Spring 5-19-2017

ATTRACTING BENEFICIAL INSECTS TO YOUR FARM: A COMPARISON OF HABITAT MODIFICATION STRATEGIES

Kelly Rourke
kellyerourke@gmail.com

This Master's Project

ATTRACTING BENEFICIAL INSECTS TO YOUR FARM:
A COMPARISON OF HABITAT MODIFICATION STRATEGIES

by

Kelly Rourke

is submitted in partial fulfillment of the requirements
for the degree of:

Master of Science
in
Environmental Management

at the

University of San Francisco

Submitted:		Received:	
................................…………..		................................………….	
Your Name	Date	Maggie Winslow, Ph.D.	Date

Table of Contents

List of Figures and Tables

List of Acronyms

ECA: Ecological Compensation Areas

AEM: Agri-Environmental Management

AES: Agri-Environment Schemes

BFF: Bee Friendly Farming

BLM: Bureau of Land Management

cAES: Collaborative AES

CCD: Colony Collapse Disorder

CRP: Conservation Reserve Program

DFS: Diversified Farming Systems

DPL: Diverse Patchy Landscape

ES: Environmental Stewardship

EU: European Union

IM: Intensively Managed Meadows

IPM: Integrated Pest Management

IVM: Integrated Vegetation Management

NRCS: Natural Resources Conservation Service

P2: Pollinator Partnership

USDA: United States Department of Agriculture

Abstract

Thoughtful planning to enhance diversity in agricultural landscapes can present a multitude of ecological, cultural and economic benefits. Land managers have many options when considering which habitat modification techniques they can implement on their agri-environment schemes. This comparative analysis of 47 peer reviewed journal articles assesses which landscape enhancements are most effective in attracting beneficial insects, namely pollinators and natural enemies to pests. Through biological control, natural invertebrate predators inhibit vegetative pests that can be detrimental to croplands. The promotion of natural enemies can decrease the need for chemical use and maintenance on farms. Pollinators contribute tremendous benefits to crop yield and fruit set of crops, and can provide various other ecosystem services that promote overall environmental health. A comparison was conducted of 1) managing field margins 2) buffer strips 3) implementing diverse patchy landscapes and 4) native plantings. For each technique, studies are examined based on their efficacy of attracting and sustaining the health of predators and parasitoids of agricultural pests and both managed and native pollinators. Additionally, survey responses from Bee Friendly Farmers were collected to gain farmer perspectives on observed benefits and challenges when adopting such practices. Findings show that through a careful selection of native plants and a combination of landscape enhancements, pollinator and natural enemies ecosystem services can be increased. Lastly, recommendations are provided for land managers and policy makers to help facilitate implementation that result in the most benefits.

Introduction

Sustainability conscious management practices of agroecosystems are vital in a time of high human demands for food, fiber and fuel. Agriculture and urban developments account for almost 40% of the Earth’s usable terrestrial land, 37% of which is designated as rangelands and croplands (Garibaldi et al. 2011). Unfortunately, much of the world's agricultural landscapes have been degraded and stunted by stagnant monocultures and the misuse of pesticides and herbicides. Many vital species are negatively affected by such agricultural practices, with an estimated 38% of these being endangered or species at risk in the United States (Bianchi et al. 2006). Implementing diversifying management practices for sustainable agriculture is an important environmental management tactic that can help restore and promote a great deal of valuable land. A diverse landscape with complex habitat is quantified primarily by the number of unique structural elements per unit volume (Langellotto and Denno 2004). Sustainable agriculture can include a multitude of techniques and follow a variety of models to achieve a highly productive, non-degrading system.

A healthy food supply is a concrete and easily supported outcome of practicing sustainable farming. Diversified Farming Systems (DFS) are those whose intentional practices promote biodiversity at multiple scales, over space and time, to encourage ecosystem services that can enhance agricultural success (Kremen et al. 2012). Such improvements include soil fertility, pest control, water conservation and pollination. DFS thrive with a combination of traditional and modern knowledge, cultures, and government regimes. Their success depends on social institutions and networks to support their goals that may not always seem obviously aligned (Kremen et al. 2012). The public is becoming increasingly aware of where their food comes from and are becoming more concerned with what they are ingesting, whether it be issues of genetically modified organisms or artificial ingredients.

It may be less known, however, that there are many other ecosystem and producer benefits that can result from sustainable agricultural practices. For example, establishing best management practices for insecticide use and vegetative pest control can prevent habitat destruction and unintended exposure of beneficial insects to harmful chemicals. Better yet, incorporating non-chemical methods of pest control, such as native hedgerows that attract natural predators, reduces the need for pesticides, improves erosion control and water retention, and can attract pollinating insects. An abundance of pollinators in an agricultural system results in higher overall productivity in conjunction with economic gain. Incorporating landscape enhancements, such as hedgerows, can attract natural enemies or predators that will help control crop-harming pests. These land modifications will also provide nesting habitat, overwintering and foraging resources for native pollinators and other wildlife.

This paper’s main research question is: How can creating a diverse agricultural landscape attract beneficial insects and deter pests while benefiting farmers? This question will be explored through the following sub-questions: How does a diverse landscape attract pollinators? How does a diverse agricultural landscape inhibit insect pests? What are the best management practices for establishing a diverse agricultural landscape? What are the benefits to producers when maintaining a diverse agricultural landscape? This comparative analysis will focus on the ecological improvements and farmer benefits that non-cropped habitat can support in terms of attracting beneficial insects, both natural predators and pollinators. Landowners willingness to adopt such landscape enhancement practices will also be investigated. This paper explores the costs and benefits to farmers and land managers when creating a diverse agricultural system. It also generates a list of best management practices for promoting diverse agricultural systems. The resources analyzed present other ecosystem benefits that are attributed to moving away from monoculture farming. The objective of this comparative analysis is to highlight support for biodiversity and native interactions found in various studies. While these benefits, such as decreased pesticide use and water conservation are important, they are mainly supportive injections to the paper's background and conclusion.

Background

Biodiversity is the one of the most fundamental facets of general ecology and conservation biology. Of all of the species discovered and described, invertebrates comprise 80% of the total. Not only do invertebrates dominate the total number of known species on earth but they also have the highest richness, abundance and biomass (Cardoso et al 2011). In terms of conservation, however, they tend to be largely ignored, with the more beautiful and iconic animals able absorb the most attention and funding. While large mammals can be keystone species, many invertebrate species can just as easily dictate ecosystem dynamics.

Diverse ecosystems are often the most healthy systems, displaying an impressive interconnectedness that is exemplary for all of Earth's systems. Consider coral reefs and tropical rainforests; these ecosystems have exceptionally high biodiversity and productivity. In order for humans to have the least negative impact on the natural world, it is important to follow nature's example and strive to create diverse systems that can be utilized by as many species as possible. Traditional ecological knowledge that has been passed on by generations of indigenous people shows a history of these types of practices. Agroecology, or the incorporation of ecological approaches in agricultural production, is one of the oldest sustainable practices that has been largely ignored by modern society. Currently, the agricultural landscape of United States is dominated by endless fields growing a single crop species.

Common Agricultural Practices

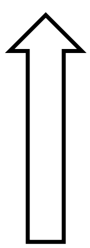
Traditional agroecosystems are seldom suitable habitat for wildlife due to their high levels of disturbance. The tremendous amount of natural land that has been repurposed for agriculture has depleted usable land for non-human species of all kinds. Agricultural production around the globe increased by 140% between 1961 and 2006, with the total cultivated areas increasing by almost 25% (Aizen et al. 2008). The use of monocultures, or vast cultivation of one crop in a certain area, is detrimental to the environment, harming soil, wildlife, and watersheds. However, this agricultural practice is so common due to the low effort, high yield perspective adopted by many producers. With high food demands in an ever-growing society, American agricultural producers are under tremendous pressure to perform to the best of their abilities. Monocrop farming techniques also reward farmers with a quick return in terms of production with more immediate financial gain. In an attempt to produce as much food as possible, farmers have relied on monocultures, which without crop rotation, strips soil of its nutrients. This in turn encourages the introduction of high amounts of fertilizers into soils that run off into waterways and can cause a multitude of problems. Inundation of phosphorus and nitrogen from fertilizers can result in water with very low or no productivity. This process of eutrophication caused by the overgrowth of algae, depletes oxygen, and kills aquatic life.

Fertilizers are not the only byproduct of agriculture that can affect nearby water and adjacent landscapes. The widespread use of harsh chemical herbicides and pesticides present another downfall of monocrop agriculture. Pesticides are formulated to kill insects, which most pollinators and natural enemies of pests are. It can be difficult to prevent the unintended consequences of pesticides on non-target species, especially when applicators are not trained properly and labels are not followed perfectly. These chemicals have also been found to negatively impact other wildlife, like the insectivorous birds that help control pests to agriculture.

Lastly, when pollinators are attracted to mass-flowering monocrops, they may experience the initial benefits of plentiful food, however what follows is not sustainable. This abrupt decline in foraging resources can impede pollinator reproduction rates long-term which will without doubt have negative effects on surrounding crop production (Saunders 2011). Many studies conducted have proved that organic farming can result in higher species diversity when compared to conventional practices (Holzschuh et al. 2008). One in particular confirmed that the incorporation of organic fields into traditional landscapes can promote pollinators, especially in non-crop habitats. By increasing organic crops to comprise 5 to 20% of the overall agricultural landscape, bee species richness in adjacent fallow lands were enhanced by 50%. Solitary bees were increased by 60% and bumble bee density, a crop specialist, was increased by 150% (Holzschuh et al. 2008). As shown here, reducing or eliminating the use of chemical on a landscape can benefit many species.

Pest control

The lack of biodiversity in an agricultural system makes it more susceptible to insect pests and disease. Monocultures, that rotate annually rely on importing natural enemies for pest control, have much less success in controlling pests than a more stable and diverse landscape. For example, if a farmer is only producing one type of vegetable, a pest that has a preference for that particular species could wipe out the entire crop. Whereas if a variety of species of a crop are being grown, some may be able to withstand or resist that pest. For example, coffee (*Coffae spp.*) grown in Central America is both economically important and susceptible to dramatic yield losses caused by insect pests, particularly the coffee berry borer (*Hypothenemus hampei*). By cultivating various species of coffee, farmers make themselves less vulnerable to pests (Saunders et al. 2016). Certain landscape types support different natural enemies of pests and therefore a diversified agricultural system with non-crop habitats can help protect crops. Figure 1 shows the various possible benefits of naturally occurring parasitoids of pests when floral resources are diversified on agricultural landscapes. The arrow indicates the trend in the value of the effect and the difficulty of achieving it (Wratten et al. 2012).



Pest populations are reduced to below the economic threshold
A higher proportion of pests are suppressed
A higher number of pests are suppressed
Individual parasitoid fitness improved
Parasitoids aggregate on floral resources

Figure 1. The hierarchy of possible effects on parasitoids of pests when floral resources are diversified. The arrow indicates the trend in the value of the effect and the difficulty of achieving it. (Wratten et al. 2012).

Natural enemies generally operate at smaller spatial scales than their herbivore pests, and as a result they are increasingly vulnerable to habitat fragmentation (Bianchi et al. 2006). Incorporating native plants and semi-natural habitat nearby or within crop fields can attract natural predators that can help control insect pests. Structurally complex landscapes at the habitat level can encourage invertebrate natural enemies. At a smaller scale, variation of vegetation, even leaves themselves, can promote abundance of such insects. Equally as important it has been found that their herbivorous prey does not exhibit a response when habitat complexity was increased (Langellotto and Denno 2004). In a meta analysis study one researcher found natural enemies to be promoted by landscape complexity in 76% of cases reviewed. In all cases, at least some positive effect was observed.

Natural enemies of pests include carabid beetles, staphylinids, spiders, coccinellids, syrids, chrysopids, mites, parasitoids, heteroptera and insectivorous birds (Bianchi et al. 2006). Predators like lady beetles and parasitoid wasps are attracted to certain herbaceous and shrub vegetation which allows farmers to use less chemical pesticides. While natural predators can be purchased and manually introduced into croplands, it is safer and more cost effective to let them be naturally drawn to one's property. Additionally, food sprays of supplemental food for natural enemies can be used to sustain them in times of prey scarcities, but they fail to provide lasting food sources and refuge (Landis et al. 2000).

Pollinators in agriculture

Pollinators are another type of beneficial insect that are attracted to semi-natural habitat on agricultural landscapes. Plant-pollinator relationship are complex and specialized, with many plants unable to reproduce without a visit from a pollinator. Flowers and pollinators have evolved together over time, with pollinator behavior being directly tied to plant mating systems. Some pollinators, like honey bees (*Apis mellifera*) are generalist and will forage on many floral resources, and others, like squash bees (*Peponapis*), have coevolved with a particular type of plant and that plant cannot produce fruit without its specialist pollinator (Mitchell et al. 2009). Pollinators are responsible for the fertilization of 70% of crop species throughout the world with bees providing pollination services for 30 major crops worldwide (Smith et al. 2013 and Sprague et al 2016). Isolation from natural areas decreases visitation from pollinators and therefore can stunt flowering crops, as predicted in optimal foraging theory (Garibaldi et al. 2011). Pollinators are not only essential to the production of many crop species, they provide various ecosystem services like erosion control, seed production, and water filtration. Figure 2 shows the various possible pollinator-related benefits of utilizing floral diversification strategies on non-cropped lands in an agricultural setting. These pollinating animals also contribute to medicinal, textile and recreational industries (Wratten et al 2012).

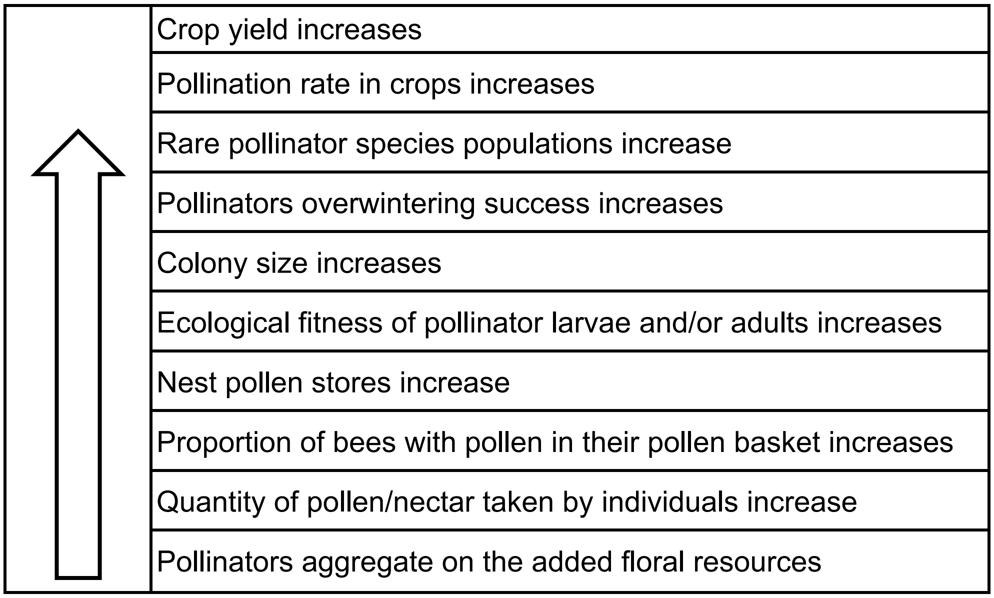


Figure 2. The hierarchy of impacts of floral diversity in farmlands on pollinator fitness and effectiveness. The arrow indicates the trend in the value of the effect and the difficulty of achieving it (Wratten et al. 2012).

Unfortunately, many species of native and commercial pollinators have been experiencing major declines as a result of pesticide misuse, pests and disease, and loss of habitat. Managed honey bees (*Apis mellifera*) in North America have expired almost a 60% decline since the 1940s. Additionally, the overall diversity of native, wild bees is decreasing rapidly across Western Europe and North America due mainly to habitat destruction (Aizen et al. 2008). In fact, in 2016 the first bumble bee species was added to the Endangered Species List in the United States. A decline in pollinators leads to a connected decline in plant reproduction.

Land use transformations and changes in farming practices have contributed to the decline in pollinators (Austin 2015). Loss of habitat is arguably the most detrimental issue causing the decline of pollinators, however luckily it is potentially the easiest problem to combat. Agricultural landscapes have the potential to not only produce food but to also serve as habitat for pollinators and other wildlife. Transforming farmlands into biodiverse, healthy systems is proven to have a multitude of ecosystem and producer benefits. Many countries, both developed and developing, are investing in pollinators by providing resources and encouragement for beekeepers and land managers. In many North American and European countries, Agri-Environment Schemes (AES) are promoted by agricultural agencies which can be implemented at various scales. Most AES efforts encourage the implementation of rich floral habitats through the establishment of hedgerows, field border plantings, temporary cover crops and buffer strips.

From 1994 to 20013 approximately 24.3 billion Euro has been expended in Europe alone on AES programs (Kleijn and Sutherland 2003). The United States Department of Agriculture (USDA) and the European Union's (EU) Agri-Environmental Regulation Initiative often offer direct financial subsidies and technical advice for these plantings and ongoing management (Wratten et al. 2012). These efforts are supported through the United States Farm Bill programs, including the Conservation Reserve Program (CRP). Through this type of mitigation for pollinator decline, over 120,000 acres of habitat have been planted for conservation on CRP lands (NRCS 2017). In a meta analysis of the efficacy of AES, 54% of the studies species experienced increases in species richness or abundance when compared to controls and 6% experienced declines (Kleijn and Sutherland 2003). Despite the many improvements in pollinator habitat restoration, pollinators can be difficult to study. They have low rates of detection and flight seasons of many species do not overlap with the entirety of most field seasons (M'Gonigle et al. 2015).

The Ecosystem Dynamics of a Diverse Agricultural Landscape

Habitat enhancements can be incorporated at the landscape, farm, crop field, or crop plant level (Wratten et al. 2012). Depending on the level and diversification strategy, systems will reap different ecosystem benefits. For instance, at the plant level, benefits include rare species conservation. At the field level, ecological benefits include wind protection and nitrogen fixation. The entire farm is improved with erosion control and surface water runoff reduction. Lastly, the greater landscape has better water quality and carbon sequestration. When comparing biologically diverse to traditional farming systems in a literature review, Kremen and Miles (2012) also found that the ecosystem services improved in a biodiverse system include: soil quality, nutrient management, water-holding capacity; weed control, lower warming potential, climate change resilience and pest and pathogen control, pollination. Natural and semi-natural lands can provide habitat for specialized species contributing temporary habitat for hibernation, breeding and rearing. One study went as far as to conclude that 63% of all animal species that interacted with the above ground agricultural landscape depended in some way on the presence of non-cropped areas (Duelli and Obrist 2002). The subsequent two sections will explore the ecological benefits and complexities that beneficial insects, pollinators and natural enemies, provide.

Pollination Dynamics

Pollinators are essential for the reproduction of over 65% of the globe's wild vegetation (Wratten et al. 2012) and over 90% of the species of modern angiosperms in the world (Aizen et al. 2008). Many studies have shown that habitat restoration on agricultural landscapes will increase pollinator abundance and overall pollinator diversity while attracting native bee species that can be extremely valuable pollinators (Benjamin and Winfree 2014). In one of the most comprehensive overviews of pollinators' presence in sustainable agriculture, Kevan et al. (1990) explore the important role that both managed and wild insect pollinators play in food production systems. The authors advocate for the promotion of native pollinator species, primarily bees, that have developed evolutionarily with certain plant species and can be tremendously effective pollinators. The maladies suffered by European honey bees (*Apis mellifera*) throughout the world helps support the practice of diversifying landscapes and attracting valuable native pollinators (Kevan et al. 1990). Pests like the varroa mite, and diseases such as deformed wing virus, plague commercial honey bees in the United States and have contributed, amongst other factors, to widespread Colony Collapse Disorder (CCD). CCD is described as the sudden and mysterious disappearance of honey bees where colonies are shrinking in size or altogether failing to survive, particularly through the critical winter months. Honey bees are also transported around the country in order to provide pollination services to various crops with particular bloom periods. This causes additional stress on commercial honey bees and can make them more vulnerable to threats. Native pollinators, like the blue orchard bee (*Osmia lignaria*), can also be managed for crop pollination and there are many studies that advocate for increased diversity within pollination services (Klein et al. 2012).

Just how much agriculture depends on pollinators has been a major topic of investigation among researchers throughout the world (Aizen et al. 2009). There is a clear correlation between pollinator abundance and global agricultural productivity with strong predictions that a decline in pollinators will greatly impact food supply (Aizen et al. 2009). One study attempted to quantify the effect of total loss of insect pollinators on global productivity and diversity in agriculture. Developed and underdeveloped societies were considered separately in terms of changes in pollinator dependence over a 46 year period from 1961 to 2006. This study found that the direct decline in total agricultural production as a result of the lack of pollinators would be between 3 and 8% (Aizen et al. 2009). This may not seem to be a huge decrease but when considering the percentage of land needed to compensate for these deficits, it would require astounding land conversion and cultivation in currently stressed landscapes. Impacts on the developing world are dramatically stronger than the developed world due to already scarce resources. Over time, agriculture has become more pollinator-dependent and the trend is projected to continue (Aizen et al. 2009). Unfortunately, human demands for food security and increasing food production have resulted in unsustainable farming systems that in many cases cause irreversible damage. Even agroecology is losing its efficacy due to the deterioration of ecological connectedness and climate change induced vulnerabilities. One suggestion to combat this is to integrate biodiversity with thoughtful balance into agricultural systems (Kumaraswamy and Kunte 2013).

Biological Control Dynamics

Conservation biological control is the manipulation of existing landscapes to enhance the health and overall effectiveness of natural enemies (Landis et al. 2000). Many studies have found that establishing natural habitat around or near crop field can be effective in deterring pests and attracting their natural enemies. Greater plant diversity in agricultural landscapes supports populations of natural enemies of pests whose value has been estimated at $4.5 billion dollars annually (Wratten et al. 2012). Top-down effects have been observed to be prominent throughout the food web. A meta-analysis found that most guilds (seven of nine) of natural enemies were more abundant in landscapes with high complexity. Strongest responses were seen with hunting and web-building spiders, with hemipterans, mites and parasitoids following closely behind (Langellotto and Denno 2001). Another study even discovered that by providing diverse vegetation on landscapes, herbivore pests can be inhibited through their diet. Presenting a diversity of plants that provide various nutrients reduces insect herbivore performance as they do not need to consume as much of one plant. This in turn results in less damage to crops and less need for pesticides (Wetzel et al. 2016).

Habitat enhancements in farms can aid in management techniques to ultimately save time and money, and still additional studies have been conducted to compare and contrast the trade-offs in agroecosystems. The benefits and cost analysis associated with natural pest control and chemical pesticides have determined that each system should be reviewed on a case-by-case basis looking at multiple species, and crops. More integrated studies that exhibit a net return of animal activity in these systems can help support the case for a diverse agricultural landscape (Saunders et al. 2016). These ecosystem dynamics dictate the economic and cultural benefits that farmers can reap when diversifying landscape with the intention of attracting beneficial insects.

Benefits to Farmers

The conservation of at-risk species and the promotion of biodiversity cannot rely solely on protected areas that have little or no interaction with humans. There is great potential in managed landscapes that can contribute greatly to wildlife needs and other ecosystem services. Land management by government agencies, public utilities, private corporations and even individuals can propel long-term conservation efforts. Farmers and ranchers comprise the largest group of people that manage land. Over half of the globe's terrestrial surface is involved in agriculture (Batary et al. 2011). Generally, environmentalist see this as a negative impact on ecology, however agroecosystems are proven to have great potential in supporting biodiversity. Supporting wildlife and natural systems becomes increasingly important in times of environmental change. Lucky for farmers and ranchers, by incorporating non-cropped semi-natural to natural, native features on their land can provide a host of positive impacts. Conservation on agricultural lands must be presented in a well-balanced way for both the ecological and farmer benefits to be realized (Batary et al, 2011).

The diversification of agricultural landscapes can result in a multitude of benefits to farmers. Table 1 lists the obvious and less obvious costs and benefits to farmers when enhancing their lands for pollinators. There are many factors that contribute to added income and less expenses to a producer. Looking back at Wratten et al.'s hierarchy of scales for benefits, from the smallest to largest level, habitat enhancements result in increased seed set and higher fruit quality which leads to higher yields in an overall sustainable farm with improved aesthetic. Pollination services are the most notable of the benefits to farmers, resulting in increased crop yield and larger fruit (Saunders et al. 2016). One study by Klein et al. on California almonds found a direct positive correlation between fruit set and percentage of natural habitat surrounding orchards. Interestingly wild bee species richness was found to be even more of an indicator of a thriving agricultural system than honey bee visitation (Klein et al. 2012). The value of wild pollinators is often overlooked considering the availability and common practice of using commercial honey bees. The increased uncertainty in the health of non-native honey bees puts even more stress on the 300% proportional increase in the number of crops needing pollination (Morandin et al. 2016). More native pollinators results in a decrease in hive rental expenses for farmers. Annually, animal pollination services account for $153 billion globally, yet the actual numerical economic benefit of pollinators directly to farmers hasn't been widely studied (Wratten et al 2012). However, when directly quantifying the economic benefits of utilizing an AES, a 2006 study found that yield and profit could both be increased when 30% of the land surrounding crop fields was uncultivated and within 750 m of the field edges (Morandin and Winston 2006).

Table 1. Obvious and less obvious costs and benefits to farmers when enhancing pollinator habitat. (Wratten et al. 2012)

Obvious Costs ● loss of cultivated land and resulting crop yields ● Potential loss of yield due to variability of wild pollinators ● Costs of restoring non-crop vegetation ● Labor **Less Obvious Costs** ● Training of habitat enhancement techniques ● Monitoring for successful floral establishment and beneficial insect populations ● Maintenance of new habitats ● Increase in pests attracted to wildflowers ● Possible lack of spillover from enhancements to crops	**Obvious Benefits** ● Savings in production costs by reducing the size of cultivated land ● Savings in honey bee hive rental fees ● Potential subsidies from AES or price premiums for environmentally friendly products **Less Obvious Benefits** ● Increase in biological control and a reduction in pesticide use ● Reduced pesticide decreases likelihood of resistance developing ● Increased soil fertility ● Suppression of weeds ● Alternative production and sale of seeds or timber ● Increased aesthetics ● Improved water quality ● Plant and insect conservation

AES subsidies help offset some of the costs outlined in Table 1, as the programs offer compensation to farmers for any loss of income associated with efforts taken to enhance landscapes beyond the scope of their production (Batary et al. 2011). Using these types of best management practices can also result in less expenses from pesticides and insecticides, water use, and mowing. These practices help create a beautiful and sustainable agricultural system in which consumers will be attracted. This becomes increasingly important in a time when more and more people are frequenting farmers markets and more establishments are sourcing local food. In fact, there are many certification programs available in which producers can take part and use to enhance product promotion and sales. USDA Organic Certification and Accreditation is the most common program in the United States in which a producer can show they do not use any chemicals to grow their products. Another program, called Bee Friendly Farming (BFF) offered by the non-profit Pollinator Partnership (P2), requires farmers to follow certain sustainability criteria in exchange for using their logo to show the public their products are coming from a bee-friendly farm. Criteria include maintaining at least 6 percent of one's landscape for pollinator habitat, using an Integrated Pest Management (IPM) approach and providing clean water for bees. IPM is a pest control strategy that focuses on ecosystem-wide and long term protection from pests. This includes a combination of habitat modifications, sustainable management practices and only using chemicals when absolutely necessary and by industry-safe standards. IPM helps prevent misuse of pesticides that can cause risks to humans, non-target organisms and the environment. Integrated Vegetation Management (IVM) utilizes similar techniques to control vegetative pests like invasives and noxious weeds. When comparing organic to conventional farming practices, the crop yield gap observed is closing due to the implementation of diversification practices. Organic yields are now only trailing conventional farming practices by 19% (Ponisio et al. 2014). While yields are still lower the environmental and societal benefits more than outweigh the loss.

Methodology

The sections that follow are an analysis of four habitat modification strategies that can be utilized to promote beneficial insects on agricultural landscapes: 1) managing field margins 2) buffer strips 3) implementing diverse patchy landscapes and 4) native plantings. Techniques were chosen based from a preliminary data review suggesting their promise of increasing biodiversity while providing benefits to farmers and other ecological system services. Each of these habitat modification strategies can be scaled down into sub-categories. Primarily, the studies examined focus on managing permanent hedgerows and windbreaks, herbaceous and grassy buffer strips, patchy island habitats and strictly native plantings. Particular emphasis is given to studies concerning pollination services and pollinator species dynamics as well as biological control. Additionally, focus was chosen for these four habitat modification strategies in part because other studies have noted that there is inconsistent or limited beneficial findings on other techniques, like ground cover crops or intercropping, on natural enemies (Landis et al. 2000). Such practices can also cause more disturbance and result in the need for more chemical management than the four chosen strategies. The techniques chosen for this paper are those that have been heavily studied and that do not always require drastic changes in farming practices. In fact, the implementation of these practices do not always demand that land be taken out of production. Instead land managers use adjacent lands, margins, or patches that go otherwise unused.

This comparative analysis utilizes findings from many academic, peer reviewed papers and government agency reports. An analysis is given of a compilation of these resources that cover a wide range of topics concerning sustainable agriculture, natural pest control and pollinators. Sources for the analysis section were chosen based on their credibility, scope and which detailed one specific, or compared multiple, agricultural landscape modification techniques. Information was also gathered from a survey of farmers to gain insight into the producer's perspective. United States, Canadian and Australian farmers enrolled in the P2's BFF program were approached to complete the survey. A synthesis of the survey results based on percentages of adoption by farmers and success in terms of pollinators, natural enemies, and consumer attractiveness is given. These interviews served as a fact-check to ensure the quality of this literature review. Discovering first hand which methods work best for producers and how willing they are to utilize these practices has helped generate a useful list of recommendations that can be easily adopted and adapted. Recommendations for farmers, public and private land managers, and policy makers are developed based on a synthesis of the studies examined and interviews recorded. Recommendations outline agricultural management techniques that are feasible and beneficial to the environment and society. Critiques of some diversification methods are noted in order to develop the best recommendations possible. Key findings from the reviewed papers that analyze the four landscape modification strategies are detailed below.

Landscape Modification Techniques

The approach and technique used to incorporate floral resources in an agricultural system can determine the valuation of the benefits. Careful design of field margins as well as increasing the presence of native plants to enhance seed banks must be considered (Rands and Whitney 2010). There are various techniques that can be used by landowners and producers when creating a diverse agricultural system. It has been found that three effective landscape modification techniques that can transform a crop field into beneficial habitat are 1) managing field margins such as ditchbanks, hedgerows, windbreaks; 2) the implementation of inter-field polycultures of various crops and arrangements; and 3) establishing weed borders, alternate rows, or by providing weeds with diverse bloom periods (Altieri and Letourneau 1982). Another study found that in tropical systems, there is increased crop yield with increased bee abundance especially when they are near home gardens, particularly those that are near forests (Motzkea, 2016). The potential for trees as adequate nesting and foraging resources in certain times of year can be an was a recurring theme in many of the papers. Windbreak placement and tree type as well as proximity to forests could be a potential consideration when recommending where to place crop fields or establish breaks. The following well-studied habitat diversification strategies have been found to be the most promising in attracting pollinators and beneficial predators: 1) managing field margins 2) buffer strips 3) implementing diverse patchy landscapes and 4) native plantings. In the next four sections, these techniques will be explored one-by-one and reports exploring the effectiveness of these techniques will be summarized.

Managing Field Margins

Managing field margins can be an effective way of reducing the negative impacts of monoculture farming while attracting pollinators and natural enemies. As depicted in Figure 3, field margins can come in many forms and sizes. In general field margins are uncultivated, semi-managed lands that separate crop fields from one another around the edges (Rands and Whitney 2010).

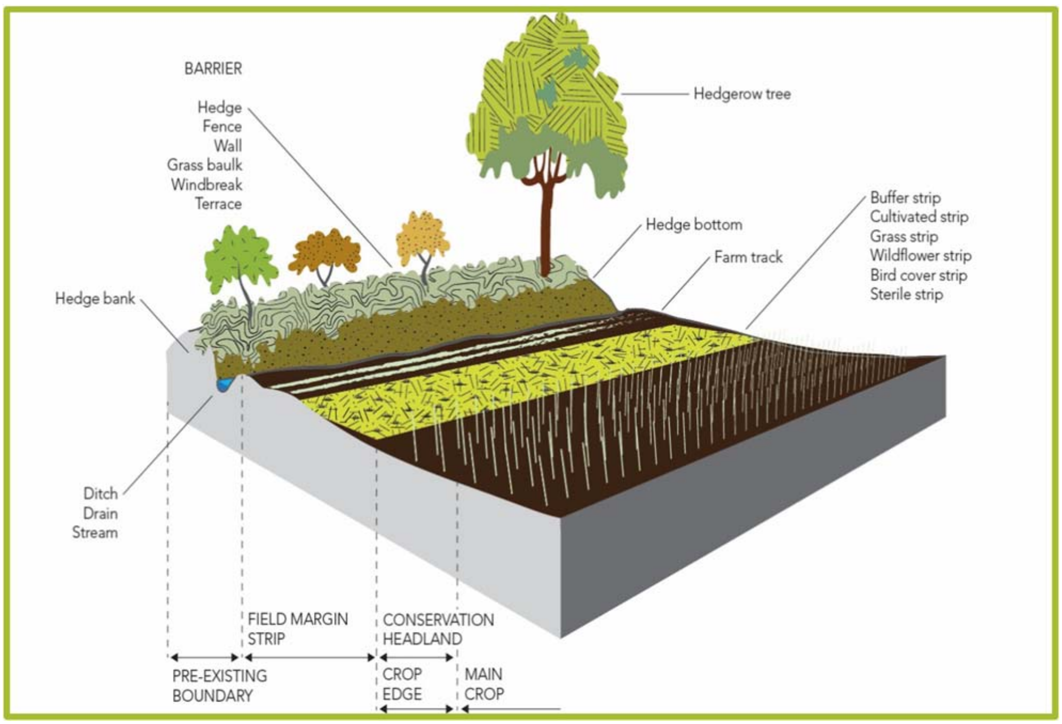


Fig. 3. Field margin types in arable farming (Marshall and Moonen 2002)

Field margin enhancements are generally a permanent landscape feature of trees, shrubs or woody perennial plants. The most common type of field margin feature is a hedgerow. Hedgerows and other field margins act as a green corridor, providing sanctuaries for wildlife. In comparison to other agricultural diversification features, field margins provide sturdy, protective and long-term habitat. Pollinators and natural enemies utilize these areas mainly for rearing, nesting, and hibernation sites. As a result, field margins can increase regional biodiversity and ecosystem services within agricultural landscapes (Rands and Whitney 2010). Field margins also prevent the transfer of pollutants to areas outside the agricultural landscape (Hackett and Lawrence 2014). High hedgerow surface cover on large landscapes can benefit both natural enemies and pollinators. One study found aphis parasitism to increase by 6% and pollinator visitation rates enhanced up to 70% (Dainese et al 2017). The hedgerow quality in this instance was not the driving factor but more importantly the hedgerow systems provide ecological corridors for beneficial insects. When utilizing hedgerows in agricultural, farms need not take land out of production but can simply conserve essential habitat.

Managing Field Margins and Pollinators

Pollinator behavior, health, and ability to provide pollination services is dependent on a multitude of factors. In terms of field margins, pollinator behavior is altered by floral resource density and floral resource type. Figure 4 shows how field margins established throughout monocrop fields can greatly increase the foraging area of a pollinator based on the location of their nest within the field margin (Rands and Whitney 2010). The layout and geometry of a landscape has been found to have a significant effect on the foraging trajectories of pollinators, however, one study found that the common bumble bee species, *Bombus impatiens*, was much more affected by density-dependent preferences. Even small increases in the width of field margins led to a greater shift in foraging behavior and increased floral resource density in the margins led to a higher preference for monoculture crops (Rands and Whitney 2010).

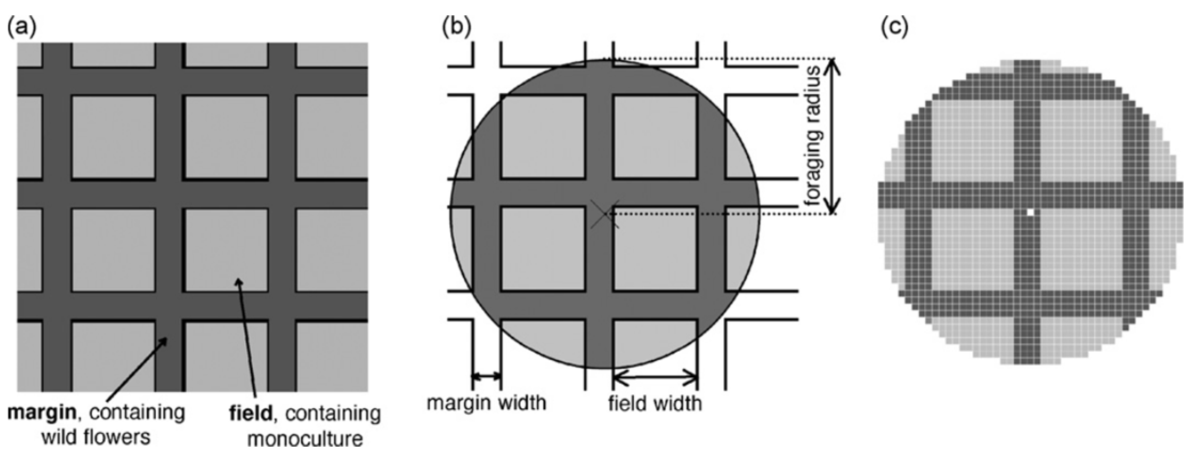


Fig. 4 Field margin geometry. (a) The square-grid landscape of grey monoculture fields separated by dark grey field margins. (b) "X" shows the site of a randomly chosen pollinator nest location in a field margin. The grey circle depicts the forage area of the pollinator within the field and margin area. (c) Square grid of the pollinator's foraging area (Rands and Whitney 2010).

When assessing pollinator communities on agricultural landscapes in the Central Valley of California where hedgerows of native flower shrubs were present, one study found hedgerows to greatly increase biodiversity (Morandin and Kremen 2013). The researchers assessed floral and nesting characteristics of the two types of field margins, and pollinator abundance, diversity and community composition was compared. As suspected, there was greater floral cover and richness in hedgerows than in the weedy edges. There were also more potential nesting sites for native pollinators in the hedgerows in the form of hollow stems and branches, while there was more unused, bare ground in the weedy edges. For both pan-trapped and net-collected native bee specimens, there was no difference in overall abundance, yet uncommon species of native bees were far more abundant than in non-managed weedy field edges. Researchers found the same to be true of uncommon syrphid fly species in addition to more net-collected honey bees in the hedgerows (Morandin and Kremen 2013). Not only can hedgerows support biodiversity in agricultural landscapes they can help restore diversity to once degraded lands by reintroducing various pollinators that will ultimately increase pollination services. One study in California compared a large dataset of approximately 9,800 specimens from 545 samples collected on intensively managed farms and compared it to restored landscapes planted with native hedgerows. They found that the latter scenario, when replicated across a large farmscape, can increase biodiversity by about 14%. Some levels of biodiversity recorded were similar to those of natural communities found on comparable landscapes (Ponisio et al. 2015).

There has been some debate surrounding whether hedgerows planted with native shrubs and forbs actually promote conservation of pollinator species or serve as transient sinks. In order to settle this debate research was conducted to determine if diverse native plant hedgerows increased pollinator occupancy, if colonization was increased, if specialist vs. generalist species were more affected and if occupancy can be related to pollinator richness patterns (M'Gonigle et al. 2015). By observing and comparing 5 restored to 10 non-restored control hedgerows the researchers found that restoration increased pollinator species richness by improving seasonal persistence and colonization. Specialized foragers strongly responded to this benefit, promoting their overall survival rates which tend to be lower than generalist species. Conventional field edges lack the important floral pollen sources, like legumes (*fabaceae spp.)*, that support specialists. Bumble bees (*Bombus spp.*) and solitary bees, such as miner bees (*Andrena spp.*) were found to benefit strongly. Most importantly, these habitat modification techniques tend to support species that are under the most threat from loss of habitat. It is interesting to note that the hedgerows were irrigated and weeded for three years after planting at which point no other maintenance was required (M'Gonigle et al. 2015).

Additionally, when comparing pests to beneficial insects found in hedgerows in California, the abundance of insects like pollinators and natural enemies is greater than pests. Unrestored, weedy edges had consistently greater pests and fewer beneficials. Of 10,323 insects collected in one study, 78% were beneficials (Morandin et al. 2011). Beneficial insect abundance was strongly correlated with the bloom period of each shrub species planted. These findings advocate for providing continuous bloom in which native invertebrates can collect nectar and pollen throughout the seasons. Hedgerows were also planted with grass buffers that in combination have been found to be quite effective (Morandin et al. 2011). These findings show that enhanced hedgerow plantings can promote beneficials while replacing other weedy areas that can serve as refuge for pests.

Managing Field Margins and Biological Control

Morandin et al.'s study from 2014 is a comparative analysis of restored, California native perennial hedgerows to unenhanced field edges consisting of commonly occurring semi-managed, non-native weeds. This study looks at how restored hedgerows can help control pests in adjacent cropland. Pests that have a major negative impact economically were found less than beneficial parasitoid wasps in hedgerows compared to weedy crop edges. Greater predator richness was found in enhanced hedgerows than in weedy edges. More predatory lady beetles and fewer aphids were founds in fields with hedgerows. Additionally, the benefits of hedgerows to pest control were found to only extend about 100 meters into the tomato fields and in comparison; farm-scale hedgerow restoration with multiple rows around fields can provide deeper benefits and pest control throughout entire fields. Based on these findings it can be concluded that hedgerows result in greater benefits than weedy edges when managing to inhibit pests (Morandin et al. 2014).

Hedgerows that are constructed of trees and shrubs have been found to be especially effective in attracting generalist parasitoids. Such parasitoids, which control lepidopteran pests in corn, soybean, wheat and alfalfa, are attracted to hedgerows due to the high density of alternative hosts and prey in the woody vegetation. These habitats also maintain a moderate microclimate that helps support parasitoids that have shorter life expectancy at more extreme temperatures (Bianchi et al. 2006). This has been demonstrated in the field and in the lab with one study showing that parasitoid wasps had a better survival rate at 25 degrees Celsius, compared to 35 degrees Celsius (Landis et al. 2000). Additionally, in corn fields, female predator parasitoids were commonly found close to wooded field edges and overall parasitism was higher in fields that had woody margins (Landis et al. 2000). Similarly, syrphid flies, who's larvae eat insect pests, are more attracted to enhanced hedgerows in comparison to unenhanced field margins. In one study, 893 occurrences and 27 of 30 species of *syrphidae* were found in enhanced hedgerows in comparison to only 540 occurrences and 26 species at control sites (M'Gonigle et al. 2015). Similarly, throughout the globe, farmers have found eucalyptus trees (*Eucalyptus torelliana*) to be a refuge for natural enemies when used as large, permanent windbreaks that line the borders of crop fields (Landis et al 2000). In instances where farmers had to use pesticide applications, predatory mites were able to recolonize quickly in the eucalyptus windbreaks. This made them more effective in managing phytophagous mites and thrips. Overwintering survival of natural predators of pests is generally low due to the absence of vegetation in crop field interiors over the winter months. When managing field margins by using windbreaks and hedgerows farmers can provide protective habitat during overwintering that will result in a more successful following growing season (Landis et al 2000).

Buffer Strips

Buffer strips are used widely in many types of managed land. They are established near bodies of water, along roadways and in farmlands to help prevent pollutants from drifting or running off to adjacent lands. The USDA Natural Resources Conservation Service (NRCS) describes conservation buffers as small areas or strips of vegetated land (NRCS 2017). Buffer strips are most commonly used in riparian areas combating many of the negative effects mass livestock ranching and non-organic farming practices cause. Figure 5 illustrates how designed buffer strips that are put in place between cropland and water bodies can intercept nutrients, transfer biomass and reduce runoff (The James Hutton Institute 2017). The benefits from buffer strips lead to enhanced water quality and reduce greenhouse gas emissions and reduced eutrophication.

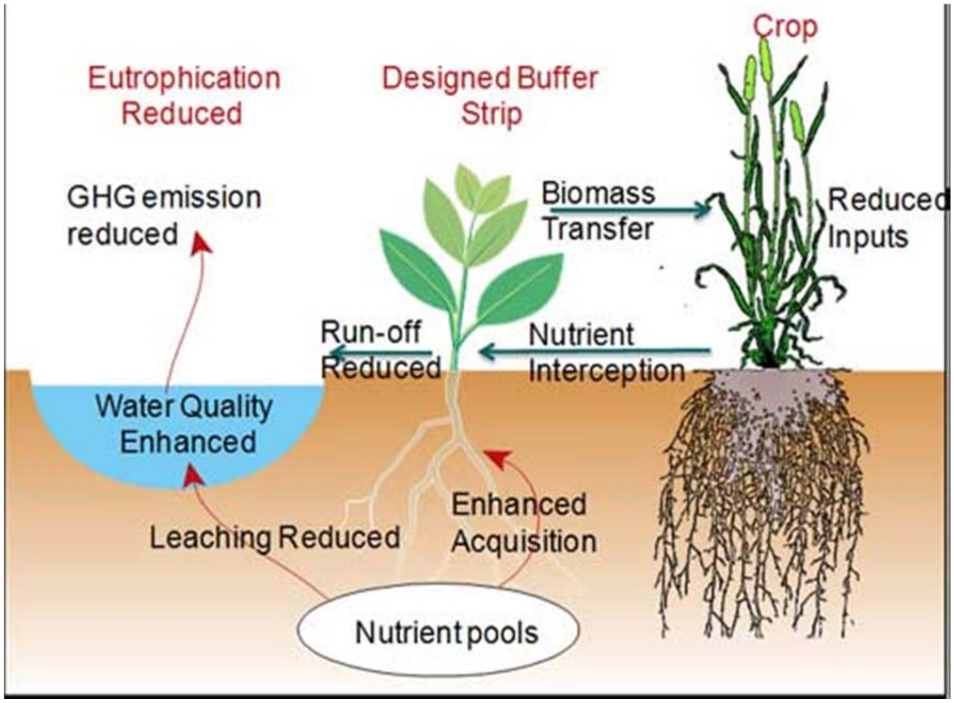


Figure 5. Engineered buffer strip (The James Hutton Institute 2017).

Conservation buffers can also slow water runoff, trap sediment, and tame harsh weather elements. In an agricultural setting, buffer strips can enhance farmlands by providing wildlife habitat while controlling pesticide drift, fertilizer runoff and nutrient retention. Figure 6 depicts a buffer comprised of tall native grasses and perennial plants (Office of the Governor of Minnesota 2017). This type of buffer strip will prevent erosion, filter pollutants and help maintain ditches, which can be positive sinks for pollutants. Some policy and land manager regulations have been put in place to help encourage the implementation of buffer strips. For example, the Governor of Minnesota proposed a bill that required 125,000 acres of land adjacent to water to be designated for buffer strips, and covered in perennial vegetation. More permanent, perennial vegetation is important in increasing the efficacy and lowering the maintenance of a buffer strip. When buffer strips are installed with rich floral resources, they will attract pollinators and natural predators that will help control pests. Buffer strips comprised of grass species are easy to establish and have been found to keep their functionality over time making them quite inexpensive for farmers. Buffer strips in or near croplands provides nesting, foraging and shelter for beneficial insects as well as game birds and other wildlife (MacLeod et al. 2004).

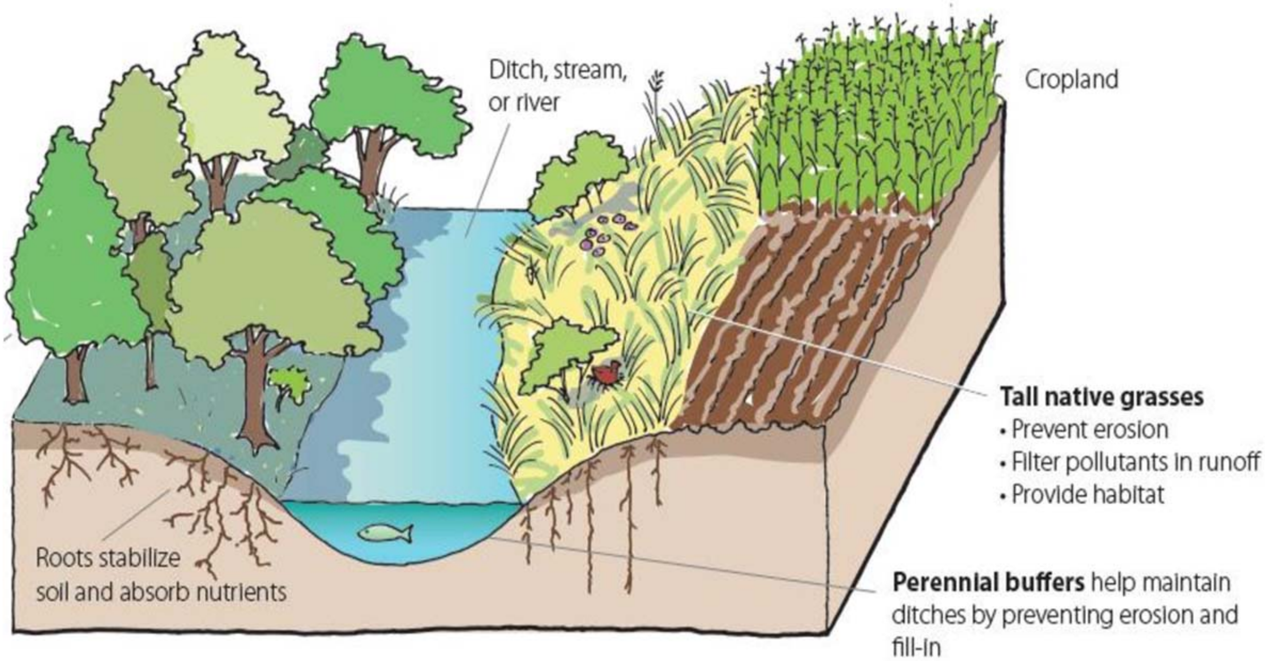


Figure 6. Agricultural landscape with a native grass and perennial vegetation buffer strip model, applicable to protecting ditches, streams or rivers (Office of the Governor of Minnesota 2017).

Buffer Strips and Pollinators

Environmental Stewardship (ES) in England has encouraged the implementation of natural habitat for pollinators on agricultural properties. ES schemes focus around restoration of degraded lands and can be quite effective in supporting pollinators. One study compared the efficacy of enhancement in marginal buffer strips for bumble bees on arable lands (Carvell et al. 2007). Arable land is capable of being ploughed and supporting crops opposed to pasture lands for grazing. These lands have great potential for promoting natural habitat and wildlife. Buffer strips sown with nectar and pollen plants were found to attract many more bumble bees than grassy margins. Bumble bees visited legume plants the most, due to their early and sustained bloom period as well as their fast growth. Overall marginal buffer strips enhanced with floral resources were found to be more effective in attracting bumble bees, however, in order to attract a diversity of beneficial insects, providing resources with longevity and varying bloom periods is critical (Carvell et al. 2007).

In a study from 2015, Austin et al. found buffer strips to be one of the two most effective landscape enhancements for pollinators. At best, a diversified agricultural landscape will provide a pollen source, nectar source, rearing location, nesting location and hibernation location for pollinators. As seen in Table 2, buffer strips provide nectar and pollen sources as well as nesting locations, or three out of the five main necessities for pollinator health and species success (Austin 2015). These three necessities are considered the most important in terms of pollinator health and while two other landscape enhancements exhibited the same three resources, buffer strips were thought to have the best quality and largest quantity of these resources (Austin 2015).

Table 2. A comparison of five landscape enhancements and whether they provide the five most important necessities for pollinator success (Austin 2015).

Landscape Enhancement	**Pollen Source**	**Nectar Source**	**Rearing Location**	**Nesting Location**	**Hibernation Location**
Hedgerow management	X	X		X	
Woodland Edge Management			X	X	X
Buffer Strip Enhancement	X	X		X	
Field Corner and Margin Management	X	X		X	
Nectar Flower Mixture	X	X			

One study conducted on conventional almond orchards in California found that in orchards with a low percentage of surrounding natural habitat, the presence of a buffer strip significantly increased the floral visitation frequency of wild bees, hoverflies (*Syrphidae*) and other native pollinators (Klein et al. 2012). They also increased the species richness of wild bees and all other visitors with a greater flower visitation frequency for wild bees at the orchard edge than the interior. The buffer strips did not increase the flower visitation frequency for managed honey bees, nor did they increase fruit set in orchards with low natural habitat. It seems that the stocking level of managed honey bee hives was more of an indicator variable for fruit set than the surrounding natural habitat (Klein et al. 2012). It is recommended that buffer strips be plowed and reestablished every 7 years (Williams et al 2015).

Buffers Strips and Biological Control

Many natural predators of pests benefit from buffer strips and their rich food sources. In Sweden, farmers use buffer strips or “weed strip management” where they have found a host of natural predators to have increased activity density such as, *Coleoptera*, *Araneida*, *Hemiptera*, and *Diptera* (Landis et al. 2000). Parasitoids have a longer lifespan and higher fecundity when substantial nectar sources are present. Chysopids, coccinellids, syrphids and parasitoids all have been observed frequently taking advantage of field nectar sources. These insects then spread into the surrounding crops aiding in pest control (Bianchi et al. 2006). One literature review looking at spider abundance in croplands showed a positive correlation in landscape diversity and abundance. Spiders are generalist predators and can be extremely effective in controlling herbivorous pests. Of the studies considered, aggregated diversification, buffer strips for example, showed an increase in 33% of the studies and interspersed diversification showed an increase in 80 percent of the studies This shows that interspersed diverse habitat patches can provide the best conditions for supporting pest control by spiders (*Araneae spp.*) (Sunderland and Samu 2000).

Insectary plants that are the best plants for attracting beneficial insects, provide nectar and/or pollen in buffer strips. Common California buffer strips, also known as insectary plantings, are comprised of flowering plants and perennial native grasses (Long et al. 1998). Adult natural enemies utilize the nectar and pollen from these plants in times of decreased prey. Natural enemies can in times fully supplement their diet with floral resources alone, however; providing continuous bloom is essential. In order to determine the extent to which beneficials were using floral resources, Long et. al injected rubidium chloride (RbCl) into the plants in their buffers so they could then see where insects were moving throughout the crop fields. They found that beneficials feeding on insectary plantings moved into and therefore benefitted nearby crops. In fact, beneficials with RbCl detected were found 250 feet from buffer strips gaining food resources and establishing themselves in crop field where they can help control pests in time of an influx of prey (Long et al. 1998).

Beetles, such as carabids or staphylinids, are ground dwelling generalist predators. These natural enemies are very effective in controlling pests in agricultural settings and have been found to inhabit grassy banks known as ‘beetle banks’ (MacLeod et al. 2004). Beetles and spiders find refuge during overwintering in these buffer strips which are being widely used in cereal fields in the United Kingdom. By making native grass strips available within crop field habitats, pests can be controlled naturally. It is important to choose a selective mix of non-invasive or aggressive species of grass when establishing the buffer strips. When observing the landscape enhancements overtime, researchers found higher densities of predators after beetle bank establishment, particularly after the first year. In this instance, an astounding 17 genera and 24 species of carabid beetles were found over seven winters (MacLeod et al. 2004). Buffer strips reported more consistent temperatures that the unmanaged field boundaries. There is a definite positive correlation between the overwintering success of predators and the stability of temperatures. Additionally, researchers found the spider community to be more robust in more a more complex compilation of vegetation. Of the 233 species studied, 84% were observed overwintering in the diverse epigeal vegetation (MacLeod et al. 2004). Similarly, rape pollen beetle (*Meligethes aeneus*) presence has been dictated by the presence of buffer strips in Northern Germany. In this instance, the beetle is a pest in oilseed rape crops (canola), and its control by larval parasites was increased with the presence of buffer strips. When the area of natural areas fell below a value of around 20%, parasitism of the pest also dropped below the threshold value of about 35%. Such a strong correlation has not been found in classical biological control (Theis and Tscharntke 1999).

Diverse, Patchy Landscapes

The techniques discussed thus far, practicing field margin management and strips of habitat, can be impediments to biological control as they can provide such good refuge the natural enemies stay there and do not benefit crop fields. Therefore, connecting this refuge to crop plants and other natural areas is critical to promote these invertebrates (Landis et al. 2000). In ecology, patch dynamics are a representation of an entire ecosystem over space and time. Patch dynamic theory looks closely at the small-scale components of a greater landscape and the structure and function that result in the larger picture. Due to modern development, including clearing natural landscapes for pastures and croplands, habitat fragmentation has had a major impact on many wildlife species. Natural enemies to pests and pollinators have been no exception. However, it can be beneficial to work with existing landscapes and see how they can be managed to decrease the isolation to natural habitats. By implementing diverse patchy landscapes on agricultural landscapes, land managers can facilitate connectivity for these beneficial insects. Natural habitat patches and corridors can help wildlife thrive in crop dominated regions. Patch size and isolation can have various impacts on species richness and population density for different species depending on inter and extra-species interactions.

Diverse Patchy Landscapes and Pollinators

According to optimal foraging theory the distance from natural habitat can decrease the pollination services provided by pollinators. Diverse patchy landscapes provide fueling stations for pollinators as they traverse agricultural landscapes. When comparing conventional farms to heterogeneous ones that incorporate habitat patches, one study found that bumble bee species richness and abundance was far greater in the diverse landscape. Interestingly, bumble bees with medium sized colonies showed the strongest correlation. Researchers concluded that these pollinators are the most affected by foraging fragmentation (Rundlof et al. 2008). Smaller native bee, like *halictids* spp., fly shorter distances and having natural areas to rest and collect nectar and pollen is vital. Crop flower visitation rates increased on average by 25 and 39% for spatial and temporal variation respectively when distance to natural areas was decreased to 1 km (Garibaldi et al. 2011). Similarly, mean visitation of pollinators decreased with isolation from natural areas. The mean fruit set of crops also decreased with isolation. These effects will be lower for pollinators with longer ranges of flight, like *Bombus spp.* in comparison. These findings prove that diverse patchy landscapes are particularly important to wild pollinators and for their contributions to crop productivity even in the presence of honey bees (Garibaldi et al. 2011).

When looking at vegetable crop pollination by bees, it has been observed that setting aside natural areas adjacent to fields can increase crop visitation. In one particular study in Indiana on cucumber crops, land cover did not affect species richness, simply having natural areas within 250 m of the vegetable patch increased visitation frequency of bees (Smith et al. 2013). Due to a decline in overall pollination services caused by increased distance to remnant vegetation, crop yields also suffer (Saunders et al. 2015). This negative correlation proposes that with the implementation of diverse patches of natural habitat can increase crop yield and fruit set.

Individual plants have been found to produce a larger quantity and larger seeds when implementing habitat enhancements that decrease distance for pollinators to travel (Albrecht et al. 2007). The most common type of AES is called ecological compensation areas (ECA), which can include a variety of landscape modifications like buffer strips, hedgerows and extensively managed meadows. On the contrary, intensively managed meadows (IM) are those that are mowed often and fertilizers are used to stimulate growth and keep out weedy plant species. One study compared the distance of potted plants on an ECA to IM, and the effect it had on pollinators. It was observed that species richness and abundance for syrphid flies, solitary bees, social bees and butterflies were significantly higher on ECA landscapes than in nearby IM. Small pollinators in IM declined more drastically with increasing distance from ECA. The actual area of the ECA did not influence the species richness and abundance, but distance played a big role in the pollinator population dynamics (Albrecht et al. 2007).

Diverse Patchy Landscapes and Biological Control

While assessing the efficacy of natural pest control in crop systems, one study suggests that natural pest control is enhanced in diverse patchy landscapes that incorporate natural habitats as compared to large monoculture cropping systems (Bianchi et al. 2003). That said, a later study by the same principal investigator found that natural enemies are most active in herbaceous habitats followed by wooded habitats and then active in patchy landscapes. Conversely, pest pressure on crops was reduced the most in patchy landscapes (Bianchi et al. 2006). When sampling herbivorous insects in 31 alfalfa fields in Canada, researchers found that more isolated fields had higher pest insect richness. Additionally, fields with more frequent disturbance regimes had lower pest richness and those that had been established for longer periods of time had higher herbivore insect richness. This points to the fact that both crop rotation and natural disturbance can be important to the patch mosaic of a landscape. Increasing the continuity in agricultural lands, by decreasing isolation can also help suppress pest populations (Fahrig and Jonsen 1998).

Island habitats have been studies widely in many facets of ecology. Island habitats on agricultural lands were first studied in the early 1990s in England in an attempt to manipulate beneficial insect behavior. Thomas, Wratten and Sotherton (1992) found that predator densities and species compositions were altered in the presence of habitat in the center of crop fields. This technique does not seek to create new boundaries or change existing habitats, but it re-creates refuge that may have previously existed. This study utilized many native perennial grass species that are found in buffer strips that have been known to increase overwintering success of many invertebrate species. They found that there was a successional shift in species composition after the implementation of the island habitats. As the habitat patches matured, specialized species were more prominent than pioneer species. Specialized species have been found to have more lasting impact on their environments than those that exploit opportunity in young landscapes (Thomas et al. 1992).

Native Plantings

Ecoregions, as defined throughout the United States and much of the world, are areas that have similar geography that receive uniform solar radiation and precipitation. As a result of these factors, the vegetative communities in these regions are consistent and help shape the definition of the ecoregions. The plants that naturally occur in these areas are thus considered native and these particular species will grow in the region's climate and they will support native wildlife. Incorporating native plants into agricultural systems will create a more productive farm overall. Native plantings increase species diversity in addition to improving food resources, soil nutrient loads and plant productivity. The Plant Conservation Alliance, chaired by the Department of the Interior Bureau of Land Management (BLM), has announced a national native seed shortage. Due to many natural and anthropogenic events and practices, native needs throughout the country have been in decline. Now at a time when there is finally a trend in planting native plants, the supply cannot keep up with the demand. By maintaining native planting on agricultural landscape farmers can contribute to the National Seed Strategy for Rehabilitation and Restoration developed by BLM (Plant Conservation Alliance 2015). Their main contribution, however, is supporting native pollinators and natural enemies, many of which are at risk.

Native Plantings and Pollinators

Nectar flower mixtures, while not providing all components of pollinator habitat, have been found to be overall one of the best habitat enhancements on agricultural land (Austin 2015). Promoting native plants on farm landscapes attracts native and managed pollinators to the area. For example, wild bees that provide pollination services to vegetable crops depend on forage resources, rearing sites, nesting sites, and overwintering sites in the agricultural landscape. When such habitat is provided, there is increased visitation to crops, which is strongest when natural areas are within 250 m of the field (Smith et al. 2013). Wild pollinators can be beneficial to crop productivity and stability even in a system where commercial honey bees are abundant (Garibaldi et al. 2011).

With a recent campaign to plant native plants in the United States, various seed mixes are being tested for their efficacy of attracting pollinators. One study tested different wildflower mixes in areas with high pollinator-dependent crops in three regions of the United States: California's central valley, north-central Florida and western Michigan. In comparison to a control plot that was left to naturally propagate with local vegetation, researchers found that in all regions, the wildflower mixes attracted a greater abundance and diversity of pollinators than unmanaged weedy edges (Williams et al. 2015). Wildflower mixes attracted 60 species of native bees in Florida, 52 in Michigan and 80 in California. These each represent high community diversity of wild bees, which continued into year two for all regions. When assessing the differences of annual and perennial wildflower mixes and their ability to attract diverse bee species, Florida showed little difference, California favored perennial mixes, and there was no significant difference found in Michigan. Response of bees to increased floral diversity within the mixes was never significant and mixes always showed seasonal shifts in abundance of wild bees (Williams et al. 2015). The strongest correlation found in attracting wild bees was year-long, continuous bloom. Honey bees exhibited a strong attraction to wildflower plots opposed to the control plot, however in all regions highly diverse mixes failed to attract a more wild bees than basic mix composition. Is found to be increasingly critical to thoughtfully identify plants and assess their efficacy as a mix. Wildflower mixes provide high quality pollen and nectar to pollinators (Williams et al. 2015).

Native Plantings and Biological Control

In the same study described above, researchers found that all native wildflower mixes supported syrphid flies. Syrphid flies are pollinators, yet they can be equally as important to biological control of pests in agricultural landscapes. Syrphid fly larvae feed on insects, like aphids and thrips and other plant-sucking insects, which can be detrimental and widespread pests to many crop species (Williams et al. 2015). Some parasitoids are dependent on their hosts for sustenance, while others need access to food sources provided by plants. Floral nectar and pollen is consumed by many insect predator species and by maintaining their health in times of host food scarcity, their parasitism rates can be increased. Nectar rich species are more important that pollen rich floral resources, as they provide nutrition and hydrate insects (Landis et al. 2000). In terms of reproduction, native plantings have been found more effective in promoting natural enemy needs. Native herbaceous species are often utilized by natural enemies as oviposition locations. For example, *Coleomegilla maculata,* the spotted lady beetle, favors native floral resources and has been observed laying more eggs on those species than crop plants (Landis et al. 2000). As in all cases described above, land managers must be selective when choosing which plants to bring into their landscape. For example, through a laboratory study on which pollen and nectar sources would be best for pest moth suppression and parasitoid promotion, the *Boraginaceae* family was chosen for future field work due to its ability to enhance parasitism while not used by the moth. Table 3 complies the finding in the previous four sections and compares the four landscape enhancements and whether they provide the four most important necessities for natural enemies. Native plantings provide 2 of the four main requirements for natural enemies, both being food sources. While other landscape enhancements may provide more benefits, the implementation factors of these strategies must be considered carefully.

Table 3. A comparison of four landscape enhancements and whether they provide the four most important necessities for natural enemies.

Landscape Enhancement	Prey Source	Supplemental Food	Climate Control	Overwintering
Field Margin Management	X	X	X	X
Buffer Strips	X	X	X	X
Diverse, Patchy Landscapes	X	X		
Native Plantings	X	X		

Implementation of Habitat Modification Strategies

The approach of farmers and agricultural producers take when implementing the techniques described above is paramount in their success. Understanding the support for and challenges of technique adoption helps to formulate feasible recommendations. While controlled studies have proven that these practices do in fact increase the number of beneficial insects on agricultural landscapes, if farmers do not adopt these practices they will not make a difference in conservation. The following sections explore what practices most farmers use, the difficulties they face and the support options they may receive. One meta-analysis looking at different Agri-Environmental Management (AEM) projects found that there is a stronger positive correlation to benefits in simple compared to complex landscapes (Batary et al. 2010). In simple landscapes, AEM had improved biodiversity and significant between-group heterogeneity. When looking at both cropland and grassland agricultural settings, species richness benefitted from AEM regardless of land-use type. One of the most important takeaways for the implementation of agricultural landscape enhancements is that there are different responses among various taxonomic and functional groups (Batary et al. 2010). Still, in general terms of beneficial insect promotion, pollinator-friendly practices were found to have significant positive impacts on both simple and complex landscapes.

Collaborative AES (cAES), in which multiple farms work together to build a landscape-wide AES, can be more beneficial than those at the single farm scale. For example, in term terms of biodiversity, over one third of the wildlife species in English farmscapes utilize habitat ranges on much larger scales than that of a typical farm (McKenzie et al. 2013). This is especially true during breeding seasons where species may need to travel farther to find mates. Size and quality of habitat is important but connectivity and distance between natural areas is vital. By decreasing habitat fragmentation and isolation that can occur in agriculturally dominated areas, beneficial insects can be promoted. Through coordination of habitat restoration on farms, invertebrates, such as native bees, will be able to thrive (McKenzie et al. 2013).

In a comparison of hedgerows to unmanaged weedy edges (controls) in California, the economic benefits of pollination ecosystem services and the savings from decreased pesticide use were calculated (Morandin et al. 2016). The cost of standard hedgerow establishment and the increased income from amplified pollination and decreased expense from natural pest control were weighed. Overall, restoration practices on farms were found to increase the presence of pollinator species, especially native bees, as well as increase the abundance of natural enemies. The installation of a hedgerow of standard size and type was found to be $4,000, although through a USDA AES program called the Environmental Quality Incentive Program, the government pays for up to 50% of the cost (Morandin et al. 2016). The estimated cost of one treatment for a pest, such as aphids, is about $692 and the benefits from pollination services can be up to $2,426 for a 16 hectare field. By utilizing native plants in hedgerows, farmers can not only increase native pollinator abundance, but they can save money on hive rentals, which is about $65 per hive. These economic benefits can begin to be observed after 5 years after implementation (Morandin et al. 2016). When advocating for, and looking at the indirect costs of implementing hedgerows, it is important to note that in general hedgerows that are part of field margins do not occupy otherwise cultivated land. They also do not generally get big enough to compete with adjacent fields for resources, like water. However, hedgerow plants do take about three years to mature, resulting in a delay in their benefits.

Bee Friendly Farming

Pollinator habitat is also utilized by other wildlife and particularly other beneficial insects like natural predators that control pests that plague agricultural fields. Pollinator Partnership (P2) is a North American focused nonprofit organization that works to promote the health of all pollinator species and their ecosystems. P2's Bee Friendly Farming (BFF) program is a self-certification program for farmers. The program requires that farmers 1) provide forage for pollinators on at least three percent of their land 2) plant a variety of plants resulting in continuous bloom 3) offer clean water 4) provide nesting, mating habitat 5) practice IPM or eliminate the use of chemicals and 6) paying an annual $35 certification fee. In exchange for abiding by these criteria, farmers are featured on P2's BFF program website and are able to use the program logo to promote their farm and products. While the program does not restrict members to a geographic location, the majority of farmers that are registered are in the United

States and Canada. Farmers can be of any size, from small farmers that simply provide for their families and neighbors, to larger commercial operations that sell to corporations and restaurants. Most however, are somewhere between, selling their products at local farmer's markets. Currently there are about 600 farmers enrolled in the program and P2 offers a map on their website in which you can see the locations of each member, see photos and be directed to their webpage if applicable. BFF offers great exposure to farmers that take sustainable practices, especially providing habitat for pollinators, into consideration when managing their lands.

In a survey conducted on Bee Friendly Farmers, landowners were asked a series of questions to assess the efficacy of utilizing habitat modification techniques on their landscapes. Responses were collected and analyzed from 18 farmers and findings are summarized in Table 4. Farms were mainly located across the United States and Canada, with one in Australia. Their operations ranged in size from 1 acre to 255 acres, the mean farm size of those surveyed was 32.5 acres. All farmers reported that they practice IVM and IPM, with some being fully organic. The farms produce a variety of crops and livestock including but not limited to poultry, hogs, cattle, vegetables, fruits, herbs, medicinal plants and nut trees. The most widely adopted landscape modification technique used was native plantings, followed by DPLs, and buffer strips, with field margin management being the least implemented. However, field margin management showed the highest percent of observed pollinator increase, with all 6 farms that use hedgerows noting pollinator benefits. DPLs and native plantings exhibited the second highest percent of increased pollinators. In terms of biological control benefits, field margin management, buffer strips and DPLs all resulted in 67% observed increases in natural enemies. While each habitat modification strategy resulted in similar results in terms of attractiveness to consumers, DPLs were slightly lower than the rest. Of those that did report consumers were more drawn to their products due to their bee-friendly practices, one Canadian farmer said that restaurants are especially happy to serve sustainable products. On the contrary, one Kentucky farmer reported that his customers simply care about market price.

Table 4: Survey result from 18 Bee Friendly Farmers. Results are represented in percentage of total individuals for techniques adopted and in terms of percent efficacy of each technique used for increased pollinators, natural enemies and attractiveness to consumers.

Landscape Modification Technique	**Percent Surveyed Farmers Adopted**	**Increased Pollinators**	**Increased Natural Enemies**	**Increased Attractiveness to Consumers**
Field Margin Management	33%	100%	67%	67%
Buffer Strips	50%	71%	67%	67%
Diverse, Patchy Landscapes	50%	88%	67%	56%
Native Plantings	89%	88%	50%	63%
Other (Cover crop, CRP, Prairies, Woodlands)	33%	50%	20%	67%

Other techniques adopted by surveyed farmers that were not researched in this paper include cover crop implementation, CRP subsidies, natural prairies and woodlands. Based on the results of the survey, none of these other techniques performed better than those outlined above. When asked if farmers observed improvements in crop production, 10 of the 18 farmers responded yes, reporting that soils are much healthier and increased pollinator abundance have improved yields as well as product quality. 13 of the 18 farmers surveyed said they, or a commercial beekeeper, introduce managed honey bees or other managed bees to their land to aid in pollination services.

Challenges of technique adoption

The main challenges described by farmers in their survey responses related to technique adoption and specific pests that require more intensive management. There are specific crops that have particular pests that can build up in the soil which means a tiller must be used to break the cycle, requiring mechanical input to solve the problem. Aphids were reported as the most common example of a difficult pest since they have been observed abundantly on native plantings but absent in planted crops. A few farmers noted physical labor as a challenge of planting new and replacing old windbreaks, hedgerows and buffers. Surveyed farmers noted some challenges with neighboring lands and individuals spraying chemicals that drift into their land. Other neighbors have been displeased with unkempt weedy, herbaceous lands. Lastly, perhaps the most obvious downfall of increasing natural areas on your landscape is that some land could potentially be taken out of production (Landis et al. 2000).

Despite many broad societal and economic benefits, there are still hesitations from producers when adopting these practices. Through an interview study in England, it was found that farmers favored small-scale options like hedgerows to more demanding, large-scale habitat creation. In this smaller sample size (32 farmers) 81% of farmers were willing to participate in cAES programs and in another larger interview study (122 farmers) 75% responded positively to participating. Financial hardships are the most commonly expressed reluctance from farmers (McKenzie et al. 2013). The most costly landscape enhancements are permanent buffer strips and nectar flower plantings, while on average the least costly enhancement are hedgerow management. In terms of lowest per unit cost, hedgerows are also the most efficient method for promoting pollinators on an agricultural landscape (Austin 2015). It should be noted that, in many cases, once landscape enhancements are well established, they require less management, upkeep and dedication from farmers.

Discussion

Selective diversity, or the thoughtful choice of plants and habitat modification techniques, must be practiced in order to enhance beneficial insects while not promoting invasive and harmful species. Findings show that through a careful selection of native plants and a combination of landscape enhancements, pollinator and natural enemies ecosystem services can be increased. Landscape enhancement is normally used in conjunction with complementary methods and it should not be used as a fix-all strategy for pollinator promotion or biological control. Methods are most effective when they are integrated into existing productions, and do not drastically alter practices. Compromises and working together with other adjacent lands and neighboring establishments is imperative in accomplishing realistic goals in on-farm conservation and wildlife promotion. cAES programs and large-scale enhancements for pollinators and natural enemies can strengthen the efforts of individual farms. Generally, wildlife operates at larger ranges than that of a single farm, and as a result many farms that make up a network of potential habitat is very effective. Connectivity between landscapes and the creation of corridors that combat habitat fragmentation is possibly the most critical component of enhancing farms for beneficial insects.

Hedgerow restoration on the farm-scale with multiple rows around fields can provide deeper benefits that extend throughout entire fields. Findings show that field margin management promotes native and uncommon, specialized species when compared to unmanaged landscapes. Effective native pollinator species, like bumble bee species, are particularly drawn to hedgerows. Woody hedgerows provide refuge and climate control for pollinators and natural enemies alike, improving their efficacy and life-span. They also provide floral resources for pollinators and additional prey for natural enemies. By utilizing this habitat modification technique, farmers will enhance ecosystem services from these beneficial insects. Hedgerow management, while sometimes having delayed economic benefits, do not require land to be taken out of production and do not compete with crops for resources like water. Hedgerows and windbreaks are labor intensive and take time to establish, however when established in conjunction with faster-growing buffer strips and native plantings, can be an effective habitat modification strategy.

In terms of maintenance, buffer strips must be rotated every 7 years but establish much faster than permanent woody field margins. When buffer strips are installed with rich floral resources, they will attract pollinators and natural predators that will help control pests. Buffer strips comprised of grass species are easy to establish and have been found to keep their functionality over time making them quite inexpensive for farmers. Yet, buffer strips sown with nectar and pollen plants were found to attract many more native pollinators than grassy margins. Buffer strips also provide nesting and overwintering location for pollinators and natural enemies. Continuous bloom in buffer strips is one of the most important factors when attracting a diverse pollinator community. Additionally, natural enemies have a longer lifespan and higher fecundity when substantial nectar sources are present in times of prey scarcity. Benefits from natural enemies were observed to often drift into nearby crops, not acting as a sink for beneficial insect occupancy. There is a definite positive correlation between the overwintering success of predators and the stability of temperatures, as provided by buffer strips. Buffers or banks of native grasses can be effective for ground dwelling natural enemies, like spiders and beetles.

Connecting this refuge to crop plants and other natural areas through diverse patchy landscapes is imperative to realize the full benefits of these beneficial insects. Providing habitat throughout landscapes is important to facilitate the movement of pollinator and natural enemies so they are able to reach crop fields and provide services. Diverse patchy landscapes provide foraging resources for pollinators on agricultural landscapes, yet the impact is species dependent based on foraging ranges. With this in mind, land managers should take into account what species they are trying to attract. Depending on the crop, diverse patchy landscapes have the ability to improve beneficial insect visitation and crop yields. Distance between habitat was a much bigger indictor than the actual area of vegetative resources, on species richness and abundance. Providing island habitats in the center of fields can not only revitalize land, but it can increase specialized beneficial insect species.

Findings show that native plantings support wild pollinators and European honey bees. Native wildflower plantings should focus on plant species that support the most abundant and diverse pollinators while providing continuous bloom throughout all seasons when regionally feasible. Planting both annual and perennial species can help balance differences in phenology and variation in weather trends. This is particularly important in current times of climate change. Seasonal shifts in wildlife and weather are inevitable, however, farmers can utilize native plantings to make the most of their growing season. Continuous bloom has been observed to be far more of an indicator of beneficial insect efficacy than just floral diversity or abundance alone. Nectar rich species, like those in the *Fabaceae* and *Boraginaceae* families, were found to be more important to beneficial insects than pollen rich foraging resources, as they offer hydration in addition to nutrition. In general, better fed animals will be healthier and have better reproduction success. Native herbaceous species are used as oviposition locations for specialized species of natural enemies. Native plantings were found to provide food for brood of beneficials while not promoting herbivorous prey species. Lastly, strictly native plant enhancements on agricultural lands, while slightly expensive for farmers, can cut down water usage.

Since the aim of this project is to inform agricultural producers, the economic benefits and time-saving aspects that are possible when adopting these farming tactics are quite effective in supporting the adoption of the reviewed habitat modification techniques. Policy makers and other land managers can influence replication of the diversification tactics outlined in this paper. Dissemination of the paper's finding can influence agricultural practices throughout all developed and some developing nations.

Recommendations

The following list of recommendations is meant for agricultural producers interested in diversifying their landscape to incorporate non-cropped areas that will improve ecosystem health. Recommendations are also given to public and private land managers and policy makers based on general and applicable recommendations for diversifying landscapes and promoting beneficial insects. These recommendations can be used separately or together depending on the particular circumstances of land management. If adopted, the following suggestions can benefit all types of land managers by decreasing costs from chemicals and maintenance while improving ecosystem health. Support and resources for land managers must be provided in order to facilitate the adoption of habitat medication techniques.

For Farmers

- Utilize IPM and IVM practices, only using chemical pesticides, herbicides and fungicides when absolutely necessary. When using chemicals, abide by label instructions and notify neighbors before use.
- Consider introducing managed bees on farms, while not becoming dependent on them for pollination services.
- Promote native pollinator species through a diversity of foraging resources and habitat necessities.
- Provide seasonal continuous bloom of pollen and nectar-rich floral resources. Utilize native plantings of both annual and perennial species.
- Provide woody species in landscape enhancements and leave dead debris for nesting and overwintering.
- Provide clean water sources for beneficial insects and other wildlife.
- Consider what species are targeted for attraction and make sure the proper requirements, like foraging range and habitat needs are met.
- Participate in cAES, self-certification, government accredited, and/or private company programs to effect large-scale landscape changes and cultural impacts.

For Public and Private Land Managers

- Utilize IPM and IVM practices, only using chemical pesticides, herbicides and fungicides when absolutely necessary. When using chemicals, abide by label instructions and properly train applicators.
- Offer incentives and educational resources aimed towards wildlife conservation for staff members.
- Reduce mowing to allow native herbaceous species to thrive. Properly train maintenance workers.
- Incorporate native plants when restoring landscapes.
- Provide clean water sources for beneficial insects and other wildlife.

For Policy Makers

- Support farmers by offering AES programs in which they can be rewarded for incorporating diverse, native habitat on their landscapes.
- Support public and private land managers by advocating for mitigation programs in which they can receive benefits or breaks for practicing ES.
- Influence policy that requires government agencies to adopt landscape habitat enhancements on federal lands.

Literature Cited

Albrecht, M., P. Duelli, C. Müller, D. Kleijn, and B. Schmid. 2007. The Swiss agri-environment scheme enhances pollinator diversity and plant reproductive success in nearby intensively managed farmland. Journal of Applied Ecology **44**:813-822.

Aizen, M.A., L.A. Garibaldi, S.A. Cunningham, and A.M. Klein. 2009. How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. Annals of Botany 1-10.

Altieri, M.A., and D.K. Letourneau. 1982. Vegetation management and biological control in agroecosystems. Elsevier Ltd. **1**: 405-430.

Austin, Z., M. Penic, D. G. Raffaelli, and P. C. L. White. 2015. Stakeholder perceptions of the effectiveness and efficiency of agri-environment schemes in enhancing pollinators on farmland. Land Use Policy **47**:156-162.

Batáry, P., A. Báldi, D. Kleijn, and T. Tscharntke. 2011. Landscape-moderated biodiversity effects of agri-environmental management: A meta-analysis. Proceedings of the Royal Society B: Biological Sciences 278:1894-1902.

Benjamin, F.E and R. Winfree. 2014. Lack of Pollinators Limits Fruit Production in Commercial Blueberry (*Vaccinium corymbosum*). Environmental Entomology **43**: 1574-1583.

Bianchi, F. J. J. A. , C. J. H. Booij, and T. Tscharntke. 2003. Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proceedings of the Royal Society **273**:1715-1727.

Cardoso, P., T. L. Erwin, P. A. V. Borges, and T. R. New. 2011. The seven impediments in invertebrate conservation and how to overcome them. Biological Conservation 144:2647-2655.

Carvell, C., W. R. Meek, R. F. Pywell, D. Goulson, and M. Nowakowski. 2007. Comparing the efficacy of agri-environment schemes to enhance bumble bee abundance and diversity on arable field margins. Journal of Applied Ecology **44**:29-40.

Dainese, M., S. Montecchiari, T. Sitzia, M. Sigura, and L. Marini. 2016. High cover of hedgerows in the landscape supports multiple ecosystem services in Mediterranean cereal fields. Journal of Applied Ecology.

Duelli, P., M. K. Obrist. 2003. Regional biodiversity in an agricultural landscape: The contribution of seminatural habitat islands. Basic and Applied Ecology **4**:129-138.

Fahrig, L., I. Jonsen. 1998. Effect of habitat patch characteristics on abundance and diversity of insects in an agricultural landscape. Ecosystems **1**:197-205.

Garibaldi, L. A., et al. 2011. Stability of pollination services decreases with isolation from natural areas despite honey bee visits. Ecology Letters **14**:1062-1072.

Governor Home Page / Office Of Governor Mark Dayton And Lt. Governor Tina Smith. *Office of Governor Mark Dayton and Lt. Governor Tina Smith*. N.p., 2017. Web. 15 May 2017.

Holzschuh, A., I. Steffan-Dewenter, and T. Tscharntke. 2008. Agricultural landscapes with organic crops support higher pollinator diversity. Oikos **117**:354-361.

Kevan, P.G., E.A. Clark, and V.G. Thomas. 1990. Insect pollinators and sustainable agriculture. American Journal of Alternative Agriculture **5**: 13–22.

Kleijn, D., W. J. Sutherland. 2003. How effective are European agri-environment schemes in conserving and promoting biodiversity? Journal of Applied Ecology **40**:947-969.

Klein, A., C. Brittain, S. D. Hendrix, R. Thorp, N. Williams, and C. Kremen. 2012. Wild pollination services to California almond rely on semi-natural habitat. Journal of Applied Ecology **49**:723-732.

Kremen, C., L. K. M'Gonigle. 2015. EDITOR'S CHOICE: Small-scale restoration in intensive agricultural landscapes supports more specialized and less mobile pollinator species. Journal of Applied Ecology **52**:602-610.

Kremen, C., A. Miles. 2012. Ecosystem services in biologically diversified versus conventional farming systems: Benefits, externalities, and trade-offs. Ecology and Society **17**.

Kremen, C., A. Iles, and C. Bacon. 2012. Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture. Ecology and Society **17**.

Kumaraswamy, S., K. Kunte. 2013. Integrating biodiversity and conservation with modern agricultural landscapes. Biodiversity and Conservation **22**:2735-2750.

Landis, D. A., S. D. Wratten, and G. M. Gurr. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual Review of Entomology **45**:175-201.

Langellotto, G. A., R. F. Denno. 2004. Responses of invertebrate natural enemies to complex-structured habitats: A meta-analytical synthesis. Oecologia **139**:1-10.

Long, R. F., A. Corbett, C. Lamb, C. Reberg-Horton, J. Chandler, and Michael Stimmann. 1998. Beneficial insects move from flowering plants to nearby crops. California Agriculture **52**: 23-26.

MacLeod, A., S. D. Wratten, N. W. Sotherton, and M. B. Thomas. 2004. 'Beetle banks' as refuges for beneficial arthropods in farmland: Long-term changes in predator communities and habitat. Agricultural and Forest Entomology 6:147-154.

Marshall E.J.P and A.C. Moonan. 2002. Field margins in northern Europe: Their functions and interactions with agriculture. Agriculture Ecosystems & Environment **89**:5-21.

McKenzie, A. J., S. B. Emery, J. R. Franks, and M. J. Whittingham. 2013. FORUM: Landscape-scale conservation: collaborative agri-environment schemes could benefit both biodiversity and ecosystem services, but will farmers be willing to participate? Journal of Applied Ecology **50**:1274-1280.

M'Gonigle, L. K., L. C. Ponisio, and K. Cutler. 2015. Habitat restoration promotes pollinator persistence and colonization in intensively managed agriculture. Ecological Applications **25**:1557-1565.

Mitchell, R.J., R.E. Irwin, R.J. Flanagan, and J.D. Karron. 2009. Ecology and evolution of plant–pollinator interactions. Annals of Botany **103**: 1355–1363.

Morandin, L., R. F. Long, C. Pease, and C. Kremen. 2011. Hedgerows enhance beneficial insects on farms in California's Central Valley. California Agriculture 65:197-201.

Morandin, L.A., R.F. Long, and C. Kremen. 2014. Hedgerows enhance beneficial insects on adjacent tomato fields in an intensive agricultural landscape. Agriculture, Ecosystems and Environment **189**:164–170.

Morandin, L. A., C. Kremen. 2013. Hedgerow restoration promotes pollinator populations and exports native bees to adjacent fields. Ecological Applications **23**:829-839.

Morandin, L. A., and M. L. Winston. 2006. Pollinators provide economic incentive to preserve natural land in agroecosystems. Agriculture, Ecosystems and Environment **116**:289-292.

Morandin, L. A., R. F. Long, and C. Kremen. 2016. Pest control and pollination cost-benefit analysis of hedgerow restoration in a simplified agricultural landscape. Journal of economic entomology 109:1020-1027.

Motzkea, I., A. Klein, S. Salehd, T.C. Wangera, and T. Tscharntkea. 2016. Habitat management on multiple spatial scales can enhance bee pollination and crop yield in tropical homegardens. Agriculture, Ecosystems and Environment **223**:144–151.

NRCS. *Nrcs.usda.gov*. N.p., 2017. Web. 15 May 2017.

Ponisio, L. C., L. K. M'Gonigle, and C. Kremen. 2016. On-farm habitat restoration counters biotic homogenization in intensively managed agriculture. Global Change Biology **22**:704-715.

Ponisio, L. C., L. K. M’gonigle, K. C. Mace, J. Palomino, P. D. Valpine, and C. Kremen. 2015. Diversification practices reduce organic to conventional yield gap. Proceedings of the Royal Society B: Biological Sciences **282**.

Rands, S. A., H. M. Whitney. 2010. Effects of pollinator density-dependent preferences on field margin visitations in the midst of agricultural monocultures: A modelling approach. Ecological Modelling **221**:1310-1316.

Rundlöf, M., H. Nilsson, and H. G. Smith. 2008. Interacting effects of farming practice and landscape context on bumble bees. Biological Conservation **141**:417-426.

Saunders, M. E., R. K. Peisley, R. Rader, and G. W. Luck. 2016. Pollinators, pests, and predators: Recognizing ecological trade-offs in agroecosystems. Ambio **45**:4-14.

Sunderland, K., F. Samu. 2000. Effects of agricultural diversification on the abundance, distribution, and pest control potential of spiders: A review. Entomologia Experimentalis et Applicata **95**:1-13.

Smith, A.A, M. Bently, and H.L. Reynolds. 2013. Wild Bees Visiting Cucumber on Midwestern U.S. Organic Farms Benefit From Near-Farm Semi-Natural Areas. Entomological Society of America **106**: 97-106.

The James Hutton Institute | Science Connecting Land And People. *Hutton.ac.uk*. N.p., 2017. Web. 15 May 2017.

Thomas, M. B., S. D. Wratten, and N. W. Sotherton. 1992. Creation of "island' habitats in farmland to manipulate populations of beneficial arthropods: predator densities and species composition. Journal of Applied Ecology 29:524-531.

Wetzel, W.C., H.M. Kharouba, M. Robinson, M. Holyoak, and R. Karban. 2016. Variability in plant nutrients reduces insect herbivore performance. Nature **539**:425–427.

Williams, N. M., K. L. Ward, N. Pope, R. Isaacs, J. Wilson, E. A. May, J. Ellis, J. Daniels, A. Pence, K. Ullmann, and J. Peters. 2015. Native wildflower plantings support wild bee abundance and diversity in agricultural landscapes across the United States. Ecological Applications **25**:2119-2131.

Wratten, S. D., M. Gillespie, A. Decourtye, E. Mader, and N. Desneux. 2012. Pollinator habitat enhancement: Benefits to other ecosystem services. Agriculture, Ecosystems & Environment **159**:112-122.

Appendix

Photos

Diverse Patchy Landscapes

Native Plantings and buffer strips

Buffer strips and hedgerows

Buffer strip and hedgerows

Bee Friendly Farming Survey Questions

1. Email address
2. Your Name
3. Organization Name
4. Where is your operation located (City and State/Province)?
5. What type of crop(s) or livestock(s) do you produce?
6. How many acres of land do you own and/or manage?
7. Do you practice Integrated Pest Management (IPM) and/or Integrated Vegetation Management (IVM)? If yes, please describe.
8. Do you utilize any of the following landscape modifications on or near your agricultural land?
    a. Field Margin Management (i.e hedgerows, windbreaks etc.)
    b. Buffer Strips
    c. Diverse, Patchy Areas
    d. Native Plantings
    e. Other: If other, please describe.
9. For each landscape modification do you notice improvements in crop production? If yes, please explain.
10. Please describe any difficulties you have faced when implementing and maintaining these types of landscape enhancements.
11. Do you notice an increase in native pollinators on your land? If yes, please describe.
12. Do you notice an increase in natural enemies of pests on your land? If yes, please describe.
13. Do you yourself, or a commercial beekeeper, introduce managed honey bees or other managed bees on your land?
14. Do you find customers to be more drawn to your products because they are produced on a bee-friendly farm? If yes, please describe.