Management implications for invertebrate assemblages in the Midwest American agricultural landscape

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Chapter 2

Comparing Roadside Management Treatments to Enhance Invertebrate Diversity

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Abstract

Roadside edges are an important part of the rural landscape that have the potential to contribute habitat for enhancing biodiversity. Roadside edges are generally managed with a variety of mowing regimes based on non-ecological objectives such as traffic safety, expense and aesthetic perceptions. We conducted a pilot study in rural Sangamon County, Illinois USA to compare the influence of roadside management regime on biodiversity along a roadside with neighboring fields planted in no-till agriculture or enrolled in a conservation program. We used sticky boards, pitfall traps and sweep netting to sample invertebrates on both the roadside and the neighboring fields. Three mowing regimes were applied to the roadside. Two of the management regimes are common in Illinois: mowing twice a year and regular mowing throughout the growing season, both leaving the clippings where they fall. The third regime was regular mowing and removing the clippings. Our study showed invertebrate richness was greatest in roadsides with regular mowing and clippings removed. When invertebrates were grouped as predators, parasites and parasitoids, omnivores, herbivores, flower visitors and detritivores, taxonomic richness remained highest in the area mowed with clippings removed, but abundance varied according to life history requirements of the invertebrates. Taxonomic diversity was not different between treatments. Our study indicates that small changes in management of roadside edges could increase invertebrate richness.

Keywords: biodiversity—central Illinois—invertebrates—mowing—removing clippings—taxonomic richness.

Biodiversity in the United States and Europe is declining as agricultural practices intensify (Stoate *et al.*, 2001; Stoate *et al.*, 2009; Hutchinson, 2011). Sustainable Development Goals have targeted biodiversity as a high priority in times of population growth and climate change (Sachs *et al.*, 2009; Griggs *et al.*, 2013). As invertebrates are the little things that run the world (Wilson, 1987) it is important to understand how management of many different habitats can enhance invertebrate biodiversity. Invertebrates are closely tied to vegetation composition and management (Sheridan *et al.*, 2008; Albrecht *et al.*, 2010). In the USA, studies often focus on stenotopic species, e.g., Lepidoptera: Hersperiidae (prairie skippers) (Schlicht and Orwig, 1992), Hemiptera: Auchenorrhyncha (prairie leafhoppers) (Hamilton, 2005; Wallner, *et al.*, 2012), and Hymenoptera: Apoidia (bees) (Slagle and Hendrix, 2009). Research in natural areas often focuses on the rare invertebrates associated with rare plants in the specialized habitat e.g. *Papiapena eryngii* and host plant *Eryngium yuccifolium* (Molano-Flores, 2001). Research in agricultural areas frequently focuses on pest species (Kogan and Kuhlman, 1982). Relatively few studies focus on invertebrate assemblages within roadsides in an agricultural landscape.

In the USA, financial incentives are provided to farmers to adopt environmentally friendly agricultural practices and take some land tracts out of agricultural production (Mausbach and Dedrick, 2004). These often-large tracts are believed to provide significant ecosystem services by reducing erosion in areas prone to losing topsoil, serving as flood storage and reducing chemical runoff into waterways (Ribaudo *et al.*, 2001). A host of smaller scale practices are also available to reduce agricultural contributions to pollution. These practices include riparian buffers, grass waterways and contour grass strips. Few of the smaller scale practices available are focused on biodiversity although attention to providing habitat for declining numbers of pollinators and other flower visitors is growing (Ries *et al.*, 2001; Potts *et al.*, 2010; Scheper *et al.*, 2013). European studies have led to management of roadsides for biodiversity in addition to safety-oriented objectives such as places to stop in emergencies, road maintenance staging areas and bikeways (Way, 1977).

Mowing regime is regarded as the most critical factor in roadside management (Parr and Way 1988, Noordijk *et al.*, 2009). Management of roadside edges has the potential to add linear connections between larger tracts of restored lands, dispersal corridors for wildlife moving through the landscape, and refugia for species unable to subsist on agricultural land (Bennett, 1991). Many invertebrates are dependent on the plants available in the environment, directly like flower visitors and herbivores, or indirectly like predators and parasitoids on herbivorous species. In this pilot study, we looked at the impact of agricultural roadside management, i.e., the mowing regime, on invertebrate diversity in the Midwest USA.

We asked three questions: 1) Does management of roadsides affect invertebrate taxonomic richness? 2) Does management of roadsides affect invertebrate taxonomic diversity? and 3) Does management of roadsides affect taxonomic richness and abundance within invertebrate functional groups? We compared three mowing regimes, two of which are common for roadsides in Illinois, USA while the third one is not. Based on studies in Europe, we expected the greatest taxonomic richness and diversity to be found in edges where clippings were removed, a practice not commonly followed in IL/US. This management technique removes biomass and keeps the vegetation nutrient-poor and species rich (Parr and Way, 1988). Invertebrates are closely tied to vegetation composition and management (Sheridan *et al*., 2008; Albrecht *et al*., 2010). In the Netherlands, for example, clippings are often baled and removed (Schaffers 2002a, b). Farmers in our area of study generally mow either twice per growing season or keep roadside edges quite short by mowing regularly, e.g., monthly in the growing season. Removal of roadside hay is not common. Our study area included a reduced tillage agricultural field and former agricultural field planted in native grasses and forbs separated by a narrow road with drainage ditches. This field is enrolled in the United States Department of Agriculture (USDA) Conservation Reserve Program (CRP) which makes payments to farmers in exchange for removing agricultural land from production and planting either trees or grassland species. We evaluated invertebrate diversity under three different mowing regimes to assess whether roadside management choice could be incorporated into practices that enhance local biodiversity. The three regimes we tested were 1) mowing twice per annum and leaving clippings, 2) mowing once ~ monthly and removing clippings; and 3) mowing ~ monthly and leaving clippings. Our hypothesis was that regime 2 would have greatest species richness and diversity followed by regime 1 and regime 3 having the least. Regime 1 has the greatest number of flowers and both regimes 1 and 3 have retained the nutrients of the clippings creating a nutrient-rich diversity-poor environment.

Materials and Methods

Study Area. The study area is located in Sangamon County in the state of Illinois, USA (39°45'23.34N, 89°28'22.34W). This is part of the Grand Prairie Natural Division (Schwegman 1973). The Grand Prairie was mostly tall-grass prairie with fertile soils developed from glacial outwash, lakebed sediments and deposited loess. It is currently modified for high yield agriculture. The topography is generally level to rolling with drainage improved by the use of tile lines and ditches. The local area has a high amount of land enrolled in CRP interspersed with agricultural fields almost exclusively sown in genetically modified corn or soybeans. For this investigation, we selected an area with row crops, CRP land, rural road and drainage ditches. This allowed control of some confounding variables such as historical roadside management, weather factors, and vegetation types. The CRP field had been sown in row crops for decades before being removed from agriculture and enrolled in CRP in 2001. The agricultural field has been managed as minimum tillage since 2001. Both fields are typical for the area. Our experimental site was a narrow oil and chip roadway (4 m) with vegetated edges including a drainage ditch (4 m) (Figure 1).

Figure 1. Photo of the study site

All plant species encountered were typical ruderal vegetation with a mix of native and introduced species. Of the latter, the dominant species were those typical of frequently mowed rural road sides: *Bromus inermis* (Hungarian brome), *Festuca arundinacea* (Common fescue), *Poa pratensis* (Kentucky bluegrass*), Plantago lanceolata* (Buckhorn plantain), *P. major* (Broadleaf plantain), *Achillea millefolium* (Yarrow), and *Taraxacum officinale* (Common dandelion). The native species, both herbaceous and woody, reflect the local floodplain community: e.g. *Leersia virginica* (White grass), *Celtis occidentalis* (Hackberry), *Morus rubra* (Mulberry), and *Urtica dioica* (Stinging nettle). Examples of this community remain nearby and may account for the surprisingly large number of species encountered in the roadside drainage ditches. Species distribution was often patchy and no species were dominant.

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 temperatures average 11.2°C. The growing season is ~185 days. (Midwestern Regional Climate Center 2009; Springfield, Illinois http:/mcc.sws.uiuc.edu). During the first year of the study (2012) precipitation was 300-400 mm below average (950.7 mm) and ambient temperatures were 2.4 °C higher than average. A wildfire burned the CRP field on July 27, 2012 after data collection for this study was complete for the season. During the second year of the study (2013) conditions in central Illinois were closer to average, with precipitation ~ 974 mm and ambient temperature was ~11°C (National Oceanic and Atmospheric Administration).

Treatment. The study was designed to test three roadsides treatments during the growing season: mow 2 times per season and leave clippings (M2); mow ~ once/month and remove clippings (M6 + R); and mow ~ once/month and leave the clippings (M6). Treatments were placed 20 m apart with 9 sampling points per treatment spaced 10 m apart. The treatment areas were 120 m with the first sampling site at 20 m which meant 40 m between samples in the different treatments (Figure 2). Each of the mowing treatments was tested on the roadside adjacent to the agricultural field and the CRP field. An equal number of samples was also collected within the CRP field and agricultural field. The agricultural field was managed under a minimum tillage, 2-yr soybean (*Glycine max*, seeded in 2012) – corn (*Zea mays* seeded in 2013) rotation. The drainage ditches received no management during the two-year study period and might have acted as a refuge for a variety of invertebrates during mowing of the roadsides or when crops were harvested from the fields.

Mowing was done with a tractor and 1.5 m brush hog (a type of rotary mower), both typical pieces of farm equipment in the USA. All areas were mown in April and September. Mowing of treatment areas M6 and M6 + R was conducted ~once/month throughout the summer. Treatment area M6 + R was raked the day after being mown. Mowing dates in 2012 were April 15, May 15, June 15, July 16, August 16, and September 12 and in 2013 were April 30, June 4, July 9, August 7 and September 16.

Sampling. Invertebrates were sampled with sticky boards and pitfall traps. Traps were set June 8, 2012, and June 16, 2013. We selected this time period to be comparable to other studies (Bedford and Usher, 1994; Hendron, 2010) and consistent between years. The trapping methods were chosen to sample varied groups of invertebrates (flying and epigeic). Sampling sites in the field interiors were ~ 15 m from the roadway. Sites on the roadside edge were 1-2 m from the drainage ditch and between the ditch and roadway (Figure 2).

Each sample site had a pitfall and sticky board. Sticky boards (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) were placed 10 m apart at the field edge parallel to the planting row. Boards were placed with ~½ above the vegetation. Boards were retrieved two days later and placed in a clear plastic cover for future identification.

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 there was no discontinuity between the edge of the trap and 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. Pitfall traps were retrieved seven days after placement and contents placed in a labeled clear Ziploc bag containing 70% isopropyl alcohol.

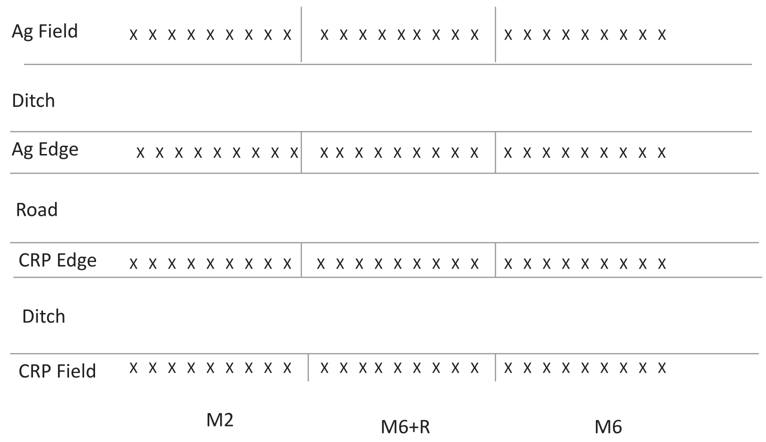

Figure 2. Sampling scheme (not drawn to scale) showing location of treatments and placement of sample locations in the agricultural (Ag) field, CRP field, and roadsides. The ditches are 4 m wide, the agriculture and CRP edges are 2 m wide and the road 4 m wide. X: address or sample site location. Sample locations are placed 10 m apart with 20 m between treatments. Treatment M2 is mowing twice per season, at the beginning and end of the growing season; treatment M6+R is mowing ~once per month and removing clippings, treatment M6 is mowing ~ once per month and leaving the clippings. The experimental area is 400 M long.

Arthropods were examined under a binocular microscope for identification. Ten percent of the samples were examined a second time as quality control. An independent expert adjudicated conflicting identifications. Numbers of arthropods smaller than 2 mm were estimated. Invertebrates larger than 2 mm were identified using taxonomic keys (Triplehorn and Johnson, 2005) and reference collections housed at the Illinois State Museum Research and Collections Center (ISM RCC). Identifications were made to lowest operational taxonomic unit (OTU) possible which in most cases was family. All OTUs were characterized to functional group (Table S1), i.e. herbivores, detritivores, flower visiting, omnivores, predators, parasites and parasitoids (Kaufman *et al.*, 2015; Evans, 2008).

Data Analysis. We used a block design in which the two edges are the blocks within which the mowing treatment was performed. The location of the treatment was selected to minimize the landscape gradient and not randomly selected. Sampling was done in two successive years at fixed sampling sites (addresses). We regarded the addresses as random sampling sites nested within locations within blocks. We applied linear mixed models for analyzing the data, in which address, year, and method are the random effect variables. Treatment (mowing regime) was the fixed effect variable. All our models were maximum random effect models, i.e., including the effects on both the intercept and the regression coefficient (Barr *et al.*, 2013). By applying a mixed effects model, samples can be regarded as corrected for the dependency that might have been introduced by the address, year or sampling method (Lazic 2010, Millar and Anderson 2004, Winter 2013). Our dependent variables were Taxonomic Richness (TR), i.e., the number of OTUs, and Taxonomic Diversity (TD), the exponentially transformed Shannon Weaver H', making it Hill numbers of order 1 (Hill, 1973; Jost, 2007). Residuals were checked in all analyses and were normally distributed for TR and TD and required log transformation when testing abundance. Data is reported as $\bar{x} \pm$ sd. For testing, we applied in all cases a Likelihood-Ratio Test (LRT, for more explanation see chapter 1 of this thesis). We performed the statistical analyses using R software 3.0.2 (R Development Core Team 2014), i.e., lmer () of the package lme4 (Bates and Maechler, 2010), version 1.1-7.

Results

Mowing regime had a significant effect on taxonomic richness (TR) with the monthly mowing and removing clippings treatment having the greatest TR followed by monthly mowing and mowing twice per season and leaving clippings. The LRT shows that the effect of treatment is significant (LRT: Chi Sq = 7.4013, df = 1, p = 0.02471) (Figure 3).

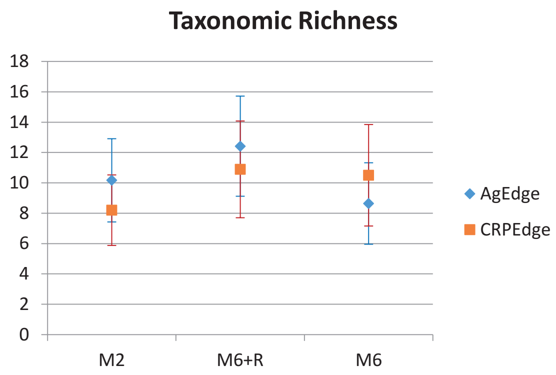

Figure 3. Average taxonomic richness (TR) per sample of roadside edges under three roadside treatments for study period. Treatment M2 is mowing twice per season, at the beginning and end of the growing season; treatment M6+R is mowing ~once per month and removing clippings, treatment M6 is mowing ~ once per month and leaving the clippings.

Taxonomic richness (TR), i.e., the number of OTUs, in the complete study area averaged 9.5 ± 3.1 (2 to 21) per sample (i.e. pitfall + sticky board at a single location) (Table 1). TR was higher in 2012 than in 2013 (10.4 vs 8.62; LRT: Chi Sq = 4.547; df = 1; p = 0.033; random variables: address and method, n = 432) and roadside edges had a higher average TR than fields but the difference was not significant (10.1 vs 8.8; LRT: Chi Sq = 1.602; df = 1; p = 0.206; random variables: address, method and year, n = 432). TR associated with agriculture (field and roadside) tended to be higher but not significantly different from the TR associated with CRP (9.6 vs 9.3; LRT: Chi Sq = 0.0621, df = 1, p = 0.803; random variables: address, method and year; n = 432).

Table 1. Average taxonomic richness (TR) and diversity (TD) (± sd) per location (n=54) for 2012 and 2013 and overall (n=216).

Complete study	TR		TD	
	2012	**2013**	**2012**	**2013**
Ag Edge	11.4 ± 3.1	9.4 ± 3.2	4.7 ± 2.0	4.4 ± 1.1
CRP Edge	11.1 ± 3.3	8.7 ± 2.6	4.6 ± 2.3	4.2 ± 1.1
Ag Field	8.6 ± 2.6	9.0 ± 2.0	4.9 ± 1.7	4.2 ± 1.6
CRP Field	10.3 ± 3.3	7.3 ± 2.7	4.9 ± 1.7	3.9 ± 1.3
All locations	10.4 ± 3.3	8.6 ± 2.8	4.8 ± 1.9	4.2 ± 1.3
Overall	9.5 ± 3.1		4.3 ± 1.7	

Mowing regime did not have a significant impact on taxonomic diversity (TD) (LRT: Chi Sq = 2.04037, df = 1, p = 0.3006; random variables: address and method, n=432). TD in the complete study area averaged 4.3 ± 1.7 (1.4 to 11.4) per sample (Table 1). TD was less in 2012 than in 2013 (4.8 vs 4.2; Table 1; LRT: Chi Sq = 14.19; df = 1; p < 0.001; random variables: address and method); TD in roadside edges was not different than fields (4.5 vs 4.5; LRT: Chi Sq = 0.0035; df = 1; p = 0.953; random variables: address, method and year, n = 432). TD associated with CRP was not significantly different from the TD associated with agriculture (4.4 vs 4.6; Chi Sq = 1.1255; df = 1; p = 0.289; random variables: address, method and year, n = 432).

Of the functional groups tested, only omnivores TR was significantly impacted with parasites trending toward significance (Figure 4). Omnivores had significantly different TR in treatment areas with M2 being greatest (LRT: Chi Sq = 6.4446; df = 1; p = 0.0399; random variables: address, method and year, n = 216). TR of omnivores averaged 2.0 (0 to 4) per sample. TR for parasites followed with an average of 1.2 (0 to 6) per sample. Parasite TR tended toward significance with treatment M6 + R being greatest (LRT: Chi Sq = 5.942; df = 1; p = 0.05125; random variables: address, method and year, n = 216). The remaining functional groups (detritivores, herbivores, flower visitors, predators) did not achieve statistical significance. Detritivore TR followed with an average of 1.7 (0 to 4) per sample (LRT: Chi Sq = 5.2032; df = 1; p = 0.07415; random variables; address, method and year, n = 216). This was followed by herbivores which averaged 3.1 (1 to 10) per sample (LRT: Chi Sq = 2.3131; df = 1; p = 0.3146; random variables; address, method and year, n = 216). The TR of flower visitors averaged 1.1 (1 to 4) per sample (LRT: Chi Sq = 0.9635; df = 1; p = 0.6177; random variables; address, method and year, n = 216). Predators averaged 2.4 (1 to 10) per sample (LRT: Chi Sq = 3.0852; df = 1; p = 0.2138; random variables; address, method and year, n = 216).

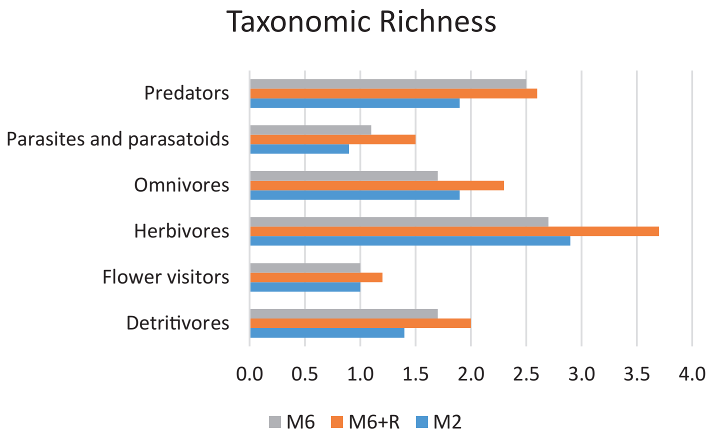

Figure 4. Taxonomic richness per sample within functional groups in each of the three treatments. Treatment M2 is mowing twice per season, at the beginning and end of the growing season; treatment M6+R is mowing ~once per month and removing clippings, treatment M6 is mowing ~ once per month and leaving the clippings. Omnivores; P = 0.0399, n = 216); parasites P = 0.05125, n = 216).

Abundance of individual detritivores was greatest (x̄= 51.3 individuals per sample) followed by omnivores (x̄ = 23.6), herbivores (x̄ = 15.5), predators (x̄ = 13.8), and parasites and parasitoids (x̄ = 4.8) (Table 2, Figure 5). Abundance was not significantly different in the three treatments (LRT: Chi Sq = 2.0554; df-1; p = 0.3578; random variables; address, method and year, n = 216). Most abundant taxa were Araneae; Isopoda; Collembola; Hemiptera: Cicadellidae and Aphidae; Coleoptera: Scarabaeidae, Mordellidae, and Curculionidae; Hymenoptera: Braconidae and Formicidae; and Diptera: Chironomidae, Culicidae, Mycetophilidae, Dolichopodidae, Muscidae, and Ulidiidae.

Table 2. Average abundance ± sd within functional groups of each of the three management treatments of the roadside edges (n=72) and overall (n=216). Treatment M2 is mowing twice per season, at the beginning and end of the growing season; treatment M6+R is mowing ~once per month and removing clippings, treatment M6 is mowing ~ once per month and leaving the clippings.

Treatment	M2	M6 + R	M6	Overall
Detritivores	37.8 ± 42.5	54.8 ± 40.6	61.3 ± 63.6	51.3 ± 50.8
Flower visitors	2.0 ± 2.6	2.1 ± 2.0	1.9 ± 2.5	2.0 ± 2.4
Herbivores	12.9 ± 15.2	19.5 ± 27.2	14.0 ± 13.8	15.5 ± 19.8
Omnivores	28.0 ± 39.3	23.7 ± 28.7	19.1 ± 25.1	23.6 ± 31.7
Parasites and Parasitoids	4.6 ± 5.9	5.7 ± 7.2	4.1 ± 4.4	4.8 ± 6.0
Predators	12.8 ± 43.0	9.5 ± 18.2	19.2 ± 43.1	13.4 ± 36.7

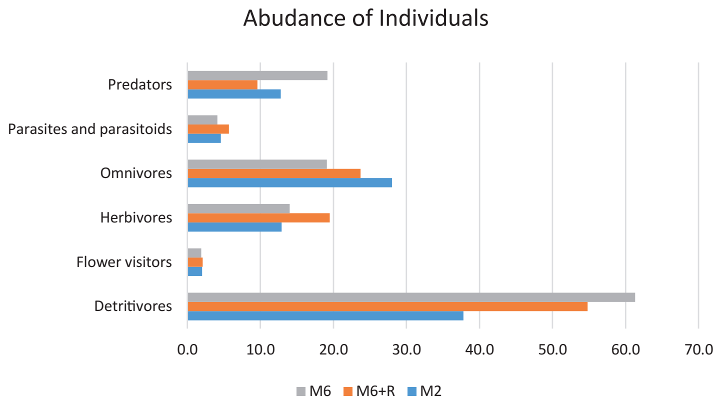

Figure 5. Average abundance per sample ± sd within functional groups in each of the three treatments. Treatment M2 is mowing twice per season, at the beginning and end of the growing season; treatment M6+R is mowing ~once per month and removing clippings, treatment M6 is mowing ~ once per month and leaving the clippings. Abundance was not significantly different between treatments.

In total, there were 98 OTUs sampled from both fields and roadside edges (Table S1). There were 43,366 individuals sampled from all sites over the two years of the study. There were 10 fewer OTUs in 2013 than in 2012. In contrast, 43% of the individuals were trapped in 2012 and 57% in 2013. Common taxa such as Heteroptera: Aphidae and Cicadellidae, Diptera: Muscidae, Hymenoptera: Braconidae and Isopoda became more abundant in the second year of sampling, while Lepidoptera and less common Diptera families dropped out of the samples. From the roadside edges 23,254 individuals were sampled over the two years of the study. There were 12 fewer OTUs in 2013 than in 2012. In contrast, 51.6% of the individuals were trapped in 2012 and 48.4% in 2013.

Discussion

Our study shows that taxonomic richness is affected by roadside treatment method and was greatest in the roadside edges that were mown regularly with clippings removed. Based on European studies, this was not unexpected (Morris, 1981; Parr and Way, 1988; Noordijk *et al*., 2009). In Spanish olive groves, removal of the natural cover below the olive trees resulted in higher abundance, family richness and dominance of epigeal beetles (Cotes, 2009). In the US, prescribed fire is a common method of removing biomass. This management technique is controversial in many areas. Of particular relevance to our study is the safety issue with smoke obscuring traffic visibility. Mowing has been shown to cause insect decline but of a shorter duration and less intensity than a similarly timed prescribed burn (Bulan and Barrett, 1971).

However, we also expected that mowing twice per year would provide similar habitat improvement for invertebrates as mowing and removing clippings. Mowing twice per year would provide a savings in money and manpower as well as having an aesthetic value. This did not prove to be the case in our study. Unfortunately, in this pilot study we were not able to test the regimen of mowing twice a year with removal of the clippings. This management type proved to be the most beneficial regimen for invertebrates in grasslands (Parr and Way 1988, Noordijk *et al*., 2009), although in low-productivity grasslands a less intensive regimen (mowing once a year with removal of hay) might be the most beneficial management type (Noordijk *et al*., 2010).

Differences in TR between the three management regimens in our study were small. This could be due to the short duration of our experiment and the fact that the sites were in close proximity. The vegetation in the study area was typical of many agricultural roadside edges and very dense. Vegetation grew quickly in the spring. When cut by the brush hog, it created a dense mat of non-living material. This was, in essence, a barrier that inhibited access to the ground surface as well as slowing new growth. We believe the area that was mown and had clippings removed allowed invertebrates access to new growth (for herbivorous insects, like the groups Hemiptera: Aphidae and Cicadellidae, and Orthoptera: Acrididae that were encountered abundantly), access to the ground for making nests and laying eggs e.g. Hymenoptera: Formicidae, and possibilities for ground dwelling species to receive warmth from the sun that allowed sufficient activity and the development of the juvenile stages in or on the ground e.g. Araneae; Coleoptera: Carabidae. On the other hand, some detritivores and hydrophilic invertebrates e.g. Gastropoda; Isopoda; and some Diptera apparently benefitted when the clippings were not removed.

The differences in TR and TD between treatments show the same pattern over the two years, although the effect of treatment on TR is significant while that on TD is not. It is also notable that TD shows no differences between roadside edges and fields, while TR does show differences. So, in our study area, TD as a measure of invertebrate biodiversity was less sensitive to treatment and differences between locations than TR. Diversity indices are not generally sensitive to species with low abundance while richness values give equal weight regardless of abundance (Magurran, 2004). We found no differences in abundance between treatments. This indicates that the differences we found in TR is because of the locally rare species found in the treatment area M6 + R rather than in increase in total abundance between treatments.

The landscape-moderated insurance hypothesis provides resiliency and stability of ecological processes in highly disturbed environments (Tscharntke, 2012). Redundancy theory suggests that the more redundancy the more an ecosystem can recover from disturbance (Naeem, 1997). In general, more species result in more stability (Naeem, 1998; Cardinale *et al.*, 2012). Different species do better under different conditions. When disruption occurs, it is likely that some species will do well and conserve the functional niche within the community. Maintaining invertebrate biodiversity can only be managed indirectly and the options for such management are not always clear (Brussaard, 2007). Until recently, the focus on invertebrate biodiversity within the agricultural landscape has mostly been on pest control (Bianchi, 2006). Loss of pollinators and impacts of neonicotinoids have drawn recent attention (e.g. Seagraves and Lundgren, 2012; Kielmanowicz *et al.,* 2015).

Our study shows that for most of the functional groups of invertebrates (detrivores, flower visitors, herbivores, parasites and parasitoids, and predators) enhancing the area between the edges of the agricultural fields and roads provides a biotope which is generally stable and increases taxonomic richness. TR was greatest in the M6 + R treated area, and this was fairly consistent across functional groups.

There was considerable difference in weather between years. The extreme drought conditions in 2012 probably affected survival and ultimately reproductive success the following year. Collections in 2012 were made early in the season before the drought had much of an impact. Water was available in the ditches and there was residual moisture in the soil. As the season progressed, the ditches dried and there was almost no rainfall during the reproductive season. The drought conditions carried over into the spring of 2013 when conditions returned to normal. Collections were made 24 days after the first mowing event in 2012 and 16 days in 2013. This difference in number of days after the mowing was related to vegetation growth. In 2012 there was little growth and in 2013 the growth was considerably richer. We attempted to collect at the same stage of vegetation growth in both years and still be consistent with collection dates. Although the weather conditions in both years was quite different, the effect of treatment was not different in the two years of our study.

This study was designed as a pilot study to provide information and guidance for a more elaborate future study. The study was initially designed with multiple sites. Permissions were obtained from the land owners and land managers who were different people, some of whom were located at some distance from the research sites. Within weeks of study initiation, the management protocols had been violated from a variety of sources and treatments. Some edges had been sprayed with herbicide and most had been mowed by well-intentioned neighbors or diligent township and county employees. This left us with the results of only two roadsides of one road that could be used for this study. So, the replication of our treatments is poor, which hinders strong conclusions and generalizations.

Summary and Conclusions

This study indicates potential for using roadside management to improve biodiversity. We belief that our results justify future research. However, issues exist that will need to be addressed before additional studies can be conducted. These same issues suggest that any change in mowing regimes will be difficult to implement within the existing agricultural culture.

A future study design should include four treatments: mowing 2X and leaving clippings, mowing 2X and removing clippings, mowing 6X and leaving clippings, and mowing 6X and removing clippings.

Any future research will need to address the issue of the involvement of well-intentioned neighbors or diligent township and county employees. Raking and removing clippings is labor intensive. Future studies should consider the use of mechanical bailing equipment. The limitations of this study are sufficiently great that it should not be considered applicable to roadsides in general and further study is indicated.

Acknowledgements
We would like to thank the landowners and land managers who graciously permitted access to their property for this study. This study would not have been possible without the assistance of D. Jostes. We are grateful to H. Eilers for his botanical survey. We thank A. Bartke for technical and editorial assistance. We are also grateful to S. Ebbing for his instant response to all library requests. All funds for this research came from a personal account.

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Table S1.

Abundance of individuals in 2012, 2013 and total abundance. Guilds are mostly detritivores (D), flower visitors (F), herbivores (H), omnivores (O), parasites and parasitoids (PA), predators (PR), or not feeding as adults (NA).

Taxa	2012	2013	Total	Guild
Class Oligochaeta: Earthworms	15	99	114	D
Class Gastropoda				
Snails	35	38	73	H
Slugs	4	9	13	H
Order Araneae: Spiders				PR
Linyphiidae: Sheet Web Spiders	85	22	107	PR
Lycosidae: Wolf Spiders	252	473	725	PR
Gnaphosidae: Parson Spiders	8	1	9	PR
Thomisidae: Crab Spiders	86	22	108	PR
Salticidae: Jumping Spiders	7	0	7	PR
Spider hatchlings	2424	510	2934	PR
Order Opiliones: Harvestmen	153	91	244	PR
Order Acari: Ticks	2	2	4	PA
Order Isopoda: Isopods				
Common Pillbugs	284	2415	2699	O
Order Diplopoda: Millipedes	45	14	59	D
Order Chilopoda: Centipedes	11	4	15	PR
Order Collembola: Springtails	3262	3120	6382	D
Order Orthoptera				
Acrididae: Grasshoppers	296	127	423	H
Gryllidae: Crickets	15	23	38	H
Order Phasmatodea: Walkingsticks				
Heteronemiidae: Stick Bugs	0	1	1	H
Order Blattaria: Cockroaches				
Blattidae: Cockroaches	0	1	1	O
Order Hemiptera:True Bugs				
Miridae: Plant Bugs	6	0	6	H
Anthocoridae: Minute Pirate Bugs	13	37	50	PR
Reduviidae : Assassin Bugs	11	4	15	PR
Lygaeidae: Seed Bugs	2	0	2	H
Largidae: Plant Bugs	7	7	14	H
Coreidae: Leaf-footed Bugs	2	0	2	H
Pentatomidae: Stink Bugs	4	2	6	H
Cicadellidae: Leafhoppers	663	1861	2524	H
Fulgoroidea: Plant Hoppers	3	28	31	H
Aphidae: Aphids	353	3702	4055	H
Order Thysanoptera: Thrips	26	0	26	H
Order Coleoptera: Beetles				
Cicindelidae: Tiger Beetles	1	9	10	PR
Carabidae: Ground Beetles	74	111	185	PR
Histeridae: Hister Beetles	2	4	6	PR

Taxa	2012	2013	Total	Guild
Silphidae: Carrion Beetles	5	3	8	D
Scaphidiidae: Shining Fungus Beetles	13	34	47	D
Staphylinidae: Rove Beetles	42	25	67	PR
Trogidae: Trox Beetles	16	31	47	D
Scarabaeidae: Scarab Beetles	360	146	506	H
Melolonthinae: June Bugs	1	1	2	H
Buprestidae: Jewel Beetles	1	0	1	H
Elateridae: Click Beetles	48	56	104	H
Phengodidae: Railroad Fireflies	2	1	3	PR
Lampyridae: Fireflies	4	2	6	PR
Cantharidae: Soldier Beetles	31	6	37	PR
Cleridae: Checkered Beetles	3117	10	27	PR
Nitidulidae: Sap Beetles	1	9	10	D
Erotylidae: Pleasing Fungus Beetles	2	0	2	D
Byturidae: Fruitworm Beetles	6	0	6	H
Coccinellidae: Lady Beetles	3	15	18	PR
Mordellidae: Tumbling Flower Beetles	146	128	274	F
Tenebrionidae: Darkling Beetles	1	1	2	H
Meloidae: Blister Beetles	1	0	1	H
Cerambycidae: Long-horned Beetles	3	0	3	H
Chrysomelidae: Leaf Beetles	41	34	75	H
Microrhopala vittata: Goldenrod Leaf Miners	0	2	2	H
Curculionidae: Weevils	72	51	123	H
Coleoptera larva ssp •	9	66	75	H
Order Neuroptera: Antlions, Lacewings	1	0	1	PR
Order Hymenoptera: Wasps, Bees, Ants				
Symphyta: Sawfly ssp	2	4	6	H
Ichneumonidae: Ichneumon Wasps	22	2	24	PA
Braconidae: Parasitic Wasps	145	784	929	PA
Chrysididae: Cuckoo Wasps	50	9	59	PA
Megachilidae: Resin Bees	59	8	67	F
Sphecidae: Thread-Waisted Wasps	1	0	1	F
Halictidae: Sweat Bees	54	9	63	F
Apidae: Bees	22	3	25	F
Bombus pensylvanicus: Bumble Bees	3	0	3	F
Mutillidae: Velvet Ants	3	1	4	PA
Vespidae: Hornets, Wasps	6	2	8	F
Formicidae: Ants	1823	1479	3302	O
Trichoptera: Caddisflies	19	7	26	NA
Lepidoptera: Butterflies and Moths				
Micro-lepidoptera ••	13	6	19	F
Hesperiidae: Skippers	33	2	35	F
Pieridae: Sulphurs	6	0	6	F
Lycaenidae: Coppers/Gossamers	14	0	14	F
Nymphalidae: Brush-footed Butterflies	3	0	3	F
Heliconinae: Fritillaries	3	0	3	F

Taxa	2012	2013	Total	Guild
Noctuidae: Owlet Moths	3	4	7	F
Lepidoptera larva ssp •	0	7	7	H
Order Diptera: Flies				
Tipulidae: Crane Flies	2	1	3	F
Chironomidae: Midges	91	142	233	NA
Culicidae: Mosquitoes	535	203	738	PA
Simuliidae: Black Flies	2	1	3	PA
Mycetophilidae: Fungus Gnats	5525	5410	10935	D
Tabanidae: Horse Flies, Deer Flies	1	1	2	PA
Dolichopodidae: Long-legged Flies	53	95	148	PR
Phoridae: Hump-backed Flies	52	1	53	O
Pipunculidae: Big-headed Flies	4	25	29	PA
Syrphidae: Flower Flies	31	40	71	F
Calliphoridae: Blow Flies	8	4	12	D
Tachinidae: Tachinid Flies	1	0	1	PA
Muscidae: House Flies	364	495	859	O
Sarcophagidae: Flesh Flies	14	28	42	O
Tephritidae: Fruit Flies	8	0	8	F
Ulidiidae: Picture-winged Flies	130	112	242	F
Diptera ssp •	1107	2647	3754	O
Diptera larva ssp •	44	313	357	O
	19239	25197	44436	

• Other species not identified due to damage of features or difficulty in identification

•• Small Lepidoptera of the Super Families Gelechioidea, Pyraloidea, Tiniodea, Gracillarioidea, Incurvarioidea, and Families Tortricidae and Pterophoridae