Maximizing arthropod-mediated ecosystem services in agricultural landscapes: the role of native plants

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Beneficial arthropods, including native bees, predators, and parasitoids, provide valuable ecosystem services worth $8 billion to US agriculture each year. These arthropod-mediated ecosystem services (AMES) include crop pollination and pest control, which help to maintain agricultural productivity and reduce the need for pesticide inputs. Maximizing survival and reproduction of beneficial arthropods requires provision of pollen and nectar resources that are often scarce in modern agricultural landscapes. Increasingly, native plants are being evaluated for this purpose. Native plants can outperform recommended non-natives and also provide local adaptation, habitat permanency, and support of native biodiversity. We predict that the success of insect conservation programs using flowering plants to increase AMES on farmland will depend on landscape context, with the greatest success in landscapes of moderate complexity. Reintegration of native plants into agricultural landscapes has the potential to support multiple conservation goals, and will require the collaboration of researchers, conservation educators, and native plant experts.

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Conservation of beneficial arthropods in agricultural landscapes is increasingly justified based on the value of the services they provide to society. The annual value of natural enemies and native pollinators to agriculture has recently been estimated at nearly $8 billion in the US alone (Losey and Vaughn 2006). These arthropod-mediated ecosystem services (AMES) include biological control of insect pests, worth $4.5 billion, and pollination of crops, worth $3.1 billion, each year. Despite the impressive economic value of these services, there is widespread concern over both the current and future status of beneficial arthropods. Farm intensification, urbanization, habitat fragmentation, climate change, diseases, and pesticides all threaten the services provided to agriculture by these arthropods (Allen-Wardell *et al.* 1998; Kremen *et al.* 2002; NRC 2007). Recognition of this situation has stimulated investigations around the globe, addressing how best to conserve and enhance arthropod diversity in intensively managed farmland (Landis *et al.* 2000; Gurr *et al.* 2004; Samways 2007; Whittingham 2007).

In a nutshell:

- Insects and other arthropods provide valuable arthropod-mediated ecosystem services (AMES) in agricultural landscapes, including pollination and pest control
- Beneficial arthropods require access to pollen, nectar, and the shelter provided by flowering plants
- The use of native perennial plants to enhance AMES has many advantages, including their adaptation to local conditions and the restoration of local biodiversity
- Development of locally adapted conservation plantings by teams comprised of scientists, entrepreneurs, and educators will enhance their adoption in developed and developing countries

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If conservation programs aimed at enhancing agricultural sustainability are to deliver the increases in AMES they are designed to provide, there is an urgent need to determine how best to manipulate agricultural landscapes to support beneficial arthropods. Coordinating such efforts so that multiple services are enhanced is expected to improve the likelihood of adoption by farmers (Gurr *et al.* 2003; Olson and Wäckers 2007), and quantifying additional benefits for native biodiversity and cultural services may further increase society's willingness to support such programs (Fiedler *et al.* 2008). Based on our recent findings (Fiedler and Landis 2007 a, b; Tuell *et al.* in press), we present a brief synthesis of the role that native flowering plants can play in sustaining pollinators, predators, and parasitoids in agricultural landscapes. We also discuss key areas of research needed to facilitate the use of native plants in conservation programs, with the goal of providing economic benefits to farmers through AMES.

Challenges to survival of bees, predators, and parasitoids in farmland

There have been dramatic changes in most US farm landscapes over the past 25 years, and these trends are expected to continue or accelerate in North America and around the world. Farmland is being encroached upon by urban areas and sold for development (Greene and Harlin

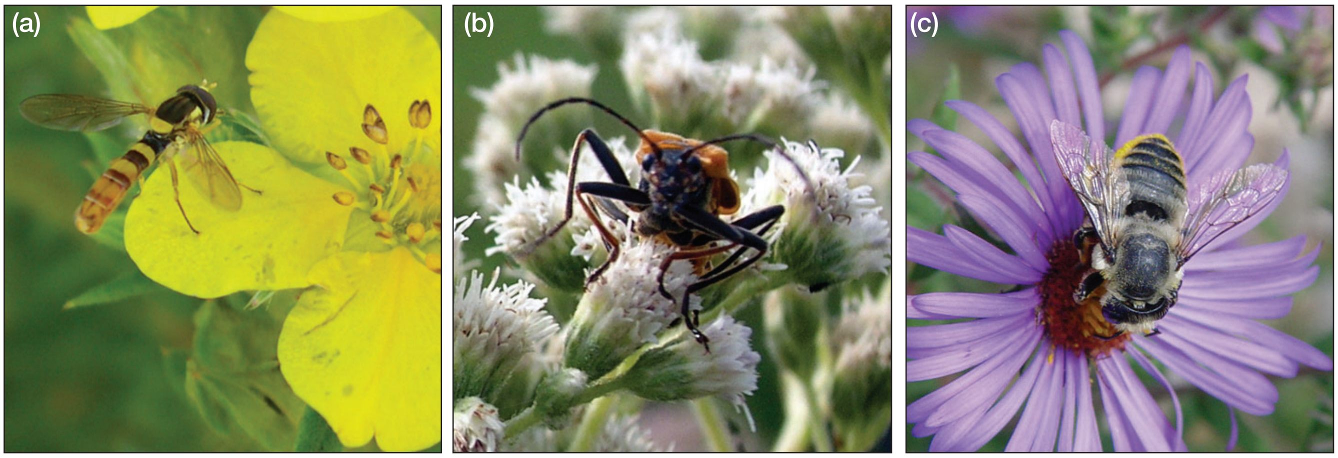

Figure 1. *Beneficial insects on native Midwest prairie plant flowers: (a) syrphid fly (*Sphaerophoria *sp) on shrubby cinquefoil (*Potentilla fructicosa*); (b) soldier beetle (*Chauliognathus pennsylvanicus*) on boneset (*Eupatorium perfoliatum*); and (c) a leafcutter bee (*Megachile *sp) on New England aster (*Aster novae-angliae*).*

1995), thereby reducing the area available for producing food or raising livestock. Invasive plant species are limiting land suitable for animal pasture (Pimentel *et al*. 2000), and global climate change is expected to further disrupt the links between soils, crops, and climate that have driven regional crop production practices (Ramankutty *et al*. 2002). The recent focus on biofuels as a partial solution to dependence on oil in the US (Pimentel and Patzek 2005) shows how land use can quickly change in response to new market opportunities or policies. Demand for corn-derived biofuels has caused a rapid increase in land planted to corn in the Midwest (NASS 2007). Gardiner *et al*. (in press) have shown that this change has caused an associated decrease in landscape diversity, in turn limiting biocontrol services in nearby soybean fields. Moreover, these changes are expected to intensify application of pesticides to cropland, compounding the detrimental effects on beneficial insects and non-target plants. Together, these changes are causing agricultural landscapes to further diverge from conditions favorable to beneficial arthropods and shift toward landscapes characterized by low structural and floral diversity that provide limited resources across large areas.

Comparisons of insect records from Europe before and after 1980 indicate that the abundance of bees and syrphid flies has declined, with a concurrent reduction in the abundance of out-crossing plant species dependent on specialist bee species (Biesmeijer *et al*. 2006). This example highlights the link between trends in beneficial insect populations and the health of plant communities. Declines in native bee populations have also caused reduced yield in cropping systems, with associated drops in economic return to farmers (Kevan *et al*. 1997; Steffan-Dewenter and Tscharntke 1999; Ricketts 2004). Many insect natural enemies are dependent on the availability of suitable food, shelter, and mating sites for survival, and these resources are often limiting in crop fields (Landis *et al*. 2000; Heimpel and Jervis 2005). This allows pest populations to increase, as top-down regulation is relaxed, increasing the need for insecticide applications. These examples highlight the importance of rebuilding landscape diversity within agricultural systems, so that resources are provided to support a diverse suite of beneficial arthropods. Such agroecological engineering will require an understanding of the optimal composition, size, and distribution of conservation areas to maximize the intended yield and quality benefits for crop production systems.

Rebuilding habitat for beneficial arthropods into farm landscapes

Almost all beneficial insects require food in the form of nectar and/or pollen from flowers (Figure 1) for optimal survival and for high levels of reproduction (Klein *et al*. 2004; Pywell *et al*. 2005). When primary hosts or prey are not available, parasitoids and predators require alternate hosts or prey to complete their lifecycles (DeBach and Rosen 1991; Menalled *et al*. 1999; van Emden 2003), and many bee species require flowers within their foraging range throughout the season, to maximize their reproductive potential (eg Williams and Kremen 2007). Habitat management efforts to support beneficial insects are founded on the establishment of flowering plants to provide these critical resources (Landis *et al*. 2000). However, there is relatively little information on which plant species are most suitable for this purpose, how they should be distributed, and the landscape context in which they will be most likely to conserve beneficial insects and provide pest control and pollination services. These are key questions as the science of insect conservation is increasingly put into practice on land where the measure of success is less about whether biodiversity is enhanced and more about whether crop production is increased.

Using native plants to support AMES

The vast majority of research on the use of flowering plants to support beneficial arthropods has focused on a few species of easily grown flowering plants with readily available seed (Fiedler *et al.* 2008). Most of these are annuals or biennials and are typically not native to the area in which they are being used. A few, including fennel (*Foeniculum vulgare*), Queen Anne's lace (*Daucus carota*), and white clover (*Trifolium repens*), are considered invasive in parts of their non-native ranges (USDA-NRCS 2008). An alternative that can avoid some of these problems is to use plants native to the area under investigation and to use perennials where possible. There are several compelling reasons to develop native perennial flowering plants for use in arthropod conservation plantings (Fiedler *et al.* 2008; Frank *et al.* 2008). These include:

- *Local adaptation*. Plants native to a given region are adapted to the local climate and frequently have lower water, nutrient, and pest-control requirements than do non-native species.
- *Habitat permanency*. Use of native perennial plants in conservation seed mixes can help to ensure year-round provision of resources to support beneficial arthropods, such as shelter and overwintering sites.
- *Increased native plant diversity*. Conversion of lands to agriculture has resulted in the decline of many native plant species. Agricultural conservation programs can contribute to ecosystem restoration through the re-establishment of otherwise declining native plant communities.
- *Minimized recurring costs*. Once established, many species will persist or re-seed themselves for decades, in contrast to annuals or biennials, which require regular re-seeding.

Potential drawbacks to using perennial native plants must also be acknowledged. These include their relatively long establishment period, during which floral provision is low compared to annual plants. In addition, native seed may be more expensive or unavailable in commercial quantities. However, if demand for these species increases, market forces are expected to reduce this limitation; moreover, the initial cost can be amortized over the longer life of the perennial planting. As with any resource plant, research on perennial native plants will need to be conducted to ensure that these plants do not contribute to increased disease or herbivore populations (Lavandero *et al.* 2006; Fiedler and Landis 2007a).

Ideally, conservation plantings for beneficial arthropods should use plant species and genotypes native to the particular ecoregion in which they are used. Such practices would ensure local adaptation, reduce the risk of plants becoming weedy or invasive, and increase the potential success of the conservation investment (Alpert *et al.* 2000; Rejmánek 2000). Consequently, regional research efforts are needed to screen native plants for their potential to conserve beneficial arthropods. Our recent experience provides an example of how scientists, native plant producers, and conservation organizations can collaborate to evaluate and select native plants in ways that foster the adoption of native plants for arthropod resources.

Screening native plants

In 2004 and 2005, we evaluated the suitability of plants native to Michigan, for use in insect conservation programs, by comparing the abundance of beneficial arthropods on and around these plants. All plants were established in a replicated trial of 1-m^2 plots, with 43 species of native, perennial plants and five non-native flowering annuals that are among the most frequently recommended resource plants (Fiedler and Landis 2007a). Native plants tested at our site represented prairie and savanna species that would have been common in many areas of the US Midwest, where agriculture now dominates. Specific species were recommended and supplied by a local native-plant nursery, based on bloom period and adaptation to a full-sun environment. Over the life of the project, native plant producers, US Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) personnel, Extension agents, Soil Conservation District staff, farmers, and native-plant enthusiasts were involved in the research and participated as presenters in our annual field days.

Of the native plants tested, 26 were highly ranked for the relative abundance of predators, parasitoids, and/or native bees, based on sampling performed during peak bloom of each species (Fiedler and Landis 2007a; Tuell *et al.* in press). These plants provide an overlapping sequence of blooms through the growing season (Figure 2), supporting a diversity of pollinators and natural enemies. Moreover, these native plants were frequently associated with a greater abundance of beneficial arthropods than were non-native species. Native bees were also more abundant on these plant species, and there was an increase in the number and diversity of native bees at the flowers through the growing season, as flower size and temperatures increased (Tuell *et al.* in press). These results provide compelling reasons to continue the search for native resource plants in other regions, where region-specific plant genotypes can be tested using similar methods. In our studies, both groups of beneficial insects responded more to floral area than to any other plant variable tested, with greater insect abundance at larger floral displays within each of the bloom periods (Fiedler and Landis 2007b; Tuell *et al.* in press; Figure 3), suggesting that initial selection of native plants for evaluation in other regions should concentrate on plants with large floral displays within their respective bloom periods.

This approach has allowed us to make direct comparisons between a wide range of flowering plants and to recommend plants that can provide resources from late spring to early fall. An extension of these studies is underway, in which plantings of the highest ranked native

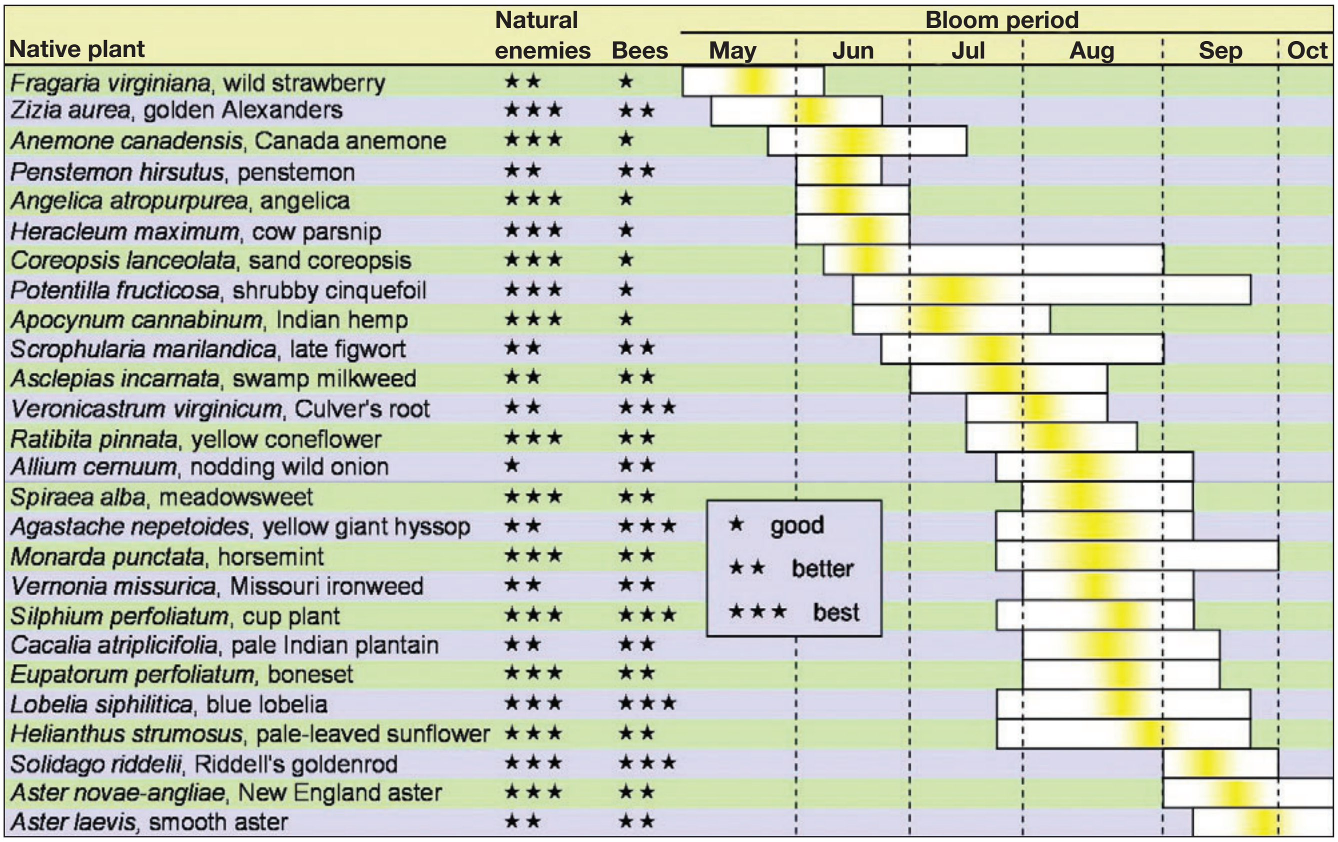

Figure 2. *Relative bloom phenology of the 26 native Midwest prairie plants most frequented by beneficial insects in a replicated study, ordered by bloom timing in 2005. White and yellow bars represent the bloom period for each species, with yellow indicating peak bloom. The number of stars after each plant indicates the frequency of visits by insect natural enemies (predators and parasitoids) and bees (pollinators), based on how many insects were collected per square meter in a 30-second sample. One star = fewer than 2 insects; two stars = 2 to 10 insects; three stars = more than 10 insects.*

plants are being tested in strips on farms producing soybean and fruit crops in different regions of Michigan, to investigate how well these plantings support the ultimate goals of reducing pest-insect abundance and increasing pollination. These studies will contribute to the body of evidence for the effectiveness of targeted plantings of flowering plants to support natural pest control (Landis *et al*. 2000) and crop pollination (Klein *et al*. 2007).

Another aspect of outreach has been to deliver information on native plants to conservation educators, farmers, and the public through our website (www.nativeplants.msu.edu) and through annual field days. These efforts have greatly facilitated the adoption process; the Michigan Natural Resources Conservation Service (NRCS) is incorporating these 26 species into its technical guidelines for field border plantings and Cooperative Extension agents are using our education and outreach materials in programs for various client groups.

Adoption of conservation practices on farmland may provide broader benefits than support of beneficial insects and the services they provide (Gurr *et al*. 2003; Bianchi *et al*. 2006; Fiedler *et al*. 2008; Frank *et al*. 2008). Setting aside land to grow a diverse community of native flowering plants can provide food and shelter for other wildlife, including threatened birds, mammals, and butterflies (Van Buskirk and Willi 2004). Depending on the size and layout, such plantings may also facilitate hunting, provide erosion control, and reduce runoff of agrochemicals into waterways. As urbanization increasingly encroaches into farmland areas, conservation plantings can provide aesthetic benefits and may help to educate urban neighbors and farm visitors about the positive steps being taken to support beneficial insects on farms. Flowers may also provide revenue through farm-stand sales, and certain species with edible berries or nuts may be suitable for use in these plantings. Such additional benefits can provide incentives for adoption of conservation plantings, depending on the land available and the function(s) desired (Tscharntke *et al*. 2005; Sandhu *et al*. 2007)

The methodology described here has the potential to be replicated in many parts of the world. Recently, the entire process has been transferred to Central Asia, as part of an Integrated Pest Management Collaborative Research Support Program project, with funding from the US Agency for International Development. In this project, local scientists in Tajikistan and Kyrgyzstan are collecting, screening, and field-testing native plants for use in increasing numbers of beneficial arthropods in their cropping systems (Figure 4). This approach encourages

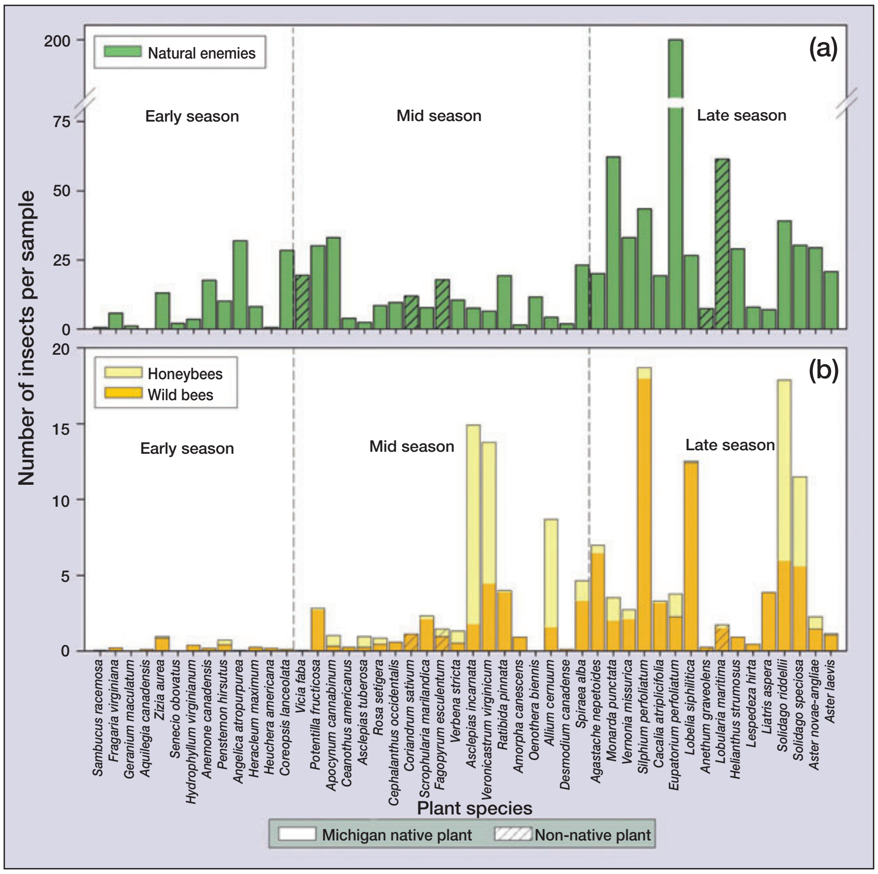

Figure 3. *Average number of (a) natural enemies and (b) bees collected during vacuum sampling at native Midwest prairie plants and five non-native plants during 2005. Collections were made three times during full bloom of each species, and relative abundance of insects at these plants was compared within bloom seasons. The bars for the non-natives are hatched.*

farmers, scientists, and local officials to collaborate, with the aim of using local biodiversity resources to enhance ecosystem services in agricultural landscapes.

■ Landscape context and arthropod conservation plantings

The diversity and abundance of arthropods available to provide biological control in crop fields are dependent on the structure and composition of the surrounding landscape (Colunga-Garcia *et al.* 1997; Thies *et al.* 2003; Schmidt and Tscharntke 2005), and similar patterns are seen for pollinators (Kremen *et al.* 2004; Winfree *et al.* 2007). Landscape variables such as habitat complexity, quality, and patchiness, as well as an organism's dispersal capability, may all impact the ability of a landscape to support biological control and pollination services in agricultural croplands (Elliott *et al.* 1998; Thies *et al.* 2003; Kremen *et al.* 2007). Moreover, crop fields are ephemeral habitats, in which anthropogenic disturbances, such as tillage, pesticide application, and harvesting, require arthropods to frequently recolonize crops (Wissinger 1997). The surrounding landscape provides the potential pool of arthropods for this recolonization, and thus may influence the level of biological control in frequently disturbed crop fields (Lee *et al.* 2001; Gardiner *et al.* in press).

Across the US, agricultural landscapes vary widely in their complexity. At the extremes, they are comprised of a matrix of intensively managed crop habitat with few non-crop areas. Other landscapes may have crops embedded within a matrix of largely non-crop habitats (Figure 5). Across this range of landscape contexts, we expect wide variation in the response of beneficial arthropods to the provision of resources from flowering plants. A consequence of this variation is that landscape context is expected to be a primary driver of the ability of conservation efforts to deliver their intended benefits. Simplified landscapes may lack critical infrastructure needed for some species, and thus limit populations and diversity of beneficial arthropod communities (Thies and Tscharntke 1999; Kremen *et al.* 2002; Steffan-Dewenter 2002; Holzschuh *et al.* 2007; Winfree *et al.* 2007), thereby limiting the ecosystem services that can be produced by such landscapes (Kremen *et al.* 2004; Tscharntke *et al.* 2005). In contrast, highly complex landscapes may benefit little from the addition of arthropod conservation plantings, because these areas already contain a rich community of beneficial insects.

Given landscape-level effects on native bees, predators, and parasitoids, we expect that the background level of AMES in agricultural landscapes will increase as habitat heterogeneity increases. We propose that the realized benefit from conservation programs that add flowering plant resources into a landscape will vary according to the "landscape–ecosystem service" hypothesis. Based on Tscharntke *et al.* (2005), this hypothesis states that AMES are unlikely to be enhanced by adding resources in highly simplified landscapes, because species pools are too impoverished to respond. Added resources are also unlikely to improve ecosystem services in complex landscapes, where biodiversity and habitat heterogeneity are already high. Additional resources will increase AMES most in landscapes of intermediate complexity, where adequate species pools and habitat heterogeneity favor a response to such management (Figure 6). Knowledge of this landscape-driven variation in response to habitat management for enhancing AMES can provide valuable guidance for farmland managers and government agencies aiming to maximize the impact of their investment in conservation programs to increase biodiversity.

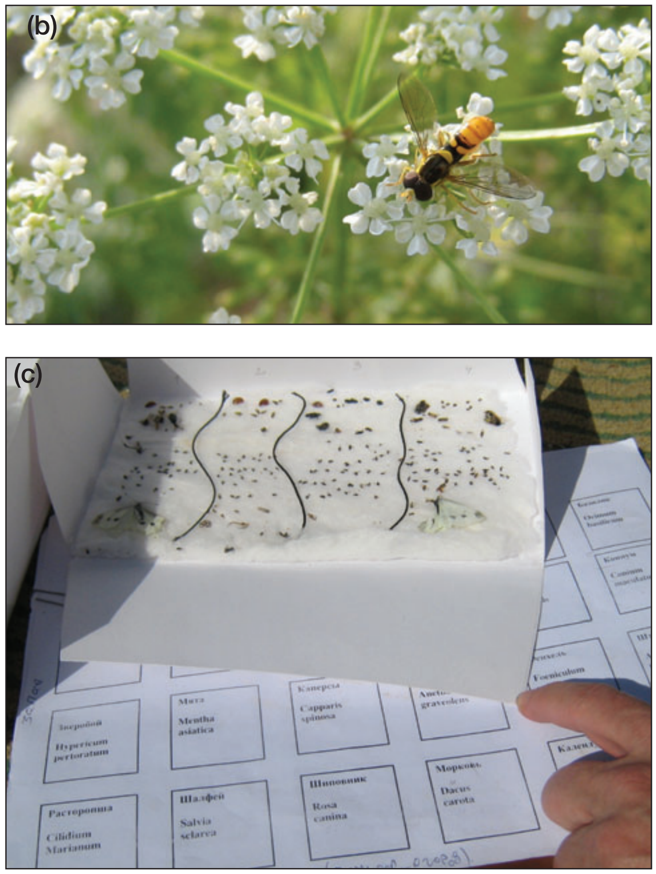

Figure 4. *Images from a field tour in Dushanbe, Tajikistan: (a) research and Extension personnel examine potential resource plants for conservation plantings; (b) a syrphid fly on a native Tajik flowering plant; and (c) a collection of insects from one day of sampling resource plants by local collaborators.*

Conclusions

Modern agricultural landscapes have been shaped by production systems aimed at maximizing crop yield and profitability, but there are compelling reasons for agriculture to broaden the range of ecosystem services it provides to society (Swinton *et al.* 2006; Fiedler *et al.* 2008). Increasing AMES is one component of meeting this challenge. If biological pest control and pollination services can be increased through conservation programs, benefits will include increased farmer profit and reduced dependence on chemical pesticides. Public pressure has stimulated new conservation measures, facilitated by the USDA, through conservation programs managed by NRCS and the Farm Service Agency (FSA). For example, a pollinator meadow enhancement program is in development for use under the NRCS-managed Conservation Security Program, and the FSA's new State Acres for Wildlife (SAFE) program specifically addresses pollinator protection in some of its latest projects (FSA 2008).

Our recent screening of perennial, native, flowering plants provides a template for the evaluation of local plant genotypes in other areas. From this, region-specific lists of plants can be developed that support biological control agents and pollinating bees through the growing season. Basing arthropod conservation plantings on optimized combinations of native plant species is expected to

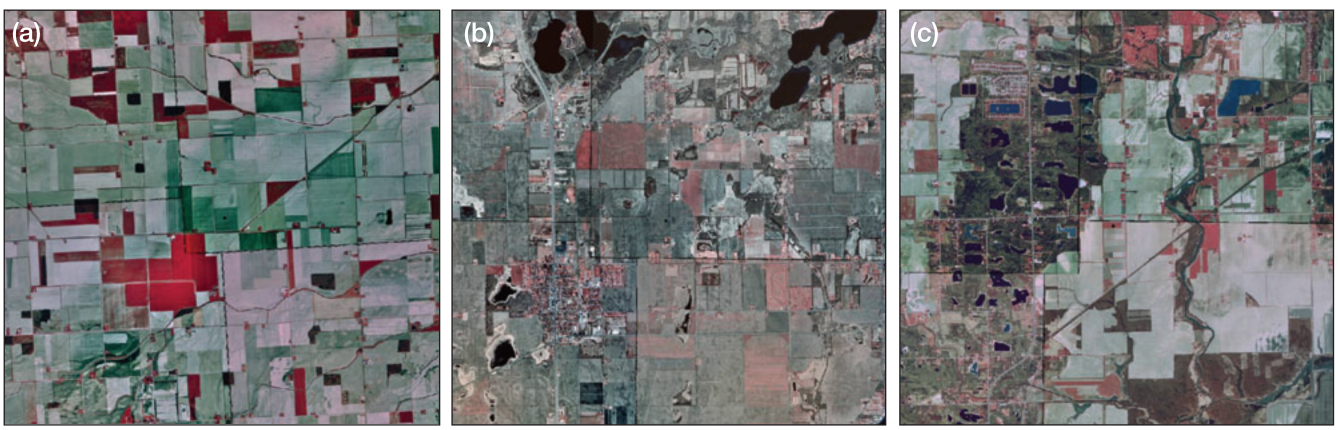

Figure 5. *Examples of (a) low-, (b) medium-, and (c) high-complexity landscapes in the agricultural regions of southern Michigan. Images show an area of approximately 7 km^2.*

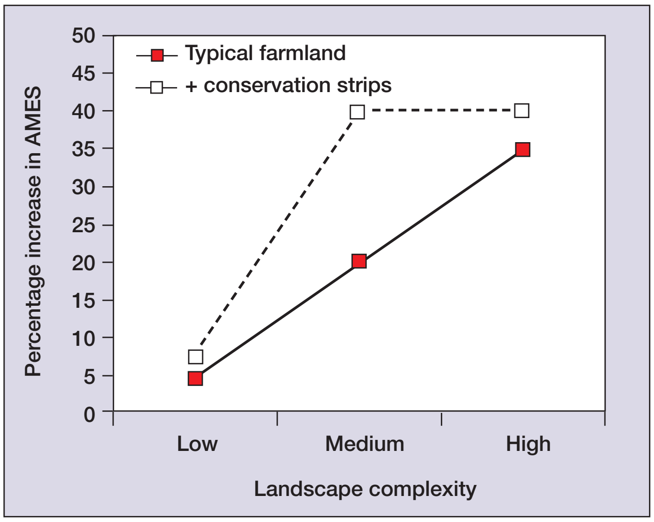

Figure 6. *Illustration of the "landscape–ecosystem service hypothesis", after Tscharntke* et al. *(2005). The proportional gain in arthropod-mediated ecosystem services is lowest in the extremes of landscape complexity, but for different reasons. Beneficial insect populations are impoverished in the low complexity landscapes, whereas in high complexity landscapes, their populations are abundant and cannot be easily increased. Only in landscapes of intermediate complexity does the addition of flowering plants provide resources that can be exploited by organisms to increase their populations.*

improve the likelihood that such programs achieve their long-term goals of supporting beneficial insects and also increasing the services they provide. Further research will be needed to determine the optimal size and distribution of these plantings and the landscape context in which such conservation investments will pay off, in terms of crop yield and quality. Agricultural producers and, ultimately, society will benefit from increased investment in understanding how best to utilize native plants to enhance AMES.

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