In: Natural Enemies
Editor: Sónia A.P. Santos
ISBN: 978-1-63485-921-9

Chapter 1

POTENTIAL OF ECOLOGICAL INFRASTRUCTURES TO RESTORE CONSERVATION BIOLOGICAL CONTROL: CASE STUDY IN SPANISH OLIVE GROVES

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ABSTRACT

World population is exponentially growing and with it, the need for quality food that supports this expansion. Current agricultural techniques rely on a massive use of chemical inputs that at the end jeopardise the sustainability of crops. New approaches are oriented towards the promotion of natural control mechanisms that guarantee biodiversity through the conservation and restoration of natural habitats. In this sense, conservation biological control is the most promising option to meet an equilibrium between production and biodiversity conservation. It is based on the creation of a suitable environment to balance the relationship

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between crop, pests and natural enemies to avoid fluctuations that can bring about production losses. In this chapter we review the state of the art of this strategy and we present a case study in Andalusian olive groves. Along the document we present the controversies that may arise after the implementation of this strategy and we discuss about possible solutions.

Keywords: ecosystem services, biodiversity, ground cover, landscape, natural enemies, crop protection

1. INTRODUCTION

The use of synthetic chemical products to control pests and diseases has led to the consolidation of farming methods based on a wide use of these inputs. Along with this practice, a number of problems that threaten both sustainability and quality of the crops and the health of people and natural systems have appeared (Meehan et al., 2011). To stop this trend, scientific and political professionals are demanding a change to pest management techniques orientated towards more sustainable strategies. Among the possible solutions, biological control is being studied and, between all the possible strategies of this method, conservation biological control is the most promising alternative to reduce the use of chemical products.

Conservation biological control (CBC) differs from other biological control strategies in that it is not based on an insect release, but rather to establish, by applying certain methods, an adequate environment where to develop the crop (Barbosa, 1998). The application of these methods does not exert its own action to control pests but promotes abundance, diversity and effectiveness of natural enemies already present in the agricultural ecosystem for optimal performance against pests (Bianchi et al., 2006; Landis et al., 2000). An increase in plant diversity in the agroecosystem would result in increasing the resources that natural enemies can exploit and, consequently, in improving natural pest control. In traditional farming systems, biodiversity has been used to protect crops from pests and diseases, minimizing the risk of crop loss, producing a varied diet and diversifying sources of income (Altieri, 1991). Therefore, in order to perform a conservation biological control strategy, it is not necessary to carry out specific actions but create an environment to balance the relationship between crop, pests and natural enemies to avoid fluctuations that can bring about production losses (Paredes et al., 2013a). Landis et al. (2000), suggested several resources that have to be enhanced to promote conservation biological control: shelter and nesting sites, supplementary food (nectar, pollen) and alternative hosts or prey. The best way to provide these resources is through the installation and management of ecological infrastructures. These are natural or seminatural non-crop lands that conserve ecosystem functions and provide associated services.

Perennial crops, which are subject to lower levels of disturbance than annual crops, are potentially more suitable for carrying out a conservation biological control strategy. The most commonly used approach has been the installation and management of a ground cover. This normally can be in the form of a strip between tree lines or, less commonly, continuous on the ground (Smith et al., 1996). They are mainly composed of planted species belonging to the families Poaceae and Fabaceae although there are studies in which a natural and spontaneous cover was allowed to grow (Paredes et al., 2013b; Rieux et al., 1999; Silva et al., 2010). Other studies chose to design ground covers with aromatic plants (Song et al., 2010). The study of ground covers has produced very positive results in the abundance and diversity of natural enemies in pear (Rieux et al., 1999; Song et al., 2010), pecan (Smith et al., 1996), apple (Bone et al., 2009), vineyards (Danne et al., 2010), citrus (Silva et al., 2010) and olive crops (Paredes et al., 2013b). However, despite any increase in the abundance of predatory and parasitic insects led by the use of ground covers, it is still uncertain whether this will translate into reduced pest densities. Much of the existing literature focuses on the effects of ground covers on natural enemies, implicitly assuming that an increase in their abundance or diversity will necessarily lead to a decrease in pest abundance. Those studies that explicitly investigate the effects of ground cover on herbivore abundance provide inconsistent evidence (Paredes et al., 2015a). There are two reasons that could explain these controversial results: the influence of the landscape context and the relationship between biodiversity and biological control.

If the crop is located within a very diverse landscape (heterogeneous), the chances of a successful conservation biological control will be greater than those that would exist if the agricultural activity has developed within a homogenous landscape. Thies and Tscharntke (1999) provided the first evidence of this fact and determined that pest damage was negatively related to the landscape diversity that was surrounding the crop. Other studies in the same subject, have also found positive results from the abundance of natural enemies and diversity on the landscape scale, as shown by the latest reviews published in this area (Bianchi et al., 2006; Chaplin-Kramer et al., 2011; Rusch et al., 2016).

The fact that the landscape context has an effect on the quality of conservation biological control has usually been unnoticed in studies that implemented ground covers. Most of the studies have focused on non-crop vegetation (landscape approach) or on the effect that ground cover installation and management can have on natural enemy performance (farm approach) (Paredes et al., 2013b; Woltz et al., 2012). Many of the studies that have assessed conservation biological control techniques have not taken into account the landscape context, thus ignoring its potential (both positive and negative) synergistic effects between seminatural habitats and the implemented techniques (Altieri et al., 2005). However, recent works on the subject already have this possibility in annual crop (Woltz et al., 2012) and perennial crops (Paredes et al., 2013b; Paredes et al., 2013c).

According to the theory, an increase in the diversity of natural enemies will have consequences for biological pest control because increasing the number of species in the community of natural enemies will increase the chances that some of these species perform effective pest control (Loureau, 1998; Straub et al., 2008). However, in most cases, the relationship between biodiversity and biological control is not usually successful (Moonen & Bàrberi, 2008) and, in cases where the biological control is effective, there is one natural enemy or a small group of them that are exerting such control (Denoth et al., 2002; Paredes et al., 2015b). Different ecosystem processes can underlie the relationship between biodiversity making it positive, neutral or even negative.

A key factor that can lead to a negative relationship between biodiversity and biological control is intraguild predation. Intraguild predation occurs when a predator consumes another predator, which competes for the same prey (Polis & Holt, 1992). This fact distorts the first predator´s action to the target species (pest), and decreases the action of the second predator on the pest by the decline of its abundance. Thus, a biodiversity increase in the agroecosystem will increase the chances that this process occurs, reducing the chances of an effective biological control. However, an increase in biodiversity would also increase the possibility that a functional redundancy process would occur. This happens when more than one species have the same functional role within the agroecosystem (Walker, 1992). With this situation, an increase in natural enemy diversity will not transfer into a decrease in pest abundance because the ways to reduce it are overlapped, thus leading to a neutral relationship between biodiversity and biological control. It is also conceivable that an increase in diversity would increase the range of functional strategies of consumption of the pest by different natural enemies. For example, a natural enemy can chase prey while another can ambush, lurking and waiting. Thus, a niche complementarity process would lead to a positive relationship between biodiversity and biological control (Straub et al., 2008).

2. GROUND COVER AND CONSERVATION BIOLOGICAL CONTROL IN OLIVE GROVES

To assess the ability of ecological infrastructures for conservation biological control of pests is not an easy task, as there are a multitude of processes, both direct and indirect, that may influence the effect of these structures on populations of different groups of arthropods. However, there are new studies where the implementation of these techniques has great potential but has been little studied. These new works show an innovative approach in several aspects. First, and to the extent of our knowledge, this is one of the first works in which the combined effects of different ecological infrastructures on arthropod abundance are analysed. Second, the detection of controversies (increased abundance of natural enemies in areas with ground cover not resulting in a decrease in the abundance of pests in the same areas) has led to the study of the relationships between the natural enemy community components and those with pests. Finally, a broad timescale (six years of observations) and spatial (over 2,528 olive trees scattered throughout the Autonomous Community of Andalusia) is used to analyse the effect of ground cover on different pest species, which has contributed to an overview of the role of this structure in conservation biological control.

The olive tree is a crop of particular importance in the Mediterranean region and especially in Spain, a country that is the top world producer with 6,538 tons on average between 2010 and 2014, more than a third of the world production (34.2%) (FAOSTAT, 2014). It also offers optimal characteristics for the implementation of a conservation biological control strategy based on habitat management. Being a perennial crop, the installation and management of a ground cover in the middle of the tree rows is easy. In addition, olive groves are characterized by an abundant and diverse community of natural enemies with a parasitic complex represented by 300-400 species of Hymenoptera order and a predator complex consisting of different orders (Arambourg, 1986). Among the main groups of predators we can find spiders, which are the most diverse with 217 species, followed by Coleoptera order with 30 species, the group of ants with 24, Hemiptera with 11 and Neuroptera with 13 species (Cárdenas, 2008; Cotes et al., 2010; Morris et al., 1999; Redolfi et al., 1999; Rei et al., 2010; Ruiz-Torres & Montiel-Bueno, 2000; Santos et al., 2007). However, several insect species attack and damage olive trees, with the key pest species being the olive fly *Bactrocera oleae* (Rossi) (Diptera: Tephritidae), the olive moth *Prays oleae* Bern. (Lepidoptera: Praydidae), and the olive scale *Saissetia oleae* Olivier (Hemiptera: Coccidae). These three phytophagous insects are widely distributed and usually cause high crop damage by reducing the amount and quality of production (Arambourg, 1986; Tzanakakis, 2006). In addition, there are other secondary pests that can cause important losses more sporadically. Among them are species such as the olive psyllid *Euphyllura olivina* Costa (Hemiptera: Psyllidae), the olive borer *Phloeotribus scarabaeoides* Bern. (Coleoptera: Scolytidae) or *Euzophera pinguis* Haw. (Lepidoptera: Pyralidae) (Alvarado et al., 2008; Campos, 2011; Civantos, 1999).

The olive grove presents varied typologies of landscapes (Duarte et al., 2009). If we consider that greater structural diversity (trees, spontaneous ground cover, patches of natural vegetation, etc.) allows a greater diversity of habitat and specific benefits, it is reasonable to think that each type of olive grove shall raise its particular way of relating to biodiversity. However, the benefits of landscape complexity have been poorly quantified in the olive grove so it is necessary to carry out specific studies and determine the weight of each of these ecological infrastructures in relation to conservation biological control, which will develop targeted measures to enhance the action of the auxiliary fauna and therefore the sustainability of the olive grove (Duarte et al., 2009).

Synergies between ground cover and adjacent natural vegetation patches have been detected in some groups of natural enemies. Spiders and parasitoids were more abundant in plots with ground cover while this structure did not affect Heteroptera predators. Large patches of woody and herbaceous vegetation patches influenced natural enemy abundance more than small patches composed of shrubs. The effect of adjacent natural vegetation was different for each group and relied on the presence of a ground cover. When both structures were present in the crop, parasitoids and spiders were positively influenced by the surrounding vegetation, while this effect was smaller or even negative in areas of bare soil, especially in the case of herbaceous vegetation patches for spiders (Paredes et al., 2013a).

Considering the effects of ground cover on spiders and parasitoids, one would expect that in areas where this structure was present, pest populations were lower than in areas where the ground was bare. However, in olive groves, ground cover did not display an effect on the abundance of *P. oleae* and *E. olivina* (Aldebis et al., 2004; Rodríguez et al., 2009; Paredes et al., 2013c). This could reflect a lack of synchronisms between pest and natural enemies that have shown a response to the presence of ground cover (Perdikis et al., 2011).

However, natural vegetation patches displayed a positive effect on biological pest control in olive groves. In particular, large areas of woody vegetation reduced the abundance of *P. oleae* and small patches of woody vegetation decreased the abundance of *E. olivina*. The effect of other ecological infrastructures showed variability between years in the abundance of the two pest species which may indicate that weather conditions play an important role in modulating the response of pests to their environment (Logan et al., 2006; Martinat, 1987).

The relationship between different natural enemy groups and pests has been explored in order to determine the source of controversy. *E. olivina* was associated with the predatory species *Anthocoris nemoralis* Fabricius (Heteroptera: Anthocoridae), as occurred in other crops such as pear (Agustí et al., 2003; Shaltiel & Coll, 2004). *A. nemoralis* overwinters in the adult stage in the vegetation adjacent to crops (Horton & Lewis, 2000; Paredes et al., 2013b). Probably, its presence in the crop is mediated by the release of herbivore-induced plant volatiles (HIPV´s) (Drukker et al., 1995). Consequently, when *E. olivina* reaches high abundance on the tree, the injured tissues can emit a blend of HIPV´s that attracts *A. nemoralis*. This is of great importance since *A. nemoralis* has also been related to low abundances of *P. oleae*. When adults of *A. nemoralis* appear on the tree at the beginning of the season, they lay the eggs of the next generation, and because of their small size, new-borns have no available prey except *P. oleae* eggs, thus reducing the abundance of this pest. As a result of this process, *A. nemoralis* could become a very effective biological control agent against the anthophagous generation of *P. oleae* (Morris et al., 1999; Paredes et al., 2015b). In addition to *A. nemoralis*, another group of natural enemies has been identified in a set of predators consisting of two families of spiders, Araneidae and Linyphiidae, and the lacewing *Chrysoperla carnea* Stephen (Neuroptera: Chrysopidae) that were also associated with a low abundance of *P. oleae*. These groups could play complementary roles determined by the way they capture their prey

(Straub et al., 2008). Nevertheless, further information is needed to confirm the trends observed in these studies.

Apparently, olive pest abundance is more affected by the presence of patches of natural vegetation and the natural enemies that they can harbour than by the presence of a ground cover within the crop. However, there are certain circumstances (landscape and climate) that could determine the role of ground cover on biological pest control. These could be masking the true effect of this structure, drawing on non-valid conclusions if studies do not take into account these characteristics or are developed at a local scale. The analysis on the effect of ground cover in a large study area and a large time scale provided much more robust evidence about the usefulness of ground cover for the conservation biological control of olive pests. Results indicated that the ground cover, as a single factor and compared with bare soil, was not effective in reducing pest abundance in olive groves (Paredes et al., 2015a). The variability explained by random factors related to the specific conditions of the plot (local scale), the landscape context (landscape scale) and climatic variability between years (regional) was much higher than those explained by ground cover.

Locally, the physical characteristics of the land (topography, microclimatic characteristics, soil type, cultivar), as well as the farm management (intensity of pesticides applied, history of land use), can have a significant effect on pest abundance. Ground cover composition (Drukker et al., 1995), density (Colloff et al., 2013), width of the strip (Hardman et al., 2011), or height of the herbs can also have an effect on the abundance of pests (Tsitsilas et al., 2011). Another factor that can influence pest populations is the historical application of pesticides (Croft & Brown, 1975). An abuse of these substances in the recent past could reduce populations of natural enemies to levels ineffective for biological control. In addition, the lack of natural vegetation patches can increase the injurious effect of pesticides because natural enemies do not have places to shelter when olive groves are sprayed (Landis et al., 2000; Bianchi et al., 2006; Simon et al., 2010).

On a landscape scale, structures are able to influence the colonization of natural enemies into the crop (Bianchi et al., 2006; Perovic et al., 2010; Thies & Tscharntke, 1999). Differences in the landscape context can have great influence on the abundance of pests (Bianchi et al., 2006; Rusch et al., 2013; Thies & Tscharntke, 1999). Natural vegetation patches characteristics; such as edge, density and landscape diversity can help to reduce the abundance of *B. oleae* (Boccaccio & Petacchi, 2009; Ortega & Pascual, 2014). This does not necessarily mean that the higher the density of natural vegetation the greater biological control because sometimes it may be the opposite effect due to negative interactions between organisms belonging to agroecosystem (Martin et al., 2013) or that these habitats have the opposite effect by removing, instead of providing natural enemies in the crop (Karp et al., 2013). Resolving these complexities requires analysing the effects of natural habitat adjacent to crops on predators, pests and predation rates (Bianchi et al., 2006; Chaplin-Kramer et al., 2011; Karp et al., 2013).

CONCLUSION

Although a clear effect of ground cover on biological control of olive pests was not observed, it can help to increase local habitat heterogeneity, showing its usefulness to maintain populations of beneficial arthropods within the olive grove. A more detailed analysis of its composition and management in order to optimize its effect on conservation biological control would be advisable because it would draw on conclusions capable of generating useful management guidelines for stakeholders. However, ground cover is recommended to enhance other ecosystem services such as nutrient recycling, prevention of erosion (Culler et al., 2008; Hartwig & Ammon, 2002), or pollination (Tscheulin et al., 2011). Effort should be made in the assessment of patches of natural vegetation surrounding the farm and in the landscape composition if the objective is to enhance the conservation biological control in olive groves.

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BIOGRAPHICAL SKETCHES

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Departamento de Protección Ambiental.
Estación Experimental del Zaidín.
Consejo Superior de Investigaciones científicas.

Research and Professional Experience: His research focuses on the study of ecosystem services in agricultural landscapes.

Education: Ph.D. Universidad Granada, Spain

Education at other institutions: MSc, Universidad de Granada; BSc Universidad de Extremadura, Spain

Honors: Cum Laude Doctor Europeus

Publications Last Three Years:

Paredes, D.; Moreno-Chocano, J.; Cano, A.; Ruano, F.; Campos, M.. (2015). Estudio de fecundidad y ciclo de vida de *Anthocoris nemoralis* (Heteroptera: Anthocoridae) en el olivar. *Revista de Fruticultura 44*, 18 – 25.

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Área biodiversidad y conservación. Universidad Rey Juan Carlos I

Research and Professional Experience: He is interested in forest ecology, conservation biology, agroecology and environment statistics developed under R software.

Professional Appointments: Associated Professor

Education: Ph.D. Universidad Alcalá, Spain

Education at other institutions: MSc in Conservation, University College of London (United Kingdom)

Honors: European PhD and Cum Laude

Publications Last Three Years:

Albuquerque, F.S.; Assunção-Albuquerque, M.J.T.; Cayuela, L.; Zamora, R.; Benito, B.M. (2013). European bird distribution is "well" represented by special protected areas: mission accomplished? *Biological Conservation* 159: 45-50.

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Research and Professional Experience: She is the head of the crop protection group at Spanish Council of Research and has and strong background in biological control of pest in olive groves.

Professional Appointments: Professor of Research

Education: Ph. D. Universidad Granada

Honors: Cum Laude

Publications Last Three Years:

Pascual, J.; Blanco, S.; García-López, M.; García-Salamanca, A.; Bursakov, S.A.; Genilloud, O.; Ramos, J.L.; van Dillewijn, P. (2016). Assessing bacterial diversity in the rhizosphere of *Thymus zygis* growing in the

Sierra Nevada National Park (Spain) through culture-dependent and independent approaches. PLoS ONE, 11(1): e0146558

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