Management implications for invertebrate assemblages in the Midwest American agricultural landscape

Evans, T.R.

Author: Evans, Tracy
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Chapter 8

General Discussion

Introduction

The aim of this thesis was to look at common vegetation management techniques within the agricultural landscape and determine the impact on invertebrate assemblages and the associated food web. This discussion begins with an overview of the specific studies comprising this dissertation. I then relate our results to the established theories of biodiversity and management. Then I compare our results with the European experience on agri-environmental schemes and relate this to the discussion on sharing or sparing. I make management recommendations based on our results and discussions. Finally, I propose additional research questions.

Answers to Research Questions

Our research focused on answering the following questions:

1) **How does mowing regime of agricultural roadsides impact invertebrate assemblages (Table 1a)?**

The mowing experiment demonstrated that mowing and removing the clippings showed the greatest improvement in taxonomic richness as measured in the edges (Chapter 2). In the conservation set-aside (CRP) edge there was a +33% increase in taxonomic richness from the least effective treatment to mowing six times per growing season and removing clippings after mowing. In the agricultural edge, there was a +44% increase in taxonomic richness from the least effective treatment to mowing six times per season and removing clippings after mowing.

2) **How do extreme earth moving (removal of topsoil and re-contour of the land) and standard vegetation control treatments (mowing and prescribed fire) impact the invertebrate community in a newly created prairie restoration (Table 1b)?**

The prairie restoration in Bloomington Grove demonstrated that invertebrate assemblages do not necessarily follow the progress of vegetative prairie restoration (Chapter 3). A combination of vegetation controls was used after restructuring of the land contours. These included prescribed fire, mowing two times per growing season and leaving clippings and mowing two times per growing season and removing clippings. Invertebrate taxonomic richness declined as time post restoration increased. There was a 48% decline in taxonomic richness between two and five years post restoration.

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3) How does a mid-summer wildfire affect a grassland invertebrate community (Table 1c)?

We had two studies, one showing the immediate impact on Lepidoptera larva and the second study showing the long-term impacts to invertebrate assemblages over three growing seasons. The immediate period post fire was beneficial to some Lepidoptera species (Chapter 4). The flush of spring-like vegetation provided a rich environment for newly hatched larvae. Not all invertebrates responded positively and after the wildfire taxonomic richness of invertebrate assemblages in our study did not completely recover three growing seasons post fire (Chapter 5). At 0-3 months, there was an increase of taxonomic richness in the burned area of +16% over that in the unburned area which shifted to a deficit of -24% in the first growing season and -25% in the third growing season.

4) How do the invertebrate assemblages in agricultural fields and edges relate to local and landscape complexity (Table 1d-e)?

The landscape complexity study demonstrated that including complexity at the level of 1000 m into the models resulted in the best fitting models for taxonomic richness, however, the difference in taxonomic richness between low and high levels of complexity at the three landscape levels is less than 15%. The landscape in our study was relatively complex in terms of crop and non-crop areas with a range of 5-78%. At 6000 m, the difference in taxonomic richness between low and high complexity landscapes is +15%, at 1000 m is + 4% and at 500 m is + 2%. More interesting than the overall shift in complexity are the different responses to complexity in the edges and in the fields (Chapter 6). In the edges the difference in taxonomic richness from low to high complexity at 500 m is + 6%, at 1000 m is 15% and 6000 m + 34%. In the fields the difference from low to high complexity at 500 m is - 3%, at 1000 m is - 2% and at 6000 m is + 8%.

5) How does the invertebrate population relate to food availability, particularly for birds during the breeding season (Table 1f)?

The study measuring food availability for breeding birds (as measured by invertebrate biomass) is dependent on local factors such as edge vegetation height and variability, length and depth of the edge and the amount of bare ground rather than characteristics of the agricultural fields and complexity at the landscape level (Chapter 7). The factor with the greatest increase in biomass was vegetation variability on the edge with a + 61% increase from the least to the most variable.

Table 1. Management implications for average taxonomic richness (TR) or abundance of our studies.

a) Mowing experiment (Chapter 2). M2 = mowing two times per growing season and leaving clippings; M6+R = mowing 6 times and removing clippings, and M6 = mowing 6 times and leaving clippings. Ag = agriculture; CRP = Conservation Reserve Program.

Location	M2	M6+R	M6
Ag Edge TR	10.2	12.4	8.6
CRP Edge TR	8.2	10.9	10.5

b) Prairie restoration in Bloomington Grove (Chapter 3).

Time post-restoration	+ 2 yr	+ 4 yr	+ 5 yr
Average TR	11.7	8.6	7.9

c) The long-term fire study (Chapter 5).

Treatment	TR 0-3 months post-fire	TR second growing season	TR fourth growing season
Burned	7.9	6.5	7.7
Unburned	6.8	8.6	10.2

d) Field Edge study (Chapter 6) overall TR.

Complexity	TR at 6000 m	TR at 1000 m	TR at 500 m
< 20 %	9.4	10.1	10.1
>30%	10.8	10.5	10.3

e) TR (model including landscape) in the fields (Chapter 6).

Complexity	TR at 6000 m	TR at 1000 m	TR at 500 m
< 20 %	8.8	9.5	9.5
>30%	9.5	9.3	9.2

f) TR (model including landscape) in the edges (Chapter 6).

Complexity	TR at 6000 m	TR at 1000 m	TR at 500 m
< 20 %	9.0	9.9	10.4
>30%	12.1	11.4	11.0

g) Bird food study (Chapter 7). Measure of abundance.

	Lower quartile	Upper quartile	% food availability
Increase edge depth	1082	1192	+10.2%
Decrease length of field	1273	1134	+12.3%
Decrease field size	1026	1174	+12.6%
Increase edge variability	843	1358	+61.1%
Increase edge height	1160	1111	- 4.2%

Methodological issues

Taxonomic resolution and species traits. Because our studies were focused on increasing biodiversity in agricultural areas, the most important response variables in all our studies except the one focused on bird food, were taxonomic richness and diversity of arthropods. We would like to discuss two methodological issues. The number of arthropod individuals sampled in the body of studies numbered in the hundreds of thousands and most of these were identified to the taxonomic level of family. However, pitfall traps inadvertently collected more than the targeted arthropods. The author felt that these non-insect invertebrates were of interest as part of the assemblage, but was unable to identify them to family. In these cases, identification was by morphospecies (Oliver and Beattie, 1996) with the lowest taxonomic unit identified named as the operational taxonomic unit (OTU). Many individuals were quite common and could be easily identified to family. Adult arachnids were identified to family; however, the juveniles were not. This level of coarse resolution has acknowledged problems, including lack of standardization between phyla. On the other hand, if we had discarded these data, we might not have identified the lack of soil dwelling invertebrates in the prairie restoration. Soil dwelling fauna create structure for water infiltration, decompose surface litter, and enhance nutrient flow (Whiles and Charlton, 2006; Zaitsev *et al*., 2016). This information is important when planning prairie restoration or evaluating its success.

The distribution of the traits of the taxa within a sample or at a location are supposed to give information of the local ecosystem functioning (Webb *et al.* 2010; Violle *et al*., 2007; Mouillot *et al*., 2013). Species functional traits are most often used in aquatic ecosystems (Chevenet *et al*., 1994; Townsend and Hildrew, 1994; Ieromina *et al*., 2016). Functional traits have been proposed to act as filters to remove all species lacking a specific permutation of characteristics (Keddy, 1992). For this reason, some of our studies looked at the feeding guild of the sampled taxa (Chapters 2, 3 and 5). It enabled a more extended description of the results.

However, other traits might also have been informative as they relate to the agricultural environment and predict presence or absence after a specific management technique. Important traits to examine in relation to my study include, but are not limited to, dispersal ability and life stage. This type of research requires a priori determination of what characteristics are important in order to construct a trait matrix (Grime, 1974; Keddy, 1992). Placing the sampled individuals within a functional guild also presented problems though, and may not even be possible at the coarse taxonomic resolution of our studies. Additionally, functional traits within a family or even within a species is often dependent on life stage.

Lack of replicates. Because part of our study was done in given situations, as mentioned in the introduction, two of them had no replicates (the prairie restoration, Chapter 3, and the fire study, Chapters 4 & 5) and one had very limited replication (the mowing study, Chapter 2). This means that the effect of what in these studies are regarded as treatments (phases of prairie restoration, burned vs non-burned and mowing regimes) cannot be separated from the effect of the different locations of these treatments (Hurlbert, 1984). The results of these studies should therefore only be regarded as first indications of the effects of prairie restoration, burning and mowing on invertebrate assemblages.

Theoretical synthesis

We examined our empirical studies in light of the ecological theories presented in the introduction (Chapter 1). The theory of island biogeography applies most appropriately to natural areas surrounded by agriculture. To a lesser extent this theory could be applied to agricultural fields surrounded by urbanized areas and perhaps fragmented by roads. This theory was somewhat applicable to the prairie restoration examined in Chapter 3, where the prairie restoration site could be regarded as being an 'island' within an agricultural 'ocean'. The 'island' of prairie was created, as if a volcanic island, and in the process of awaiting arrival of appropriate species.

The general principles of metapopulation theory apply to individual species and their populations. Application of this theory is to spatially isolated members of the same species and includes both source-sink and patch dynamics. Our studies (except chapter 4) are focused at communities, not individual species. However, metapopulation theory, with its support of species occupation of unsuitable habitat, suggests that also the fields may play a role in the presence of viable populations of invertebrates in field edges, because they may be sinks that enable species to have a large populations size. The fact that we found relatively high taxonomic richness within the fields (Chapters 6 and 7) supports this idea.

Metacommunity paradigms do not necessarily require identification to species when taxonomic richness and diversity are the central focus of the study (Leibold *et al.*, 2004). The simple scheme of four key processes (selection, drift, speciation, and dispersal) presented by Vellend (2010) help us apply metacommunity theory to our studies. Coarse identification remains a limiting factor in all of our studies except the short-term fire study (Chapter 4). That being said, it is interesting to look at the patterns observed in our studies and try to use metacommunity theory for the interpretations of the results. Both selection and dispersal may be applicable to our studies with speciation and drift less applicable to the observed patterns.

Species composition and diversity are dependent on the regional pool of species. The importance of the surrounding landscape is most clearly confirmed in our study of the taxonomic richness and diversity of field edges and field interiors in different landscapes (Chapter 6). Most remarkable is that complexity seems to have a positive effect on field edges, but a negative on field interiors. If this can be supported by further study, it opens up possibilities for new management measures for conserving biodiversity at the landscape level. The actual effect of landscape complexity on taxonomic richness may not be large, but since it could be working in huge areas, the ultimate national effect could also be great. A consideration is that the complexity that exists in this landscape today is not original, but degraded from pre-settlement conditions. The complexity that exists in the agricultural areas of our study was in the form of forest. The prairie which once existed is no longer part of the landscape. However, for cultural reasons as well as traffic safety, the edges in our studies (Chapters 2, 6, and 7) may be more suitable to prairie vegetation rather than trees.

The importance of the surrounding landscape is not only shown in the studies of edges (Chapters 2, 6 and 7), but also in the Bloomington Grove study (Chapter 3). The substrate was taken to bedrock and the vegetation was restored. But the colonization of ground and soil invertebrates seems problematic and is in line with island theory that says that the size of the restoration patch and the distance from intact prairie may require a great deal of time if it ever occurs. In this study, the lack of a ground and soil dwelling species pool from which to draw appropriate assemblages may have had an important role.

Land managers continue in their belief that "if you build it, they will come" (modified quote from the film Field of Dreams). This rationale does not acknowledge the need for a source population. Our study of the prairie restoration is an example of this belief. "It" was built but there was no appropriate place from which "they" could come: the only place for soil invertebrates to emigrate from was agricultural fields. Prairies once covered 61% of the Illinois landscape (CTAP 2001). Only 930 ha of high quality prairie which is about 0.01% of the pre-settlement acreage remains (CTAP 2001). Remnant prairies are generally located in places inaccessible to farm implements or in pioneer cemeteries with minimal disturbance (Taylor et al. 2009). The nearest intact prairie to the Bloomington Grove site is a 2-ha cemetery prairie 40 km to the northeast (against prevailing winds). The vegetation is similar to the restoration site. Common grasses include big bluestem, little bluestem, prairie dropseed and Indian grass. Typical prairie forbs include shooting star, prairie gentian, compass plant and wood betony. Management practices on both sites are similar and include prescribed burning and exotic species control.

Dispersal and lack thereof are also extremely important within the agricultural landscape. Recent studies have shown that flying invertebrates may not always suffer from landscape fragmentation and isolation (Tscharntke et al., 2002; De Bie et al., 2012). This is confirmed in our study of the immediate effects of a wild fire (Chapter 4), where it was shown that some butterflies are capable of immediately finding new vegetation that can be eaten by their larvae. However, plants are known to have troubles with colonization (Blomqvist et al., 2003; Ozinga et al., 2009; Evju et al., 2015) so that vegetation recovers slowly, which might be the main reason for the slow recovery of the invertebrate community after the wild fire (Chapter 5).

Selection of species is dependent on adaptation to the specific characteristics of the landscape both at the local and regional scale. Local factors showed to be important in the mowing study (Chapter 2) and the study of bird food (Chapter 7). This relates to the hypothesis of "ecological contrast" (Kleijn et al., 2011). The effects of conservation or restoration efforts are expected to be greater as the ecological contrast increases (Batáry et al., 2015). In our studies of edges (Chapters 2, 6, and 7), the edges were generally narrow and there was small ecological contrast between edges but greater contrast between fields and edges. In addition, the "natural areas" in our study were not remnant habitats from pre-settlement times. Rather they were mostly converted from farmland. Based on this information, predictions made using the ecological contrast theory would be that improvement in biodiversity or bird food availability would be small, as we found in our studies. Increased arthropod richness is predicted where there is increased local structure (Evans, 1988; Tscharntke and Greiler, 1995; Dennis et al., 1998). Our bird food study (Chapter 7) demonstrates that edge structure is the best way to provide this life history requirement.

Biodiversity Conservation

The agricultural landscape provides food, fuel and fiber; regulates ecosystem processes; and it provides habitat and cultural services for human physical and mental wellbeing (Cardinale et al., 2012). Moreover, it provides opportunity for biodiversity conservation. It is important to separate conservation initiatives targeted at rare species and protection of high quality natural areas from initiatives focused on the agricultural landscape with its high human impact. Studies have repeatedly shown that conserving what is left is more effective than trying to retrieve what has been lost (Matson and Vitousek, 2006). Our studies are directed to the areas of high commodity production rather than pristine natural areas.

Many ecologists believe that preservation of biodiversity has the consequence of preserving ecosystem services as well (de Groot et al., 2014; Jax and Heink, 2015). However, the complex interactions of both biotic and abiotic factors in preserving ecosystem services thru biodiversity are not clearly understood (Van Oudenhoven et al., 2012; de Groot et al., 2014). Scales of observation range from microbes (Van Der Heijden et al., 2008; Fierer et al., 2013) to landscapes (Tscharntke et al., 2005) and milliseconds (Vincent et al., 2012) to epochs (Behrens et al., 2014). Research has shown mixed effects with response effects dependent on complexity and management of the surrounding landscape at various levels (Burel et al., 1998; Kleijn et al., 2009; Batáry et al., 2015; Cormont et al., 2016).

Conservation initiatives are most effective when targeted to specific taxonomic groups or ecosystem services (Cormont et al., 2016). Conservation initiatives within the American Midwest agricultural landscape should be focused on keeping landscape complexity and ecosystem services such as crop pollination (Kremen et al., 2007; Potts et al., 2010) or pest control (Bauer et al., 2015; Letourneau et al., 2015). In keeping with the above research, there are underutilized parts of the agricultural matrix that may be managed to enhance biodiversity (Chapters 2, 6, and 7). This does not necessarily mean restoration to an earlier vegetative state but could in fact be a “novel” ecosystems (Hobbs et al., 2009; Morse et al., 2014). Highly disturbed ecosystems respond with changes in species composition and ecosystem function (Chapters 4 and 5). Restoration of disturbed ecosystems to a past state may be very difficult (Chapter 3), if not impossible, as well as very expensive (Palmer et al., 2014). Ecosystems are dynamic and change naturally over time (Friend et al., 2014). Choosing a single reference point in time requires extensive documentation of both biotic and abiotic factors that may not exist (Higgs et al., 2014).

Often goals that favor conservation are in opposition to those that favor economic interests of the farmer. It is important to find a means of balancing these objectives. There is high potential for meeting the objectives of both interests utilizing financial incentives for providing ecological services on agricultural lands. The answer of what scale meets the requirement of the ecosystem service should determine how conservation initiatives should be distributed in order to safeguard the service. Building redundancy into the system will allow for different species performing the same function at differing scales to be protected, thus enhancing system resilience (Tscharntke et al., 2012). Our studies show a way to meet these objectives using existing management techniques with little to no impact on the agricultural fields.

Sharing or sparing; farming in the Midwest US and western Europe

There is a movement in the US that recognizes the need for an agricultural ecosystem that is more sustainable than at present (NRC, 1989). In general, this requires stepping back from intensification, or in other words ‘land sharing’. Evaluation of which practices provide the most benefit for the least amount of money is part of this process. Encouraging practices that provide limited benefits and costly trade-offs are difficult to justify both in Europe and the US. This body of research did not look at in-field practices that are found in western Europe, although European research would allow us to apply the practices that have been found to work the best.

In the EU, the typical sharing approach of agri-environmental schemes (AES) has been in place for a sufficient period of time to determine effectiveness. Biodiversity continues to decline despite implementation of AES (Kleijn *et al.*, 2011). A meta-analysis of published studies concluded that conservation management should be adapted to the structure of the landscape and targeted taxa (Batáry *et al.*, 2016).

Ecological contrast may be an important factor in evaluation of effectiveness (Kleijn *et al.*, 2011). To justify conservation expenditures, the cost benefit ratio should be part of the practice evaluation (Ansel, 2016). The mixed results of the EU indicate that the EU does not yet have the answer to the question "How do we stop the trend of biodiversity decline?" It is imperative that we keep looking for the answer (Edwards and Abivardi, 1998).

It is important to note that the area of my study is among the top counties in agricultural yield in the state (USDA, 2015) and 33% higher than the national average (USDA, 2016). Specific research sites were in areas of high vegetative complexity mostly created by reclamation of previously farmed land. There were few, if any, untouched natural areas within my study area. The land sparing philosophy is most successful with intact ecosystems, rather than recovered/restored land (Law and Wilson, 2015). The area of our study is one of high yield within a degraded landscape with a small proportion of land 'spared'. I suggest management actions could improve biodiversity with the addition of 'sharing' philosophies to the existing 'sparing' philosophy of the Midwest (Law and Wilson, 2015).

In a free market economy, as yield increases, prices of crops drop, forcing farmers to increase acreage farmed in order to maintain income. This loss of income, derived from economic markets is not generally subsidized. Thus, land that could be freed for restoration may continue to be farmed. Alternatively, this economic loss may provide the incentive to place marginally producing farmland into set-asides as a means of providing predictable income. The limitation of these programs is that the farmers often want assurances that they can withdraw from the programs when commodity prices rise.

There are several existing examples from the US of sharing oriented measures. Growing multiple crops in rotation is one of them and has multiple benefits such as slowing the development of weed and pest resistance and putting nitrogen back into the soil (Kremen and Miles, 2012). Whether or not this reduces yield in light of the future expense of remediation is in question (Kremen and Miles, 2012). Another example is genetically modified crops that are dominant in the US. Many protesters are concerned that ingesting GM products may be harmful to human health. Studies have not found any detrimental effects (James, 2003; Johnson et al., 2007). The benefits of increased yield and pest resistance are well documented (James 2003).

However, the impact of chemical inputs on the soil microbiota and surrounding environment is questionable (Sanchez-Bayo, 2014). Pollinator decline is an issue of great concern both in Europe and the US and may have different proximate causes on the two continents (Biesmeijer *et al.*, 2006; Cameron et al., 2011).

In Chapter 1, I indicated how agricultural history and practices in the US and Europe are different. They are similar with the push to increase productivity and efficiency and with opposing needs to preserve ecosystem function and biodiversity. Differences in prevalence of GM crops, livestock husbandry, landscape complexity with its associated matrix, and use of fire as a management tool, created the question of generalizability of research across continents. That being acknowledged, biological processes are obviously the same on both continents. In my view, it may be necessary for the US and EU to both "share" and "spare" whenever possible. My research points toward low cost measures to reduce the loss caused by management practices within the local landscape. However, my experiences while conducting this research, indicated that implementing any practice, will require active involvement of all of the stakeholders (Landis, 2016).

Recommendations for effective management

Continued loss of invertebrate abundance and diversity will eventually be detrimental to the agricultural ecosystem. Europe implemented a variety of practices with the hope and expectation of stemming the losses. Mixed results have caused the public and various governmental entities to question the expenditures. Yet the alternative of doing nothing is not viable. A suite of practices to improve invertebrate conservation dependent on acceptance by the local residents may help stem the losses. As studies in the EU have shown, gaining cultural acceptance is a large part of battle.

My studies show that practices should consider invertebrates as part of the planning process. Practitioners of pre-scribed fire are focused on the management of vegetation. Urban housing developments are focused on visual appeal as well as water catchment. Mowing is the concern of everyone. And of primary importance is the goal to keep the complexity that currently exists, because one it is gone, it is difficult to get it back.

My results are first indications and not strong enough to make policy recommendations. They will probably not grab the attention of the media. Implementation is unlikely at this point. However, getting my research published is a first step to drawing attention to management possibilities within the agricultural ecosystem.

Roadsides. The convenient access to roadsides makes a change in management regimes an easy ecological target. An increase in vegetation structural complexity creates habitat that meets the needs of both invertebrates and birds. The difficulties with this option are both political and cultural. During our studies, we found multiple jurisdictions responsible for mowing within the same field edge. Changes to roadside management would require voluntary changes to behavior of both farmers and managers of rural roadsides. One important rationale for mowing was visibility for traffic safety. In addition, the landowner frequently engaged in what is locally termed "recreational mowing". Many landowners enjoy seeing neatly mown edges. They explained that this demonstrates responsible farming practices; i.e. short vegetated edges and no weeds in the fields. Enhancing biodiversity is a motive unlikely to cause a shift in mowing regimes. Changing these viewpoints may be a challenge.

Recommendations:

- Landowners could be offered financial support for creating structure with wildlife friendly bushes and forbs. A simple mower or tractor attachment to catch clippings would allow removal of organic material. Mowing could be done as needed or in a more complex mosaic of mowing regimes. Setting the mower height high would keep the vegetation from scorching in hot dry periods during the summer.
- A management plan could be developed by those departments responsible for roadside management. It could allow for adaptive changes in response to the citizen feedback and safety considerations. A variety of mowing regimes could be considered to provide flexibility rather than a "one size fits all" approach.
- Non-native plants could be replaced with natives as funds or local sponsors become available. A priority list to get the most benefit to the

landscape context could be developed. Getting local environmental groups involved provides "buy-in" and assistance in maintenance. There are programs in many local areas that remove litter.
- An educational promotion of direct benefits to the farmer of enhancing pollinators and natural enemies of pest species would facilitate change of the social culture in the agricultural community.

Prairie Restoration. A return to prairie vegetation may be a more complicated transition than we realize. After decades of agricultural use the soils have changed in response to disturbance and chemical input. We can plant the appropriate prairie vegetation and have a visually perfect landscape. However, it is also important to have the correct soil structure. This is an essential component of the system which allows for uptake of water and nutrients. Research has shown the impact of earthworms on local ecology (Jones *et al.*, 1994; Edwards, 2004). In the Midwestern United States, earthworms disappeared during the last glacial episode 10,000 years ago (Reynolds and Wetzel, 2004). This would indicate that our prairie flora evolved in tandem with migration of soil fauna. The prairie restoration in our study seemed depauperate of soil inhabiting invertebrates.

Recently there has been an increased interest in pollinators with a focus on the decline of the European honeybee. We know that reproduction of some plant species depends on having appropriate pollinators which may be specialists specific to certain plants. Often, however, we do not know which pollinator is specific to the plant in question. In our study, we saw a decline in the taxonomic richness as the prairie vegetation became better established. This might indicate a mismatch between common invertebrates and the newly established prairie vegetation. Sustainability of the prairie vegetation may require specialist invertebrates that cannot reach the newly established prairie without human translocation efforts.

Recommendations:

- Fire and mowing are both excellent methods of getting prairie vegetation established. This allows an extensive root system to become established before the upper structure. The prairie restoration in our study used a combination of mowing and fire as vegetation management.

- Once vegetation is established, invertebrates could be inventoried with particular attention paid to the trophic guilds and available niches and translocated from existing grasslands if necessary.
- After vegetation establishment fire, could be low intensity and used sparely. Mowing or short term grazing could be used as a viable alternative. Refugia in the form of exclosures could always be provided.

Prescribed Fire. The wildfire on one of our study sites presented an opportunity to document invertebrate assemblages after a fire which may have mimicked historic conditions. A meta-analysis of wildfire research showed a lack of publication for reasons including study design flaws (Zaitsev *et al*., 2016). This study suffered from the same lack of replication as similar wildfire studies and may be a contributing factor to the “file drawer” effect (Zaitsev *et al*., 2016). We attempted to compensate for design flaws with robust statistical design (Winter, 2013; Anderson, 2007).

During the immediate period post fire, we documented an increase in Lepidoptera larva in response to the new lush vegetation (Chapter 4). Later collections documented a failure to reach the same diversity and abundance as in the unburned area (Chapter 5). This is similar to some other studies and contrary to others. We simply do not know enough about invertebrate assemblages and their responses to fire to continue as we have to burn without consideration of this important ecological group.

Changing the way, we conduct prescribed burns will require some effort. There are difficulties with changing attitudes fire management. Often prescribed fire is “sold” to governing entities as “fuel load reduction”. Leaving fuel unburned is contrary to the state purpose of the fire. Some managers are paid by the “number of acres burned”. Leaving areas unburned reduces the paycheck. Often the biologists requesting the fire are not part of the technical crew implementing the fire. Convincing non-biologists to leave areas unburned to save invertebrates may seem inane.

Recommendations:

- Fire could be prescribed to leave areas unburned either through exclosures or under such conditions that not all areas are burned. This could also be through a mosaic of fire rotation. Patch Mosaic

Burning should be carefully evaluated before instituting (Parr and Anderson, 2006)

- Fire interval could be increased with hand removal of undesirable plants during the interim.
- All fire plans could have built into them the concept of refugia for both plants and animals including invertebrates.

Spatial complexity at local or landscape scales. The overriding theme to all of our studies revolves around complexity at both the local and landscape scale. We examined specific vegetation management techniques in the context of how best to maintain or improve invertebrate taxonomic richness and abundance. Our studies support the proposition "land sparing" and preserving what complexity we have is important (Landis, 2016). But we have also shown the benefits of "land sharing". The land shared offers numerous opportunities for enhancement of invertebrate richness and abundance. Conservation initiatives are generally more effective with off-field practices (Batáry *et al.*, 2015). Off-field practices would probably have easier acceptance by the farming community. Gradually, the expansion of the area encompassed by off-field practices could be introduced. Unless there is a particular rare or endangered species conservation measures should be general, inexpensive and easy to implement.

Recommendations:

- Edges could be planted and maintained to enhance structurally complexity. Our studies show a benefit to both invertebrates and avian species. Presumably the structure would enhance habitat for other species as well.
- Existing waterways and riparian areas could also be planted and maintained to enhance structural complexity. Expansion of these practices could be inexpensive by allowing natural vegetative succession to occur which would allow associated fauna to follow.
- Ecosystem services could become the theme of conservation measures within the agricultural landscape. Reduction of chemical input and run-off, decreasing soil erosion, enhancement of wild pollinators are all services which would enhance invertebrate biodiversity.

Recommendations for further research

Needs for agricultural products will continue to grow as we provide food, fuel and fiber to a growing world population. The balancing act between increased production and reduced impact will remain important. Ecosystem services and biodiversity are central to maintaining health and life. There is much that is unknown about the agricultural landscape. Our studies were limited in scope and further research is needed. The most important conclusion of our research is that management takes place within the larger context of the ecosystem and is more nuanced than we understood. Research questions arising from our studies include 1) Does translocation of invertebrates with limited mobility help repopulate an area after habitat destruction caused by topsoil removal or fire?; 2) What are the long-term impacts on invertebrate assemblages in other areas and with fires at other seasons and fire intervals?; 3) What different roadside management regimes are not a hazard to traffic and culturally acceptable to the general public as well as the farming community?; and 4) How does bird use and reproductive success in the agricultural context change as edge structure changes naturally or is changed by the land managers?

It is necessary to examine the shortcomings and limitations of this body of research. Design flaws and lack of replicates created issues with inferences to the general population. This body of research (Chapters 2, 4 and 5) suffered heavily from "demonic intrusion" (Hurlbert, 1984) in the form of drought, wildfire and roadside 'neatniks'. Ideally studies would have been designed and executed with sufficient interspersion and replicates (Hurlbert, 1984). The isolated block layout of the mowing study was designed to minimize the impact of the landscape gradient as well as invertebrate dispersal. When it became clear non-independence of samples may be an issue we dealt with the problem statistically (Winter, 2013; Millar and Anderson, 2004). The course taxonomic resolution made it difficult to discuss specifics and about 'pest species' or functional guilds other than in general terms. There is a lack of reference sites for the Bloomington Grove study (Chapter 3). There is so little prairie remaining in the state that all existing sites are protected. It is possible, but highly unlikely to obtain permits to collect from these sites.

There are additional issues in the agricultural ecosystem outside the scope of this study that are important to invertebrate assemblages. These issues include the decline in pollinators, genetic modification of crops, and use of pesticides. Issues rising in importance are the food production and distribution issues, use of CRISPR technology to modify crops, antibiotic use in livestock and soil health. Additional research questions include 1) how do we restore habitat for native pollinators so we are less dependent on imported honey bees?; 2) how do we maintain effectiveness of existing pesticides as well as use lesser amounts?; 3) What are the unintended consequences of CRISPR (clustered regularly interspaced short palindromic repeats) technology not only at the species level but the ecosystem level?; 4) how do we address the social issues of food security and distribution; and 5) What are the impacts of chemicals on both micro and macro invertebrates that inhabit the soil?

There is a purported Chinese blessing/curse "May you live in interesting times". We do, indeed, live in interesting times. Technology presents us with both the threat and possibility of increased agricultural production through targeted application of fertilizers and pesticides, satellite monitoring of soil moisture and drought conditions, and crop modification through CRISPR. All these technological advances offer the promise of providing fuel, food and fiber on less land and with less impact thus "sparing" land for nature and associated biodiversity. I can only hope we take the high road and leave room for "the little things that rule the world".

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