



Non-crop habitat management: Promoter of natural enemies of crop pests

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ABSTRACT

Non-crop habitats provide essential resources for natural enemies such as plant-derived food, such as nectar or pollen, shelter, alternative prey, protection from pesticides and other disturbances, and moderate microclimate and hibernation sites. The main aim of habitat management is to offer a favourable ecological infrastructure within the landscape. Different ways of habitat management such as selecting appropriate plant species, understanding behavioural mechanism, maintaining the spatial scale and spatial arrangement with heterogeneity has a positive impact on conservation biological control. Harmful conditions are mitigated or favourable conditions are increased for natural enemies in conservation biological control. In previous days, conservation and biological control were not applied a lot, but it has gotten more attention. Natural pest management can be conducted at different spatial scales like at the landscape scale and at the field scale; natural pest management at the landscape scale through habitat management is focused on in this essay. In agricultural landscapes, non-crop habitats are comprised of hedgerows, field margin, road verges, fallows, meadows and often woody forests. Different agricultural pest species and many natural enemies are associated with these non-crop habitats. The proportion of habitat defines landscape complexity can influence the diversity of animals, plants and microorganisms. Ecosystem services that improve ecosystems through nutrient cycling, water regulation and pest suppression are positively influenced by landscape complexity that can help reduce pest density and crop injury. Habitat management has a higher level of opportunity to maximize multi-functional ecosystem services through a wider scale of landscape management. Therefore, habitat management can be combined into land use types of local, regional, nationwide, and worldwide economic aspects to reduce the dependency of high input based on existing agriculture.

Key Words: Agricultural landscapes, Biological control, Ecosystem services, Pest regulation and Sustainable agriculture.

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I. Introduction

Habitat management, an essential element of biological control, favours natural enemies in agricultural landscapes (Landis et al., 2000). The ultimate goal of habitat management is to offer a favourable ecological setup within the landscape for providing resources like food for natural enemies, alternative hosts or prey and shelter from hostile conditions (Landis et al., 2000; Hassan et al., 2016; Pfiffner and Wyss, 2004). Habitat management is defined as managing plant communities in a landscape to enhance natural enemies' activities (Fiedler et al., 2008; Tscharncke et al., 2005). Different ways of habitat management such as selecting appropriate plant species, understanding behavioral mechanism, maintaining the spatial scale and spatial arrangement with heterogeneity has a positive impact on conservation biological control. With conservation biological control in agricultural landscapes, harmful conditions are mitigated, or favourable conditions are increased for natural enemies (Landis et al., 2000; Rusch et al., 2017). Habitat management issue is a comparatively new but rising facet for conservation biological control and less attention has been paid to manipulating landscape through habitat management for ecosystem services (Fiedler et al., 2008; Landis et al., 2000).

Non-crop habitats offer significant resources for natural enemies such as plant-derived food resources like pollen, nectar, shelter, alternative prey, protection from pesticides and other disturbances, a moderate hibernation and microclimate sites (Landis et al., 2000; Geiger et al., 2009). Non crop habitats are the most favourable sites that can expressively augment the number of natural enemy species and stimulate beneficial arthropods like natural enemies on arable land. Botanical diversity, permanent vegetation layer and structural complexity characterize non-crop habitats and support the objectives of agroecology and natural conservation (Pfiffner and Luka, 2000; Mala et al., 2020). The main focus of habitat management research is to understand the importance of plant provided resources on natural enemies and how these resources influence the biology and ecology of natural enemies to inhibit pest populations (Fiedler et al., 2008). Habitat management can provide several kinds of ecosystem services; pest suppression is one of the critical services. Habitat management functions in the first trophic level that can easily distress numerous ecosystem services. Habitat management also serves many additional ecosystem services such as biodiversity conservation, aesthetics, weed suppression, and wastewater treatment. However, the main focus of previous research on habitat management was on the maximization of natural pest control services, not on other additional services. Ecological restoration, biodiversity conservation, biological control and other ecosystem services have mostly been overlooked in past habitat management research (Fiedler et al., 2008).

Natural pest management promotes bio-control in agroecosystems and this pest management can be conducted at different spatial scales (Fahad et al., 2020). Natural enemies can be stimulated at the field scale by increasing crop diversity and reducing soil disturbance. At the landscape scale, resources for natural enemies can be conserved by creating or stimulating non-crop habitats close to cropped areas (Landis et al., 2000). This essay focuses on natural pest management at the landscape scale through habitat management. Landscape complexity is well-defined by the proportion of habitat that impacts the ecological stability of crops and pest species through biological control, but still, it is not well quantified (Marshall and Moonen, 2002). Agricultural landscapes are becoming more simplified due to intensified cultivation systems with the expansion of agricultural areas by removing non-crop habitat. Simplified landscape composition negatively influences the population of natural enemies as well the interchange of natural enemies between crop and non-crop habitats (Bianchi et al., 2006). There are multifarious interactions between non-crop and cropped areas and these interactions are greatly influenced by arthropods species and habitat variation. A clear understanding of these interactions is essential to design field margin arrangements that conserve farmland wildlife at the landscape scale (Marshall and Moonen, 2002).

II. Ecological significance of non-crop habitats

Non-crop habitat is an essential source of natural enemies for near arable lands because many natural enemies prefer to hibernate in non-crop habitats from where they may colonize arable fields in the following spring. Higher spring colonization ensures higher reproduction of natural enemies that will be helpful to control higher pest population. Therefore, the availability of food and hibernation sites like a non-crop habitat is vital for the biological control of pests (Geiger et al., 2009).

In agricultural landscapes, non-crop habitats are comprised of hedgerows, field margin, road verges, fallows, meadows and often woody forests. Different agricultural pest species and a large diversity of natural enemies are associated with these non-crop habitats. Non-crop habitats provide alternative hosts and prey for natural enemies, enhancing natural pest management systems. Different resources like nectar are also provided by non-crop habitat that is directly related to the reproduction capability of parasitoids (Bianchi et al., 2006).

Moderate microclimate of non-crop woody habitat is another attractive condition for parasitoids compared to microclimate of the center of the crop field. Non-crop habitats are also used as hibernation sites for natural enemies and pests, but they can be modified for specific arthropods like creating beetle banks for predators. After a hibernation of more significant numbers of natural enemies in non-crop habitats can help increase the availability of more natural enemies in surrounding fields in the following season, which can also help limit the pest population. Non-crop habitats provide desirable life-support functions through favourable floral composition that augment the diversity and abundance of natural enemies in the agricultural landscape. High qualities of natural areas serve as core reservoirs of many species of rare biota and pests' natural enemies (Fiedler et al., 2008).

Multidimensional services of habitat management

Habitat management plays a vital part in establishing biological control through importation, augmentation and conservation of natural enemies (Ehler, 1998). Even though the main purpose of habitat management is pest suppression, it has several additional abilities to provide directly or indirectly a wide range of ecosystem services (Mace et al., 2012). Habitat management provides different ecosystem services like provisioning, supporting, cultural and regulating services (Fiedler et al., 2008; Pereira et al., 2005).

Supporting services

Habitat management can provide different kinds of supporting services in agricultural landscapes. Habitat management contributes to various support services such as photosynthesis, primary production, soil formation, water cycling, and nutrient cycling as a pest control practice. If habitat management is conducted at sufficiently large scales, better crop management and pest management can be achieved as supporting services (Altieri et al., 2017; Fiedler et al., 2008; Power, 2010).

Provisioning services

Habitat management can provide food, fresh water, wood and fiber, fuel, or ornamental resources as provisioning services. Incorporating multi-functional species in habitat management is directly related to provisioning services (Maltby et al., 2017). Switch-grass (*Panicum virgatum* L.) is an excellent example of provisioning services considered a promising biofuel candidate in the US (Fike and Parrish, 2013). Day by day, the interest in biofuel is increasing and people can get biofuel as a different outcome by habitat management. In addition, switch-grass is also favourable for various grassland nesting birds. It is also extremely attractive to natural enemies when grown with prairie forbs during mixed culture (Fiedler et al., 2008; Vandever et al., 2015).

Regulating services

Pest regulation is the basic service of habitat management (Gurr et al., 2017; Hassan et al., 2016). In addition, it has a potential role in other regulatory services for flood regulation, disease regulation, climate regulation, erosion reduction, water purification, improvement of soil biota, and water runoff and renews through modifiable biodiversity and wildlife conservation as well as habitat connectivity. Such as the Conservation Reserve Program (CRP) in the US, agri-environment schemes in the EU are regulatory ecosystem services directly related to habitat management (Adhikari and Hartemink, 2016; Fiedler et al., 2008).

Cultural services

Several researchers already recognize the artistic worth of the flowering plants in habitat management. Preservation of native plants for educational, medicinal, recreational, religious or cultural purposes has been potentially influenced by habitat management (Löki et al., 2019). Displays of native plants on a larger scale also have a higher potential to accelerate eco- or agro-tourism (Fiedler et al., 2008; Kim and Jamal, 2015).

III. Importance of landscape manipulation through non-crop habitat

Habitat management or manipulation can enhance the effectiveness of landscape on natural pest suppression in the agricultural field (Bianchi, 2006). Habitat management is a fragment of a conservation biological control tactic that mainly focuses on pest management by enhancing the impact of natural enemies by manipulating plant-based resources in the landscapes (Fiedler et al., 2008). Generally, selected plants are incorporated within the landscape, providing a higher range of resources such as nectar, pollen, or shelters to the natural enemies of insects-pests (Landis et al., 2000). In addition, medicinal plants for humans may also be merged with habitat management that can help to improve provisioning service (Fiedler et al., 2008). Woltz et al. (2012) reported that habitat manipulation could also improve predator abundance and coccinellids were considerably higher in buckwheat strips compared to control field margin in 2009 (Woltz et al., 2012).

Several current lands use practices within well-maintained landscapes can be manipulated to increase ecosystem services. Sometimes flowering plants are incorporated in these existing land uses to make the landscapes more attractive for natural enemies. Incorporation of appropriate flowering plants in filter strips, riparian buffer strips, and hedgerows can also accelerate the activities of natural enemies' population and help enhance the population in soil. Existing roadside vegetation is known as a source of disease and weed pressure may be changed for pest suppression by incorporating appropriate plant species like flowering plants. Manipulation by appropriate flowering species serves for natural enemies and increases the aesthetic value of the landscape (Fiedler et al., 2008).

Agricultural landscapes are becoming more simplified with the influence of intensified cultivation systems by expanding agricultural areas by removing non-crop habitats. Simplified landscape composition negatively influences the population of natural enemies and natural pest control and the alteration of natural enemies between non-crop and crop habitats (Bianchi et al., 2006). Habitat management with a higher range of variation will be helpful for complex interactions of cropped and non-crop areas (Marshall and Moonen, 2002). Conservation or incorporation of genetic diversity, especially local genotype, can help to improve natural enemies density in agricultural landscapes (Fiedler et al., 2008).

Other landscapes that were not focused yet for habitat management can be included. For example, in green spaces, parklands, urbanized areas, home landscapes, rain gardens and green spaces all have the potential to contribute to ecosystem services. Several areas of our daily use are also not a part of habitat management, such as fencerows, woodlots, roadside verges, utility rights of way, wetlands and stream corridors. However, appropriate management of those areas can increase our habitat diversification and complexity, providing similar opportunities for ecosystem services (Fiedler et al., 2008). Therefore, a better understanding of food and hibernation sites of natural enemies in non-crop habitats can enhance a wide range of natural enemies and further increase invasion of surrounding crop fields (Bianchi, 2006).

IV. General effects of landscape complexity on natural enemies

In general, landscape complexity is measured by the proportion of habitat, such as the proportion of crop, natural habitat or non-crop in a particular landscape. Although natural enemies and pest populations are both influenced by landscape complexity, natural enemy populations are more influenced than pest populations, according to the available evidence. Natural enemies are benefitted from landscape complexity without considering arthropod response type. Agricultural pest control by using natural enemies is an opportunity for sustainable pest management and this opportunity also has an economic impact on crop production systems (Gardiner et al., 2009). Landscape complexity can affect the mixture of animals, plants, and microorganisms. Different ecosystems services like pest suppression, nutrient cycling and water regulation provided by beneficial insects are positively influenced by landscape complexity (Woltz et al., 2012). It can also decrease pest density and crop injury (Gardiner et al., 2009).

Gardiner et al. (2009) stated the extent of biological control deal in soybean fields across Wisconsin, Michigan, Minnesota and Iowa across two years (2005–2006). The biological control services index (BSI) was calculated in his experiment by the comparative defeat of aphid populations based on related landscape assortment and configuration of adjacent experimental sites. It was observed that BSI values were increased with the upsurge of landscape diversity. The abundance of predators,

specifically Coccinellidae and beetles, was dominant in non-crop dominated landscapes compared to crop-dominated landscapes. Natural enemies also support regional ecosystem service by suppressing soybean pests, which also helped reduce insecticide applications. Finally, it was suggested that landscape management is the key opportunity to maintain or enhance diversity for stabilizing or increasing natural pest control amenities (Gardiner et al., 2009). Different types of non-crop habitat such as short grassy field margins, herbaceous field margins under a tree line, forest and ditch support natural enemies differently and among them, herbaceous non-crop habitats are a more effective refuge for the predator in conservation biological control (Geiger et al., 2009).

Bianchi et al. (2006) reviewed 28 papers with the hypothesis that simple landscapes have less favourable crop and non-crop habitats planning for pest regulation than complex landscapes. They also hypothesized that pest control benefits the proportion of non-crop habitat of a landscape and the patchiness of landscape. Their review referred to complex landscape as high proportions of hedgerows, field margins, forest, tree lines, grassland, field margins, fallows, wetlands or channels and landscape with few of mentioned habitats considered as simple. They classified in their reviewed 28 studies, allowing the proportions of observation having a negative, neutral or positive effect with 95% confidence level of significance. According to their review, complex landscapes enhance natural enemies' population in 74% of cases. Pest pressure was also reduced in higher cases (in 45% papers) by landscape complexity, where pest density was articulated in densities, pest establishment, and survival or population growth rate and crop injury levels. Non-crop habitats of complex landscapes provide favourable environments and fundamentals for natural enemies and often increase crop field activity. Finally, they conclude that diversified and complex landscapes have the potential to conserve biodiversity and sustainable pest management (Bianchi et al., 2006).

V. Response of specialist and generalist enemies to pest population

In general, a specialist enemy prefers one host species, whereas a generalist enemy does not prefer specific host species (Chaplin-Kramer et al., 2011). Different natural enemies are attracted by different kinds of vegetation's or non-crop habitats, which are also related to different host species. For example, alternative hosts of generalist parasitoids feed on trees and shrubs and control lepidopteran pests of different crops such as corn, soybean, wheat and alfalfa. Woody and herbaceous vegetation also provide food like pollen and nectar to natural enemies, prerequisites for longevity and fecundity of parasitoids such as Chrysopids, Coccinellids, Syrphids (Bianchi, 2006). Therefore, the distinction of specialist and generalist is critical to understanding the enemy distributions (Chaplin-Kramer et al., 2011).

Generalist natural enemies respond positively to landscape complexity, especially at a larger scale, whereas specialist natural enemies respond more actively on a smaller scale than larger landscape scales. However, there is no difference between the effect size of specialist natural enemies on a smaller scale and generalist natural enemies on a larger scale. Therefore scale size is important for generalist and specialist natural enemies to suppress pest population. For example, in a specific system or for a specific pest, specialist natural enemies are more effective than generalists depending on local management by individual growers. On the other hand, on a large scale, mainly generalists make available the majority of pest control in a scheme where cooperative approaches are necessary to boost the activities of generalist natural enemies' population for natural pest management (Chaplin-Kramer et al., 2011).

Similarly, not all-natural enemies respond to the component of landscape complexity. Generalist and specialist enemies have favourable habitats surrounding the farm for food and hibernation. For example, generalists are more dependent on nearby areas for alternative host plants or prey. In most cases, generalist enemies have sturdier reactions to landscape complexity for the on-farm abundance than specialist enemies (Chaplin-Kramer et al., 2011). Generalist and specialist natural enemies respond to mixed vegetation differently because mixed vegetation is less preferable to specialist enemies compared to general enemies. In addition, mixed vegetation provides more alternative prey for generalist natural enemies (Letourneau, 1987).

However, there is a lack of information about diversity between generalist and specialist pest retort to landscape complexity due to the failure to use appropriate scale. Generalist and specialist are more appropriate terms for natural enemies than pest populations. Sometimes specialist pests respond like

a generalist pest due to unavailability of host plants. Therefore the distinction of generalist and specialist may provide better insights to understand enemy distributions than pest populations (Chaplin-Kramer et al., 2011).

The progressive retort of natural enemies does not always result in successful pest control until pest abundances display any critical response to landscape complexity. However, we have limited landscape indulgence on pest dominance and enemy impact estimated in minimal landscape-scale studies. Therefore, measuring population dynamics is more important than immobile counts to understand the association between pest control services and landscape complexity of natural enemies (Chaplin-Kramer et al., 2011).

V. Invasion of natural enemies in crop fields from adjacent non-crop habitats

In general, natural enemies pass mainly from a particular type of habitat to another, some of them persist on a new habitat by creating a source-sink dynamic and some of them return to the last habitat after a particular time with their bi-directional movement. Some natural enemies benefit from source-sink dynamic and some can benefit from bi-directional movement. For example, hoverflies and parasitoids need herbivorous insects as hosts for their larvae but use floral resources as food because floral resources help them increase their longevity and potential fecundity. Other external resources like nectar can significantly improve the control of crop pests by specific species (Tscharntke et al., 2007).

On the other hand, crop fields are not suitable habitats for natural enemies as transient habitats where natural enemies face frequent and intensive disturbances due to crop production system. For example, pesticides, frequent tillage systems and bare field by crop harvests are examples of disturbance in crop fields and negatively impact natural enemies. Therefore early in the season or after initial disturbance, arable fields depend on surrounding non-crop habitats such as field margins, woodlots, hedges, hedgerows and fallows to colonise natural enemies. In this regard, the spatial distribution of natural enemies in the arable field significantly impacts the natural pest control system (Tscharntke et al., 2005).

Natural enemies, especially arthropods, predators and parasitoids, offer appreciated ecosystem services through suppressing pest populations in agricultural crop fields. Several natural enemies are influenced directly or indirectly by non-crop habitats available surrounding agricultural fields. Different landscape variables such as scale, patterns, and quality influence the landscape effectiveness to influence natural enemies. An organism's dispersal capability also impacts landscape effectiveness to control natural pest pressure on crop fields. The surrounding landscape functions as a reservoir of natural enemies for the frequently disturbing crop fields (Gardiner et al., 2009).

There are five types of spatial distribution patterns of arthropods are found in the landscape. Those are stenotopic species, cultural species, dispersers, ecotone species and ubiquitous species. Stenotopic species are restricted to non-crop habitats; for example, genus *Amara* of Carabidae, which prefer hedgerows. In contrast, cultural species prefer crop fields during season and margin after harvesting; genus *Pterostichus* is an example of cultural species. Dispersers prefer to colonize into crop fields from non-crop habitats, but densities are found higher near the field edge than in the field interior; lacewings *Chrysopa spp* is the example for those species. Ecotone species are generally observed in between crop and non-crop habitats. The final type is ubiquitous who do not have any specific preference for crop and non-crop habitat, which means they are available everywhere (Tscharntke et al., 2005).

Besides spatial distribution of natural enemies, sometimes the timing of field colonization influences the natural pest control in agricultural fields. Generalist enemies colonize early after overwintering, whereas specialist natural enemies typically arrive later in the season. Availability of natural enemies early in the season is critical to protect against higher pest infestation and pest outbreaks by suppressing pest population. On the other hand, non-crop habitats provide higher natural enemies to arable land through re-colonization after they are cleared for harvest. Non-crop habitat enhances the exchange of arthropods, especially natural enemies, and defends undesirable interactions between crop and non-crop areas (Tscharntke et al., 2005). As a part of ecosystem function, natural pest control, directly and indirectly, depend on colonization of natural enemies in arable land. Colonization

of natural enemies in arable fields can help to reduce pest densities. As a result, crop damage levels and yield loss can be minimized. Finally, this situation also influences the reduction of chemical pesticides that provide sustainable crop production (Tschardt et al., 2007).

VI. Future research needs on non-crop habitat

In general, maximum research on habitat management or landscape was conducted for 1-2 years, which is insufficient to assess the rate of exceeding a certain threshold level of damage or pest abundance. Therefore, longer term data are needed to understand the constancy of pest control amenities and pest population dynamics (Chaplin-Kramer et al., 2011).

In order to take full advantage of habitat management, it is essential to practice at larger landscape scales. However, most previous studies have focused on comparatively small scales like forming experimental plots in urban, home landscapes, or golf course locations or fields of flowering plants in orchards, and annual crop fields. Therefore further research should be focused on farm level and regional landscape level with a larger landscape area (Fiedler et al., 2008).

Moreover, most previous research only focused on the pest management aspect. However, habitat management serves pest management and other additional ecosystem services such as water treatment, conservation of biodiversity, aesthetics, and weed suppression within the landscapes. Therefore multi-functional ecosystem services of habitat management also should take into account for sustainable betterment of future agriculture (Fiedler et al., 2008).

Plant species are also important for multi-functional ecosystem services of habitat management and relatively few plant species have received the most attention for the suitability of habitat management. Local or native plant species also were not considered in higher range, but those may provide the best solutions according to local demands. Therefore higher screening of plant species especially native species, should be focused on in future research to increase multi-functional ecosystem services for the suitability of habitat management (Fiedler et al., 2008).

VII. Conclusion

Non-crop habitat plays a vital role in conservation biological control because it is an important refuge for natural enemies (Geiger et al., 2009). Nowadays, habitat management is an issue of pest management and an important component of sustainable agriculture due to having potentiality in agro-biodiversity conservation (Bianchi et al., 2006). As a bio-control component, habitat management has a higher level of opportunity to maximize multi-functional ecosystem services through wider scale of landscape management. As a result, multi-functional ecosystem services can help us reduce the dependency of high input based on current agricultural practices (Fiedler et al., 2008). In this regard, habitat management could be combined into land-use types in native, local, nationwide and worldwide economic aspects. Other landscapes that were not focused yet for habitat management can be included because appropriate management of those areas can increase habitat diversification and complexity. The ultimate benefits of habitat management are increased due to a better understanding of the role of multi-functional ecosystem services (Fiedler et al., 2008). Achieving landscape complexity by maintaining appropriate habitat management may be the greatest option for extensive biological control and future sustainable crop production (Tschardt et al., 2007).

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