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A simple bioindication method to discriminate olive orchard management types using the soil arthropod fauna

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ABSTRACT

Bioindication has proved to be a useful tool to evaluate the state of conservation of an ecosystem based on the living organisms it contains, and thus many studies have used arthropods as bioindicators. In the cultivation of olive (*Olea europaea* L.), several management methods are employed, from organic production to conventional intensive farming. This study uses arthropod fauna as a means of discriminating between management types and takes into account the features of sampling methods and the data set used in order to make the discriminant method more effective.

A total of 15 olive orchards were considered under three types of management (organic production, conventional non-tillage, and traditional conventional farming). During the summer of 2007, sampling was undertaken fortnightly using pitfall traps in the interior (under the canopy) as well as exterior (in the orchards lanes) soil. The samples were identified to the order level or taxonomic categories easiest to recognise, and two datasets were built ("management type" and "organic/non-organic"). A Linear Discriminant Analysis (LDA) was applied with cross validation by the leave-one-out (LOO) method, for all the scenarios analysed.

The olive orchards under organic management registered greater abundance, diversity, and richness of orders. Also, significant differences between management types were detected with respect to the main groups, particularly between organic and non-organic. *Formicidae* and Coleoptera predominated in the interior and exterior soil, respectively. The soil-arthropod community considered at the order level proved useful to discriminate between management types, especially between organic and non-organic approaches. In light of the results, sampling of the interior soil and the use of the set of orders that significantly differ in the test of mean differences are suggested in order to optimise the discriminant analysis. In this way, classification accuracy reaches 100%, and 99% using cross validation with LOO.

1. Introduction

The intensification of agricultural practices has led to the reduction and fragmentation of the original landscape (Andrén, 1994; Burel et al., 1998; Wilcove et al., 1986), causing the decline of biodiversity in agrosystems (Aebischer, 1991; Nentwig, 2003; Pfiffner and Luka, 2003). A key ecological strategy to achieve production sustainability is to improve the functional biodiversity of agrosystems (Altieri, 1999). Some researchers have expressed the need to link biodiversity to economic aspects (Paoletti, 1999) in search of a solution, and attempts have in fact been made to quantify the value of biodiversity (Pimentel et al., 1997). Landscape ecology has played a central role in this sense, bolstering the cultural dimension of the landscape.

In Europe, the evaluation, protection, and management of biodiversity in agrosystems has been identified as one of the major challenges of the future, because agriculture constitutes the dominant soil use, representing almost half of the surface area of continental Europe (Bennett et al., 2006). In recent years, major changes in policies and agricultural practices have taken place, with broad implications for ecology and agrosystems (Stoate et al., 2001, 2009). The impact (either positive or negative) of intensive agricultural practices is far-reaching, affecting areas quite distant from the production site (Green et al., 2005). Therefore, the economic, environmental, and ethical repercussions need to be taken into account (Colman, 1994). In this sense, some of the recent measures adopted at the European Community (EC) level refer to EC Regulation No. 1107/2009 and Directive 2009/128/EC on the sustainable use of pesticides. In response, Spain has recently passed regulation (Real Decreto 1311/2012) which establishes the action framework for the use of alternative techniques in sustainable pest management. Such normatives have a direct application in all types

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Table 1
Summary of the agricultural characteristics of each type of management.

Management	Abbreviation	Weed control	Pest control	Fertilizer	Tillage	Tree age
Organic	ORG	Mowing	*Bt*[a]	Organic	No	20–25 years
Non-tillage	NT	Without mowing	Insecticides	Mineral	No	20–25 years
Conventional	CON	Herbicides	Insecticides	Mineral	Yes	15 years

[a] Treatment with *Bacillus thuringiensis*.

of crops. The cultivation of olive (*Olea europaea* L.) is widespread in the Mediterranean region (Loumou and Giourga, 2003), the world's leading olive grower being Spain, especially the southern Andalusia provinces of Jaén, Córdoba, and Granada. The olive orchard constitutes the most extensive plant formation in Andalusia, wielding great economic weight (Duarte et al., 2009), fundamentally by the production of olive oil (García-Brenes, 2006).

The natural and semi-natural vegetation in this region continues to be eliminated to increase the area of olive-orchard cultivation, and therefore the original landscape has been reduced and fragmented (de Graaff and Eppink, 1999; Milgroom et al., 2007; Parra-López and Calatrava-Requena, 2006). This activity has impoverished the arthropod fauna in the agrosystem of the olive orchard (Guzmán and Alonso, 2004; Hadjicharalampous et al., 2002; Ruano et al., 2004; Santos et al., 2007a). With such agricultural policies, and the growing demand for organic products, it becomes urgent to develop that facilitate the certification of agricultural practices in different olive orchards.

Bioindication is a valuable tool, as it permits the evaluation of the state of conservation of an ecosystem based on the living organisms that it contains (Burel et al., 2004). For many arthropods, survival in agrosystems depends on the suitability of the habitat, which in turn is strongly influenced by agricultural management, as well as by the characteristics of the surrounding landscape (Jeanneret et al., 2003). Numerous studies use arthropods as bioindicators, generally focusing on a specific group and using very low taxonomic levels, such as genus or species. This requires detailed taxonomic knowledge and is extremely costly. In fact, sampling and identification costs are strongly correlated with the taxonomical level considered (Williams and Gaston, 1994), and different authors have proposed the use of higher taxonomic levels, such as order or family (Balmford et al., 1996; Biaggini et al., 2007; Cotes et al., 2011), to develop bioindication methods. In the present study, our proposal is to use the taxonomic level of order for the olive orchard, following different criteria.

This work seeks to answer the following questions: (1) can the study of the higher taxonomic levels soil arthropod fauna of olive orchards discriminate the different orchard-management types? Diverse agricultural practices heavily alter the arthropod community and therefore we assume that such effects can be detected even at high taxonomic levels, such as the order. (2) What characteristics should the sampling have in order to optimise the discriminant analysis? We hypothesise that the results are determined by the location of pitfall traps in the soil under the canopy or in orchard lanes (interior and exterior soil, respectively, in the text) determine the results, by the season, and by sampling duration. The interior soil is often more sheltered from the sun, has more moisture and food for the arthropod fauna, and undergoes less agricultural work (ploughing and herbicides, mainly). (3) Which groups are useful to discriminate management types? Within bio-indicator organisms, some are notable for their abundance while the real value of others lies in their scarcity in certain environments or conditions. We assume not only that the orders having the highest abundance are the ones that differentiate the management types, but also that those of low relative importance can also play a major role in bioindication. (4) Can the above objectives be fulfilled with low sampling effort? We propose that an adequate sampling during the months of greatest arthropod activity in the olive orchard is sufficient to provide a complete representation of the arthropod fauna of the olive orchard.

2. Materials and methods

2.1. Study area and crop management systems

The study was conducted in the area of Montes Orientales, 30 km north of the city of Granada (Spain). The study area extended around 20 km from east to west and around 18 km north to south. This is a rather homogeneous zone, with altitudes of 960–1130 m a.s.l. The climate is extreme continental Mediterranean, with long, cold winters, and equally long, warm summers. The mean rainfall does not reach 600 mm annually, falling mostly in the months of October to May. The main crop is olive, predominantly the cultivar 'Picual', grown under conventional as well as intensive systems. Also, cereals and other herbaceous crops abound in the area.

Three types of management were considered (organic production, conventional non-tillage, and conventional farming), seeking uniformity with respect to the orographic and geophysical characteristics of the different olive orchards.

Olive orchards under organic production (ORG hereafter) for more than 15 years, following EC Regulation no. 2092/91 of 1991, follow environmentally friendly agricultural practices based on environmental and economic sustainability. In this sense, no agrochemicals were used nor was the soil ploughed. During the study, only one treatment of *Bacillus thuringiensis* Berl. was applied between May and June, depending on the orchard.

In the olive orchards under conventional management, pesticide and herbicide use was widespread and usual, though two types of management were distinguished according to ploughing depth: strict conventional (CON hereafter) and conventional non-tillage (NT hereafter). In the latter, at most, shallow tillage was only applied under the tree canopy at the beginning of spring. The agricultural characteristics of the different management types are listed in Table 1.

2.2. Experimental design and arthropod collection

A total of 15 olive orchards were selected ("sampling stations" hereafter), 5 for each type of management considered, with more than 500 m distance between them to ensure independence of the data. Both the soil underneath the canopy ("interior") and the soil in the orchard lanes ("exterior") were sampled by means of pitfall traps (Greenslade, 1964). In each olive orchard, 4 olive trees were chosen in a row, and a strip of around 40 m long was delimited in one of the lanes adjacent to the row of trees (Fig. 1). Four pitfall traps were set in the interior soil and another four in the exterior soil along the lane. For the interior soil, a trap was set in the shade of each sampled tree, at 20 cm from the base of the trunk facing north. For the exterior soil, four traps were set along the lane adjacent to each station, 12 m apart. A sampling unit was considered to be the measurement of these four traps placed at each olive-orchard sampling station separating the interior from the exterior soil.

The pitfall traps consisted of a 125-ml glass 7 cm in diameter fit into a hole dug in the soil, taking care to disturb the soils and