EIP-AGRI Focus Group

'Pests and diseases of the olive tree'

Biodiversity and pest management

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1. Introduction

Maintaining biodiversity and the associated ecosystem services is an objective of the European Union, implemented through agri-environmental programmes. Biodiversity decline is occurring at a worldwide scale and has twofold implications. From a conservation point of view, the number of extinct and endangered species increases, and this impoverishment of natural ecosystems reduces their resilience. From an agronomical point of view, reduction of biodiversity affects processes that hamper crop productivity, such as pollination or pest management, being the consequence of this biodiversity decline a reduction in agroecosystem sustainability. But both, ecosystem resilience and agro ecosystem sustainability are not isolated. In the case of pest control, in many cases it is assumed that it depends on biodiversity. However, a positive relationship between biodiversity of natural enemies and pest suppression is not always the case. In fact, in some cases this relationship does not occur (Fig.1), and the success of biological control depends not on biodiversity, but on the presence of one or only few species of natural enemies. As an example, in the case of olive trees, a single species such as *Anthocoris nemoralis* or relatively simple predator assemblages are associated with better biological control than complex assemblages (Paredes *et al.*, 2015). However, it seems that the general rule in different agroecosystems is that biodiversity rather than abundance of natural enemies is linked to pest control, although this has been proven mainly in annual crops and in non-mediterranean environmental conditions (Dainese *et al.*, 2019).

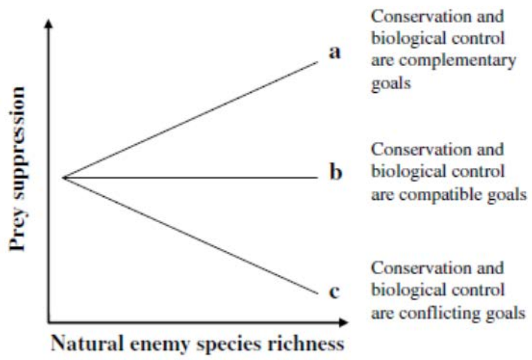

Figure 1: Relationships between natural enemy species richness and pest suppression from the perspective of a predator-prey interaction (Straub *et al.*, 2008)

The objective of this minipaper is to evaluate if there is a knowledge gap regarding the link between biodiversity and pest control in the case of the olive agroecosystem. If this is the case, we aim also to find out which direction research should follow to contribute to foster biological control through an increase of biodiversity. Although our main focus is on natural enemy biodiversity, we aim to analyze biodiversity in a broad sense, including aspects of plant biodiversity and general arthropod biodiversity, and links with landscape complexity because natural ecosystems and agroecoystems are not isolated.

2. Which biodiversity is relevant in the context of pest management?

The conservation and management of biodiversity in agricultural ecosystems is often considered within the so-called Agroecological approach in agriculture. Agroecology applies ecological principles to the design and management of biodiverse, productive and resilient farming systems and defines, classifies and studies agricultural systems from an ecological, as well as socio-economic perspective (Altieri, 1995). Agroecological strategies are meant to enhance ecosystem services provided by biodiversity which depend on the degree of (agro)biodiversity at gene, species and landscape levels.

Agrobiodiversity is a very broad term including all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agroecosystems. The concept of biodiversity management and use in agroecosystems has a dual approach: at one hand, agriculture is regarded as providing environmental conservation 'functions' for species or habitats which are endangered, vulnerable or rare. Indeed, environmental-friendly farming practices and landscape management can contribute to biodiversity conservation in various ways. In this context, the olive agroecosystem is a provider of diverse externalities, being biodiversity one of them. On the other hand, biodiversity can provide significant agroecosystem services, such as pollination, nutrient, and most important, biological pest control. However, the “useful” (functional) part of biodiversity should be selected and fine-tuned to every given context (agroecosystem). Specifically, functional agrobiodiversity is regarded as this part that delivers important agroecosystem services and supports sustainable agricultural production, delivering benefits to the regional and global environment and the public at large. Following this approach, the agroecosystem should be analyzed in terms of the expected and desired functions and services and of the (groups of) organisms providing or contributing to it. The importance of having diversity of a certain trait of the elements composing a "functional group" of biodivertsity to fulfil a desired agroecosystem service(s), is also specifically regarded as a genuine approach to define the functional part of biodiversity elements (Moonen and Barberi, 2008).

3. Research steps need to relate biodiversity and pest control

Biodiversity has a role in supporting the control pest population’s outbreaks, which encompasses the promotion of biological protection through native auxiliary fauna. These natural enemies’ populations have the advantage of coexisting in time and space and classically have a high reproductive response to slight increases in host density. Ideally from the pest management perspective, they would also show seasonal reproductivity responding to the pest population. However, to actually be able to assign a role in suppressing pest population size, several knowledge gaps need to be fulfilled (Fig.2).

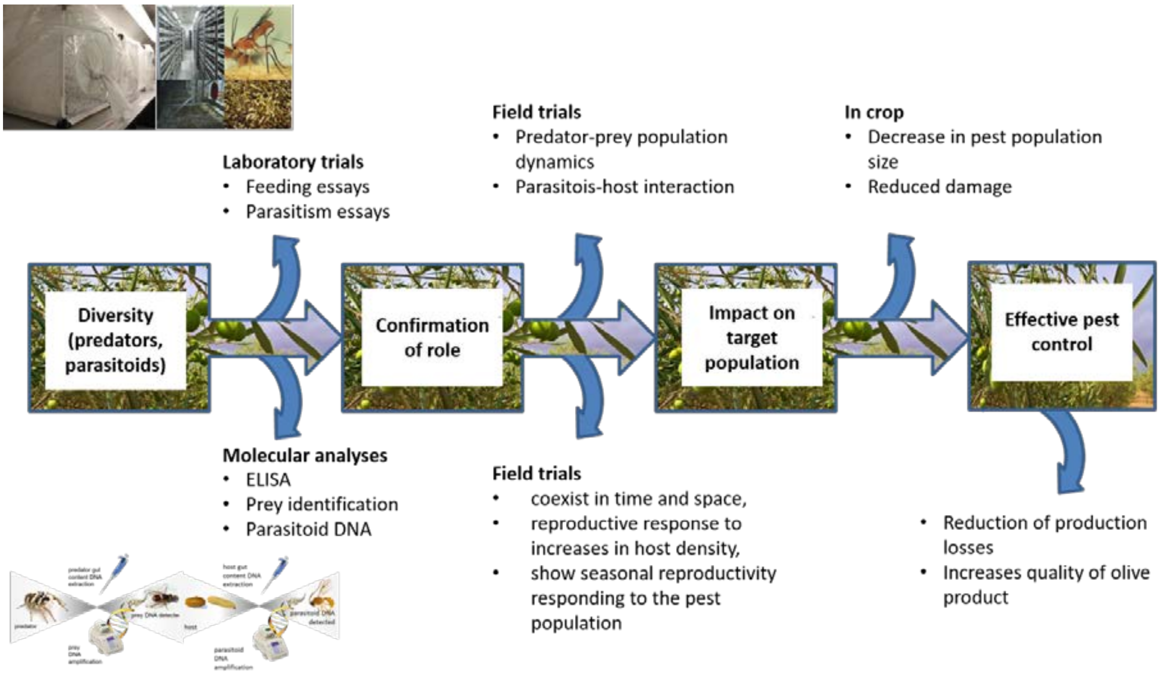

Figure 2: Schematic representation of research steps needed to relate auxiliary fauna and pest management. The final aim is an increase of both quantity and quality of olive production.

Unarguably, the first step is a biodiversity assessment, which for the aim of management of the putative target pests should focus on the entomological diversity and on the main guilds of natural enemies: predators and parasitoids. However, their presence does not indicate *per se* that: 1) they feed on or parasitize the desired host pest; 2) their ecological dynamics matches the one of the targeted putative pests; and 3) that increase rates of parasitism/predation actually cause a reduction of pest population. The final proof-of-concept has to be a measurable decrease in crop damage, that can be attributed to the action of this auxiliary fauna, and in parallel induce an increase in yield and/or in the quality of the olive products.

4. The spatial context to measure biodiversity and pest control. The landscape scale

Natural biological pest control in an agricultural field depends on the intensity of the parasitism and/or predation of pests by natural enemies. Both pests and natural enemies are not isolated in the agricultural orchard, but experience the environment at the landscape scale. Thus, pest control at local scale depends not only on local factors, such as management, presence of cover crops, etc. but also on landscape structure around the field. The general assumption is that in structurally complex landscapes, biological control is higher and crop damage lower than in simple landscapes, as has been shown in some agroecosystems (Thies and Tscharntke, 1999). The final goal of studying the effect of landscape structure on pests and natural enemies is the “design” of landscapes less conducive to the development of pests.

Landscape simplification can affect pest control directly and/or indirectly. Directly, larger crop areas would favour pest populations and landscape structure can also favour or hinder the movement of insect pests between crop patches (O'Rourke and Petersen, 2017). The indirect effect is mediated by an increase of biological pest control, because larger areas of seminatural habitats provide natural enemies with refuge, and alternative host/prey. In the case of the olive agroecosystem, complex landscapes are associated with lower populations of insect pests, such as *Bactrocera oleae* or *Prays oleae* (Ortega and Pascual, 2014; Villa *et al.*, 2017b) see below), but not in all the studies carried out (Picchi *et al.*, 2016). Also, relationships between landscape structure and parasitism and predation rates of *B. oleae* have been reported (Boccaccio and Petacchi, 2009; Ortega *et al.*, 2018). On the other hand, there are also reports of negative effect of landscape complexity on abundance of some predators (Picchi *et al.*, 2016), and in other cases the effect of local factors is more intense than the landscape effect (Ortega *et al.*, 2018). Regarding arthropod biodiversity in general complex landscapes seem to be related with richer arthropod assemblages (Cotes *et al.*, 2011; Gkisakis *et al.*, 2018), but again this is not always the case (Scalercio *et al.*, 2012).

Thus, there is not a consistent response of pests, natural enemies, and arthropod abundance and/or biodiversity to landscape structure in the olive agroecosystem, which has been reported also in meta-analysis for crop pests and predators in different crops (Karp *et al.*, 2018). This can be a result of the different response of species to landscape structure because different species have different habitats and foraging distances, but also on the different environmental conditions of the studied sites, such as climate, topography, edaphology, varieties or management. Also, the diverse ways to measure landscape complexity (composition and configuration indices) may contribute to the different results obtained. Despite these diverse results and the lack of a complete knowledge on the effect on landscape on pest control, it seems that the proposed general rule indicating only an indirect effect of landscape on pest control throughout an increase of biodiversity, but nor abundance of natural enemies does not apply completely to the olive crop. More research is needed in this field, for example to know the level of landscape complexity amenable to modifications to favour biocontrol, i.e., manipulations to increase semi wild habitats to favour pest control will be more successful in areas dominated by olive groves than in areas where this dominance is reduced.

5. Complexity of food webs as a measure of ecosystem “health” and ability to control pests

Trophic relations between plants and arthropods (also called food webs, Fig.3) are poorly known, despite increasing effort to better understand nature through ecology these last years. As for insects, plants also evolve and these relations may change rapidly, especially considering chemical ecology and communication between plants being attacked, pests and their predators.

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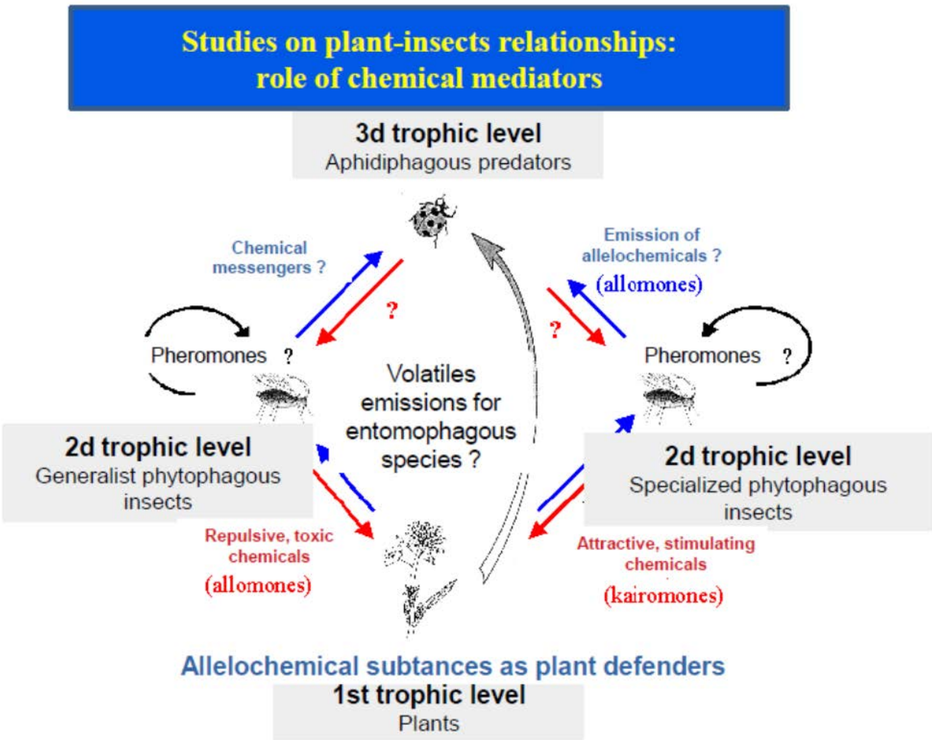

It is reported that the 'Mediterranean garrigue' adjacent to olive groves promotes predation of *B. oleae* pupae, although the processes involved, and/or the plant and natural enemy species implicated are not well known. Also, the potential of some specific plants for biological control has been pointed out: *Dittricchia viscosa* is attacked by an insect which shares parasitoids with *B. oleae* (Warlop, 2006); as well as other species such as *Asphodelus ramosus, Lactuca viminea* or *Verbascum sinuatum*. These species have however not been shown to significantly reduce olive fly damages so far.

Plants with exposed nectaries are preferred as a food source by *Chrysoperla carnea*, because of its short mouth parts (Nave *et al.*, 2016), and some plant species are better than others regarding the nutritional values of pollen for natural enemies (Villa *et al.*, 2016). Vegetal covers are advised in olive groves, because they have a beneficial effect on abundance and diversity of natural enemies of pests (Campos, 2017), even seed mixtures are commercially available to favour natural enemies. However, information is needed on biocontrol efficacy of the different plants/mixtures seeded, regarding the different pests, as some studies indicate small and inconsistent effects of ground cover on the abundance of pests.

6. The state of the art regarding the different pest species

6.1. *Bactrocera oleae*

This tephritidae is considered the key olive pest in the Mediterranean olive groves. From April to November, olive fruit fly population is mainly located in the tree canopy. Biological control in this period relays mainly on hymenoptera parasitoids, although many other animals are potential predators (birds, spiders...). The most abundant and common belong to the Superfamilies Ichneumonoidea and Chalcidoidea (Table 1), parasitizing larvae and pupae inside the olive fruits. The parasitoid complex is mainly active in summer and autumn, and it is able to parasitize the last two larval stages and pupae (Warlop, 2006; Calabrese *et al.*, 2012; Andalucía, 2015). Spontaneous vegetation in the grove and surroundings are nectar and pollen resources that enhance both parasitoid longevity and fecundity. Most of them are highly polyphagous, unspecific to *B. oleae*. Consequently, a biodiverse environment may favor the increase of the populations of these parasitoids. For instance, the ground cover favors the presence of *E. urozonus* and *C. latipes*, and the proximity to forests and fruit trees stimulates the presence of *P. mediterraneus* and *P. concolor*. In spite of the numbers and abundance of those parasitoids, and the knowledge of the interspecific and tritrophic relationships between them and their different hosts in the olive groves, its effectiveness on *B. oleae* has not yet quantified in terms of real reduction of damage produced by this insect.

From October to March, most fruit fly population is composed by larval and pupal stages in the soil, being exposed to soil predators. Several generalist soil dwelling predators have been proposed to control fruit fly in this period. Scolopendromorpha, Araneae, Formicidae, Carabidae, Dermaptera, Staphilinidae predate on them actively (Dinis *et al.*, 2016; Albertini *et al.*, 2017). The efficacy of this predation is highly variable, depending on the grove, pest management, soil management, year, landscape, etc (Ortega *et al.*, 2018). The environmental context of olive grove is less relevant than pest management, since they are very sensitive to certain pesticides (Picchi *et al.*, 2017). The 'Mediterranean garigue', characterized by low vegetation, mainly composed of shrubs and herbs, increases predation; in contrast, a woody area as a biodiversity source does not contribute to the provisioning of olive fruit fly predators (Albertini *et al.*, 2017; Picchi *et al.*, 2017). Despite the knowledge generated by many studies on soil predators species that inhabit the olive groves and their sure predation on pupae, the true extent of this predation in the reduction of damage caused by the olive fly in the olive groves is not known. This predation shall also be linked to soil cultivation practices, as a bare soil will strongly reduce potential for ground biocontrol.

Table 1. Main hymenoptera parasitoids of *B. oleae* species in Mediterranean olive groves

Species	Superfamily Family	Parasitism	Stage host	Active period	Other hosts / Vegetal species
Eupelmus urozonus	Chalcidoidea Eupelmidae	Ectoparasitoid	L3-Pupae	July-October	Hyperparasitoid of *Pnigalio mediterraneus, Eurytoma martelli, Psyttalia concolor* Other hosts: *Myopites stilata (Dittrichia viscosa)* *Phloeotribus scarabeoides (Olea europaea)* *Lobesia botrana (Vitis spp)* *Dasineura gleditchiae (Gleditsia triacanthos)*
Eurytoma martelli	Chalcidoidea Eurytomidae	Ectoparasitoid	L3	August-September	Unknown
Pnigalio mediterraneus	Chalcidoidea Eulophidae	Ectoparasitoid	L2-L3	All year	*Prays oleae (Olea europaea)* *Phyllocnistis citrella (Citrus spp)* *Phyllonorycta blancardiella (Malus spp.)* *Tischeria complanella (Quercus ilex)* *Phyllonorycter millierella (Celtis australis)*
Psyttalia concolor	Ichneumonoidea Braconidae	Endoparasitoid	L3-Pupae	All year	*Ceratitis capitata (Citrus spp, Malus spp, Ziziphus spp, Ficus carica, etc)* *Capparymia savastanoi (Capparis spinosa)* *Carpomya incomplete (Ziziphus jujuba)*
Cyrtoptyx latipes	Chalcidoidea Pteromalidae	Ectoparasitoid	L2-L3	August-October	*Hypolixus truncatulus (Amaranthus spp)* *Coleophora stephanie (Atriplex maximus)*

6.2. *Prays oleae*

The most common groups found to predate on olive pests are the Coccinelidae, Neuroptera, Formicidae, Thysanoptera, Carabidae and Araneae. Of the Neuroptera group, the species that have been reported to predate on eggs of *Prays oleae* are *Chrysoperla carnea*, *Mallada flavifrons*, *Mallada picteti*, *Mallada prasina*, *Nineta vittata* and *Rexa lordina* (Bento et al., 1999). The *Coccinelidae* has a wide range of prey species, including olive pests. Also, the Formicidae family is known to have several species that predate and control the populations of other insects and several species were described to feed on *P. oleae*. The genus *Camponotus sp*. is one of the most referenced: different *Camponotus* species were confirmed predators of *P. oleae* using ELISA (Morris *et al.*, 1998; Morris *et al.*, 1999). With ELISA or PCR based methods, it is possible to have a confirmation of the predatory role of a given insect on a specific species. The predatory role of species as *Tapinoma nigerrimum*, *Plagiolepis pygmaea*, *Formica subrufa*, *Crematogaster scutellaris* on *P. oleae* was in this way established. Finally, the group that includes spiders, pseudoscorpions, and other arachnids are known to have a wide range of different type of predators, most of them being generalists.

Regarding parasitoids, most studies found only emphasized the frequency with which parasitoids are observed in olive groves, especially those belonging to the Braconidae, Chalcididae, Eulophidae, Ichneumonidae, and Trichogrammatidae (Hymenoptera). The beneficial species reported as being the most important in the control of *P. oleae* populations are *Apanteles xanthostigma* (Haliday) (Braconidae), *Pnigalio agraules* (Walker) (Eulophidae), *Elasmus flabellatus* (Fonscolombe) (Elasmidae), *Diadegma armillata* (Gravenhorst) (Ichneumonidae) (Hymenoptera), *Ageniaspis fuscicollis* var. *praysincola* (Dalman) (Encyrtidae) and *Chelonus elaeaphilus* Silvestri (Braconidae) (Bento el at., 2007). Going a bit further, it has been established that *C. elaeaphilus* is an efficient parasitoid of grouped eggs, deposited by the first two generations of the olive moth, being able to reach values up to 80% of parasitism; however, its effectiveness in the parasitism of dispersed eggs, deposited by the third generation is much smaller (Civantos and Caballero, 1993). On the other hand, the action of *A. fuscicollis* can reach values of 70% of parasitism in areas where it is well established.

Table 2. Main natural enemies of P*. oleae* species in Mediterranean olive groves

species	Superfamily/ Family	role of natural enemy	stage prey	Active period
		Predators		
Chrysoperla carnea	Neuroptera	larvae polyphagous (adults not predators)	egg	spring and summer
Mallada spp.	Neuroptera	larvae often specific (preferentially aphids); adults polyphagous	egg	spring to autumn
Nineta vittata	Neuroptera	polyphagous	egg	spring and summer
Rexa lordina	Neuroptera	polyphagous	egg	spring and summer
Several species	Coccinelidae	polyphagous	larvae eggs	spring to autumn
Camponotus spp.	Formicidae	polyphagous	unknown	summer to autumn
Tapinoma nigerrimum	Formicidae	polyphagous	unknown	spring to autumn
Plagiolepis pygmaea	Formicidae	polyphagous, but associated with the butterflies	unknown	spring to autumn
Formica subrufa	Formicidae	polyphagous, also feed on seeds, nectar and sap	unknown	spring to autumn
Crematogaster scutellaris	Formicidae	polyphagous	unknown	summers to autumn
	Araneae	polyphagous	unknown	species dependent
	Pseudo scorpionidae	polyphagous	unknown	species dependent
		Parasitoids		
Apanteles xanthostigma	Braconidae	ectoparasitoid of Yponomeutidae (but also other Lepidopteran)	larvae	?
Pnigalio agraules	Eulophidae	ectoparasitoid	larvae pupae	all year
Elasmus flabellatus	Elasmidae	gregarious, ectoparasitoid	L3 pupae	
Diadegma armillata	Ichneumonidae	Endoparasitoid, microlepidoptera (one generation per yr on *Yoponomeuta* sp.)	larvae pupae	?
Ageniaspis fuscicollis	Encyrtidae	endoparasitoid of Yponomeutidae	egg larvae	?
Chelonus elaeaphilus	Braconidae	Yponomeutidae (host-specific parasitoid of the olive moth ?)	larvae	?

6.3. *Saissetia oleae*

Natural enemies associated with *S. oleae* include entomophagous arthropods with several species of predators and parasitoids. Regarding predators, they mostly belong to the Coccinellidae family. Since many decades Coccinellidae species, like *Chilocorus bipustulatus* is described as having an important role in the natural limitation of *S. oleae* populations (Argyriou, 1974), while other species, such as *Pullus* sp. (Carrero *et al.*, 1977) or *Scymnus* sp. (Santos, 2007) are also considered as important.

In terms of parasitoids of *S. oleae*, they can be divided in two groups in terms of the stage of the scale attacked, namely i) nymphal and ii) adult parasitoids. Hymenopteran families, like Aphelinidae, Encyrtidae and Pteromalidae are described as providing such important services (Torres, 2007). Since the 1960's *Metaphycus flavus* (family Encyrtidae) and *Coccophagus lycimnia* (family Aphelinidae) (Hymenoptera: Aphelinidae) were the cited as the natural enemies of *S. oleae*, while *Scutellista caerulea* (family Pteromalidae) is described to feed on the *S. oleae* eggs (Pasos de Carvalho, 2003). Here again, farmers practices shall be modified accordingly. Treatments with compounds such as sulfur or Spinosad may have significant side-effects on beneficial species, and especially micro-hymenoptera.

7. Knowledge exchange on biodiversity and pest control

Biodiversity is generally accepted as an essential characteristic for the correct function of natural ecosystems. Nevertheless, that concept is questioned when is applied to agroecosystems and, moreover, in a non-scientific environment. Therefore, the knowledge exchange on the impact of biodiversity in the agroecosystems is a key factor for improving the understanding of the farmers.

This knowledge exchange with and among farmers should start with experimental farms where the methodology has been applied for a period and where farmers and consultants can learn the impact of increasing biodiversity on pest control. The development of reliable measurable indicators is a crucial factor to translate the scientific knowledge to farmers and vice versa. Those indicators should be easy and cheap to collect and analyse, giving some conclusions of the biodiversity and its possible impact on farms. Although in many cases biodiversity indicators, as well as the possible implementation of ecological infrastructures can be site-specific, it is desirable to produce information deliverable to an ample range of farms. A good example could be the thresholds in integrated pest management, for example the olive IPM guide published by the Ministry of Agriculture of Spain.

An example with Ecoorchard project 50 European organic apple growers have been invited to use simple methods to assess biodiversity in their own orchard after having set up agroecological infrastructures (such as flower strips) or changed a practice (such as mowing or spraying). Their feedback in using Ecoorchard's handbook demonstrated that fast and simple tools can help farmers in recognizing functional biodiversity and changing their practices. See more at https://ebionetwork.julius-kuehn.de/index.php?menuid=25

Farmers have a different daily concern than the scientific community. These differences could be mostly due to economic reasons in short term and can lead to wrong decisions. However, none knows better the changes in farms than farmers and their perception about all the small changes (animal, plants, etc.) is a high valuable knowledge. This information should be linked with the scientific knowledge and transformed in indicators for evaluating the biodiversity on farms.

8. Conclusions and future possibilities

It is assumed that biodiversity is good for maintaining ecosystem services such as pest control, and regulations promote it already. For example, the presence of *Ditricchia viscosa*, *Capparis spinosa* and hedgerows in olive groves is recommended for *B. oleae* control (Ministerio de Agricultura, 2014). However, we do not have a complete knowledge on what biodiversity can be recommended to olive growers, i.e., there is a knowledge gap. Functional biodiversity is hardly understandable and predictable. Many field researches come

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to contradictory results and a given technique may even increase some natural enemies and hamper others in the same cropping system. Results obtained in some conditions may not always occur on others, because of the many factors interfering (management practices, local environmental conditions, etc.). Therefore, effective modelization of ecosystem services seems to be difficult so far.

How deeply should research investigate in the relationship between biodiversity and pest control in the olive agroecosystems? So far we can recommend diversifying the landscape in areas where large scale olive cultivation takes place, maintaining lineal elements (hedges, stone walls, etc.), and areas of natural vegetation, such as Mediterranean scrublands. We know also that cover vegetation is useful to avoid soil erosion, but we need more knowledge on which species are recommendable for the biological control point of view, or as a start point, to discard species which are beneficial to pests and diseases (Bejarano-Alcázar *et al.*, 2004; Villa *et al.*, 2017a). Testing vegetation covers in real farms could be a starting point in the implementation of innovations in biodiversity friendly olive growing. Other ecological infrastructures, traditionally used in annual crops could be also assayed in the olive agroecosystems, for example the use of beetle banks to promote *B. oleae* predation. Practices should also be considered when looking for biodiversity enhancement: soil cultivation and pesticides (including natural) should be reduced.

General species biodiversity does not need to be related to biological control and priority should be given to functional features easily measured and indicating actual relationship with biocontrol. Regarding arthropod biodiversity in some cases easily evaluated features, just as the size may condition biocontrol ability, for example the size of a carabid conditions its ability to predate on *B. oleae*. Or in the case of plant species, morphology of flowers defines them as food sources for natural enemies.

Our challenge is to establish general rules that affect biodiversity and pest control in the olive agroecosystem, as well as the way to adapt them to the specific local conditions of each farm. In any case and taking into account the importance of biodiversity globally, not only for biological control, it is appropriate to recommend to farmers the prioritization of Functional Agrobiodiversity infrastructures according to their means, motivations or constraints.

References

Albertini, A., Pizzolotto, R., Petacchi, R., 2017. Carabid patterns in olive orchards and woody semi-natural habitats: first implications for conservation biological control against *Bactrocera oleae*. BioControl 62, 71-83.

Altieri, M.A., 1995. Agroecology. The Science Of Sustainable Agriculture. Boulder: Westview Press Inc.

Andalucía, Junta de, 2015. Fauna auxiliar de la mosca del olivo. In: Publicaciones, J.d.A. (Ed.).

Argyriou, L.C., 1974. Data on the biological control of citrus scales in Greece. Iobc Wprs Bulletin 3, 89-94.

Bejarano-Alcázar, J., Rodriguez-Morcillo, V., E., C.-F., 2004. Virulencia diferencial de los patotipos defoliante y no-defoliante de *Verticillium dahliae* sobre especies utilizadas como cubiertas vegetales en olivar. XII Congreso de la S. E. F., Lloret de Mar, Gerona, Spain., p. 83.

Bento, A., Lopes, J., Torres, L., Passos-Carvalho, P., 1999. Biological control of Prays oleae (Bern.) by chrysopids in Trás-os-Montes region (northeastern Portugal). International Society for Horticultural Science (ISHS), Leuven, Belgium, pp. 535-540.

Bento, A., Torres, L., Cabanas, J., Pereira, J., 2007. A traça-da-oliveira, *Prays oleae* (Bernard). In: Torres, L., Azevedo, J. (Eds.), Manual de protecção integrada do olival, Mirandela, Portugal, pp. 202-229.

Boccaccio, L., Petacchi, R., 2009. Landscape effects on the complex of *Bactrocera oleae* parasitoids and implications for conservation biological control. BioControl 54, 607-616.

Calabrese, G., Ladisa, G., Proscia, A. (Eds.), 2012. Guidelines for the management of biodiversity in century-old olive groves.

Campos, M., 2017. Cubiertas vegetales y servicios ecosistémicos. Phytoma España 293 El olivar: retos de la Sanidad Vegetal e innovación tecnológica, 116-117.

Carrero, J.M., Limon, F., Panis, A., 1977. Note biologique sur quelques insects. Carvalho J.P., Aguiar AMF (1997). Pragas dos citrinos na ilha da Madeira. DRARAMINIA e EAN Madeira, pp 411.
Civantos, M., Caballero, J.M., 1993. Integrated pest management in olive in the Mediterranean area. Bulletin OEPP/EPPO Bulletin 23, 367-375.

Cotes, B., Campos, M., Garcia, P.A., Pascual, F., Ruano, F., 2011. Testing the suitability of insect orders as indicators for olive farming systems. Agric. For. Entomol. 13, 357-364.

Dainese, M., Martin, E.A., Aizen, M., Albrecht, M., Bartomeus, I., Bommarco, R., Carvalheiro, L.G., Chaplin-Kramer, R., Gagic, V., Garibaldi, L.A., et al. 2019. A global synthesis reveals biodiversity-mediated benefits for crop production. bioRxiv, 554170.

Dinis, A.M., Pereira, J.A., Pimenta, M.C., Oliveira, J., Benhadi-Marin, J., Santos, S.A.P., 2016. Suppression of *Bactrocera oleae* (Diptera: Tephritidae) pupae by soil arthropods in the olive grove. J. Appl. Entomol. 140, 677-687.

Gkisakis, V.D., Barberi, P., Kabourakis, E.M., 2018. Olive canopy arthropods under organic, integrated, and conventional management. The effect of farming practices, climate and landscape. Agroecology and Sustainable Food Systems 42, 843-858.

Karp, D.S., Chaplin-Kramer, R., Meehan, T.D., Martin, E.A., DeClerck, F., Grab, H., Gratton, C., Hunt, L., Larsen, A.E., Martinez-Salinas, A., et al. 2018. Crop pests and predators exhibit inconsistent responses to surrounding landscape composition. Proc. Natl. Acad. Sci. U. S. A. 115, E7863-E7870.

Ministerio de Agricultura, A.y.M.A., 2014. Guía de gestión integrada de plagas olivar. In: Ministerio de Agricultura, A.y.M.A. (Ed.). Ministerio de Agricultura, Alimentación y Medio Ambiente. Secretaría General Técnica. Centro de publicaciones, Madrid, Spain.

Moonen, A.C., Barberi, P., 2008. Functional biodiversity: An agroecosystem approach. Agr. Ecosyst. Environ. 127, 7-21.

Morris, T.I., Campos, M., Kidd, N.A.C., Symondson, W.O.C., 1999. What is consuming *Prays oleae* (Bernard) (Lep.: Yponomeutidae) and when: a serological solution? Crop Prot. 18, 17-22.

Morris, T.I., Symondson, W.O.C., Kidd, N.A.C., Jervis, M.A., Campos, M., 1998. Are ants significant predators of the olive moth, *Prays oleae*? Crop Prot. 17, 365-366.

Nave, A., Goncalves, F., Crespi, A.L., Campos, M., Torres, L., 2016. Evaluation of native plant flower characteristics for conservation biological control of *Prays oleae*. Bull. Entomol. Res. 106, 249-257.

O'Rourke, M.E., Petersen, M.J., 2017. Extending the 'resource concentration hypothesis' to the landscape-scale by considering dispersal mortality and fitness costs. Agr. Ecosyst. Environ. 249, 1-3.

Ortega, M., Pascual, S., 2014. Spatio-temporal analysis of the relationship between landscape structure and the olive fruit fly *Bactrocera oleae* (Diptera: Tephritidae). Agric. For. Entomol. 16, 14-23.

Ortega, M., Sanchez-Ramos, I., Gonzalez-Nunez, M., Pascual, S., 2018. Time course study of *Bactrocera oleae* (Diptera: Tephritidae) pupae predation in soil: the effect of landscape structure and soil condition. Agric. For. Entomol. 20, 201-207.

funded by European Commission

Paredes, D., Cayuela, L., Gurr, G.M., Campos, M., 2015. Single best species or natural enemy assemblages? a correlational approach to investigating ecosystem function. BioControl 60, 37-45.

Pasos de Carvalho, J. P. (2003). A cochonilha-negra: *Saissetia oleae* (olivier, 1791): (Homoptera: Coccidae). Instituto Nacional de Investigaçao Agraria, Universidade de Tras-os-Montes e alto Douro, Escola Superior Agraria de Bragança, Portugal.

Picchi, M.S., Bocci, G., Petacchi, R., Ending, M.H., 2016. Effects of local and landscape factors on spiders and olive fruit flies. Agr. Ecosyst. Environ. 222, 138-147.

Picchi, M.S., Marchi, S., Albertini, A., Petacchi, R., 2017. Organic management of olive orchards increases the predation rate of overwintering pupae of *Bactrocera oleae* (Diptera: Tephritidae). Biol. Control 108, 9-15.

Santos, S.A.P., 2007. Action of predators against the black-scale, *Saissetia oleae* (Oliv.) in Trás-os-Montes olive groves. Universidade de Aveiro (Portugal).

Scalercio, S., Brandmayr, P., Iannotta, N., Petacchi, R., Boccaccio, L., 2012. Correlations between landscape attributes and ecological traits of Lepidoptera communities in olive groves. Eur. J. Entomol. 109, 207-216.

Straub, C.S., Finke, D.L., Snyder, W.E., 2008. Are the conservation of natural enemy biodiversity and biological control compatible goals? Biol. Control 45, 225-237.

Thies, C., Tscharntke, T., 1999. Landscape structure and biological control in agroecosystems. Science 285, 893-895.

Torres, L.M., 2007. A Protecçao Integrada do Olival no Contexto da Produçao Integrada. In: Acevedo, J. (Ed.), Manueal de Protecçao Integrada do Olival. Torres, L.M. (Coordenador científico), Viseu, Portugal, pp. 31-125.

Villa, M., Marrao, R., Mexia, A., Bento, A., Pereira, J.A., 2017a. Are wild flowers and insect honeydews potential food resources for adults of the olive moth, *Prays oleae*? J. Pest Sci. 90, 185-194.

Villa, M., Santos, S.A.P., Benhadi-Marin, J., Mexia, A., Bento, A., Pereira, J.A., 2016. Life-history parameters of *Chrysoperla carnea* s.l. fed on spontaneous plant species and insect honeydews: importance for conservation biological control. BioControl 61, 533-543.

Villa, M., Santos, S.A.P., Sousa, J.P., Ferreira, A., Martins da Siçva, P., Patanita, I., Ortega, M., Pascual, S., Pereira, J.A., 2017b. Efecto del paisaje y del manejo del olivar sobre la polilla del olivo *Prays oleae* (Bernard). X Congreso Nacional de Entomología Aplicada, Logroño , Spain.

Warlop, F., 2006. Limitation of olive pest populations through the development of conservation biocontrol. Cahiers Agricultures 15, 449-455.

funded by European Commission