M	ground nest	2	ground glean	insects, seeds, spiders, grass and forb seeds, some fruit	edge, ag, grassland savanna
Brown-Headed cowbird	*Molothrus ater*	1.1%	M	parasitic, shrub and ground	1-80 eggs	ground glean	insects, seeds, spiders, few snails, grain, grass and forb seeds	edge, ag, woodland forest edge, grassland
Dickcissel	*Spiza americana*	-3.5%	M	shrub, herbs 0-2'	1	ground glean	insects, seeds, younger birds 70% grain grass and forb seeds, 30% insects: adults is reverse	early succession, grasslands, meadows, savanna, cultivated and abandoned fields

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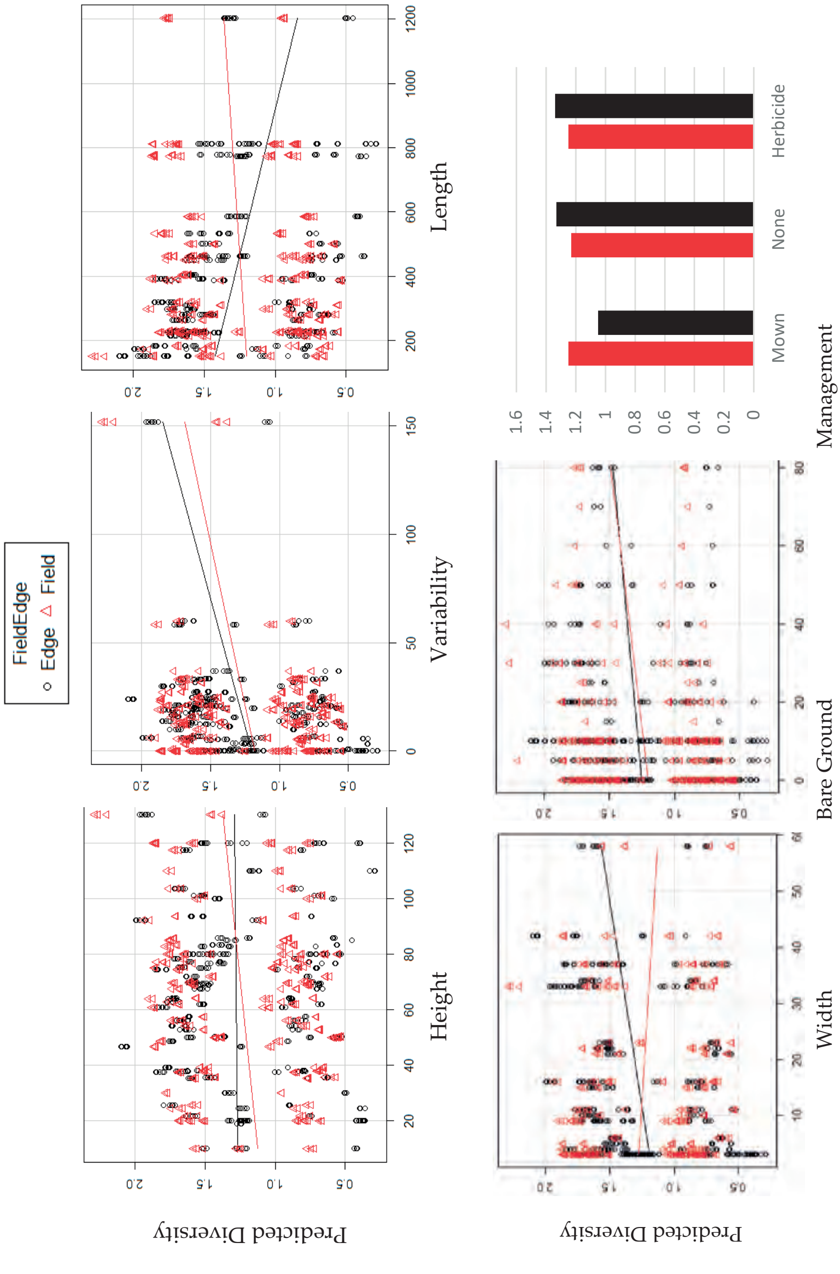

Figure 2. Diversity in fields and edges as predicted by each of the edge variables.

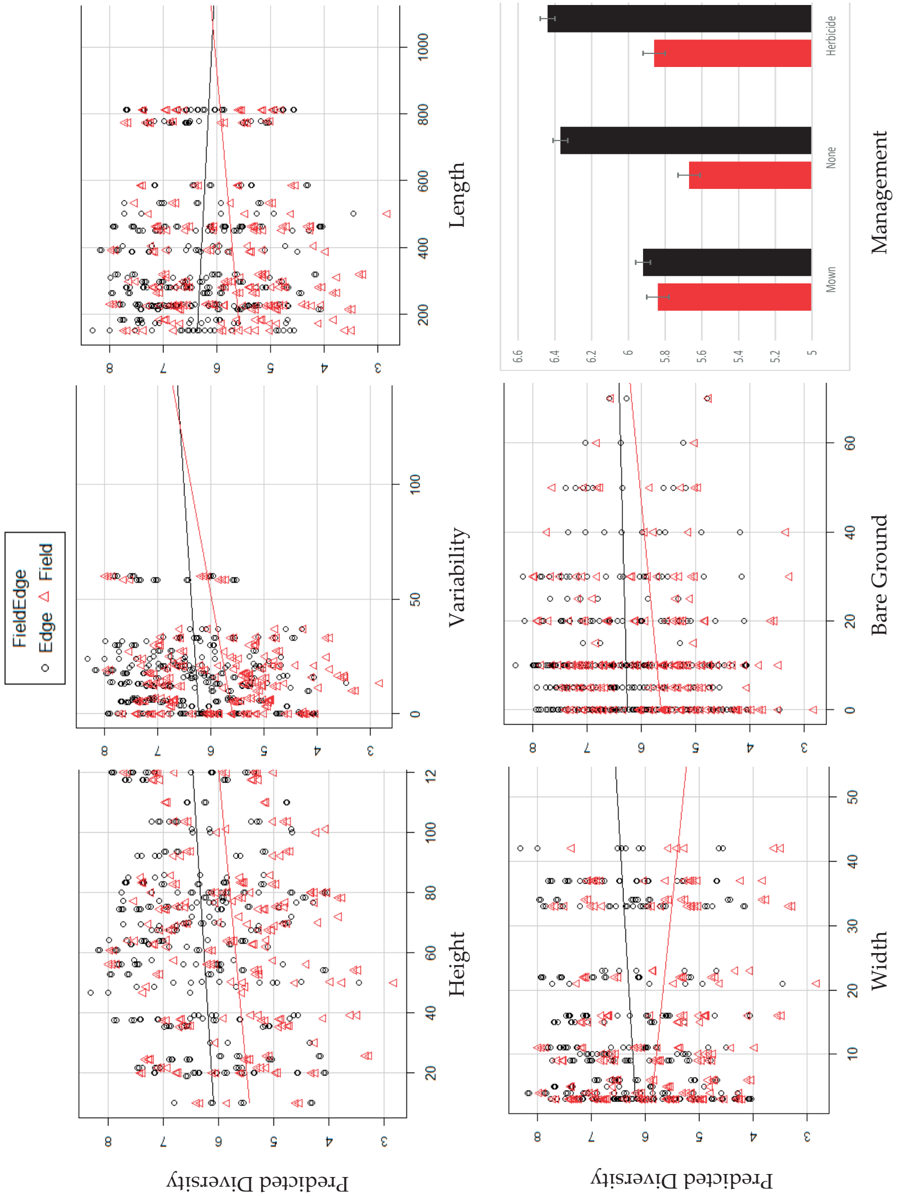

Figure 3. Biomass in fields and edges as predicted by each of the edge variables.

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Discussion

Our study shows that TD and WT are most impacted by features in the edges. The height and variability of the vegetation is a reflection of the vegetation diversity of the edge. It provides a number of niches for invertebrates to occupy (Noordijk *et al.*, 2010a; Kang *et al.*, 2013). Many edges in our study were planted in grasses and mown at some time either recently or possibly the end of the last growing season. In these cases, the vegetation was monoculture of uniform height. More varied vegetation height was generally found in edges that were not managed. Similar to other studies, as the biodiversity of the vegetation in the edges increased the biodiversity and biomass of the invertebrates increased as well (Scheffer *et al.*, 1984; Healy, 1985).

The length of the edges is related to field size and has been increasing over time. As the field length increases the TD and WT decline. As the length of the field increases so does the distance to the nearest non-tilled areas that serve as refugia or source populations in recovery after adverse events (Pryke and Samways, 2012).

As the depth of the edge increases TD and WT in the edges both increase. This could be from the lack of pesticide drift further from the agricultural field (de Snoo *et al.*, 1998; Frampton and Dorne, 2007) as well as less exposure to road pollutants (Muskett and Jones, 1980; Forman, 1998). This increases the area for occupation by invertebrates as well as provide more area for escape from predators.

The amount of bare ground has been shown to be directly related to TD as it was in our study. Mowing and removing clippings allows greater insolation and access to vegetation (Morris, 1981; Parr and Way, 1988; Noordijk *et al.*, 2010b).

Edges planted in grasses were sometimes managed with mowing. We noted if they had been mown since the start of the growing season. If the edges were mown, there was less WT in the fields. It is possible that they were more exposed to predation by having little to no place to hide or they moved to refugia immediately after the mowing event and had not repopulated the sampling site. Many invertebrates are susceptible to desiccation and might have left the sampling site if it was too hot and dry after mowing. The response to herbicide drift was interesting. Impact of herbicide drift mostly evident in areas with tall grass. The structure of the grasses remained in place with new growth under the upper layer of dead vegetation. This allowed for refugia from predation, access to the soil surface, and protection from excessive drying.

While the effects on invertebrate assemblages were predictable based on other research, it was interesting to note the effects on the fields did not parallel the effects in the edges. Invertebrates in the fields had a less strong reaction to the characteristics of the edge (Table 3).

Birds are an important part of the agricultural ecosystem. They consume many insects such as mosquitoes, Japanese beetles and European corn borer moths. Without birds, many of these insects would do considerably more damage to crops and spread diseases such as West Nile Virus. Birds are also bio-indicators of environmental pollution with DDT contamination being an extreme example (Temple and Wiens, 1989; Furness, 1993; Padoa-Schioppa *et al.*, 2006). The birds in our study are generally considered common with some species increasing and others decreasing over time (Table 4). Our bird observations were somewhat limited because the time of day we conducted our sampling for invertebrates was a time of day birds were not very active. The birds noted in our study is an indication of what birds might benefit from enhancing the agricultural edges.

A limiting factor of our study is that when measuring the availability of bird food during the breeding season the sampling is concurrent with bird predation. When insects are at low densities, the impact of bird predation is proportionately greater (Holmes *et al.*, 1979). We have looked at insect availability defined as abundance of potential prey items within the agricultural edge that has the potential for being used by a bird searching for food. Whether an available insect is actually eaten depends on factors outside the scope of this study such as its probability of being detected, its acceptability and its chances of being caught and eaten.

Our study supports the theory that increasing ecological contrast has the potential for the enhancement of both invertebrate and avian taxa (Hammers *et al.*, 2015). Birds use a variety of habitat components and the best configuration would be a matrix that had all needed components to fill life history needs (Leopold, 1970; Smith *et al.*, 2011). Here we show that edges features effect the diversity and biomass of potential food. Our study shows that the area outside the cultivated field has the potential for improving invertebrate diversity and abundance with minimal impact to the cultivated fields, and irrespective to factors in the surroundings. The characteristics of the field edges are such that they can be achieved by the simple act of not mowing. This has the advantage of not requiring monetary expenditures or additional effort by the landowners.

While management of linear agricultural areas to enhance local structure is easy to apply, there are some disadvantages. There is often social resistance to management of this type. Farmers like their fields to look manicured from the roads. There can be visibility issues from a traffic standpoint. There can also be increased bird fatalities from impact with vehicles. However, there are also side benefits such as reduced soil erosion, creation of pollinator habitats, and enhanced visual experience for the public. Land sharing with enhanced local edge structure has the potential of lessening the decline of those bird species that use the agricultural landscape. More study is needed to determine the impacts of edge management and how to overcome social resistance.

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Appendix

Models and summary tables for taxonomic diversity (TD) and biomass (WT). Variables included Location (FI or FE); average vegetation height (EdgeHt), variation in the vegetation height (EdgeSD), length of the field (Length), depth of the area between tilled area and roadway or next field (EdgeDepth), percentage of bare ground (Bareground), treatment of the edge (none, herbicide drift, mowing), and a correction factor for sample size (ln Abundance). Our random factors were method of collection (sticky board, pitfall trap, or sweep net) and field within county within year (RegionYearField).

a) TD~(FieldEdge * (EdgeHt + EdgeSD + Length + EdgeDepth + Bareground + Treatment)) + ln.Abundance + (1|RegionYearField) + (1|Method)

Taxonomic Diversity	Estimate	Std. Error	z value
Intercept (FI)	1.21E+00	2.73E-01	4.412
Location FE	4.65E-02	1.67E-01	0.278
EdgeHt	-3.89E-05	1.04E-03	-0.037
EdgeSD	9.90E-04	1.35E-03	0.736
Length	-3.01E-04	1.50E-04	-2.001
EdgeDepth	2.05E-03	2.31E-03	0.887
Bareground	1.13E-03	1.75E-03	0.645
TreatmentNone	2.54E-01	8.29E-02	3.062
TreatmentRU	1.89E-01	1.05E-01	1.804
ln.Abundance	-1.48E-02	1.67E-02	-0.888
FieldEdgeField:EdgeHt	1.80E-03	1.31E-03	1.372
FieldEdgeField:EdgeSD	2.74E-03	1.58E-03	1.735
FieldEdgeField:Length	4.88E-04	1.78E-04	2.740
FieldEdgeField:EdgeDepth	-4.48E-03	2.92E-03	-1.533
FieldEdgeField:Bareground	1.15E-03	2.36E-03	0.489
FieldEdgeField:TreatmentNone	-3.03E-01	1.06E-01	-2.863
FieldEdgeField:TreatmentRU	-2.24E-01	1.45E-01	-1.540

b) Wt ~ (FieldEdge * (EdgeHt + EdgeSD + Length + EdgeDepth + Bareground + Treatment)) + (1|RegionYearField) + (1|Method)

Weight	Estimate	Std. Error	z value
Intercept (FI)	5.77E+00	6.33E-01	9.120
Location FE	5.97E-02	3.64E-01	0.164
EdgeHt	3.68E-03	3.24E-03	1.136
EdgeSD	-6.84E-03	4.65E-03	-1.472
Length	-7.75E-05	5.12E-04	-0.151
EdgeDepth	6.47E-03	8.36E-03	0.773
Bareground	3.82E-03	4.78E-03	0.798
TreatmentNone	3.26E-01	2.45E-01	1.331
TreatmentRU	4.19E-01	3.12E-01	1.342
FieldEdgeField:EdgeHt	4.45E-04	2.90E-03	0.154
FieldEdgeField:EdgeSD	1.35E-02	4.10E-03	3.295
FieldEdgeField:Length	3.68E-04	3.97E-04	0.929
FieldEdgeField:EdgeDepth	-1.70E-02	6.49E-03	-2.622
FieldEdgeField:Bareground	2.82E-03	5.40E-03	0.523
FieldEdgeField:TreatmentNone	-7.27E-01	2.32E-01	-3.134
FieldEdgeField:TreatmentRU	-5.71E-01	3.25E-01	-1.754