Chapter 7
Agroecological Management of Insect Pests from Field to Landscape

Adrien Rusch

7.1 Introduction

The idea of modifying the environment at the field scale or larger spatial and temporal scales to limit insect pest populations has been around a while. There are many historical examples of what we would call agroecological engineering today, such as the use of weaver ants by Chinese farmers to control citrus insect pests around 1200 AD, or when Pliny the Elder and Dioscorides noticed in the first century AD that certain plants such as wormwood had repellent virtues against insect pests. Managing insect pest populations by modifying the environment is obviously closely linked to the birth and development of agriculture. Throughout history, man has sought to control the factors limiting food production, and especially the crop losses associated with insect pests. Farmers have traditionally used techniques available to them at the field scale. Researchers have only relatively recently shifted their attention to the broader spatial dynamics of insect pest populations and begun to understand that environmental factors influencing population levels can operate on much larger scales than a single crop field. Agroecology research has been striving to produce detailed knowledge on the mechanisms governing insect population dynamics and biological regulation processes by their natural enemies in agricultural landscapes. The aim of this work is to manage these processes in order to reconcile agricultural production and environmental concerns. This chapter provides an overview of current knowledge on the effects of farming practices and landscape structure on insect pest management by considering conservation biological control approaches.

A. Rusch (✉)
SAVE. INRAE, Bordeaux Sciences Agro, ISVV, Villenave d'Ornon, France
e-mail: adrien.rusch@inrae.fr

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7.2 Principles of Conservation Biological Control

Conservation biological control aims to maintain pest populations below a harmful threshold by combining direct approaches (e.g. olfactory or visual disturbance of the host plant's location) and indirect approaches that favour natural enemy abundance, diversity, development and activity to control pests (see Chap. 6). There are three types of natural enemies: (i) predators that feed directly on insect pests or disease vectors (in this case, vertebrates or invertebrates), (ii) parasitoids that lay their eggs in or on their host and kill their host during their development, and (iii) pathogens, which are microorganisms capable of injuring or killing their host. This chapter mainly deals with predators and parasitoids.

Implementing conservation biological control strategies requires a detailed knowledge of species biology and ecology, such as their essential needs for survival and reproduction, their dispersal abilities and their behaviour. Natural enemies encompass a wide range of species with highly varied life history traits and ecologies. However, they are generally mobile species that use several resources located unevenly across different habitats during their life cycle. Understanding the dispersal abilities of the species present and their life cycles is crucial in order to gain insights into their dynamics over space and time, which can then inform successful conservation biological control strategies. But first, we should go into a little more detail about the key resources for natural enemies involved in natural pest control.

Predatory and parasitoid arthropods need three types of resources to thrive in agricultural landscapes: refuges, nectar or pollen sources, and alternative hosts or prey (Landis et al. 2000). Most predators and parasitoids need refuges, such as overwintering or summering sites to protect themselves from poor weather or environmental disturbances related to farming practices (e.g., pesticide applications, mowing, soil tillage). Some natural enemies need additional food resources such as pollen or nectar as well as alternative prey or hosts to survive when their preferred prey (insect pests) are not present (or in insufficient numbers), or when pests are not at the life stage where they would be preyed upon by the natural enemies. Providing refuges, food resources and alternative hosts helps to maintain sufficient levels of natural enemy populations and promotes the establishment of natural pest control relatively early in the year. Semi-natural habitats are generally home to a higher proportion of neutral or beneficial arthropods than arthropod pests. It is often said that nine out of ten natural enemy species require an uncultivated habitat at some point in their life cycle, whereas this is the case for only one out of every two pests.

Refuges can be special habitats created either within the cultivated field or in the landscape environment. Within cultivated fields, grass and flower strips and cover crops can all provide refuges for many species as well as favourable microclimates. Semi-natural habitats, such as woodlands, hedgerows, meadows and field margins, are often places that provide shelter and food for predators in a relatively stable way over time because these habitats are subject to less disturbance than cultivated habitats. Thus, wooded habitats often offer a more moderated microclimate than the middle of a crop field, and can protect predators and parasitoids from extreme temperatures during the growing season (Landis et al. 2000). Grassy habitats, such as natural meadows, provide overwintering sites for many species of spiders, rove beetles, ground beetles, lady beetles and neuropterans (Sarthou et al. 2014).

Pollen and nectar are essential for many species of natural enemies. For example, parasitoid hymenopterans feed on floral and extrafloral nectar. Providing sugar resources to parasitoids has been shown, both under laboratory conditions and in experimental plots, to generally increase the longevity and fecundity of females, and thus their potential to parasitize their host (Wäckers et al. 2005). Studies have shown that nectar availability determines the longevity and fecundity of female parasitoids of *Diadegma semiclausum* (Hellen, 1949) (Hymenoptera: Ichneumonidae), and the associated parasitism rate of the diamondback moth *Plutella xylostella* (Linnaeus, 1758) (Lepidoptera: Plutellidae) is higher when female parasitoids have access to nectar sources (Winkler et al. 2006).

Providing alternative hosts or prey is particularly important during periods of low host and prey densities in crop fields and ensures that resources are present throughout the growing season. This is especially true for generalist predators which, by definition, have a broader diet than specialists. For instance, it has been shown that if wheat aphid populations colonize fields later in the season, then the predatory lady beetle *Coccinella septempunctata* (Linnaeus, 1758) (Coleoptera: Coccinellidae) becomes dependent on aphid populations located in semi-natural habitats (Bianchi and van der Werf 2004). As a result, lady beetles are especially vulnerable to periods of food limitation in cultivated fields when the availability of prey in semi-natural habitats is low.

To sum up, it is important to have a detailed understanding of the needs, responses and behaviours of natural enemies in changing environmental conditions to tailor natural pest management strategies to each specific situation. Providing food resources, alternative hosts and refuges helps maintain natural enemy communities in and around cultivated fields, and preserving, restoring and creating habitats that offer these resources across time and space are key to promoting natural pest control. Below we detail the effects of different agricultural practices on natural enemies and insect pest control at the plot and cropping system scales.

7.3 Effects of Farming Practices at Field Level

7.3.1 Plant Diversity over Space and Time

Plant community diversity at field level has a major effect on upper trophic levels, and thus on insect pests and their natural enemies. Many syntheses of current knowledge have shown that cultivated fields with higher plant diversity tend to have a higher abundance and/or diversity of natural enemies, lower densities of herbivores and lower damage resulting from insect attacks compared to monoculture fields (Letourneau et al. 2011). These beneficial effects of plant diversification on natural pest control at field level result from two complementary mechanisms: the action of natural enemies and the direct effect of heterogeneous resource distribution on insect pests. As explained above, diverse vegetation cover hosts a more abundant and richer community of natural enemies due to a greater diversity of potential resources (Langellotto and Denno 2004). A diverse plant cover will generally harbour smaller populations of phytophagous insects and suffer less damage because of the lower probability of a given pest species to locate its host plant (Root 1973). This effect is mainly attributed to chemical confusion or physical disturbances, as well as to changes in the physiological state of plants due to interspecific interactions.

On a small spatial scale, positive effects that can be explained by at least one of the two above mechanisms have been shown for different diversification strategies, such as combined crops, trap crops, the push-pull strategy and flower strips. The scientific literature is full of many examples, observed across the globe, of the positive effects of plant diversification on limiting insect pest pressure. For example, push-pull strategies to protect maize and sorghum crops from various lepidopteran pests have proved very successful and significantly increased yields in East Africa (Cook et al. 2007a). These strategies combine species mixtures to repel pests and lead them away from the main crop towards trap plants, which are chosen because they attract parasitoids and thus increase the parasitism rates of pests. Such strategies have also been used on oilseed rape and potato pests (Cook et al. 2007a; Martel et al. 2005).

Plant diversity over a longer time-frame – i.e. beyond the field level for a given year – and thus as it pertains to crop sequencing can also be an important element in managing insect pests, weeds and pathogens. The basic principle, developed empirically by farmers, is to break the pest cycle by rotating host crops in a field (Ratnadass et al. 2012). Studies have also suggested that the abundance, activity, reproduction and diversity of natural enemies such as ground beetles tend to increase with longer crop rotations combined with reduced fertilizer and pesticide use, suggesting higher levels of biological control in such systems (Büchs et al. 1997). However, further studies are needed to confirm this.

7.3.2 Nitrogen Fertilization

The physiological state of plants, and more specifically their nitrogen status, plays an important role in pest population dynamics and survival, notably by influencing plant resistance, the pest's choice of host plant and the plants' compensatory abilities. Two hypotheses have been put forward about the link between host plant quality and herbivore population levels: the plant stress hypothesis and the plant vigour hypothesis (Price 1991; White 1984). The plant stress hypothesis states that physiologically stressed plants are subject to more attacks by phytophagous insects because of the plant's nutritional state or a decline in their resistance mechanisms. Conversely, the plant vigour hypothesis suggests that more vigorous plants would be subject to greater attacks by herbivores, as they would prefer them as better quality food sources. There is evidence in the scientific literature that these two hypotheses are valid for different species, but literature reviews indicate that there are more cases where phytophagous insects respond positively to more vigorous or more fertilized plants than the opposite (Butler et al. 2012). However, this depends on particular life history traits of the species. Sap-sucking insects appear to show a more marked response to the nitrogen status of crops than chewing insects.

The fertilization method can also impact natural enemy communities, although this subject has not been well covered in the scientific literature. Reincorporating crop residues can replenish the system with different nutrients, including nitrogen. This practice generally has positive effects on predator communities, namely by increasing the organic matter in the soil (which in turn positively affects decomposer communities), as well as by providing important microhabitats for different species.

Nitrogen fertilization can also have effects on higher trophic levels, such as on parasitoid performance. For example, diamondback moth parasitism rates on cruciferous crops are lower in moth populations that have developed on less fertilized plants (Sarfraz et al. 2009). These phenomena show the interest of taking trophic interactions into account in order to fully understand the direct and indirect effects of nitrogen fertilization and host plant quality on insect pest attacks.

7.3.3 Tillage Practices

A common approach in agroecology is to change tillage practices, which has known effects on pest management, including on phytophagous insects. Organisms respond to tillage in highly variable ways and depending on taxa, but the abundance and number of species of soil fauna generally tend to increase with reduced tillage intensity. Different variables can also impact natural enemies and phytophagous insects, from tillage intensity to the equipment used, the frequency of operations or the period of time when tillage is performed. Deep tillage will have a strong impact on biological communities, namely by modifying microhabitat quality, the soil's physicochemical structure and prey availability for predators. Tillage can also have direct lethal mechanical effects, as well as indirectly force organisms to migrate or expose them to predation. The effects of tillage on natural enemies and pest control can therefore be equivocal. For example, deep and intensive tillage is generally an effective practice for controlling slug populations, with direct effects on slug mortality and indirect effects through changes in habitat structure. However, we also know that intensive tillage is rather negative for natural enemy populations, and that reducing or maintaining crop residues on the surface increases natural enemy activity and even biological control. For instance, Tamburini et al. (2016) recently showed under real cropping conditions that conservation rather than conventional tillage increases the natural regulation level of wheat aphids by 16%. The potential underlying mechanisms that explain this positive effect are: (i) the presence of physicochemical barriers linked to crop residues that directly disturb pests' movement and ability to located the host plant; (ii) reduced competition between natural enemy species due to a more complex environment that is favourable to microhabitats; (iii) greater resource and alternative prey availability; (iv) more favourable microclimatic conditions and greater availability of organic matter reducing predator mortality.

7.3.4 Organic Farming

If we go beyond the effects of individual farming practices at the crop management sequence scale, the question arises regarding the overall sensitivity of cropping systems to pest attacks and their ability (or lack of) to support natural herbivore control. To answer this question, we can look at organic farming, which imposes specifications that support ecological processes such as natural control. It is now well established that organic farming practices at the field scale favour the abundance and species richness of many taxa, from plants to mammals and birds, compared to conventional farming. Several recent meta-analyses have shown that the abundance and number of species increase by an average of 30% in organic fields (Bengtsson et al. 2005; Tuck et al. 2014). These studies show that insects, plants and birds in particular respond positively to organic farming practices. Furthermore, a recent global meta-analysis shows that organic farming practices increase the levels of pest control services provided by natural enemies and that infestation levels in organic fields are ultimately not any higher than in conventional fields (Muneret et al. 2018). These findings indicate that organic farming practices promote natural pest control processes that can be just as effective as conventional farming methods in managing pest populations. In addition to these local effects, recent work has shown that the effects of organic farming are modulated by the landscape structure, and especially the presence of semi-natural habitats and how farming practices are implemented across the landscape (Muneret et al. 2019). The following section outlines current knowledge on the effects of the landscape environment on natural enemy communities and insect pest control.

7.4 Biological Pest Control at the Landscape Scale

7.4.1 Transition Areas Between Cultivated and Non-cultivated Habitats

Transition areas, known as ecotones, between cultivated and non-cultivated habitats can offer insights into how individuals move on wider spatial scales. Individual movements – whether by natural enemies or phytophagous insects – between cultivated and non-cultivated habitats take place in a bidirectional way and are largely determined by the available resources. The direction and strength of the flows appear to depend mainly on differences in primary productivity between habitat types, on resource phenology (food or refuge), as well as on the relevant taxa, which may seek complementary or substitute resources during their life cycle. Arthropods living in agricultural landscapes show a variable degree of specialization for cultivated or semi-natural habitats. Species are found along a continuum and range from those confined solely to natural or semi-natural habitats (called stenotopic species) to those specialized in cultivated areas. A large majority of organisms lie somewhere between these two extremes and rely on both cultivated and uncultivated habitats to varying degrees during their life cycles; most species will need a semi-natural habitat at least once during their lifetimes.

The scientific literature contains many examples illustrating the role that transition areas between cultivated and non-cultivated habitats can play in the dynamics of insect pests and their natural enemies. For instance, research in Australia demonstrated that vine rows near woodland margins had more lady beetles and parasitoids, along with higher rates of predation and parasitism of a moth species, than central vine rows (Thomson and Hoffman 2013). Similarly, a study conducted in South Africa showed that the distance of mango plantations from natural vegetation patches was a key factor in the abundance of Tephritidae fruit flies, leaf-galling flies and pathogenic fungi (*Fusarium* spp.) (Henri et al. 2015). Other studies have highlighted flows of predatory or parasitoid natural enemies between different managed agroecological areas, such as grass or flower strips, and crop fields. These studies generally show fewer movements as distance to the managed area increases and higher levels of pest control at the field margins than in the centre, suggesting a limiting effect on natural enemy dispersal ability.

7.4.2 Landscape Structure and Natural Pest Control

Considerable research has focused on the effect of landscape structure on natural enemies, trophic interactions and natural pest control. The initial aim of these studies was to analyse the relationships between natural enemy abundance or diversity and landscape composition, which is most often characterized by proportions of land use types. Researchers then shifted their attention to the effects of landscape configuration by analysing how the spatial arrangement of habitats (e.g. functional connectivity) could affect natural enemy population dynamics and communities. A large majority of the studies exploring the effects of landscape structure on insect pest control have considered the effects of the proportion of semi-natural habitats in the landscape, because it generally correlates with other variables that indicate landscape heterogeneity. Additionally, and as mentioned above, semi-natural habitats are especially important in terms of resources for natural enemies and pests, which explains why many studies have focused on this issue at the landscape level.

For example, the abundance and number of natural enemy species in cultivated fields has been shown to rise as the proportion of semi-natural habitats in the surrounding landscape increases (Bianchi et al. 2006; Chaplin-Kramer et al. 2011).

Meanwhile, a review by Bianchi et al. (2006) indicated that in 74% of published cases, the abundance of natural enemies increased in tandem with the proportion of semi-natural habitats in the landscape, while no effect was detected in 21% of cases and 5% of studies indicated a decrease in natural enemy abundance. Maintaining habitats that provide key resources (e.g. overwintering and summering sites, food resources and alternative hosts) enables populations and communities to survive and even thrive in agricultural landscapes. The direct impact of landscape heterogeneity on the energy reserves and fecundity of some natural enemy populations can even be measured. For instance, omnivorous *Poecilus cupreus* ground beetles that live in more heterogenous landscapes are larger and have fecundity rates that are three times higher than individuals in simple landscapes (Bommarco 1998). However, the effects of landscape composition on natural enemies appear to be moderated by various parameters, and especially by the functional features (such as the degree of specialization or dispersal abilities) of the individuals or species under consideration. Thus, the positive effects of landscape heterogeneity on natural enemy abundance and diversity seem relatively marked for generalists (e.g. ground beetles or spiders), but not for specialists (e.g. parasitoids).

The positive effects of the proportion of semi-natural habitats on natural enemy abundance and diversity tend to result in greater natural pest control levels (via predation or parasitism) (Chaplin-Kramer et al. 2011; Rusch et al. 2016). This is explained by the processes of complementarity between species as described in Chap. 6. A recent study confirmed that an increase in cultivated land area in the landscape significantly decreases the potential for natural pest control (Rusch et al. 2016). In this case, natural aphid control was half as strong on average in homogeneous landscapes that were dominated by crops compared to more heterogeneous landscapes dominated by semi-natural habitats. Ongoing studies on other pests indicate significant variability in pest response to landscape heterogeneity, which again suggests that these effects are modulated by certain life history traits such as dispersal abilities, life cycle complexity or feeding behaviour diversity.

Other important landscape aspects can also affect insect pest population dynamics. For example, the diversity of crops or production systems (e.g. organic farming) at the landscape level can have a considerable structural impact on natural enemy communities and natural pest control. Muneret et al. (2018, 2019) demonstrated this in vineyard landscapes, where farming practices at the local and landscape scales strongly impacted natural enemy communities and natural pest control services. As more cropland was converted to organic, a higher average abundance of predatory spiders was found on the soil of organic fields but not in conventional fields, indicating local filter phenomena that modulate the positive effects on spider communities in organic vineyards. Landscape configuration, i.e. the spatial arrangement of landscape elements, can also influence natural enemy and pest population dynamics (Martin et al. 2019). For example, ground beetles in arable crop landscapes have been found to be much more affected by landscape configuration, and more specifically by a reduction in field size, which favours their functional diversity, than by the type of crop management or the proportion of semi-natural habitats (Gallé et al. 2019).

Very few studies have sought to characterize the effects of landscape structure changes on trophic interaction networks with regard to crop insect pests ("vertical approach", explained in Chap. 6). One study on the effects of host-parasitoid networks on cereal aphids showed that increased landscape heterogeneity resulted in simpler host-parasitoid networks and higher aphid parasitism rates, suggesting that at the space and time scales considered, the theoretical relationship between network complexity and functioning was not necessarily valid (Gagic et al. 2011). High-throughput sequencing technology, which has recently become much more accessible, can be used to analyse the structure of trophic interaction networks at large spatial scales. Various research programmes are currently exploring this issue but little evidence exists. These programmes will eventually be able to provide more mechanistic insights into network structures, and especially into the specific network patterns that explain the links between land-use change, trophic interactions and natural insect pest control.

7.5 Conclusion

Studies carried out to date reveal that the relative effects that different aspects of landscape structures have on natural enemies and biological control appear to depend on the landscapes themselves and the different taxa studied. We must now step back from the contextual dependencies emerging from all the experimental studies to see the bigger picture and identify information that can be extrapolated to other contexts. Functional and trophic network ecology approaches that integrate the functional traits of different species offer interesting perspectives that should soon lead to predictive tools on natural insect pest control. To date, very few studies have attempted to integrate the diversity of known factors from the plant scale to the landscape scale. However, it is vital that we do so if we are to truly understand the multiple interactions between agroecological drivers, synergies and even antagonistic forces and optimize natural pest control strategies. There are also very promising prospects for modelling trophic interaction networks.