EFECTOS DEL MANEJO AGRÍCOLA SOBRE LAS AVES PASERIFORMES EN EL OLIVAR MEDITERRÁNEO

Effects of agricultural management on small bird communities (Passeriformes) in Mediterranean olive groves

TESIS DOCTORAL

Juan Carlos Castro Caro

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TITULO: *Efectos del manejo agrícola sobre las aves paseriformes en el olivar mediterráneo.*

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TESIS DOCTORAL

Dr. Francisco Sánchez Tortosa   Dra. Isabel Catalán Barrio

CÓRDOBA, 2015

TÍTULO DE LA TESIS: Efecto del manejo agrícola sobre las aves paseriformes en el olivar mediterráneo.

DOCTORANDO/A: Juan Carlos Castro Caro

INFORME RAZONADO DEL/DE LOS DIRECTOR/ES DE LA TESIS

El objetivo de esta tesis es evaluar la efectividad de las medidas agroambientales sobre las comunidades de aves paseriformes en el olivar mediterráneo. Los resultados obtenidos tienen importantes implicaciones para optimizar el diseño de futuras medidas que hagan del olivar un cultivo sustentable integrando producción y conservación.

En el primer capítulo de esta tesis se evalúa si la efectividad de las medidas agroambientales en el olivar, en concreto el uso de cubiertas vegetales, sobre las comunidades de aves paseriformes es dependiente del contexto paisajístico. Este artículo ha sido publicado en la revista *Journal of Ornithology* (Vol.155: 357-365)

En el siguiente capítulo se analiza, por primera vez en cultivos leñosos, el efecto combinado de diferentes medidas agroambientales (implementación de cubiertas vegetales y conservación de setos). Los resultados de este capítulo aportan información para la conservación de la biodiversidad en el olivar. Este artículo ha sido aceptado para su publicación en la revista *Acta Ornithologica*.

En el tercer y cuarto capítulo se analiza el efecto de la depredación sobre los nidos, y el potencial efecto de las cubiertas vegetales como trampas ecológicas. Estos capítulos suponen un nuevo enfoque a los métodos tradicionales de evaluación de la efectividad de las medidas agroambientales basados exclusivamente en índices de biodiversidad. Uno de los artículos ha sido publicado en la revista *Bird Study* (Vol. 61: 537-543) y el otro está pendiente de ser enviado a una revista científica.

Dado que tres de los cuatro capitulos que conforman esta tesis han sido publicados o aceptados en revistas científicas indexadas en el *Journal Citation Report*, consideramos que esta tesis cumple todos los requisitos de calidad para su presentación.

Por todo ello, se autoriza la presentación de la tesis doctoral.

Córdoba 5 de Noviembre de 2015

Firma del/de los director/es

Fdo.: Isabel Catalán Barrio

Fdo.: Francisco Sánchez Tortosa

Esta tesis ha sido presentada como compendio de publicaciones. Los siguientes trabajos han sido publicados en revistas incluidas en los tres primeros cuartíles de su área temática en el año de su publicación/aceptación.

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GENERAL INDEX

RESUMEN 2

SUMMARY 4

INTRODUCTION 6

OBJECTIVES AND STRUCTURE 16

CHAPTER 1. Is the effect of farming practices on songbird communities landscape-dependent? A case study in olive groves of southern Spain. 18

CHAPTER 2. Effects of hedges and ground covers on passerine communities in Mediterranean olive groves. 31

CHAPTER 3. Herbaceous ground covers reduce nest predation in olive groves. 47

CHAPTER 4. Can agri-environmental measures act as ecological traps? A case study with ground covers, songbirds and olive groves. 62

GENERAL DISCUSSION 77

AEMs in conventional olive groves: a new approach to assess their effectiveness.

Future directions: Designing AEMs for olive groves.

CONCLUSIONS AND RECOMMENDATIONS 83

CONCLUSIONES Y RECOMENDACIONES 85

AGRADECIMIENTOS 87

REFERENCIAS 88

RESUMEN

EFECTOS DEL MANEJO AGRÍCOLA SOBRE LAS AVES PASERIFORMES EN EL OLIVAR MEDITERRÁNEO

El olivar es uno de los usos predominantes de tierra en la cuenca mediterránea, donde 5 millones de hectáreas se dedican a este cultivo (la mitad de los cuales están en España), con significativas implicaciones sociales, ambientales y económicos. En las últimas décadas la intensificación agrícola ha llevado a una homogeneización y simplificación de los paisajes tierras de cultivo en toda Europa con consecuencias ambientales negativas. La contaminación del agua, la pérdida de biodiversidad y, sobre todo, la erosión del suelo, han sido identificados como las principales preocupaciones en la región mediterránea debido a la intensificación agrícola. Para evitar la erosión del suelo y siguiendo las políticas agrícolas recientes, muchos agricultores han comenzado a aplicar la cubierta vegetal herbácea dentro de los cultivos y el mantenimiento de pequeños hábitats residuales como setos. Ambas medidas agroambientales (AEMs) puede ofrecer beneficios en términos de biodiversidad en los ecosistemas agrícolas, ya que aumentan la complejidad estructural de los hábitats y proveen recursos para las aves. Sin embargo, una configuración dispersa de parches de buena calidad de hábitat (olivar con cubiertas vegetal), puede tener consecuencias inesperadas si actúan como una trampa ecológica.

Esta tesis se centra en la evaluación de la eficacia de la AEMs en cultivos leñosos de la zona del Mediterráneo , para el que existe poca información. La mayoría de los estudios se han llevado a cabo en las zonas templadas de Europa y sus implicaciones de gestión podrían no ser aplicables a los cultivos perennes mediterráneas. Uso de las comunidades de aves paseriformes como un indicadoras , analizó por primera vez el efecto de diferentes AEMs cuando se aplican en combinación para cultivos leñosos perennes. La eficacia de esas medidas es evaluada a través de varios criterios. Además de los enfoques tradicionales que comparan los índices de diversidad de aves (es decir, riqueza y abundancia) en áreas con y sin AEMs , también tomamos en cuenta su éxito reproductor para evaluar el papel potencial de las AEMs en los agro-ecosistemas como trampas ecológicas .

Mis resultados mostraron que las cubiertas vegetales y los setos beneficiaron significativamente la biodiversidad de aves en el olivar mediterráneo. Cuando ambas medidas se aplican en combinación tienen efectos aditivos en la diversidad de las comunidades de aves paseriformes. Sin embargo , las cubiertas parecen tener un efecto más fuerte en la promoción de la diversidad de aves en los olivares. No encontré ninguna evidencia de que los olivares con cobertura del suelo actuaran como trampas ecológicas , ya que no hubo preferencia de las aves por anidar en

olivaes con cubiertas vegetaleslas. Además, para aquellas aves que crían en olivares con cubierta el éxito reproductor no se resintió, por lo que estos parches de hábitat de buena calidad tampoco actúan como sumidero.

En esta tesis se demuestra que soluciones eficaces para promover la biodiversidad en los olivares tradicionales están disponibles y, a veces mano. En la mayoría de los casos, cambios relativamente pequeños en las prácticas agrícolas pueden ser suficientes para alcanzar los objetivos de biodiversidad. Por ejemplo , el mantenimiento de setos y cubiertas de tierra en el suelo podría ser fácilmente promovido. Ambas prácticas se han mostrado como las más costo-eficientes en los agro-ecosistemas mediterráneos. Dadas sus ventajas medio ambientales y agronómicos, la aplicación de estas AEMs podría recomendarse para garantizar la sostenibilidad de los agroecosistemas mediterráneos.

SUMMARY

EFFECTS OF AGRICULTURAL MANAGEMENT ON SMALL BIRD COMMUNITIES (PASSERIFORMES) IN MEDITERRANEAN OLIVE GROVES

Olive farming is one of the predominant land-uses in the Mediterranean basin where 5 million ha are dedicated to this crop (half of which are in Spain), with significant social, environmental and economic implications. Over the last decades agricultural intensification has led to a homogenization and simplification of farmland landscapes across Europe with negative environmental consequences. Water pollution, biodiversity loss and, especially, soil erosion, have been reported as major concerns in the Mediterranean Region following agricultural intensification. To prevent soil erosion and following recent agricultural policies, many farmers have started implementing herbaceous ground cover within the crops and maintaining small residual habitats like hedgerows. Both agri-environment measures (AEMs) can deliver benefits in terms of biodiversity in agro-ecosystems because they increase structural complexity of the habitats and provide resources for foraging and breeding birds. However, a patchy configuration of good quality habitat, i.e. olive groves with ground cover, may have unexpected consequences if they act as an ecological trap.

This thesis focuses on the assessment of the effectiveness of AEMs in woody crops of the Mediterranean area, for which little information exists. Most studies have been conducted in temperate areas of Europe, and their management implications might not be transferrable to Mediterranean perennial crops. Using songbird communities as an indicator, I analyse for the first time the effect of different AEMs when applied in combination to perennial woody crops. The effectiveness of such measures is assessed using several criteria. In addition to traditional approaches comparing diversity indices of foraging birds (i.e. species richness and abundance) in areas with and without AEMs, we also take into account their breeding success to evaluate the potential role of AEMs in agricultural fields as ecological traps.

My results showed that ground covers and hedges consistently promote songbird diversity in Mediterranean olive groves. Hedges and ground covers, when applied in combination, have additive effects on the diversity of songbird communities. However, hedges seem to have a stronger effect in promoting bird diversity in olive agro-ecosystems. I found no evidence that olive groves with ground cover are acting as ecological traps, since songbirds did not preferentially breed in olive groves with ground cover. Also, for those birds breeding in areas

with ground covers there was no hindrance in breeding success, so these patches of good quality habitat are not acting as a sink.

This thesis demonstrates that effective solutions to promote biodiversity in conventional olive groves are available and sometimes already in place. In most cases, relatively small changes in farming practices may be sufficient to attain biodiversity goals. For instance, the maintenance of hedges and ground covers on the soil could be easily promoted. Both of these practices have been suggested to be the most cost-efficient measures in Mediterranean agro-ecosystems. Given their environmental benefits and their agronomic values, the implementation of these AEMs could be recommended to ensure the sustainability of Mediterranean agro-ecosystems.

INTRODUCTION

More than half of the Earth's terrestrial surface is moulded by agriculture. One of the greatest challenges facing the global (human) community is the provision of sufficient food resources to feed an expanding population, while maintaining farmland biodiversity and the associated ecosystem services. Biodiversity conservation requires strategies for managing whole landscapes including areas allocated mainly to production (Margules and Pressey 2000). There is a pressing need to maximise the contribution that agricultural landscapes can make to the conservation of biodiversity, and the contribution of sustainable management of agricultural areas to biodiversity is critical for successful long-term conservation (Tallis et al. 2009).

The second half of the 20th century saw an unprecedented development in agricultural practice, which surpassed any previous agricultural revolution (Blaxter and Robertson 1995). Economic and technological incentives to increase agricultural production in postwar Europe and North America resulted in rapid agricultural intensification (Gardner 1996, Krebs et al. 1999). Agricultural intensification increases the yield per unit area, but it comes with serious costs to biodiversity (Donald et al. 2001, Green et al. 2005). For example, wheat yields in Europe between 1960 and 2010 have increased by 201% due to a combination of more efficient tillage, application of fertilizers and pesticides, and plant breeding (Gardner 1996).

Agricultural intensification has occurred at different levels. At the field scale, intensification occurs through increased use of pesticides and fertilisers, shortened crop-rotations, or machine-driven farming. All these practices reduce the suitability of agricultural fields for a wide range of organisms (Benton et al. 2003, Tscharntke et al. 2005). On a landscape scale, fields have been amalgamated and enlarged to enhance farming efficiency, resulting in homogeneously farmed landscapes with little non-crop area. Similarly, this homogeneization at the landscape level is likely to reduce the diversity of organisms in agro-ecosystems (Tscharntke et al. 2005).

One major consequence of agricultural intensification has been the widespread loss of farmland biodiversity (Krebs et al. 1999, Reidsma et al. 2006). Severe declines in the abundance and diversity of farmland plants and invertebrates (Wilson et al. 1999, Sutcliffe and Kay 2000, Andreasen and Stryhn 2008), have in turn reduced the populations of animals that depend upon them for food. These include butterflies (Feber et al. 2007, Van Dyck et al. 2009), moths (Conrad et al. 2006), bees (Carvell et al. 2007), mammals (Wickramasinghe et al. 2003) and birds (Krebs et al. 1999, Donald et al. 2001, 2006). Birds are among the organisms for which population monitoring is better documented, and farmland specialists have suffered the most severe declines across Europe (Gregory et al. 2005, Voříšek et al. 2010; **Figure 1**).

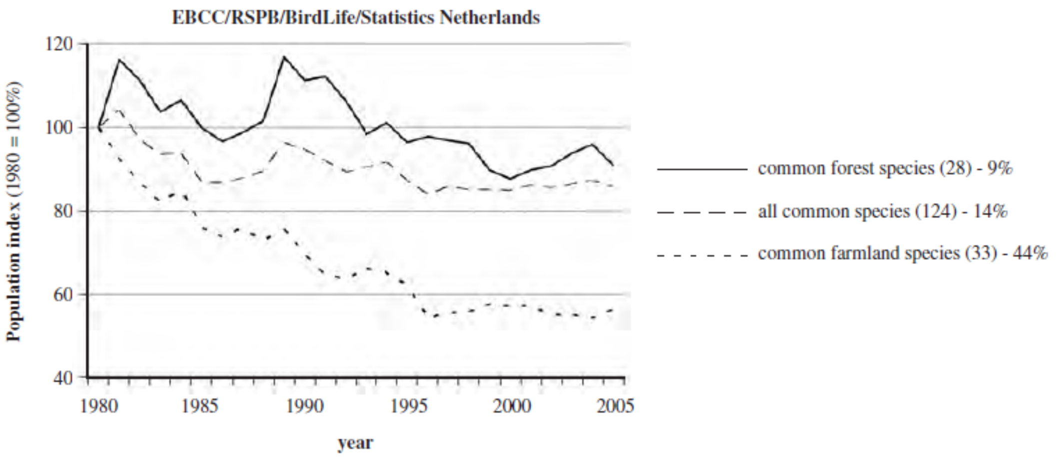

Figure 1. Generalized declines of bird species have been recorded for different bird groups across Europe since 1980: common forest species (solid line), all common species (dashed line) and common farmland species (dotted line). Trends indicate changes in population size of common breeding birds, relative to 1980; values above the 100% line show increases, and values below indicate decreases. The numbers in parentheses show the numbers of species considered in each group; for full lists of species see www.ebcc.info/pecbm.html. Source: EBCC/RSPB/BirdLife/Statistics Netherlands (Klvanova et al. 2009).

Small-bird communities are good biological indicators of agroecosystem degradation, particularly in the context of agricultural intensification (Gregory et al. 2005, Everard 2008). Passerines (small birds) have a broad functional spectrum of diets (e.g., insectivorous, granivorous, frugivorous: **Figure 2**) and, therefore, might reflect the availability of different food items. The main mechanism through which intensive farming practices have led to a severe decline of farmland bird populations (Donald et al. 2001, 2006) might be the reduction of food supplies (Vickery et al. 2009). Agricultural intensification through an increased use of herbicide and insecticide and the loss of uncultivated field margins has led to a reduction in food availability that has contributed to bird declines (Wilson et al. 1999). However, recent studies suggest that increased predation rates might also be an important factor. Simplification of farmland habitats may increase populations of generalist predators or enhance their predation rates (Evans 2004). Nest predation is the primary cause of nest losses for a wide range of bird species in different habitats and geographic locations (Ricklefs 1969, Martin 1993, Schmidt and Whelan 1999), and has probably contributed to the decline of passerine populations in landscapes heavily modified by agriculture and other human developments (Robinson et al. 1995, Bayne and Hobson 1997, Donovan et al. 1997, Willson et al. 2001).

Figure 2. Songbirds are effective biological indicators of agroecosystem degradation, as they have a broad spectrum of diets and reflect the availability of different food items. In olive groves a range of feeding modes can be found. For example, Eurasian Blackcap *Sylvia atricapilla* (A) is a frugivorous bird that uses olive groves as a wintering quarter feeding on ripes olives. European Serins *Serinus serinus* (B) are resident granivorus finches. Woodchat Shrikes *Lanius senator* (C) are insectivorous trans-Saharan migrants that breed in olive groves. Pictures from *Wikimedia Commons, the free media repository* (https://commons.wikimedia.org/wiki/Main_Page)

Agricultural practices aimed at reducing biodiversity loss in agricultural landscapes and to mitigate other harmful effects of modern agriculture, i.e. agri-environmental measures (AEMs; **Box 1**), were introduced in the European Common Agricultural Policy (CAP) in the early 1990s (Concepción et al. 2008). Although AEMs are considered the main policy instrument currently available in Europe to promote environmentally-friendly farming practices (Donald and Evans 2006), there is still relatively little information regarding the effects of these measures on biodiversity. In the last decade, some studies have evaluated the effects of conservation initiatives on farmland in different European countries showing mixed effects (Kleijn et al. 2011, and references therein). Some initiatives seem to consistently enhance biodiversity (Holzschuh et al. 2007) whereas others are not as successful (Feehan et al. 2005, Blomqvist et al. 2009). Furthermore, the effect of a particular AEM can even differ between regions (Rundlöf and Smith 2009).

The adoption of AEMs is still relatively feeble in southern Europe despite the high biodiversity of this region (López-López et al. 2011) and the effectiveness of AEM to maintain farmland biodiversity in this region remains poorly evaluated. In Mediterranean areas the effects of AEM have been mostly analyzed in extensive arable systems (Moreno et al. 2010, Reino et al. 2010). In permanent woody crops, studies have focused on measures aimed at pest control by reducing chemical input or limiting the use of synthetic agrochemicals (i. e., integrated production and organic farming) in fruit orchards (Genghini et al. 2006) and vineyards (Bruggisser et al. 2010). However, less is known about AEMs aimed at increasing structural complexity, such as ground covers and the maintenance of hedges in woody crops. These AEMs have shown to enhance farmland biodiversity in other habitats (Merckx et al. 2009), and have been strongly recommended for permanent woody crops (Vickery et al. 2002) but their effectiveness in these systems remains to be tested.

Most studies examining the effects of conservation initiatives on farmland compare biodiversity at sites with low-input, nature-friendly management with control sites that are managed following conventional agricultural practices. The ecological effects of conservation initiatives are then calculated as the difference in a biodiversity index (usually species richness or abundance) between sites with conservation management and control sites. Although estimates of bird abundance and species richness provide valuable information, they do not provide the whole picture as they do not necessarily correlate with changes in reproductive success or survival. Increased bird abundance in areas with agri-environmental management can, for example, be the result of mere bird relocation rather than increased reproduction, turning the area into a potential sink rather than a source (Geertsma et al. 2000). Hence, crude estimates of density or abundance may provide misleading information about habitat quality or suitability for some species (Van Horne 1983, Vickery et al. 1992, Hughes et al. 1999), raising concerns of the efficacy of AEM to revert biodiversity declines in farmland. For example, it has been suggested that AEM implemented in agricultural fields may act as ecological traps for farmland birds (Schlaepfer et al. 2002, Shochat et al. 2005) by providing a deceivingly suitable habitat. In this sense, prey species may congregate in areas that in turn attract the highest concentration of nest predators (Donald 1999, Pescador and Peris 2001).

On the other hand, the design of cost efficient AEMs is an important concern at the European level. Studies have shown that, for a variety of organisms, the effectiveness of conservation initiatives is higher in simple landscapes than in complex landscapes for a variety of organisms (weeds Roschewitz et al. 2005, invertebrates Rundlöf and Smith 2006, Holzschuh et al. 2007, birds Smith et al. 2010). This effect has been termed the *landscape-dependence hypothesis* (LDH; Tscharnke et al. 2005), and predicts that the effectiveness of AEMs in terms of enhanced species richness and abundance of a variety of organisms will be smaller in complex landscapes (with a high proportion of semi-natural habitats) than in simple landscapes (with a low proportion of semi-natural habitats), because more complex landscapes are likely to already have higher diversity (**Figure 3**). In agricultural landscapes, more intensified practices will lead to more homogeneous, simpler landscapes, wheras in less intensified areas, landscapes will be more heterogeneous. Although there is ample evidence supporting this hypothesis, a few studies have found contrasting results. For example, Duelli and Obrist (2003) concluded that AEMs have a greater chance of success in more heterogeneous regions where source populations survive in nearby natural or semi-natural habitats. Similarly, Kleijn and Sutherland (2003) suggested that AEMs may have much more pronounced effects in extensively, more heterogeneous farmed landscapes than in intensively farmed landscapes. However, most evidence has come from annual crops, but it is unknown whether the LDH would apply to perennial systems like olive groves, which are more stable agro-ecosystems (Foster et al. 2002).

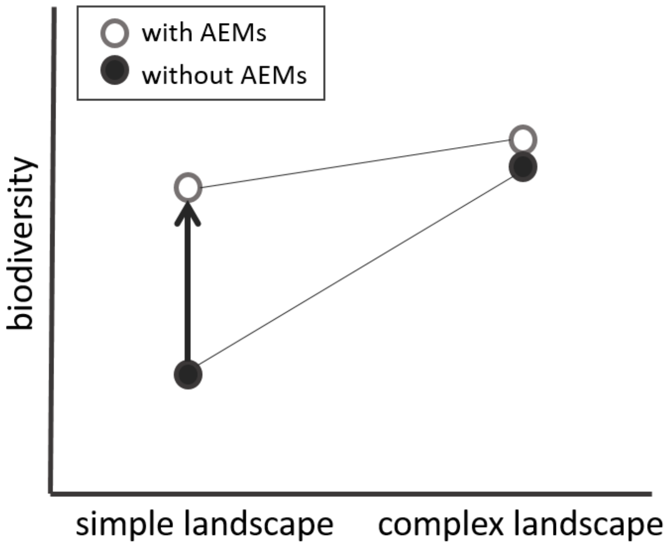

Figure 3. According to the landscape-dependence hypothesis, the effects of agri-environmental measures (upward arrow from areas without AEMs (filled symbols) to areas with AEMs (open symbols)) on biodiversity (species richness) will be much larger in simple than in complex landscapes. Modified from Batary et al. 2010.

In the Mediterranean Basin, olive groves are one of the primary agro-ecosystems and they are important winter quarters and breeding ranges for numerous European bird species (Rey, 2011). The importance of this habitat is particularly evident in the case of birds as it provides overwintering habitat for frugivorous and insectivorous birds from central and northern Europe. Originally, these migrations from the north would have been prompted by the abundance of high production of energy-rich fruits in the Mediterranean areas (Herrera 1982, 1984; cited in Rey, 2011). Following the gradual replacement of the shrublands by olive plantations, olive agroecosystems have attracted large number of frugivorous birds which depend on these systems for their food supply over autumn and winter periods (Muñoz-Cobo and Purroy 1980, Rey 1993). For instance, it is estimated that between 3.5 and 8 million frugivorous birds over-winter in olive orchards in southern Spain (Rey 2011). In Europe, the largest area of olive farming is in Spain, where 2.5 million ha are dedicated to this crop. Nowadays, conventional farming involving the intensive use of agrochemicals is the traditional and most common production system (85% of crop area).

Agricultural intensification in the Mediterranean basin since the 1950s has eliminated most hedgerows between fields (Kizos and Koulouri 2006, Sokos et al. 2013), leading to vast homogeneous landscapes (**Figure 4A**). The rare hedges still present are small, often undetectable in the landscape (Rey 2011), although there are some areas, especially in the less intensive landscapes (e.g. on the slopes) where they still remain (**Figure 4B**). Since the mid-1980s, the Common Agricultural Policy of the European Union (CAP) has been central in the intensification of olive plantations (**Box 1**). This policy favoured an increase in production, but overlooked the importance of environmental protection (Beaufoy 2001), which has led to significant negative environmental consequences including water pollution by nitrates and herbicides and, especially, soil erosion (Gómez et al. 2009). In 2003, the CAP was modified to favour agro-environmental measures (cross-compliance) that reduce erosion and maintain the structural complexity of agro-ecosystems. These measures include the implementation of ground cover and preserving stone walls or hedges, which are the only AEMs now in practice in conventional olive groves (Sokos et al. 2013).

Ground covers can provide environmental and agronomic benefits by reducing soil loss and erosion, increasing soil fertility and water content, and activating soil microbial processes (Moreno et al. 2009). Ground cover in olive groves is known to benefit the biodiversity of some organisms such as arthropods (González et al. 2004), and are likely to have a positive effect on the biodiversity of birds. The herbaceous layer can provide seeds and insect prey for foraging birds. The composition of the ground cover, its structure, and dynamics are critical for some species of small birds, e.g., *Serinus serinus*, that feed their nestlings protein-rich seeds, e.g., *Diplotaxis virgata* and *Erodium sp*. (Valera et al. 2005). Herbaceous ground covers within olive groves comprise annual species adapted to Mediterranean climates that set their seeds before the summer drought. Herbaceous flora in olive groves can be relatively diverse. For instance, in southern Spain 500-900 species have been reported in olive groves, often reaching more than 100 species per hectare (Pujadas-Salvà 1989). Generally, ground covers are present throughout the groves except in the area below tree crowns, which is kept plant-free by the application of contact and systemic herbicides; ground covers are mowed in Spring to avoid water competition between weeds and crops.

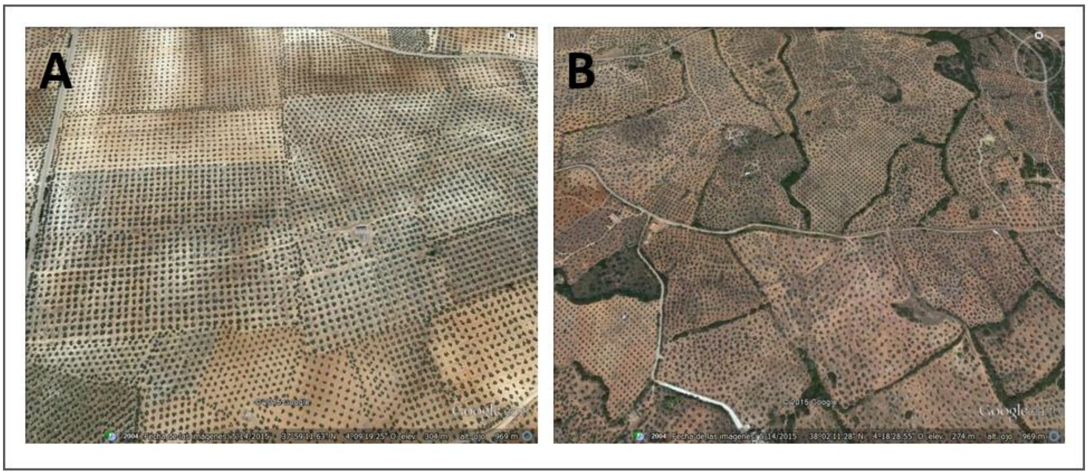

Figure 4. Aerial photographs of olive grove landscapes in less intensified areas in the hillslopes of Sierra Morena (A), and more intensified areas in the Guadalquivir valley (B). In the less intensified area landscapes are more heterogeneous and some hedgerows and shrub patches are still found. In the more intensified landscape hedges and separations among fields have been removed, leading to a homogeneous landscape. (Aerial photos taken from Google Earth, https://earth.google.com/)

On the other hand, the importance to biodiversity of small residual habitats (e.g., shrub patches, hedges, scattered trees; **Figure 4B**) has been reported for a range of agricultural landscapes (Berg 2002). Hedgerows are important components of farmland landscapes throughout the world (Hinsley and Bellamy 2000, Manning et al. 2006) and increase the heterogeneity of habitats and resources within these systems (Benton et al. 2003, Fischer et al. 2005). Hedges have been recognized as one of the most important drivers in maintaining plant and wildlife diversity; particulary for birds (Hinsley and Bellamy 2000). Hedgerows and field margins are excellent at providing birds with appropriate nesting, roosting and foraging habitats (Hinsley and Bellamy 2000, Douglas et al. 2009). Not only do they fulfill these essential functions, but they also provide cover for local movements and can facilitate long-distance travels through different landscapes (Hinsley and Bellamy 2000, Moles and Breen 1995, Demers et al. 1995).

Ground covers are likely to stimulate biodiversity of conventional olive groves, but the effect of hedges has never been evaluated in Mediterranean woody crops. In addition, because these elements potentially provide different resources, they may have complementary effects when applied in combination.

Box 1. The Common Agricultural Policy

The Common Agricultural Policy (CAP) is the most significant policy directly affecting olive farming in the European Union. There are two groups of measures, corresponding to the two pillars of CAP:

- Pillar I - "market" regime for olives: includes subsidies paid to farmers to support their income.
- Pillar II - "structural" and "accompanying" measures: includes agri-environment measures (AEMs).

The CAP market regime of Pillar I for olives has by far the greatest influence on the sector. Since 1960s farmers were eligible for subsidies on the basis of amount of olive oil produced. This led to an intensification of production with negative environmental consequences (e.g. soil erosion, lost of biodiversitiy, high water pollution). As a result, the subsidy system was decoupled from current production in an attempt to integrate production with environmental aspects, whereby support to olive farmers was integrated in the Single Payment Scheme. With the total decoupling of the agricultural subsidies under the newly established rules of CAP, formalised in 2005 (EU Council Regulations Nos. 2183/2005 and 1782/2003), cross-compliance (eco-conditionality) has become mandatory, meaning that olive growers will only be entitled to subsidies if they comply with certain rules of good agricultural and environmental practices defined by each Member State. For instance, the AEMs adopted by Spain for olive farming were: 1) the maintenance of small residual habitats like hedges, semi-natural vegetation remnants, drystone walls, isolated trees, etc., and 2) the implementation of a living or inert (pruning remains and/or stones) ground cover with a minimum width of 1 m between rows in olive groves with average slope over 10%.

Concerning Pillar II, in the CAP reform of 1992 (EU Council Regulation Nos. 2078/1992) all EU Member States were required to implement agri-environment programmes (i.e. organic farming). Within this framework, farmers are compensated if they adopt practices directed to maintain the environment. To qualify for support, a 5-year commitment is required.

The European Commission proposal for the post-2014 CAP (EU Council Regulation Nos. 0280/2011) introduced a 'greening component', in which 30% of direct payments are tied to environmental conditions, in order *"to ensure that all farms deliver environmental and climate benefits through the retention of soil carbon and grassland habitats associated with permanent pasture, the delivery of water and habitat protection by the establishment of ecological focus areas and improvement of the resilience of soil and ecosystems through crop diversification"* (Lefebvre et al. 2012). However, there have been certain exemptions for some crops; for instance organic farming and permanent crops like olive groves do not have obligations under greening.

In this thesis, we use the term agri-enviormental measures (AEMs) equally for those measures under cross-compliance regime of the pillar I and for the agri-environment schemes (AESs) of the pillar II.

In addition, breeding birds select their territories in olive orchards according to the availability of food resources such as seeds and arthropods (Muñoz Cobo 2009). As a result, birds may prefer to settle on fields with herbaceous ground cover, and nest density in these fields is expected to be higher compared to bare-ground olive groves. Yet according to theoretical models (Stephens and Krebs 1986) the foraging effort of predators may be directed towards patches with the highest cumulative prey availability. Such decoupling of habitat attractiveness from suitability may lead to the development of an ecological trap (Robertson and Hutto 2006). For example, in Spain most farmland birds favour fallow fields for nesting; however, due to the intense use of herbicides fallow fields are rare nowadays and the few available patches have high nest densities, attracting predators, and thus exposing nests to very high predation rates (Pescador and Peris 2001). Nest predation has been identified as one of the major reasons for reproductive failure of birds (Evans 2004) and most studies have shown higher nest predation rates in intensified agricultural landscapes (Baine and Hobson 1997, Hannon and Cotterill 1998, Castro-Caro et al. 2014, but see Zuria et al. 2007; **Figure 5**). However these studies have been carried out with artificial nests, and there is no information about the effects of landscape intensification on breeding success of songbirds by searching and monitoring real nests.

Figure 5. Predated nest of Linnet (*Carduelis cannabina*) showing remnants of eggshells. Bite marks suggest predation by rodents.

In sum, two main AEM, ground covers and the maintenance of hedges, have been implemented in olive groves to sustain farmland biodiversity. However, the effectiveness of these practices to attain biodiversity goals has not been adequately addressed. The assessment of such practices has been carried out by comparing diversity indices of foraging bids (i.e. species richess and abundance) in areas with and withour AEM but overlooking some others indicators about habitat quality or suitability raising concerns about whether fields that implement AEM are acting as ecological traps. Informed management guidelines shoud thus include othe indicators of population fitness, such as breeding success.

OBJETIVES AND STRUCTURE

The purpose of this thesis is to evaluate the effectiveness of AEMs on biodiversity of perennial crops in Mediterranean ecosystems, using as a case study songbird communities inhabiting olive groves in southern Spain. Specifically, the objectives are to evaluate the effects of landscape complexity on the effectiveness of ground covers to enhance bird diversity (chapter 1), the potential interactive effect when two AEMs are simultaneously implemented regardless of landscape complexity (chapter 2), and the potential of AEMs to act as ecological traps (chapters 3 and 4).

Chapter 1.

In conventional olive farming the most extended AEMs is the implementation of ground covers. This practice is mainly aimed at preventing soil erosion, but at the same time it enhances the structural complexity of agro-ecosystems and provides resources for foraging birds. There is good evidence that, for a variety of organisms, the effectiveness of AEMs depends on the complexity of the landscape (i.e. the landscape context hypothesis; Tscharntke et al. 2005), being largest in simpler, more homogeneous landscapes. Most studies have focused on annual crops and it remains unknown whether the effectiveness of AEMs in perennial systems like olive groves depends on the landscape context. In **Chapter 1 I assess the effect of ground covers on the diversity of songbird communities in olive groves and evaluate if this effect is landscape-dependent.**

Chapter 2.

Agricultural intensification in the Mediterranean basin since the 1950s has eliminated most of small residual habitats, e.g. shrubs, hedgerows, isolated trees. The importance of hedgerows as an influence on biota has been reported for a range of agricultural landscapes, but the effect of hedges on bird diversity has never been evaluated in Mediterranean woody crops. Alongside with ground covers, the preservation and promotion of hedges in those areas where they are still present is another common AEM now in practice in conventional olive groves. Because these elements potentially provide different resources, they may have complementary effects when applied in combination. **The purpose of chapter 2 is to assess the effect of hedges on songbird diversity in olive groves, and their potential interactive effect when implemented simultaneously with ground covers.**

Chapters 3 and 4.

Anthropogenic alteration of farmland ecosystems has created an environment in which prey populations might be more sensitive to predation, as habitat change may increase populations of predators or enhance their predation rates. Nest predation is the primary cause of nest losses for a wide range of bird species, in different habitats and geographic locations, and it has probably contributed to the decline of passerine populations in landscapes heavily modified by agriculture and other human developments. **In chapter 3 we carried out a field experiment with artificial nests, to investigate the role of nest predation in sites with and without ground covers.**

In Mediterranean farmland, isolated good-quality olive orchards with ground cover embedded in a bare-ground-dominated olive matrix are expected to attract breeding birds, but also their predators, turning these orchards into a potential sink habitat rather than a source. Thus, any approach to assess the effectiveness of AEMs should take into consideration reproductive success. **In chapter 4 we investigate whether olive orchards under different degrees of agricultural intensification are acting as an ecological trap by searching and monitoring real nests and quantifying reproductive success.**

CHAPTER 1

Is the effect of farming practices on songbird communities landscape-dependent? A case study in olive groves of southern Spain

CASTRO-CARO, J.C., BARRIO, I.C. & TORTOSA, F.S.

ABSTRACT

Extensive farming practices and landscape heterogeneity promote biodiversity in agro-ecosystems. The effect of such practices, however, might be landscape-dependent; specifically, the effect might be greatest where the loss of heterogeneity has been largest. In recent decades, agricultural intensification and landscape simplification have dramatically affected the Mediterranean region, where olive groves are one of the predominant crops. For instance, in Spain, from 1996 to 2008, the amount of land dedicated to olive groves increased by 300,000 ha (12%). In conventional olive farming, to minimize competition between crop and swards for water, herbicides are applied intensively; however, to prevent erosion, many farmers are maintaining swards within crops. This practice likely benefits farmland biodiversity, although the heterogeneity of the surrounding landscape might have an influence on the extent of these effects. This study assessed the effects of herbaceous cover on the abundance and species richness of songbird communities in six matched pairs of olive groves (ground-cover or bare-ground) in homogeneous and heterogeneous landscapes over a 3-yr period. We predicted that 1) the presence of ground cover and landscape heterogeneity will have a positive effect on songbird communities, and 2) the effect should be greatest in homogeneous environments. Although bird community composition differed among landscape types and farming practices in the olive groves in southern Spain, the effect of ground cover was not landscape-dependent. The presence of ground cover had a positive effect on the abundance and richness of songbirds, including sensitive species, but landscape heterogeneity did not have an effect. This study underscores the important role of agricultural practices in preserving farmland bird communities, while suggesting that landscape heterogeneity might not be very important in Mediterranean perennial farming systems. The positive effects of ground cover can be important in the preservation of the wintering quarters of numerous European bird species, including species of conservation concern.

INTRODUCTION

Intensification of agriculture leads to tremendous increases in food production, but there are significant negative environmental consequences (Matson et al. 1997). Agricultural intensification entails the simplification and homogenization of the landscape, which leads to a decline in farmland biodiversity (McLaughlin and Mineau 1995, Benton et al. 2003). Some studies have demonstrated the importance of specific farming practices on ameliorating the effects of agricultural intensification on biodiversity (Freemark and Kirk 2001), but others have not (Weibull et al. 2000, Purtauf et al. 2005). In some cases, the absence of demonstrable effects has been attributed to the overriding influence of landscape heterogeneity (Weibull et al. 2000, Bengtsson et al. 2005, Tscharntke et al. 2005). For example, in fields embedded in a structurally simple landscape, biodiversity might not be subsidized by the steady colonization of these fields by species from the surrounding environment; thus, the effects of environmentally-friendly farming practices that promote biodiversity locally should have their greatest effect in simpler landscapes (Tschantke et al. 2005). However, landscape complexity and field-scale species richness may interact with local management effects, leading to non-linear effects (Concepcion et al. 2008, 2012). Thus, the effect of agri-environment practices on species richness will be maximal in landscapes of intermediate complexity (Tscharntke et al. 2005), decreasing to zero in the simplest and the most complex landscapes. Studies have shown that, for a variety of organisms, the effectiveness of conservation (i.e., the difference in species richness between sites with and those without conservation initiatives) is higher in simple landscapes than it is in complex landscapes (weeds Roschewitz et al. 2005, invertebrates Rundlöf and Smith 2006, Holzschuh et al. 2007, birds Smith et al. 2010), which underscores the need for carefully designed farm-scale studies that take the landscape context into account (Bengtsson et al. 2005).

However, the impact of landscape context on the effectiveness of environmentally-friendly farming practices that promote farmland biodiversity might differ between farming systems (Batáry et al. 2011). To date, most studies have focused on annual crops, but it is unknown whether the landscape-dependence hypothesis would apply to perennial systems like olive groves, which are more stable agro-ecosystems (Foster et al. 2002).

Small-bird communities are indicators of agrosystem degradation because they have a broad spectrum of diets (e.g., insectivorous, granivorous, frugivorous) and, therefore, might reflect the availability of different food items. The benefits of birds as indicators of ecosystem degradation, particularly in the context of agricultural intensification are known (Gregory et al. 2005). Birds are sensitive to environmental change (Heath and Raymem 2003), and agricultural intensification is a major cause of the declines in farmland birds in Europe (Donald et al. 2006). In the Mediterranean region, agricultural intensification has been common since the 1950s, with increases in mechanization, removal of natural vegetation, fertilization, and the use of pesticides, all of which have contributed to a reduction in fruit and other resources required by birds (Kizos and Koulouri 2006).

In the Mediterranean region, olive orchards are one of the primary agro-ecosystems and they are an important winter refuge for birds from Central and Northern Europe (Rey 1993). In Europe, the largest area of olive farming is in Spain, where 2.5 million ha are dedicated to this crop and has significant possibilities for expansion (Beaufoy 2000). For instance, from 1996 to 2008, the amount of land dedicated to olive orchards in Spain increased by 300,000 ha (Barea and Ruíz 2009). Since the mid-1980s, the Common Agricultural Policy of the European Union (CAP) has been central in the intensification of olive plantations. That policy favoured an increase in production, but overlooked the importance of environmental protection (Beaufoy 2001), which has lead to significant negative environmental consequences including the polluting of waters by nitrates and herbicides, and soil loss caused by erosion (Francia et al. 2000). In 2003, the CAP was modified to favour agro-environmental measures that reduce erosion and maintain the structural complexity of the agro-ecosystems, such as promoting herbaceous ground cover and preserving stone walls or hedges. Conventional farming, which involves the intensive use of agrochemicals, is the prevailing production system in Spain, and the only agro-environmental measure now in practice is the use of ground cover. Ground cover can provide environmental and agronomic benefits by reducing soil loss and erosion, increasing soil fertility and water content, and activating soil microbial processes (Moreno et al. 2009). Ground cover in olive groves is known to benefit the biodiversity of some organisms such as the arthropod communities in the soil and the canopy (González et al. 2004), and it is likely to have a positive effect on the biodiversity of birds.

The aim of this study was to evaluate the effects of farming practices (i.e., use of ground covers) and landscape heterogeneity on the songbird communities of conventional olive crops in southern Spain. We predicted that 1) ground cover and landscape heterogeneity will have a positive effect on small-bird communities and 2) these positive effects should be landscape-dependent; that is, the positive effects of ground cover should be greatest in the most homogeneous environments (Bengtsson et al. 2005, Smith et al. 2010).

METHODS

Study area and sampling design

The study was performed in two contrasting olive-grove-dominated landscapes within 10 km of Villa del Río, Córdoba province, southern Spain (37º 59’ N, 4º 17’ W). The Guadalquivir River divides the area from east to west into two contrasting landscapes, representative of the endpoints of a historical intensification gradient in olive farming practices (Falucci et al. 2007): the Guadalquivir Valley (intensively-managed homogeneous landscape) and the slopes of the Sierra Morena (less intensive, heterogeneous landscape). The valley is flat, underlain by clay soils and, historically, has been used for intensive agriculture, which has eliminated most of the woodlots, copses, hedgerows, and other live fences between fields (Rey 2011). In contrast, the slopes of Sierra Morena are on siliceous substrates and olive orchards are part of a mosaic landscape, with hedges, dry-stone walls and rocky outcrops with associated native vegetation in the most inaccessible sites. Landscape heterogeneity of each area was quantified using the proportion (%) of remaining natural vegetation patches within a 500-m radius of each sampling point (following Batáry et al. 2010). The slopes had significantly (ANOVA, $F= 8.793$, $p=0.007$) higher coverage of natural vegetation than did the sites in the valley.

To determine whether landscape heterogeneity or farming practices influenced the diversity of species in the bird communities in olive groves, we selected six independent pairs (minimum distance between pairs 0.5 km) of orchards that were managed using conventional olive-grove farming practices. Sizes of olive groves did not differ between homogeneous and heterogeneous landscapes (t-test, $t=-1.814$, $p=0.103$; heterogeneous landscapes mean size (±SE) = 16.00 (±3.38) ha; homogeneous landscapes mean size (±SE) = 10.67 (±2.42) ha), nor between pairs (paired t-test, $t=-0.268$, $p=0.799$). Three pairs of the olive groves corresponded to heterogeneous landscapes (slopes of the Sierra Morena) and three pairs to homogeneous landscapes (Guadalquivir Valley). In each pair, one of the groves had ground cover and the other had bare soil (i.e., neither natural grass nor cover crops were present). The herbaceous ground cover comprised annual species that are adapted to Mediterranean climates and set their seeds before the summer drought. Cover was present throughout the groves except in the area below tree crowns, which was kept plant-free by the application of contact and systemic herbicides. The amount of area covered by ground cover varied among plots (20-85%), but was consistent within plots over the 3-yr period. In the second half of May, the ground cover was mowed and left on site. The pairs of groves were selected at random, although an effort was made to choose pairs of olive groves of the same age and tree density. All of the olive orchards were in flat areas, had trees >100 years old at a density of ~ 100 trees/ha, and were subjected to the same pruning schemes. On the slopes of Sierra Morena, to avoid the undue influence of edge effects, the pairs of groves were at least 300 m away from large natural vegetation remnants.

Bird counts

Bird counts were conducted monthly between January 2009 and December 2011 (n= 36 visits). Two bird sampling points at least 200 m apart were chosen randomly within each of the 12 study groves; counts for the two points within a grove were sampled in the same day and were pooled for further analyses. Counts at these bird sampling points had a fixed radius of 30 m and were sampled during periods of 5 min. Counts were performed by the same observer (JCCC) within two hours after sunrise during good weather. Based on the guidelines suggested by SEO/Birdlife (2003), birds heard or seen when the observer approached the sampling point were included in the counts. During each survey, care was taken to not count individual birds more than once. Birds that flew high above the sampling point and were not foraging in the area were not included in the counts, except when it was obvious that they were using the space that surrounded the sampling point; e.g., birds that made short flights from tree to tree or birds that sing in flight rather than from a perch such as Alaudidae. Unidentified birds (~6.84% of the total) were not included in the analyses.

For each grove and visit, two parameters were used to describe songbird communities: bird abundance (number of birds detected on each visit) and bird species richness (number of species detected on each visit). In addition, to assess the completeness of our survey we estimated species richness using Chao2 for each type of olive grove. This estimator asymptotically approximates total species richness by controlling how rare species are detected when individuals or sampling units are increasingly and randomly incorporated to the sample (Walther and Morand 1998, Vavrek 2012).

Statistical analyses

To evaluate the effect of ground cover and landscape heterogeneity on songbird communities in conventional olive orchards in southern Spain, we used Generalized Additive Mixed Models (GAMM). To account for the nestedness of the data, grove identity, pair of orchards and year were included as random factors. The response variables (bird abundance and species richness) were modeled using a Poisson distribution and a log link function. The predictor variables included the landscape (heterogeneous or homogeneous), the proportion of herbaceous ground cover, the interaction between these two factors, and the effect of month, allowing for a non-linear temporal response by including a smoother estimated using cubic regression splines (Zuur et al. 2009). Including different smoothers per year did not improve model fit, so we fitted one smoother for all years. Model selection was based on Akaike's Information Criteria corrected for small sample sizes (AICc; Symonds and Moussalli 2011). The direction of the effect of a variable was based on an evaluation of its estimated coefficient. For the comparisons presented in **Table 1.1**, groves in homogeneous (valley) landscapes were used as reference. No spatial or temporal autocorrelation was found in the residuals of the models (Zuur et al. 2009), so residual independence could be safely assumed.

Table 1.1. Statistics from the GAMMs for bird abundance (a) and bird species richness (b) in conventional olive groves in southern Spain. Baseline levels for comparisons are groves in homogeneous landscapes. edf: estimated degrees of freedom.

a) GAMM for abundance			
Response variable: abundance Random factor: grove within pair, year Family: Poisson			
	Estimate (±SE)	**t**	**p**
intercept	0.669±0.086	7.82	<0.001
ground cover	0.007±0.001	4.95	<0.001
	edf	**F**	**p**
s(month)	4.26	7.57	<0.001
b) GAMM for richness			
Response variable: richness Random factor: grove within pair, year Family: Poisson			
	Estimate (±SE)	**t**	**p**
intercept	0.422±0.084	5.03	<0.001
ground cover	0.006±0.001	4.32	<0.001
landscape heterogeneity	-0.226±0.114	-1.99	0.047
	edf	**F**	**p**
s(month)	5.14	5.72	<0.001

To describe community composition, we used a non-parametric multivariate analysis of variance (Anderson 2001), which allows for the direct partitioning of the variance in complex models through the use of permutations. Bray-Curtis dissimilarity was used as a distance metric, and 1000 permutations were run. Our four different types of observations (e.g., in groves that differ in landscape heterogeneity and presence of ground cover) can be plotted using non-metric multidimensional scaling (NMDS), which allows the visual inspection of patterns of resemblance among observations based on community composition. All statistical analyses were performed using R 2.14 (R Development Core Team 2011); specifically, the packages *mgcv* (Wood 2006) and *vegan* (Oksanen et al. 2011) were used to build the GAMMs and run the multivariate analyses, respectively, and *fossil* (Vavrek 2012) to calculate species richness estimators.

Table 1.2. Species of birds detected during monthly counts between Jan 2009 and Dec 2011 in olive groves in southern Spain that had different landscapes and farming practices. Species that had an 'unfavourable conservation status' (Birdlife International 2004) are indicated in bold, and species of conservation concern in Spain (Madroño et al. 2004) are indicated by an asterisk. R: resident; M: migratory in the study area. Total number of species detected and estimated species richness (chao2) for the total duration of the study are also indicated.

		Heterogeneous landscape		Homogeneous landscape		
species	status	with ground cover	without ground cover	with ground cover	without ground cover	**total**
Galerida cristata	**R**	**11**	**2**	**5**	**5**	**23**
Lullula arborea	**R**	**9**	**0**	**0**	**0**	**9**
Motacilla alba	M	3	2	0	1	6
Cercotrichas galactotes*	**M**	**0**	**0**	**4**	**0**	**4**
Erithacus rubecula	M	7	5	8	1	21
Phoenicuros ochruros	M	0	2	0	0	2
Turdus merula	R	3	3	0	0	6
Turdus philomelos	M	50	11	33	10	104
Hippolais polyglota	M	1	0	1	0	2
Sylvia melanocephala	R	11	7	33	23	74
Sylvia hortensis	**M**	**0**	**0**	**1**	**0**	**1**
Sylvia borin	M	0	0	1	0	1
Sylvia atricapilla	M	6	1	29	20	56
Phylloscopus trochilus	**M**	**0**	**0**	**1**	**1**	**2**
Phylloscopus collybita	M	7	8	9	15	39
Parus caeruleus	R	1	0	0	0	1
Parus major	R	63	53	61	62	239
Certhia brachydactyla	R	10	7	5	8	30
Lanius senator*	**M**	**11**	**1**	**8**	**0**	**20**
Cyanopica cyana	R	4	8	0	0	12
Sturnus unicolor	R	7	0	0	0	7
Passer domesticus	**R**	**18**	**4**	**2**	**1**	**25**
Fringilia coelebs	R	4	3	17	11	35
Serinus serinus	R	39	54	29	33	155
Carduelis chloris	R	22	8	41	22	93
Carduelis carduelis	R	3	3	3	4	13
Carduelis cannabina	**R**	**31**	**19**	**16**	**17**	**83**
Unknown		15	11	32	20	78
TOTAL		321	201	307	234	1 141
Total nr species detected		22	19	20	16	
Estimated species richness		25	20	24	22	

RESULTS

In the olive groves embedded in a homogeneous landscape in the Guadalquivir Valley, Córdoba, Spain, 307 and 234 birds were recorded in counts on groves that had ground-cover and bare-ground, respectively. In the heterogeneous landscapes of the slopes of Sierra Morena, nearby, the corresponding numbers of birds were 321 and 201 (**Table 1.2**). Altogether, 27 bird species were recorded and estimated species richness ranged between 20 and 25 for the different types of olive groves; the number of birds detected per visit ranged between 0-10 individuals from one to five species (**Table 1.2**).

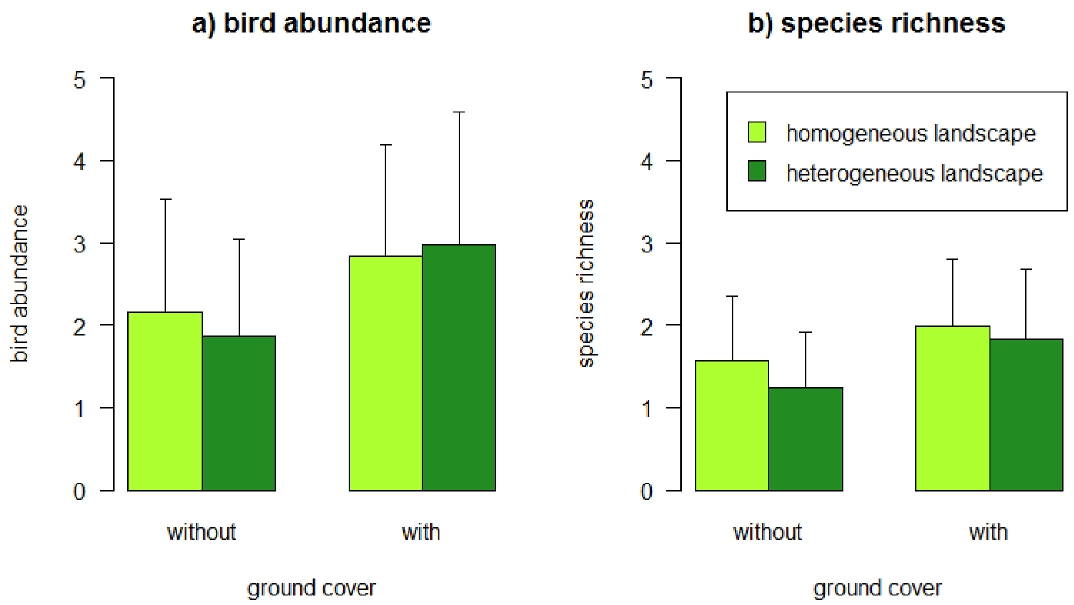

Figure 1.1. The presence of ground cover, bird abundance (number of birds; a) and species richness (number of species; b) in homogeneous and heterogeneous landscapes of olive groves in southern Spain. Mean values ±standard errors are shown.

In none of the models was the interaction between landscape heterogeneity and the presence of ground cover statistically significant (bird abundance: F=0.06, p=0.810; richness: F=0.07, p=0.793), which suggests that the effect of ground cover on bird communities was similar in homogeneous and heterogeneous landscapes (**Figure 1.1**). Ground cover had a positive effect on bird abundance and species richness (**Table 1.2**), which were, respectively, 1.4 and 11.4 times higher in the plots that had herbaceous ground cover than they were in the bare-ground groves. Landscape heterogeneity did not affect bird abundance (t=-1.02, p=0.310) and only marginally for species richness (**Table 1.2**). In all cases, month had a significant non-linear effect, which reflects the seasonal variation in the response variables (**Table 1.2**; **Figure 1.2**).

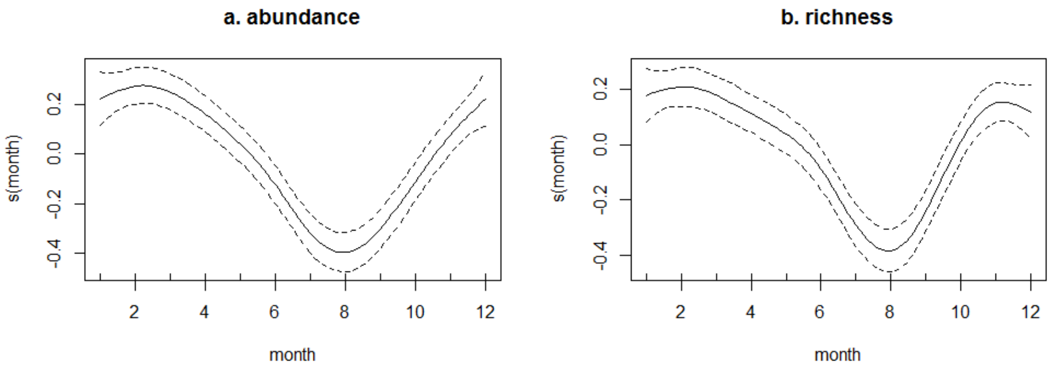

Figure 2. Estimated smoothing curves for the effect of month on a) bird abundance and b) species richness of songbird communities in olive groves in southern Spain. Dashed lines indicate 95% confidence intervals.

The non-parametric MANOVA indicated that the accumulated species composition of the bird communities in each grove differed significantly between landscape types (pseudo-F=3.22, p=0.002; (**Figure 1.3**) and between groves with and without herbaceous cover (pseudo-F=3.10, p=0.003). The interaction between landscape type and ground cover was not significant (pseudo-F=0.314, p=0.937), which indicates that the effect of ground cover on the songbird species composition of communities in the olive orchards did not differ between heterogeneous and homogeneous landscapes.

DISCUSSION

Our study tested the hypothesis that the positive effects of herbaceous ground cover on avian biodiversity are landscape dependent; however, in the olive orchards in southern Spain, the interaction between farming practices and landscape heterogeneity did not have a significant effect on species richness and bird abundance or on species composition over the 3-yr study. There are at least three possible explanations for this lack of interation. First, although environmentally-friendly farming practices can increase species richness and abundance of birds (Smith et al. 2010) and other species (Roschewitz et al. 2005, Rundlöf and Smith 2006, Holzschuh et al. 2007) in homogeneous, but not in heterogeneous landscapes, studies have mostly compared contrasting annual-crop-dominated landscapes (e.g., cereal, cereal and legume mixture and ley, and more rarely beet and oil seed rape), where disturbances by management practices are particularly intensive (Bruggisser et al. 2010). Indeed, the impact of the landscape context on the effectiveness of environmentally-friendly farming practices might differ between farming systems. In a recent meta-analysis, Batáry et al. (2010) showed that agri-environmental management had positive effects on plant and bird communities, independent of landscape complexity, possibly because most of the studied grasslands were perennial agro-ecosystems. Perennial agro-ecosystems have lower disturbance intensities (Bruggisser et al. 2010), and thus may foster more stable plant and animal communities (Foster et al. 2002) and provide more predictable seasonal resources. Cultivated olive trees derive from the wild variety *Olea europaea var. sylvestris* by human selection over millennia (Breton et al. 2006), but still provide important resources to birds, such as winter fruits, and may act as alternative habitats for bird communities (Rey 2011). Although species composition of songbird communities was different in the two landscape types, they were affected similarly by farming practices. Many species may perceive landscapes in complex ways and utilize resources from different land uses, so the description and measurement of heterogeneity should be based on the expected functions (e.g. provision of food, nesting sites, dispersal routes) provided to the species or species group(s) of interest (Fahrig et al. 2011). The lack of interaction between farming practices and landscape heterogeneity in our study may be due to the similar functionality of olive groves in both landscapes, providing similar resources for bird communities despite the differences in landscape heterogeneity. Thus, the landscape-dependent hypothesis might not apply to perennial farming systems such as the olive groves in southern Spain. Second, non-linearities in the relationship between species richness and landscape complexity (Concepción et al. 2008, 2012) may set complexity thresholds that determine the effectiveness of agri-environmental measurements. The actual location of minimum and saturation thresholds along the landscape gradient and the specific shape of this relationship are expected to differ among taxa, depending on their perception of landscape complexity and their dispersal ability (Concepción et al. 2008). Determining where such thresholds occur is therefore critical for effective implementation of agri-environmental policies.

Lastly, an alternative explanation is that the effects of farming practices that occur at a local (field) scale override the potential effects of the landscape context. In fact, in the olive groves in southern Spain, herbaceous ground cover consistently favored the abundance and richness of songbirds, and other studies in the region have also shown that ground cover can have a significant effect on the abundance of birds in olive groves. Muñoz-Cobo (2009) found that the bird densities in olive groves that had, respectively, 10% or 25% highly diverse ground cover were twice and thrice as high as they were in bare-ground conventional olive groves. In our study, the differences in abundance were more moderate than those, but the effects of ground covers were still evident. The positive effects of herbaceous ground cover are probably related to increases in structural complexity, which benefits invertebrates, particularly if the sward is species-rich and structurally complex (Wilson et al. 1999, Vickery et al. 2009). The herbaceous layer can provide seeds and insect prey for foraging birds. The composition of the ground cover, its structure, and dynamics are critical for some species of small birds, e.g., *Serinus serinus*, that feed their nestlings protein-rich seeds, e.g., *Diplotaxis virgata* and *Erodium sp*. (Valera et al. 2005). In southern Spain, the olive groves can have high plant diversity (500-900 species), and often more than 100 species per hectare can be found (Pujadas-Salvà 1989). Similar results have been found in other woody crops (vineyard Arlettaz et al. 2012, coffee Philpott et al. 2008, oil palm Jambari et al. 2012), in which structural complexity and more specifically ground cover had a positive effect on bird communities.

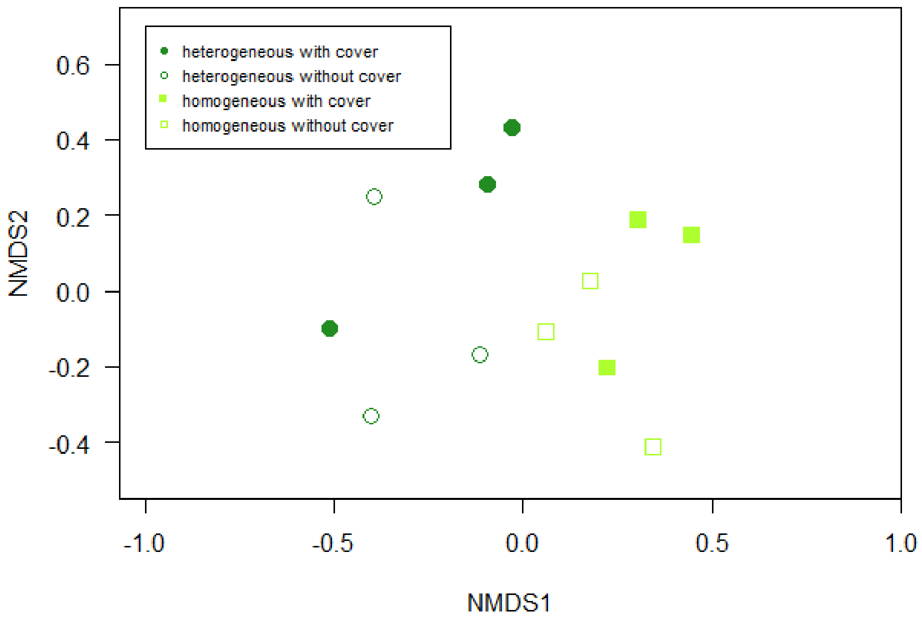

Figure 1.3. Non-metric multidimensional scaling plot of songbird communities in olive groves in southern Spain that differed in landscape (circles: heterogeneous landscape; squares: homogeneous landscape) and farming practices (solid symbols: with herbaceous ground cover; open symbols: without ground cover).

In the Mediterranean Basin, numerous species of birds from Central and Northern Europe use olive orchards in winter (Rey 2011) and many of them have generalist diets. For example, in winter, species of *Turdus, Sylvia, Sturnus,* and *Erithacus* develop frugivorous diets or, at least, adopt mixed diets that have a high proportion of fruit (Debussche and Isenmann 1985). Other resident species such as Sardinian Warbler *Sylvia melanocephala,* Blackbird *Turdus merula*, and

Azure-winged Magpie *Cyanopica cyana* alter their winter diet to include many fruits (Herrera 1984). Although the Mediterranean region has a long history of losses of natural habitat and transformations to agricultural landscapes, olive orchards might serve as alternative habitats for the conservation of frugivores because they can provide food when the olives ripen (Rey and Valera 1999, Rey 2011). In the three years of our study, the species richness and abundance of songbirds were highest in winter, with higher densities of frugivorous wintering species (mostly *Erithacus rubecula*, *Turdus philomelos*, *Sylvia atricapilla*, and *Sylvia melanocephala;* 23 birds / 10 ha) relative to summering species (*Cercotrichas galactotes* and *Lanius senator;* 3 birds / 10 ha). Studies have shown that olive orchards are the most important winter habitats for large populations of *S*. *atricapilla* and *T. philomelos* (Rey 1993).

In general, extensive farming practices have positive effects on farmland biodiversity; however, few studies have assessed the ecological effects of environmentally friendly practices on uncommon bird species, and the results are mixed. Some studies showed that agro-environment schemes benefit common species primarily, and are of limited use in the conservation of uncommon species of farmland wildlife (Kleijn et al. 2006). However, recent studies suggest that agro-environmental schemes can increase the populations of rare and declining species on farmland (Pywell et al. 2012; e.g., *Miliaria calandria* in Scotland, Perkins et al. 2008, *Tetrax tetrax* in France Bretanoglle et al. 2011). In our study, 15% of the birds (8 species) detected in the olive orchards have an unfavourable conservation status in Europe (Birdlife International 2004; **Table 1.2**), and two of the species (*Cercotrichas galactotes* and *Lanius senator*) are, respectively, endangered (EN) and Vulnerable (VU) in Spain (Madroño et al. 2004). In the olive orchards in southern Spain, the presence of ground cover had a positive effect on those species (70% of individuals of these species were detected in the olive groves that had ground cover). Some agro-environment schemes such as a reduction in the use of fertilizers and pesticides can have a positive effect on endangered birds (Kleijn et al. 2006). We showed that in the absence of any other agro-enviromental measure, ground cover can benefit some uncommon bird species; however, the possibility of additive or interactive effects with other agri-environmental measures cannot be discounted, and more research is needed.

In conclusion, our study suggests that the effects of farming practices on bird communities in olive groves of southern Spain are not landscape-dependent. The presence of ground cover had a positive, landscape-independent effect on songbird communities, which might be important for the conservation of the wintering quarters and breeding ranges of numerous European bird species and, particularly, those bird species of conservation concern.

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CHAPTER 2

Effects of hedges and ground covers on passerine communities in Mediterranean olive groves

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ABSTRACT

In recent decades, agricultural intensification and landscape simplification have dramatically affected farmland biodiversity. To halt this trend agri-environmental measures (AEMs) of the Common Agricultural Policy (CAP) were launched in the European Union in the early 90s. Since then an effort has been made to asses the efficacy of these measures; however, in the Mediterranean region, where olive groves are one of the predominant crops, the effectiveness of AEMs to maintain farmland biodiversity remains poorly evaluated. In conventional olive farming the only AEMs now in practice are the implementation of herbaceous, non-crop vegetation within crops (i.e. ground covers) aimed at preventing soil erosion, and the maintenance of hedges. These practices, when applied separately, can increase structural complexity, likely benefitting farmland biodiversity at different spatial scales; however, little is known about the potential synergistic effects when these measures are applied in combination in Mediterranean agroecosystems. This study assessed the combined effects of herbaceous ground cover and hedges on passerine communities of olive groves over a 4-yr period. Hedges, and to a lesser extent ground covers, efficiently increased the abundance and richness of passerine communities of olive groves, particularly that of insectivorous birds, but the effects of both measures were independent of each other. Hedges were particularly relevant to the richness and abundance of passerine communities, particularly at short distances (<50 m). Therefore, we suggest that management should promote the creation of a hedge network embedded in the olive grove matrix, for example by promoting or maintaining hedgerows located between properties. This study underscores the important role of increasing structural complexity in Mediterranean perennial agro-ecosystems, either through the implementation of ground covers or maintaining hedges, to preserve farmland passerine communities, and encourages the use of these agri-environmental measures as a tool in landscape planning and conservation.

INTRODUCTION

Agricultural intensification entails the simplification and homogenization of the landscape, which leads to a generalized decline of farmland biodiversity (McLaughlin and Mineau 1995, Benton et al. 2003). Reversal of the negative effects of modern agriculture on the environment is an important concern at the European level (Smith et al. 2010, Tryjanowski et al. 2011) and European policies promote wildlife–friendly approaches (Fischer et al. 2008). Thus, biodiversity conservation on European farmland encompasses a range of different practices aimed at enhancing biodiversity by restricting farming intensity, maintaining low-input farming practices or creating landscape elements, such as hedges, ponds or wildflower strips that increase structural complexity of farmland habitats (Benton et al. 2003, Burel et al. 2013). Many of these measures are subsidised in the framework of agri-environment schemes of the European Common Agricultural Policy (CAP) (Kleijn et al. 2011).

Although AEMs are considered the main policy instrument currently available in Europe to promote environmentally-friendly farming practices (Donald and Evans 2006), there is still little information regarding the effects of these measures on biodiversity. In the last decade, some studies from various European countries have evaluated the effects of conservation initiatives on farmland biodiversity showing mixed effects (Kleijn et al. 2011, and references therein). Moreover, the adoption of these practices is still relatively feeble in southern Europe despite the high biodiversity of this region (López-López et al. 2011) and the effectiveness of AEMs to maintain farmland biodiversity in this region remains poorly evaluated. In Mediterranean areas the effects of AEMs have been mostly analyzed in extensive arable systems (Moreno et al. 2010, Reino et al. 2010). In permanent woody crops, studies have focused on reducing chemical input or limiting the use of synthetic agrochemicals for pest control (i.e., integrated production and organic farming) in fruit orchards (Genghini et al. 2006) and vineyards (Bruggisser et al. 2010). However, less is known about AESs aimed at increasing structural complexity in woody crops, such as ground covers and hedge promotion (but see Castro-Caro et al. 2014a), although they have been highly recommended (Morelli et al. 2014) because they have been shown to enhance farmland biodiversity in other habitats (Chamberlain and Wilson 2000, Merckx et al. 2009).

In the Mediterranean Basin, olive orchards are one of the primary agro-ecosystems and they are important winter quarters and breeding ranges for numerous European bird species (Rey 2011). In Europe, the largest area of olive farming is in Spain, where 2.5 million ha are dedicated to this crop. Conventional farming is the traditional and most common production system (85% of crop area). To keep soils bare and weed-free, conventional farming involves the intensive use of agrochemicals and superficial ploughing, which has led to significant negative environmental consequences including water pollution and, especially, soil erosion (Gómez et al. 2009). However, to prevent erosion, many farmers are now maintaining herbaceous, non-crop vegetation within crops (i.e. ground covers), which likely increases structural complexity and provides resources for foraging birds (Wilson et al. 1999, Vickery et al. 2009, Castro-Caro et al. 2014a). These ground covers are 5-40 cm high and generally comprise annual species that are adapted to Mediterranean climates and set their seeds before the summer drought. On the other hand, agricultural intensification in the Mediterranean basin since the 1950s (Kizos and Koulouri 2006, Sokos et al. 2013) has eliminated most hedgerows between fields, and the rare hedges still present are small, often undetectable in the landscape (Rey 2011). Hedgerows are important components of agricultural landscapes throughout the world (Hinsley and Bellamy 2000, Manning et al. 2006) and increase the heterogeneity of habitats and resources within these systems (Benton et al. 2003, Fischer et al. 2005). The benefitial effects of hedges or small vegetation remnants on bird communities in intensively used farmland has been even reported for the shrub patches around electricity pylons (Tryjanowski et al. 2014). Hedges also act as corridors and facilitate longer distance travels through different landscapes (Demers et al. 1995, Hinsley and Bellamy 2000), maintaining species richness in fragmented agricultural landscapes (Gilbert et al. 1998). The importance of small residual habitats (e.g., shrubby areas, hedges, scattered trees) as an influence on biota has been reported for a range of agricultural landscapes (Berg 2002, Fischer et al. 2004), and fine-scale heterogeneity is particularly emphasized in cultural landscapes in Europe (Farina 1997, Pino et al. 2000, Herzon and O'Hara 2007). Responses to AEMs however, may vary with the spatial scale at which its effects are perceived by the target species (Concepción and Diaz, 2011). For instance, at the scale of foraging activities (i.e. whitin-field and hedgerow habitat structure), consideration of the surroundings at different, progressively larger spatial extents is fundamental to understand the response of birds to habitat heterogeneity (Kattan and Murcia 2002).

So far, the only AEMs now in practice in conventional olive groves are the use of ground covers and the maintenance of hedges (Sokos et al. 2013). Ground covers can stimulate biodiversity of conventional olive groves (Castro-Caro et al. 2014), but the effect of hedges has never been evaluated in Mediterranean woody crops. In addition, because these elements potentially provide different resources, they may have complementary effects when applied in combination. In our study, we used passerine communities as indicators of agroecosystem degradation because they have a broad spectrum of diets (e.g., insectivorous, granivorous, frugivorous) and, therefore, might reflect the availability of different food items. The benefits of birds as indicators of ecosystem degradation, particularly in the context of agricultural intensification, are well known (Gregory et al. 2005, Everard 2008). Detailed analyses of the relative abundance of different functional groups of birds have been successfully used to evaluate the effects of habitat management or cumulative habitat changes and to develop biotic indicators of habitat quality (Whitaker and Montevecchi 1999, Canterbury et al. 2000, Jones et al. 2000). When the functional role of each species is taken into account, the focus of analysis becomes more ecological, since the composition of a given community is a reflection of the equilibrium between the intra and interspecific relationships with the rest of the biotic and abiotic environment (Soriano 2000).

The aim of this study is to evaluate the combined effect of two AEMs, the promotion of hedges and the implementation of ground covers, on passerine communities of olive groves of Southern Spain. Specifically, our questions are:

1) Do hedges and ground covers benefit the abundance and richness of different functional groups of farmland passerines? And if so, do their effects interact?

We predict that hedges and ground covers will have a beneficial effect on all functional groups of birds. These effects might be stronger when both AEMs are used in combination, because of the complementary resources each AEMs provides.

2) At which spatial scale is the effect of hedges more relevant to farmland passerines?

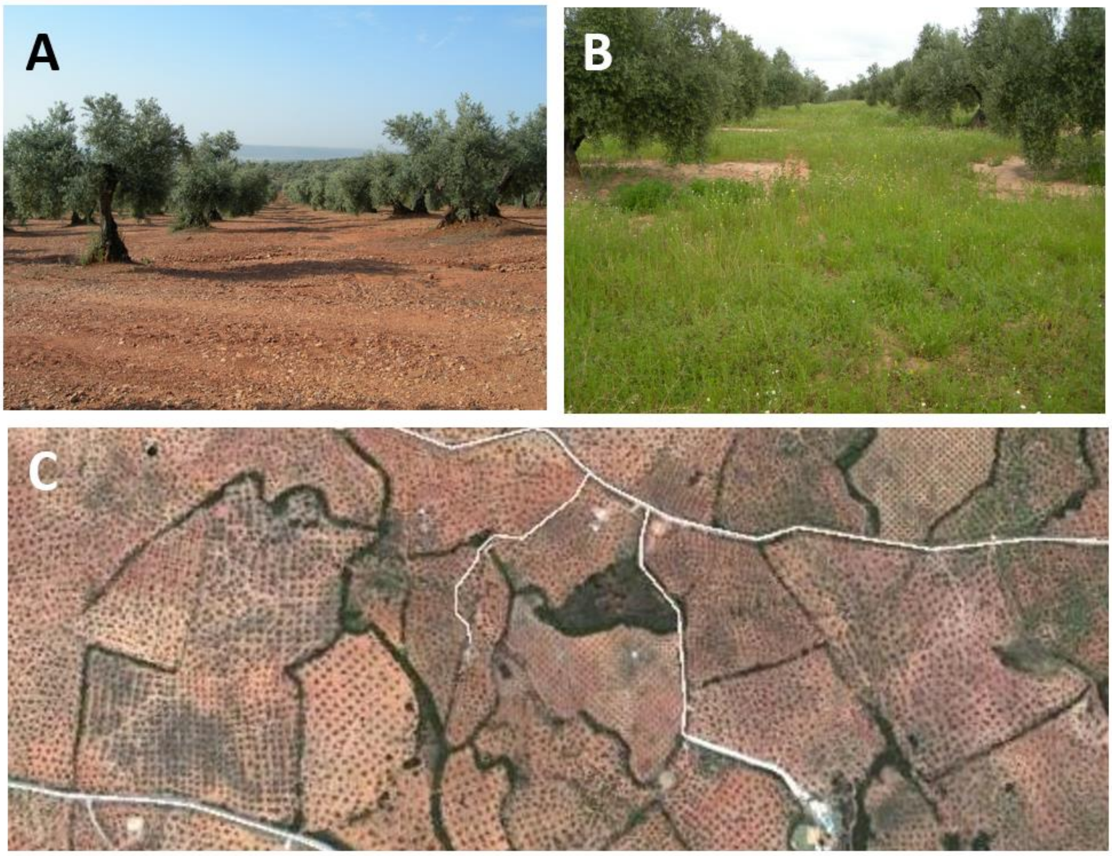
We expect the effect of hedges on passerines to be stronger at finer spatial scales (i.e. closer to the hedge) than farther away, given the relatively small ranging distances of these birds.

METHODS

Study area and sampling design

We conducted our study from 2009 through 2012 in the slopes of Sierra Morena, Córdoba province, southern Spain (38º 02’ N, 4º 18’ W, 300 m asl). The climate of the region is Mediterranean, with a mean annual temperature of 18º C and 500 mm rainfall concentrated in a few months, in Autumn and Spring. There is a marked dry period in summer, which coincides with high temperatures, often above 40º C. The physiognomy of the area exhibits sedimentary hill features with gentle slopes (up to 20%) on siliceous substrates.

The landscape is dominated by an olive grove matrix resulting from historical intensive land-use, which has eliminated most of the copses, hedgerows, and other live fences between fields (Rey 2011). Where still remaining, hegdes are dominated by Mediterranean evergreen shrubs (*Pistacia lentiscus*, *Quercus coccifera* and *Olea europaea* var. sylvestris). Herbaceous ground covers are implemented in some groves to prevent excessive soil erosion. Ground covers are typically present throughout the groves except in the area below the tree crowns, which is kept plant-free by the application of contact and systemic herbicides (**Figure 2.1**); ground covers are mowed in the second half of May to avoid water competition between weeds and crops.



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gure 2.1. Conventional olive groves are usually kept without ground cover (A: image of a conventional olive orchard in early Spring). Ground covers are generally implemented to prevent excessive soil erosion (B: Image of an olive orchard with ground cover in early Spring). The area below the tree crowns is kept plant-free by the application of contact and systemic herbicides. Hedges are still maintained at some sites (C: aerial image of a network of hedges within a matrix of olive groves).

To evaluate the effect of the presence of ground covers and hedges on passerine communities, we chose 40 survey points, at least 200 m apart, distributed over 14 km^2 in 7 plots. Plots were at least 1.5 km apart and were selected based on the availability of groves with ground covers and hedges. Three plots (4 survey points in each, 2 with and 2 without ground cover) had no hedges within a 300 m radius of each survey point; the other four plots had hedges at a maximum distance of 50 m from each survey point. From the latter, two plots (containing respectively 5 and 7 survey points) had ground cover and the other two (8 survey points in each) had bare ground. In our study, olive groves were similar, with olive trees older than 100 years at a density of ~ 100 trees/ha, and were subjected to the same pruning schemes. The area covered by ground cover was similar among plots (60%), and was consistent within plots over the 4-yr study period.

To test the effect of heterogeneity created by hedges at different, progressively larger spatial scales on bird communities, we estimated hedge cover in four non-overlapping circular areas that surrounded each focal survey point at, respectively, 10-m (hereafter R10), 20- to 50-m (R20-50), 50- to 100-m (R50-100), and 100- to 250-m (R100-250) radius. Hedges were digitized from an aerial photograph of the area and ground-truthed; hedge cover was estimated as the proportion (%) of the surface in each circular area covered by hedges (for descriptive statistics see **Table 2.1**). For this part of the study we used only the four plots in olive groves with hedges.

Table 2.1. Effect of hedges at different scales on all birds, insectivorous birds only and omnivorous birds only. Coefficient estimates (± standard errors) are shown. '*' P<0.05; '**' P<0.01; '***' P<0.001; '^{ms}' marginally significant, p<0.06.

	10 m radius	**20-50 m ring**	**50-100 m ring**	**100-250 m ring**
Mean percent cover of hedges (± SE) [range]	10.95 (±0.47) [0.00-59.98%]	5.76 (±0.15) [0.00-20.85%]	6.16 (±0.14) [0.00-18.85%]	7.42 (±0.18) [0.00-31.16%]
a) Songbird abundance				
All birds	0.007 (±0.003)*	0.046 (±0.013)***	0.008 (±0.014)	-0.011 (±0.010)
Insectivorous birds	0.005 (±0.003)	0.024 (±0.013)	0.014 (±0.014)	-0.005 (±0.011)
Omnivorous birds	0.010 (±0.005)*	0.067 (±0.019)***	-0.002 (±0.021)	-0.022 (±0.016)
a) Songbird richness				
All birds	0.004 (±0.003)	0.042 (±0.011)***	0.012 (±0.012)	-0.014 (±0.009)
Insectivorous birds	0.005 (±0.003)	0.031 (±0.013)*	0.018 (±0.013)	-0.013 (±0.011)
Omnivorous birds	0.006 (±0.004)	0.053 (±0.015)***	-0.002 (±0.017)	-0.013 (±0.012)

Bird counts

Bird counts were conducted at monthly intervals, between January 2009 and December 2012 (n= 48 visits) in each focal point; counts at 12 out of the 40 focal points began one year later

(January 2010; 36 visits only). Two plots were visited per day, and to minimize effects of time of the day we systematically switched the order in which the two plots and focal points within a plot were visited in the corresponding day. At each focal point all passerine birds seen or heard within a 30 m radius during 5 min were counted (i.e. following the guidelines suggested by SEO/BirdLife (2003) for censusing common birds). We made no assumptions of territorial singing males represent a breeding pair; this methodology is widely applied (Smith et al. 2010, Castro-Caro et al. 2014a) but may lead to slight underestimation of abundance of certain species during the breeding period. Birds heard or seen at the focal point (i.e. within the 30 m radius) when the observer approached the point were included in the counts (SEO/BirdLife 2003), and special care was taken not to count individual birds more than once.. All counts were performed by the same observer (JCCC) within two hours of sunrise under good weather conditions. Detectability of birds using this method in perennial crops is high (Castro-Caro et al. 2014a) and not affected by seasonal variations because the structure of orchards is constant throughout the year (i.e. olive trees have perennial leaves) and our study species do not gather in flocks during winter (see for example Myczko et al. 2013).

For each focal point and visit, two parameters were used to describe songbird communities: bird abundance (number of birds detected on each visit) and bird species richness (number of species detected on each visit). Unidentified birds (~10%) were not included in the analyses of richness or abundance.

Data analysis

We separately analyzed functional groups of passerine birds based on their diet when using the olive groves of Southern Spain. Species that include less than 20% vegetable material in the adult diet were classified as insectivorous, and those including more than 20% vegetable material as omnivores (**Appendix 2.1**). We based this classification on, in order of priority, Muñoz-Cobo (2001a,b), Holland et al. (2006) and Siriwardena et al. (1998); in the case of wintering migrants we also followed Herrera (1983).

The combined effect of hedges and ground covers on passerine communities of intensive agricultural landscapes of Southern Spain was evaluated using Generalized Additive Mixed Models (GAMM), with a Poisson distribution of errors and a log link. The abundance (number of individuals) and richness (number of species) of all birds, invertebrate feeders and omnivores observed in each visit at each sampling point, were respectively the response variables of the 6 models built; sampling point, olive grove and year were included as random factors to account for the sampling design. The fixed component of the model consisted of the interaction between the presence of hedges and the presence of ground cover, and a non-linear temporal effect (including a smoother of month estimated using cubic regression splines; Zuur et al. 2009).

To evaluate the effect of hedges at different spatial scales (i.e. in the non-overlapping areas surrounding each survey point) on the abundance and richness of passerine communities, we used Generalized Additive Mixed Models (GAMM) with a Poisson error distribution and a log link. The response variables were respectively the abundance and richness, of all birds, invertebrate feeders and omnivores; sampling point, olive grove and year were included as random factors. The percentage cover of hedges in four non-overlapping rings that surrounded the sampling points were used as predictor variables, as well as a non-linear effect for month. Pairwise correlations between hedge cover in the non-overlapping rings were in all cases $r<0.65$. Modelling assumptions, including lack of temporal correlation, were checked by visually inspecting residual patterns (Zuur et al 2009). All analyses were run on R 2.14 (R Development Core Team 2013) using the library *mgcv* (Wood, 2011) for building GAMMs.

Table 2.2. Results of GAMM models for the combined effects of hedges and ground cover on passerine communities of olive groves of Southern Spain. Coefficient estimates (± standard errors) are shown. '*' P<0.05; '**' P<0.01; '***' P<0.001; '^{ms}' marginally significant, p<0.06.

	HEDGE	**COVER**	**HEDGE*COVER**
a) Passerine abundance			
All birds	0.77 (±0.21)***	0.54 (±0.29) ^{ms}	-0.45 (±0.33)
Insectivorous birds	0.75 (±0.19)***	0.68 (±0.24)	-0.19 (±0.27)
Omnivorous birds	0.77 (±0.32)*	0.41 (±0.43)	-0.94 (±0.50)^{ms}
a) Passerine species richness			
All birds	0.59 (±0.19)**	0.46 (±0.25)	-0.30 (±0.29)
Insectivorous birds	0.68 (±0.19)***	0.42 (±0.26)^{ms}	-0.02 (±0.26)
Omnivorous birds	0.48 (±0.25)^{ms}	0.26 (±0.30)	-0.58 (±0.36)

RESULTS

Effect of hedges and ground covers on passerine communities

A total of 3040 birds of 35 species were detected in olive groves of Southern Spain over the 4 yr study period. The number of birds detected per visit ranged between 0 and 13 individuals, and the number of species ranged from one to six. The presence of hedges and ground cover had different effects when considering all birds together or when separating them by dietary groups (**Table 2.2, Figure 2.2**). The general trend for all birds was dominated by that of insectivores, which represented nearly 80% of bird species present (27 out of 35; **Appendix 2.1**), and 55% of birds observed (1678 out of 3040 birds). This trend (**Figure 2.2b, 2.2e**) indicates an additive, non-interactive effect of hedges and herbaceous covers on abundance and richness of insectivorous birds.

For all birds, and for the dietary groups separately, hedges had a significant, positive effect on abundance and richness (**Table 2.2**); the effect of cover was non-significant but showed a trend towards positive effects. On average, plots with hedges had twice as many birds as plots without hedges (mean number of birds detected ±SD; with hedges: 2.09±2.25, without hedges: 1.14±1.54), while plots with ground covers had only slightly more birds than plots without ground covers (mean number of birds detected ±SD; with ground covers: 1.92±2.02, without ground covers: 1.75±2.17). Some species only occurred in plots with hedges (**Appendix 2.1**), while there were no species exclusive for plots with ground covers. Only in the case of the abundance of omnivores was there a marginally significant interaction between the presence of hedges and the presence of ground cover, with highest abundances of omnivorous birds in olive groves with hedges but no ground cover (**Figure 2.2c**). Species richness of omnivores was similar across plots implementing different AESs (**Figure 2.2f**).

Temporal patterns

Independently of the effects of hedges and ground cover, higher abundance and species richness were detected in the olive groves during the winter months (October to February; **Figure 2.3**). These temporal trends within years differed markedly for plant-feeders/omnivores and insectivorous birds. Omnivores showed sharp seasonal patterns, reaching their minimum abundance and species richness during the summer months (May to August; **Figure 2.3c,f**). The bulk of wintering birds was thus comprised by plant/feeders omnivores (88.93% of birds counted; **Appendix 2.1**), while most breeding birds were insectivorous (76.70%). In contrast, abundance and species richness of insectivorous birds showed no temporal variation (**Figure 2.3b,e**).

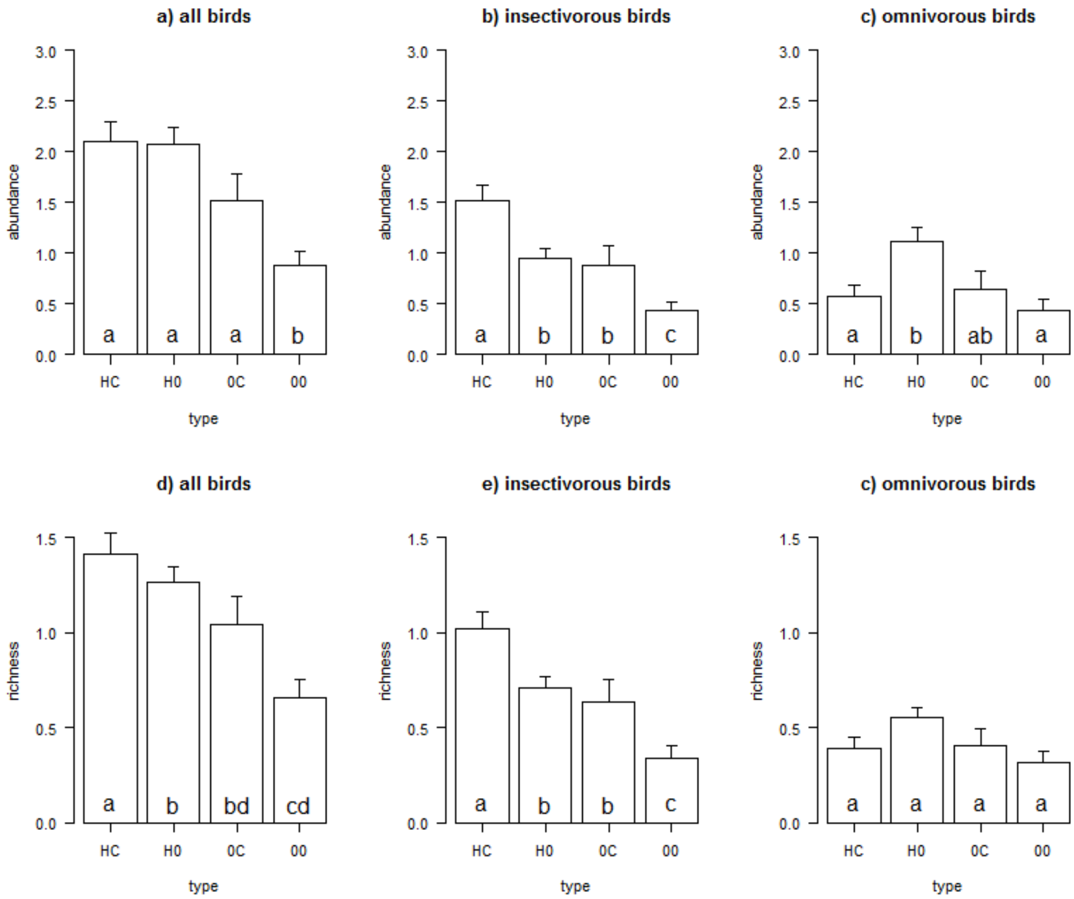

Figure 2.2. Abundance (number of individual birds per count; a-c) and richness (number of bird species per count; d-f) of passerine communities of intensive agricultural landscapes of Southern Spain, for all birds together (a,d), insectivorous birds only (b,e) and omnivorous birds only (c,f), in olive groves implementing different agri-environmental measures: hedges and ground cover (HC), hedges only (H0), ground cover only (0C) or no agri-environmental measures (00). Bars with different small-case letters indicate significant differences (p<0.05) between agri-environmental measurements implemented in olive groves.

Effect of hedges at different spatial scales

The percentage cover of hedges had a significant effect on songbird abundance and richness especially at smaller scales, i.e. <50 m radius surrounding the survey point (**Table 2.1**). Hedge cover 20 m around the survey points ranged between 0 and 40% (mean 7.8%). For the abundance of insectivorous birds no strong effects of hedges were detected at any scale, but for species richness we found a consistent, positive effect of the percentage cover of hedges in a 20-50 m radius in both functional groups of birds.

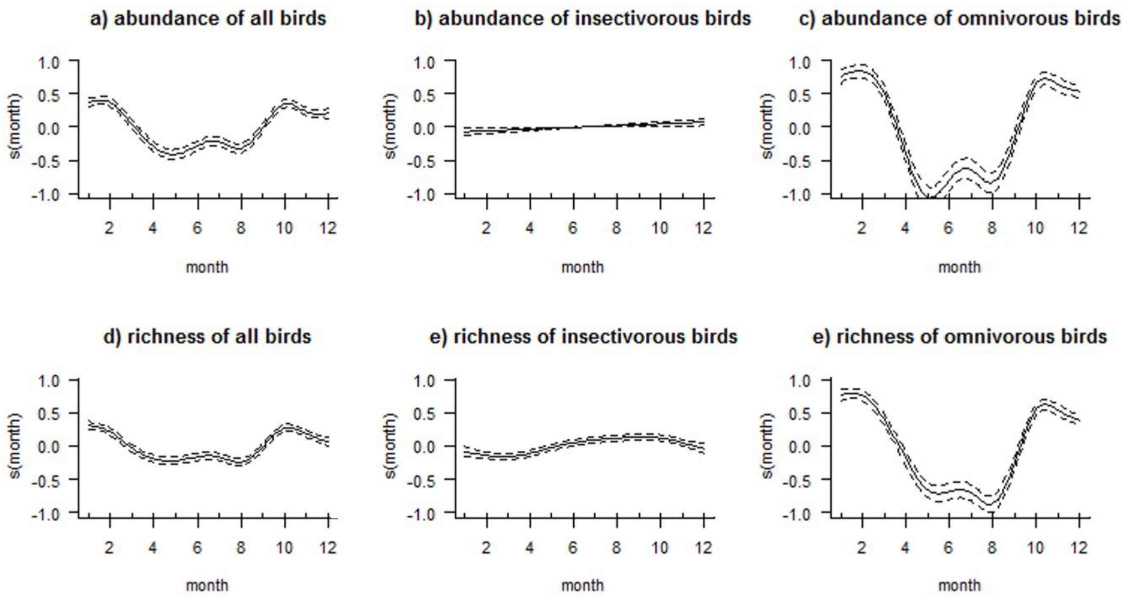

Figure 3. Estimated smoothing curves for the effect of month, independent of presence of hedges and ground cover, on the abundance (a-c) and richness (d-f) of passerines in olive groves of Southern Spain, for all birds together (a,d), insectivorous birds only (b,e) and omnivorous birds only (c,f). The y-axis (s(month)) indicates the contribution of the smoother to the fitted values. The smoothing term was highly significant ($p<0.001$) in all models except for the model of the abundance of insectivorous birds (b). Dashed lines indicate 95% confidence intervals.

DISCUSSION

Bird richness and abundance of birds in olive groves of Southern Spain is enhanced by the presence of hedges and herbaceous ground covers, particularly that of insectivorous birds that use the orchards year round. The presence of hedges had a strong effect, especially at a local scale (<50 m). These AESs have an additive effect and should be used in conjunction to promote farmland biodiversity in Mediterranean farmland.

Semi-natural vegetation remnants in agricultural areas can be a major determinant of bird species richness and abundance (Hinsley and Bellamy 2000, Batáry et al. 2010, Rey 2011, Morelli 2013). The presence of small residual habitats (e.g., hedgerows, rocky outcrops, scattered trees) diversifies the landscape of olive orchards, promoting heterogeneity and structural complexity, and connecting the landscape for nomadic birds. The positive relationship between landscape heterogeneity and bird species richness may be partially related to the process of landscape complementation (Dunning et al. 1992, Fuller et al. 2004, Myczko et al. 2013). For example, a range of farmland birds in Europe use different types of landscape elements for foraging and breeding and availability of these elements is critical for their persistence (Atkinson et al. 2002, Berg 2002, Fuller et al. 2004). Hedges can also provide key resources for birds, such as nesting and sheltering sites and food in agricultural areas (Hinsley and Bellamy 2000). Permanent crop systems provide predictable seasonal feeding resources; in the case of olive orchards, ripe olives represent a key food resource for large populations of wintering frugivorous birds from central and northern Europe (Rey 2011). In turn, hedges can provide complementary food resources all year long, even in summer (e.g. fleshy fruits produced by the false olive *Phillyrea angustifolia*), making olive orchards more similar to natural habitats in fruit diversity and phenology (Rey 2011). Hedges also increase the abundance of arthropods (Thomas and Marshall 1999, Pollard and Holland 2006), and invertebrate-feeding birds particularly benefit from the greater habitat diversity found in extensive farming management (Smith et al. 2010; this study).

The management of herbaceous ground covers in woody crops entails a reduction in the use of herbicides and increases structural complexity (Wilson et al. 1999, Vickery et al. 2009). Herbaceous ground covers, in the absence of hedges, greatly promote abundance and richness of songbird communities in olive groves (Muñoz-Cobo 2009, Castro-Caro et al. 2014a) and in fruit orchards in the Mediterranean (Genghini et al. 2006) and other regions (Chamberlain et al. 1999, Freemark and Kirk 2001). In our study, however, we only found a positive trend for the effect of ground covers, which was largely overridden by the effect of hedges. A stronger effect of hedges can be explained by the greater diversity of resources they provide to birds in agricultural areas, in terms of food and of nesting and sheltering sites (Hinsley and Bellamy 2000). An alternative explanation is that the relationship between species richness and landscape complexity may set thresholds that determine the effectiveness of different agri-environmental measurements and their combinations (Concepción et al. 2008, 2012). It is likely that the saturation threshold given by the hedges in the studied olive orchards is such that the effect of ground covers goes unnoticed.

Our study also analyzed the effects of hedges on passerine communities at different progressive extents. Surprisingly, the hedge effect did not emerge at the spatial scale expected from the large foraging range and wide mobility of plant-feeders/omnivores and was mostly significant at the finest scale (<50 m). The same pattern was found for frugivorous birds (i.e. thrushes) in a forest landscape in northern Spain (Garcia and Chacoff 2007). This pattern may be related to a hierarchy of levels of foraging behavior in these frugivores. Frugivorous songbirds can move easily among fruit-rich patches performing high-height, broad exploratory flights (García and Ortiz-Pulido 2004). For instance, Mediterranean wintering passerines can track fruit abundance at broad landscape scales (Gonzalez-Varo 2010). Once within the feeding patches, however, birds choose in which tree or shrub to feed according to neighborhood fine-scale features, such as the presence of protective canopy and co-fruiting individuals of the same and other species (García et al. 2001, Saracco et al. 2005). As a result, focal spots of natural vegetation remnants that offer fruits and additional resources and protection in nearby areas probably showed enhanced frugivory, independent of their degree of isolation at a larger scale. In the case of the abundance of insectivorous birds, however, we did not find a clear effect of hedges at the smaller scales, despite the fact that these species tend to have smaller home ranges. In turn, we found a consistent effect of the percentage cover of hedges in a 20-50 m radius on bird richness in both diet groups of birds. The reason for this finding may be that hedges are effectively increasing habitat diversity and niche availability for songbird species (Kisel et al. 2011, Morelli 2013).

This study shows an independent, additive effect of hedges and ground cover on songbird communities in olive agro-ecosystems. Although the effect of herbaceous ground covers seems to be overridden by that of hedges, they can still be used as an effective tool for delivering biodiversity in perennial woody systems (see Castro-Caro et al. 2014a and references therein). This would be particularly advisable where hedges have been eliminated over the years and their creation might be hampered by the lack of space between orchards (i.e. in the more intensively managed landscapes). In turn, the creation and restoration of hedges, in combination with the implementation of herbaceous covers, would be the best option in extensive landscapes (Morelli 2013). Hence, different agri-environment measures should be designed for different landscape types (Geiger et al. 2010). In addition, the present study demonstrates the greatest effect of hedges on songbird communities at shorter distances, suggesting that measures should be directed towards the promotion of networks of hedges and natural vegetation remnants embedded in the olive grove matrix (e.g., hedgerows located between properties, as suggested by Rey 2011), rather than concentrating these elements in specific areas. Even small hedges can promote bird abundance; for instance, 2–5 m-wide hedges are sufficient to increase the local abundance of some species (Rey 2011). Also, the restoration of hedgerows used to separate the farmlands seems to be a suitable measures to ensure the presence of many farmland bird species (Morelli 2013). In southern Spain, AEMs have been applied to olive farming in a very feeble way, although the cost-efficiency of these measures in Mediterranean ecosystems has been reported (Sokos et al. 2013). Moreover, olive groves and other woody crops have been excluded from the compliance of conditionality criteria 'greening' in the new revision of the Common Agricultural Policy (CAP) of the European Union. Nevertheless, the creation and management of hedgerows and other field margins might be encouraged by this policy, as part of rural development (Evans and Green 2007), or through non-productive investments which can be used to enable farmers to undertake works not linked to production on their lands, such as planting hedges (Poláková et al. 2011).

In conclusion, our study suggests that hedges, and to a lesser extent ground cover, have additive positive effects on passerine communities in olive groves of southern Spain. The presence of hedges had a positive effect at local scale (<50 m), which suggests the usefulness of maintaining or creating landscape elements, such as hedges and other live fences between properties, for the conservation of the wintering quarters and breeding ranges of numerous European bird species. Landscape planning and conservation of agro-ecosystems demands a common effort of planners, researchers, decision-makers and stakeholders, especially considering that one of the main aims of the new Common Agricultural Policy (CAP) concerns the reduction of negative biodiversity trend, entrusting this task to each European country.

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We thank all the farmers who gave us permission to work in their fields. Special thanks go to C. G. Bueno for useful discussions and statistical advice, and B. MacWhirter for improving the English version. The University of Córdoba funded this project. ICB was supported by a postdoctoral fellowship provided by the Consejería de Educación, Ciencia y Cultura (JCCM, Spain) and the European Social Fund.

SUPPLEMENTARY MATERIALS

Appendix 2.1. List of bird species detected during monthly counts between January 2009 and December 2012 in olive groves of Southern Spain with implementation of different agri-environmental (AESs) practices: maintenance of hedges and ground covers. Phenology of each species in the study area is indicated, if present only during spring (Sp-Br; spring migrants and breeding period of resident species) or as wintering (W) populations. Diet groups, either insectivorous (I) or omnivores (O), are based on the main diet of the species when using the olive groves of Southern Spain (see text for more details).

Species	Phenology	Diet group	Without hedges		With hedges		Total
			Without cover	With cover	Without cover	With cover	
Aegithalos caudatus	Sp-Br	I	3	4	7	4	18
Carduelis cannabina	Sp-Br	O	21	31	31	54	137
Carduelis carduelis	Sp-Br	O	5	3	3	6	17
Carduelis chloris	Sp-Br	O	8	22	30	17	77
Cercotrichas galactotes	Sp-Br	I	0	0	4	12	16
Certhia brachydactyla	Sp-Br	I	8	10	5	16	39
Coccothraustes coccothraustes	W	O	0	0	2	0	2
Cyanopica cyana	Sp-Br	I	8	8	90	36	142
Erithacus rubecula	W	O	6	7	99	25	137
Ficedula hypoleuca	Sp-Br	I	0	0	0	2	2
Fringilla coelebs	Sp-Br	I	4	7	35	24	70
Galerida cristata	Sp-Br	I	2	11	4	3	20
Galerida theklae	Sp-Br	I	0	0	12	6	18
Hippolais polyglotta	Sp-Br	I	0	1	5	88	94
Lanius senator	Sp-Br	I	1	11	14	20	46
Lullula arborea	Sp-Br	I	0	12	14	9	35
Luscinia megarhynchos	Sp-Br	I	0	0	20	7	27
Motacilla alba	W	I	2	3	0	4	9
Muscicapa striata	Sp-Br	I	0	0	0	2	2
Cyanistes caeruleus	Sp-Br	I	1	1	22	20	44
Parus major	Sp-Br	I	67	83	185	160	495
Passer domesticus	Sp-Br	I	4	19	31	9	63
Phoenicurus ochruros	W	I	2	0	1	11	14
Phoenicurus phoenicurus	W	I	0	3	0	0	3
Phylloscopus bonelli	W	I	1	0	5	3	9
Phylloscopus collybita	W	I	9	8	31	33	81
Serinus serinus	Sp-Br	O	72	54	89	41	256
Sturnus unicolor	Sp-Br	I	1	7	3	10	21
Sylvia atricapilla	W	O	3	10	510	69	592
Sylvia cantillans	Sp-Br	I	0	0	12	14	26
Sylvia hortensis	Sp-Br	I	0	0	1	70	71
Sylvia melanocephala	Sp-Br	I	9	15	181	36	241
Troglodytes troglodytes	Sp-Br	I	0	0	1	3	4

Turdus merula	Sp-Br	I	3	7	51	48	109
Turdus philomelos	W	O	12	54	98	37	201
Unidentified birds			14	27	207	116	364
Total nr of species detected			23	24	31	33	

CHAPTER 3

Herbaceous ground covers reduce nest predation in olive groves

CASTRO-CARO, J.C., CARPIO, A.J. & TORTOSA, F.S.

ABSTRACT

We performed nest predation experiments with artificial nests during the breeding season in 2013, in two areas of southern Spain, to asses the effect of different soil management regimes on nest predation rates in olive groves. Each artificial nest (n=300) contained three quail *Coturnix coturnix* eggs, two were unmanipulated and the third one was emptied and injected with plaster. Predators were identified by marks on eggs filled with plaster. Ground nests were significantly more depredated, irrespective of the presence of ground cover; tree nests were less depredated in fields with ground cover. There was a clear difference in nest predators of ground and tree nests. Rodents were the most frequent predators of tree nests. Lower predation rates of tree nests in orchards with ground cover, are probably linked to a change in the foraging behavior of rodents, which in these more complex habitats might be restricted by predation risk. This study underscores the important role of agricultural practices in preserving farmland bird communities, particularly tree-nesting species, suggesting that for this group, implementation of ground cover in olive groves might enhance breeding success by reducing nest predation.

INTRODUCTION

In recent decades, many farmland songbirds have experienced population declines in Europe (Donald et al. 2006). Degradation of habitats, particulary the simplification and homogenization of agricultural landscapes, has been suggested as the main factor affecting the decline of these bird populations (Benton et al. 2003, Tscharntke et al. 2005). The alteration of farmland ecosystems has created an environment in which prey populations might be more sensitive to predation, i.e. habitat change may interact with predation rates (Evans 2004). Nest predation is the primary cause of nest losses for a wide range of bird species, in different habitats and geographic locations (Ricklefs 1969, Martin 1993, Schmidt and Whelan 1999), and it has probably contributed to the decline of passerine populations in landscapes heavily modified by agriculture and other human developments (Robinson et al. 1995, Bayne and Hobson 1997, Donovan *et* al. 1997, Willson et al. 2001). For example, in Spain most farmland birds favour fallow fields for nesting; however, due to the intense use of herbicides fallow fields are nowadays a rare habitat type and the few favorable patches have high nest densities, attracting predators, and thus exposing nests to very high predation rates (Pescador and Peris 2001). A similar situation occurs with Skylarks *Alauda arvensis*, which preferentially nest in set-aside fields, but suffer high nest predation rates owing to high nest densities in this habitat type (Donald 1999). Such decoupling of habitat attractiveness from suitability may lead to the development of an ecological trap (Robertson and Hutto 2006).

In the Mediterranean Basin, olive orchards are one of the primary agro-ecosystems and they are important winter quarters and breeding areas for numerous European bird species (Rey 2011). In Europe, the largest area of olive farming is in Spain, where 2.5 million ha are dedicated to this crop. In recent decades, agricultural intensification and changes in land use have replaced the traditional mosaic structure of olive groves interspersed with other crops, with extensive monocultures, resulting in a more homogeneous landscape (Sokos et al. 2013). Conventional farming, involving the intensive use of agrochemicals, is the traditional and most common production system (85% of the crop area), which has lead to significant negative environmental consequences including water pollution and, especially, soil erosion (Gómez et al. 2009). However, to prevent erosion, many farmers are now maintaining (or implementing) herbaceous ground cover within crops, which likely increases and provides structural complexity and resources for foraging birds (Wilson et al. 1999, Vickery et al. 2009). For instance, Castro-Caro et al. (2014a) have shown that herbaceous ground cover consistently favored the abundance and richness of songbirds in the olive groves of southern Spain. In addition, breeding birds select their territories in olive orchards according to the availability of food resources such as seeds and arthropods (Muñoz Cobo 2009). As a result, birds prefer to settle on fields with herbaceous ground cover, and songbird density in these fields can be at least twice as high compared to bare-ground in conventional olive groves (Muñoz-Cobo 2009, Castro-Caro et al. 2014a).

According to theoretical models (see patch use theory; Stephens and Krebs 1986) the foraging effort of predators may be directed towards patches with the highest cumulative prey availability. In Mediterranean farmland, isolated good-quality olive orchards with ground cover embedded in a bare-ground-dominated olive matrix are expected to attract breeding birds, but also their predators. Empirical data has shown that land use intensification in Mediterranean farmland is associated with an increase in the abundance of generalist predators, such as foxes, feral dogs and cats, which exert a significant predatory pressure on some farmland species, particulary ground-nesting birds (Yanes and Suárez 1996, Pita et al. 2009). Therefore, olive groves with ground covers may act as an ecological trap for birds, because they may not experience an increase in fitness in terms of reproductive success from settling in these preferred habitats (Robertson and Hutto 2006).

On the other hand, there is a debate as to whether nest predation rate is related to spatial structural complexity. Some studies have shown higher nest predation rates in agricultural landscapes compared to those in contiguous forests (Baine and Hobson 1997, Hannon and Cotterill 1998), while others have found a higher risk predation in the more structurally complex habitats (Zuria et al. 2007). However, these studies focused mostly on field-forest areas, and little work has addressed nest predation in non-forested habitats (but see Ludwig et al. 2012). In the present study, we compared nest predation in olive orchards of southern Spain under two different soil management regimes (herbaceous ground cover vs. bare ground) using artificial ground and tree nests. If orchards with herbaceous ground cover are attracting predators, and thus acting as an ecological trap we should predict that 1) predation rates could be higher in olive orchards with ground cover, and 2) ground nests will suffer from higher predation pressure than tree nests, because ground nests are exposed to a greater diversity of predators.

MATERIAL AND METHODS

Study area and study design

The study was conducted in 2013 in three study sites of Southern Spain from mid April to early June, coinciding with the breeding period of most common nesting species birds in the area (Muñoz-Cobo et al. 2001). Two sites were located in Villa del Río (37° 58' N, 4° 17' W), and the other in Montilla (37° 34' N, 4 ° 37' W), Córdoba province. All sites were embedded in an olive-dominated landscape, where agricultural intensification has eliminated most of the natural vegetation (Rey 2011). A more detailed description of the study area is provided by Castro-Caro et al. (2014a). In each study site we selected two independent plots of 4 hectares each, one with ground cover and the other with bare ground. The distance between plots was at least 500 m. The herbaceous ground cover comprised annual species that are adapted to Mediterranean climate and set their seeds before the summer drought. Cover was present throughout the groves except in the area below tree crowns, which was kept plant-free by the application of contact and systemic herbicides. The amount of area covered by ground cover varied among plots (50-75%). Ground cover was not mown during the experiment. All experimental plots were olive orchards that were managed under conventional olive-grove farming practices and were selected at random, although an effort was made to choose olive groves of the same age and tree density. All of the olive orchards had trees >100 years old at a density of ~ 100 trees/ha, and were subjected to the same pruning schemes.

Community of tree-nesters in the studied olive groves is dominated by Cardueline finches, mainly European Serin *Serinus serinus*, European Greenfinch *Carduelis chloris* and Common Linnet *Carduelis cannabina*, while Crested larks *Galerida cristata* and Woodlarks *Lullula arborea* represent ground-nester communities (Muñoz-Cobo 2009, Castro-Caro et al. 2014a, Castro-Caro et al. unpublished data).

The assemblage of potential nest predators includes corvids like Crows *Corvus corax*. The most common mammalian carnivores are Red Fox *Vulpes vulpes*, feral dogs and cats (Duarte and Vargas 2001). Small mammals have been reported to be one of the main predator guilds of nests (e.g., Rats *Rattus sp.* and Garden Dormouse *Eliomys quercinus*; Gil-Delgado et al. 2010).

Nest predation experiment

Artificial nests resembled those of Crested larks *Galerida cristata*, which build ground nests, and of Serins *Serinus serinus*, which build open cup nests on the outer parts of olive tree branches.

Both bird species breed in olive agro-ecosystems in Spain; their breeding season extends from March to early June, and two or three broods per year are common. Clutch size for Crested larks ranges between three and seven, and for Serins between two and five eggs; incubation time is around 13 days for both species (Cramp and Perrins 1994).

We exposed 100 artificial nests in every study site, 50 of them in the plot with ground cover and 50 in the plot with bare ground. In each plot, half of the nests were placed on the ground and the other half were placed on trees, following a 30 X 30 m grid in alternating positions (following Ludwig et al. 2012). Therefore, the distance between two nests of the same type was 60 m. Ground nests were placed on a small hollow dug on the ground at the border of the tree canopies and were oriented north, while tree nests were fixed to branches at a height of about 2 m and oriented randomly (see supplementary material). So, altogether, 300 nests were exposed to predators for a two-week period and were controlled every three or four days. The first period of exposure took place in the study site of Villa del Río from 18th April to 2nd May; the second period was in Montilla from 6th to 20th May, and the third period was in Villa del Río again, from 23rd May to 6th June. A nest was considered as predated, if any of the eggs was damaged or lost. Nest predation rate was estimated as the percentage of nests predated in every plot.

We used artificial nests to overcome the extreme difficulty of finding real nests in the study area (Castro-Caro, unpublished data), thereby obtaining sufficiently large sample sizes to test ecological hypothesis. The use of artificial nests is an indirect method to estimate the impact of predation and has been widely used in bird studies (Zannete 2002, Beja et al. 2013). We used commercially available open-cup nests made of hempen braid 8 cm in diameter and 5 cm deep. Nests were exposed to the weather for at least 14 days before use, to dispel any artificial scent (Zuria et al. 2007). In each nest we placed three quail *Coturnix coturnix* eggs, two were unmanipulated and the third one was emptied and injected with plaster. In this way the three eggs had the same external appearance (Yanes and Suárez 1997), and plaster eggs could be used to identify teeth marks left by the predator (Major et al. 1991, Willson et al. 2001, Carpio et al. 2013). Quail eggs have been useful to estimate spatial variation in nest failure risk for ground-nesting passerines (Cortés-Avizanda et al. 2009, Vögeli et al. 2011). Latex gloves and clean footwear were used during the placing of the nests to prevent scents that might be attractive to predators (Beja et al. 2013). Predators were identified by marks on eggs filled with plaster (Yanes et al. 1997, Duarte and Vargas 2001). In addition, four automatic cameras (Bushnell Trophy Cam) were placed in each plot to identify predators and were moved to another nest if the nest was predated. Automatic camera systems have been used extensively to identify potential predator species (Laurance and Grant 1994). Photographic evidence was used to confirm the identification based on marks on the plaster moulds (Herranz et al. 2002a, 2002b); identification was correct in 100% of cases (see supplementary material).

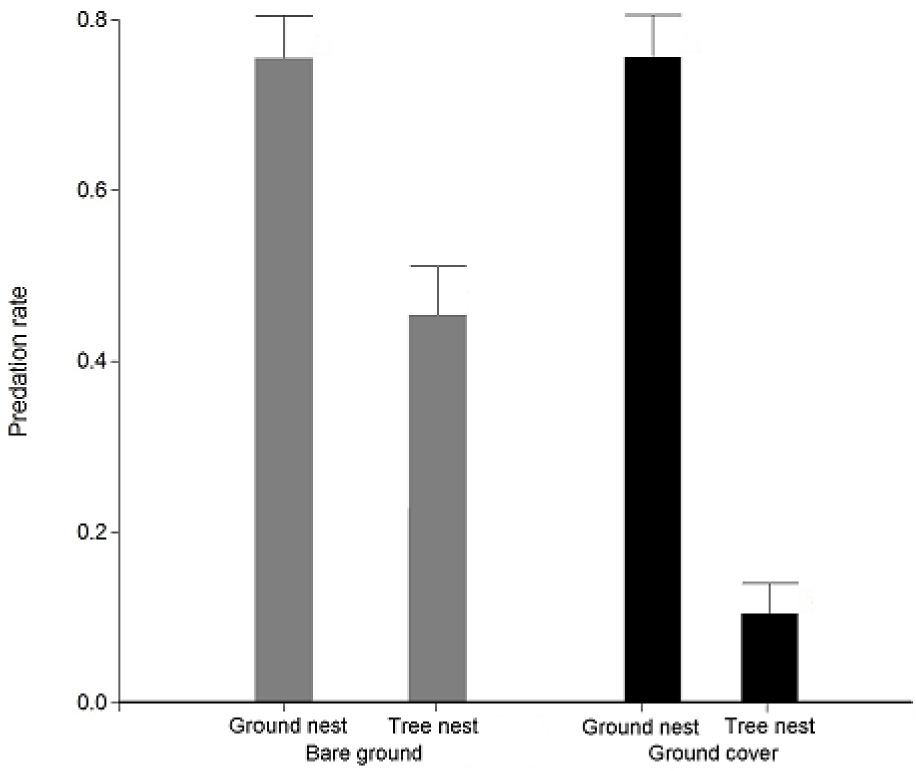

Figure 3.1. Nest predation rate as a function of the interaction between cover type (Ground cover vs. Bare ground) and nest site (Ground vs. Tree) based on the 25 nests in each of the treatments ± SD.

Statistical analysis

Predation level of a plot or nests inside each plot may be influenced by the presence of landscape features that promote landscape heterogeneity, such as hedges, ditches or roads (Chalfoun et al. 2002, Whittingham and Evans 2004, Zuria et al. 2007). To account for these effects we calculated the distance from each nest to the nearest hedge, ditch and road using ArcGIS 9.3.

Chi^2 tests were used to compare nest predation rate between groups of predators depending on the vegetation cover (ground cover vs. bare ground), and on the type of nest (ground vs. tree). To evaluate the relationships between the level of nest predation and several experimental variables we used a generalized linear mixed model, in which 'site' was considered a random variable and 'plot' was nested within 'site' for the random effect. In this model, nest site (categorical as ground vs. tree), vegetation cover (categorical as ground cover vs. bare ground) and the distance to road and the distance to hedge-ditch were included as explanatory variables. The dependent variable used in the model was whether the nest was predated or not. We used a binomial distribution, with a logit-link function.

Akaike's Information Criterion corrected for small sample sizes (AICc) (Burnham and Anderson 2002) was used to perform a backward model selection; the model with the lowest AICc was considered the best one (Zuur et al. 2009). The statistical software INFOSTAT proposed by Balzarini et al. (2001) was used.

RESULTS

A total of 300 nests were exposed during the breeding season, of which 157 nests were predated (52%). In orchards with ground cover, 65 nests were predated (41%) versus 92 nests (59%) in plots with bare ground. Ground nests were significantly more predated, either in bare ground or with ground cover (Mann-Whitney *U* test, *Z*= -0.142, *P* >0.05) whereas tree nests were less predated in ground cover (Mann-Whitney *U* test, *Z*= -4.8, *P* = <0.01; **Figure 3.1**).

Table 3.1: Best model (AICc criteria, following the guidelines of Burnham and Anderson 2002) for nest predation. The reference level for the variable vegetation cover is 'Bare ground' and for the nest site is 'Ground nests'.

Variable	d.f.	Estimate ± SE	*F*	*P*
Intercept		1.53 ± 0.41	70.1	<0.001
Ground cover	1	-0.02 ± 0.38	7.1	<0.01
Nest site	1	-1.31 ± 0.36	72.9	<0.001
Distance to Road	1	-0.02 ± 0.02	0.4	0.48
Distance to Hedge-ditch	1	-0.01 ± 0.01	0.9	0.33
Ground cover x Nest site	1	-1.95 ± 0.58	11.8	<0.01

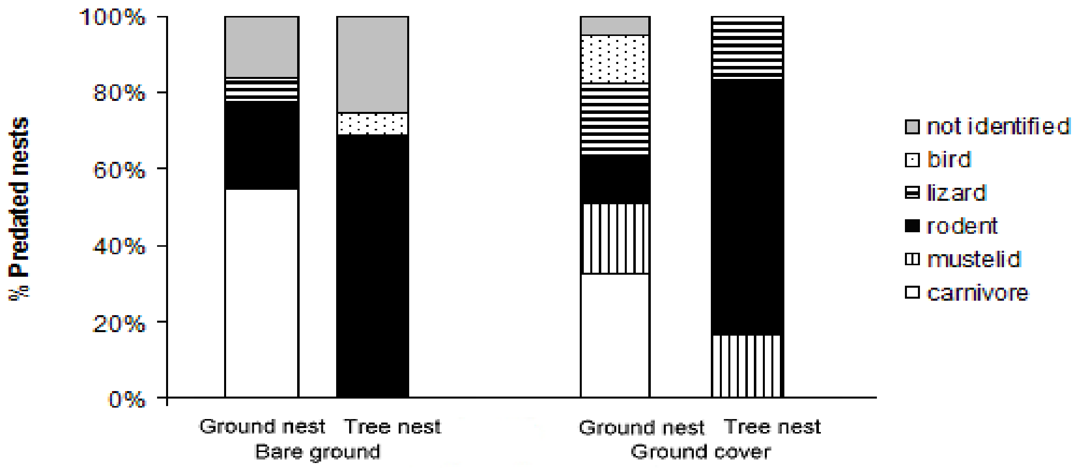

Figure 3.2. Percentage of nests predated for each predator group in each cover type (Ground cover vs. Bare ground), and at each nest site (Ground vs. Tree).

The full model turned out to be the best one, which included nest site, ground cover, distance to road and distance to hedge-ditch and the interaction between 'ground cover x nest site' (**Table 3.1**). Finally, we found that the most frequent predators of tree nests were rodents (65% of nests predated, $Chi^2 = 23.2$, df = 6, $P < 0.001$). However, no one type of predator of ground nests predominated ($Chi^2 = 1.8$, df = 6, $P = 0.11$) – see **Figure 3.2**. When considering all plots (ground cover and bare ground) rodents turned out to be the main predator group ($Chi^2 = 3.8$, df =6, $P < 0.001$ and $Chi^2 = 3.8$, df = 6, $P < 0.001$ respectively; **Figure 3.2**).

DISCUSSION

Our results show that nest predation was lower in plots with ground cover than in those placed in the bare ground plots. However, these results may be attributed to the lower predation rate on tree nests in fields with herbaceous cover, while similar predation rate was found in ground nests when soil management regimes were compared. Rodents were the most frequent predator on tree nests and we found that predation rate on tree nests was remarkably relatively low in orchards with ground cover. It has been shown that ground cover increases the structural complexity in perennial woody systems (Arlettaz et al. 2012, Castro-Caro et al. 2014a), which benefits invertebrates, particularly if the sward is species-rich and structurally complex (Wilson et al. 1999, Vickery et al. 2009). Potentially, such patches constitute a suitable habitat for small farmland mammals such as rodents. For instance, the total autumn small mammal biomass found in a UK farmland was three times higher on 6-m wide field margins than on arable field without such margins (Shore et al. 2005). Rodents select microhabitats where they can optimize their anti-predator and foraging requirements (Mandelik et al. 2003, Macdonald et al. 2007). In southern Spain, Boulay et al. (2009) showed that rodents preferred to forage in covered microhabitats, where they consumed a larger proportion of seeds, probably because they were less visible to potential predators.

Some studies have shown that the observed variations in patterns of nest predation are determined by the distribution, abundance or species composition of nest predators and their specific foraging behaviors in different landscapes and habitats (Martin 1987, Ricklefs 1989, Andrén 1995). For instance, seasonal patterns in habitat use by rodents appeared to be largely a response to seasonal disturbance and the availability of cover in the fields (Todd et al. 2000). In fields with ground cover, rodents could extend their foraging areas beyond the olive trees to the ground which provides food resources and shelter from their predators. Therefore, predation pressure on tree nests is likely to be lower in the more structurally complex olive orchards, whereas this pressure might be higher in bare-ground orchards where the foraging effort of rodents could be more intensive in the olive trees.

An alternative explanation to the lower nest predation rate on tree nests when ground cover occurs is through what is called 'mesopredator release hypothesis' which states that larger predators help limit populations of smaller predators with concomitant decreases in predation pressure on prey (Terborgh et al. 1999, 2001). This hypothesis has been used to explain the decline in nest success of many tropical migrants (Soulé et al. 1988, Ritchie and Johnson 2009). In our study, ground cover is likely to be more suitable habitat for some predators such as mustelids and reptiles which consume mainly rodents (McDonald et al. 2000). In fact, in our study, these predators only predated nests in orchards with ground cover. As a result, higher predation pressure on rodents in ground-cover orchards may decrease their predation rates on nests.

Artificial nests placed on the ground were more predated than those placed on trees regardless of the type of soil management regime. This result agrees with established patterns of nest predation noted in the literature (e.g., Ricklefs 1969, Wilcove 1985, Melampy et al. 1999) which postulates that ground nests have higher rates of predation because of the presumed greater diversity of terrestrial predators. Furthermore, in this study, carnivores were the main predators of ground nests (**Figure 3.2**), particulary red foxes *Vulpes vulpes* and feral dogs. Nevertheless, experimental studies carried out with captive foxes have shown that aural cues (e.g., chicks alarm calls) are particulary important in stimulating and directing search behavior (Österholm 1964).

For instance, captive foxes and trained hunting dogs were unable to find nests without chicks unless in close proximity (<1m) to the nest (Österholm 1964, Storaas et al. 1999). When chicks are present, mammalian predators can detect them from a much greater distance (Storaas et al. 1999), suggesting that in real nests the predation pressure on ground nesters may be even greater since chicks are more susceptible to mammalian predator than their clutches (Storaas et al. 1999). On the other hand, if foxes are relatively inefficient predators of nests when only eggs are present, we suggest that in our experimental study, ground nest losses to foxes are expected to be 'incidental' (*sensu* Vickery et al. 1992). Larks Incidental predation occurs when secondary prey items are encountered and subsequently consumed, not through directed search for such prey, but through their casual encounter by a predator engaged in search for primary prey (Schmitd et al. 2001). In Mediterranean farmland, rabbits are primary prey for most of the carnivores (Delibes-Mateos et al. 2008); however, carnivores may predate on ground nests as a secondary prey when found during their foraging bouts. Incidential predation by rabbit abundance has been used to explain, for example, the declining population of Larks in an Iberian semiarid shrubsteppe (Yanes and Suarez 1996). Interestingly, Carpio et al. (unpublished data) have found high density and abundance of rabbits in the studied olive groves.

The idea that complex habitats have lower predation rates was supported by this study, which may be the result of a greater biodiversity of either, predators or microhabitats. Indeed, the variety of predators may promote intraguild competition and mesopredator release, with larger predators controlling smaller ones, which may be an important factor in structuring predator communities (Ritchie and Jhonson 2009). Herbaceous ground cover may effectively increase microhabitat diversity and niche availability in the olive orchards making them more suitable for foraging and sheltering for both rodents and their potential predators (Kisel et al. 2011). Olive orchards with ground cover are known to be preferred by birds when compared to those having bare ground (Muñoz-Cobo 2009, Castro Caro et al. 2014a), so that the lower nest predation rates of tree nests in groves with ground cover, provides some evidence that, at least for tree-nesting songbirds, these orchards are not acting as ecological traps, which might increase the intrinsic value of this practice in enhancing biodiversity in olive groves, in addition to their agronomic benefits and soil erosion protection. Nevertheless, more research is needed to disentangle the magnitude of predator-prey interactions , which should be taken into account as a tool to promote biodiversity in farmland systems.

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SUPPLEMENTARY MATERIAL

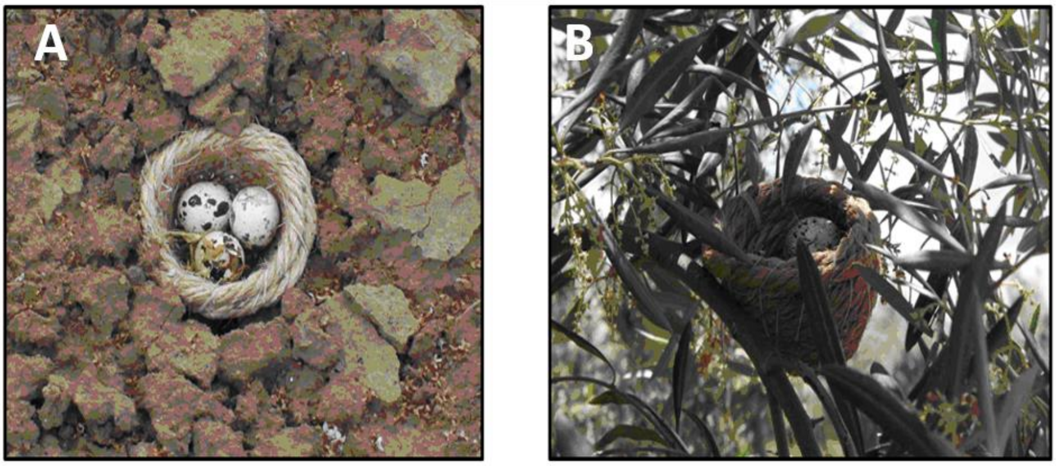

Figure S3.1: Examples of artificial nests used in the nest predation experiment. Artificial nests were commercially available and were made of hempen braid. Three Quail eggs (2 unmanipulated and one filled with plaster) were used in each nest. Nests were placed on the ground (A: Ground nest), resembling those of Crested Larks, or on the external branches of olive trees (B: Tree nest), mimicking those of Serins.

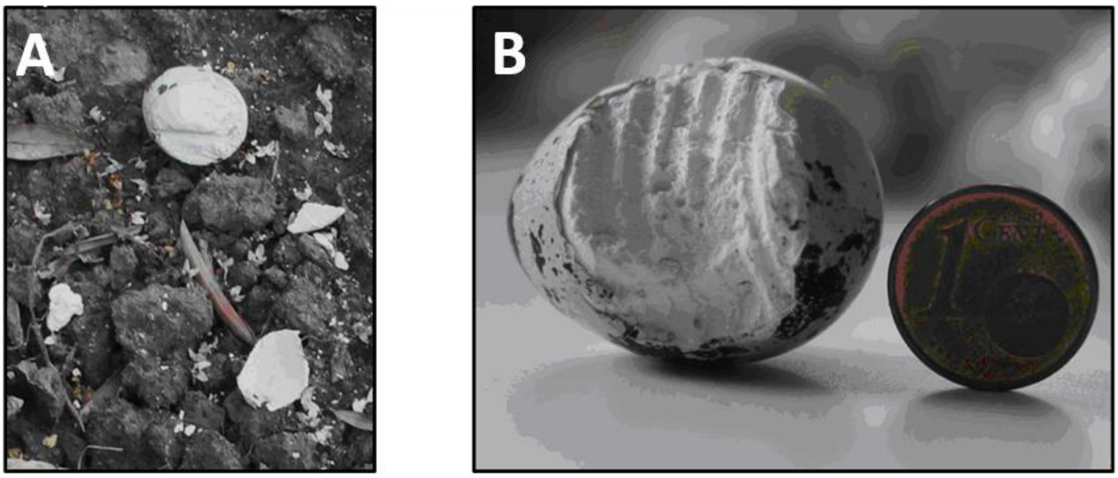

Figure S3.2: A) artificial egg with fang marks. B) Artificial egg with brands incisors after being predated by a carnivore like a fox.

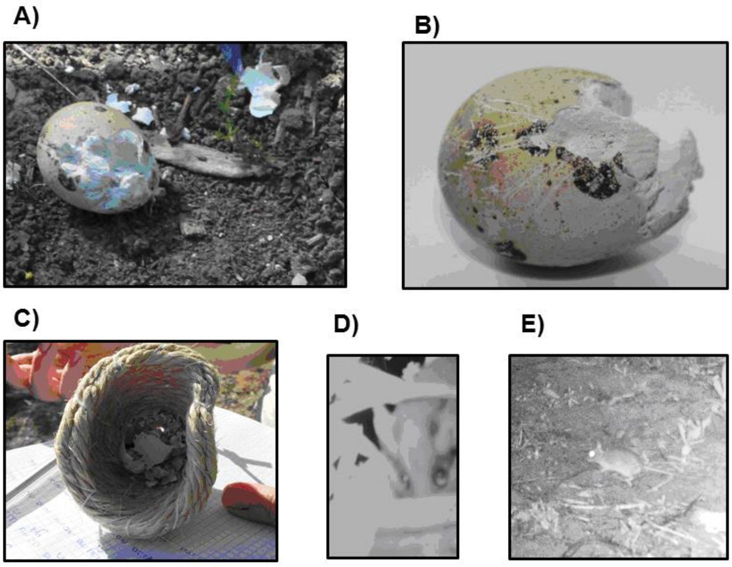

Figure S3.3: A) Artificial egg with marks rodent incisors. B) Artificial egg with scratches and marks left by a rodent's incisors. C) Gnawed remains of egg shells. D) Picture captured by photo-trapping of an artificial nest being preyed upon by a Dormouse *Eliomys quercinus*. E) Capture image taken by photo-trapping of a Field Mouse *Apodemus sylvaticus* very close to a ground nest.

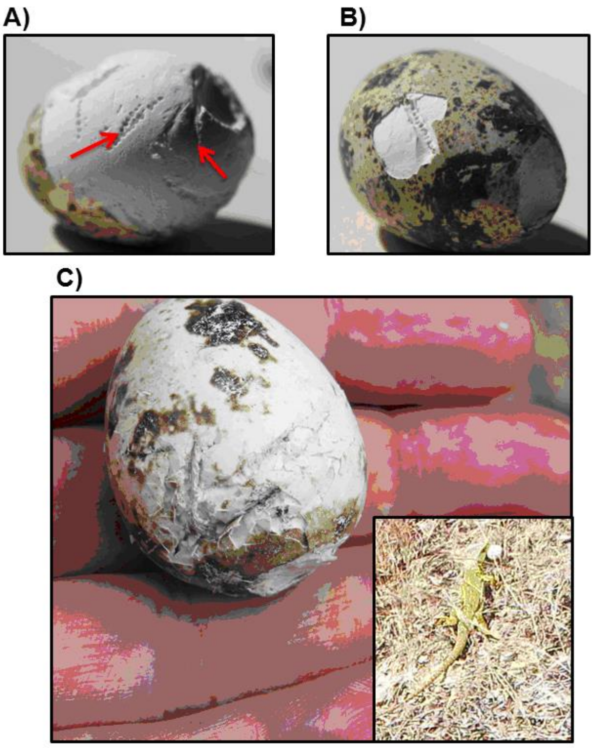

Figure S3.4: A, B) Typical reptile bite marks from a lizard. C) Remains of an artificial egg after being predated by an Ocellated Lizard *Lacerta lepida*; the inset shows an image captured by camera traps at the time of predation.

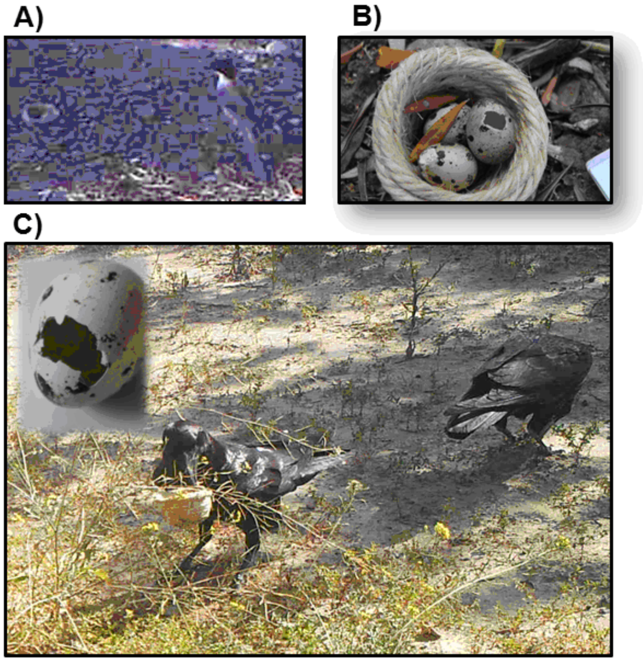

Figure S3.5: A) Image of an Azure-winged Magpie *Cyanopica cyana* approaching a ground nest just before predating the eggs. B) Remains of a ground nest after being predated by a bird. Note the typical marks left by the peck. C) Image captured by photo-trapping at the time of a ground nest predation event by two Crows *Corvus corax*. See the marks on one of the natural eggs after predation.

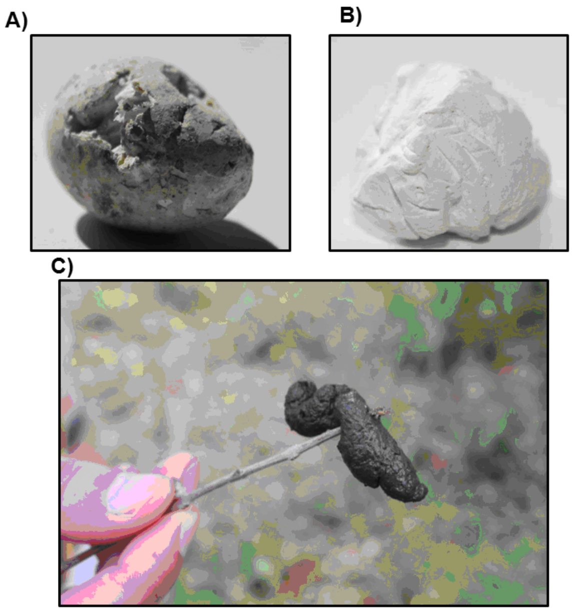

Figure S3.6: A, B) Artificial egg with teeth marks on the plaster after being predated by a mustelid. C) Faeces of Stone Marten *Martes foina*.

Figure S3.7: Ocellated Lizard *Lacerta lepida* caught by photo trapping biting an egg.

Figure S3.8: Red Fox *Vulpes vulpes* caught by photo-trapping.

Table S3.1. Percentage of nest predated in each treatment by each predator group.

	Ground		**Tree**	
Group	Ground cover	Bare Ground	Ground cover	Bare Ground
carnivore	32.5	55	0	0
mustelid	18.75	0	16.75	0
rodent	12.5	22.75	66.5	68.75
lizard	18.75	6.25	16.75	0
bird	12.5	0	0	6.25
Not identified	5	16	0	25

CHAPTER 4

Can agri-environmental measures act as ecological traps? A case study with ground covers, songbirds and olive groves

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ABSTRACT

Agrienvironmental measures are aimed at reversing the negative impacts of modern agriculture on farmland biodiversity. In perennial woody crops in the Mediterranean region, practices like implementation of ground covers can effectively increase the abundance and diversity of songbird communities. However, this benefitial effect might be spurious if these patches do not increase fitness of the individuals settling in them, turning these patches into potential population sinks rather than sources; that is, if agri-environmental measures are acting as ecological traps. We monitored nest success of songbird communities over 3 years in 17 olive groves of southern Spain that had (or not) ground covers to evaluate their potential role as ecological traps. Ground covers were benefitial to the overall breeding success of some common breeding species (e.g. greenfinch *Carduelis chloris*), or affected differently particular steps of the breeding cycle, but their influence seems to be modulated by the degree of landscape intensification. Thus, herbaceous ground covers do not seem to be acting as ecological traps in olive groves and might be recommended as an agri-environmental measure to promote biodiversity in perennial Mediterranean agro-ecosystems.

INTRODUCTION

Increases in food production through agricultural intensification come at the cost of significant negative environmental consequences to farmland biodiversity (Matson et al. 1997). Widespread declines in diversity have been reported for several taxa including mammals (Flowerdew 1997), arthropods and flowering plants (Sotherton and Self 2000), and birds (Donald et al. 2006) in intensified agricultural systems. To halt these negative trends, agri-environmental measures (AEMs) were introduced in the European Common Agriculture Policy (CAP) in the early 1990s (Kleijn et al. 2011). The efficacy of AEMs has been assessed by documenting the presence or absence of target species (Kleijn et al. 2006, Birrer et al. 2007, Davey et al. 2010), or their relative abundance (Ralph et al. 1995). However, crude estimates of density or abundance may provide misleading information about habitat quality or suitability for some species (Van Horne 1983, Vickery et al. 1992, Hughes et al. 1999), raising concerns of the efficacy of AEMs to revert biodiversity declines in farmland. For example, it has been suggested that AEMs implemented in agricultural fields may act as ecological traps for farmland birds (Schlaepfer et al. 2002, Shochat et al. 2005) because they provide a deceivingly suitable habitat during periods of high energetic demand, such as the breeding season. In turn, aggregation of prey species in these areas may also attract higher numbers of nest predators (Donald 1999, Pescador and Peris 2001) that would compromise the benefits of AEMs. Informed management guidelines should thus include other indicators of population fitness, such as reproductive success.

In the Mediterranean Basin, olive orchards are one of the primary agro-ecosystems. Olive orchards are important winter quarters and breeding ranges for numerous European bird species (Rey 2011). In recent decades, agricultural intensification and changes in land use have replaced the traditional mosaic structure of olive groves interspersed with other crops, with extensive monocultures that result in homogeneous landscapes (Sokos et al. 2013). Conventional farming, involving the intensive use of agrochemicals, is the traditional and most common production system (85% of the crop area), which has led to significant negative environmental consequences including water pollution and, especially, soil erosion (Gómez et al. 2009). To prevent erosion and follow CAP recommendations (Beaufoy 2001), many farmers are now maintaining (or implementing) herbaceous ground covers within crops, which likely increases structural complexity and provides resources for foraging birds (Wilson et al. 1999, Vickery et al. 2009). Ground covers can have a positive effect on the abundance and richness of farmland bird communities (Castro-Caro et al. 2014a, Castro-Caro et al. under review) and on the reproductive success of ground-nesting birds (Norment 1993, DeLong et al. 1995). However, coinciding with birds' breeding season in Spring, ground covers are usually mowed to avoid competition for water between olive trees and ground covers. This practice might have significant negative consequences for nesting birds because valuable resources are removed when the birds' energetic requirements are at their maximum (Muñoz-Cobo 2009). In this sense, ground covers may act as an ecological trap for birds (Robertson and Hutto 2006).

Small-bird communities are good indicators of agrosystem degradation because they have a broad spectrum of diets (e.g., insectivorous, granivorous, frugivorous) and reflect the availability of different food items (Gregory et al. 2005). Birds are sensitive to environmental change (Heath and Raymem 2003), and farmland birds are an example of declining organisms in European farmland (Donald et al. 2006, Butler et al. 2007). Degradation of habitats, particulary through the simplification and homogenization of agricultural landscapes, has been proposed as the main factor driving these declines (Donald et al. 2006). Anthropogenic alterations to the farmland ecosystem through habitat simplification can increase the abundance of generalist predators in these systems (Yanes and Suárez 1996, Pita et al. 2009). Nest predation has been identified as one of the major reasons for reproductive failure of birds (Evans 2004) and most studies have shown higher nest predation rates in intensified agricultural landscapes (Baine and Hobson 1997, Hannon and Cotterill 1998, Castro-Caro et al. 2014b; but see Zuria et al. 2007). Yet, these studies have been conducted with artificial nests, partly due to the difficulty in locating nests in the field (Bent 1950, Lane 1968), and there is limited information on the effects of landscape intensification on breeding success of songbirds by searching and monitoring real nests. In turn, nest predation can vary across landscapes and habitats, because of the specific foraging behaviors of predators present in the nest predator community (Andrén 1995), and may constrain nest success at different stages of the breeding cycle depending on the predator community present at each site (Winter 1999, Davis 2003).

The aim of this study is to evaluate if AEMs, in particular ground covers, are acting as an ecological trap for breeding songbirds of olive groves in southern Spain. To demonstrate the presence of an ecological trap, two types of evidence are required (Robertson and Hutto 2006): (1) individuals should exhibit a preference for one habitat over another, and (2) the fitness of the individuals that settle in the preferred habitat must be lower than the fitness attained by the same individuals in adjacent habitats. In other words, individuals do not experience an increase in reproductive success from settling in the preferred habitat (Robertson and Hutto 2006). Therefore, we expect that if ground covers are acting as an ecological trap, 1) nest density in olive groves with ground cover will be higher, and 2) breeding success will be lower in groves with ground cover relative to bare ground groves. In addition, the extent to which ground covers act as an ecological trap will be modulated by the degree of landscape intensification; that is, the negative effects of ground cover should be larger in the most intensified, homogeneous environments because isolated patches of good quality habitat would be more attractive to predators. We assessed the rate of nest success in different stages of the breeding cycle (egg laying, hatching and fledging) because nest predation may constrain specific stages of the breeding cycle. In particular, we expected hatching to be the stage most sensitive to predation because the nest predator community in olive groves (mainly rodents) relies primarily on visual rather than on auditory cues (Castro-Caro et al. 2014b).

METHODS

Study area and sampling design

The study was conducted over 3 years (2010-2012) in two contrasting olive-grove-dominated landscapes within 20 km of Villa del Río, Córdoba province, southern Spain (37^{o} 59' N, 4^{o} 17' W). The Guadalquivir River divides the area from east to west into two distinct landscapes, representative of the endpoints of a historical intensification gradient in olive farming practices (Falcucci et al. 2007): the Guadalquivir Valley (intensively-managed, homogeneous landscape) and the slopes of the Sierra Morena (less intensive, heterogeneous landscape). The valley is flat, underlain by clay soils and has been historically used for intensive agriculture, which has eliminated most of the woodlots, copses, hedgerows, and other live fences between fields (Rey 2011). In contrast, the slopes of Sierra Morena are on siliceous substrates and olive orchards are part of a mosaic landscape, with hedges, dry-stone walls and rocky outcrops with associated native vegetation in the most inaccessible sites. The climate is typically Mediterranean, with warm dry summers and cool humid winters. Mean annual temperatures range between 15 and 18.5°C, and annual precipitation between 460 and 1,020 mm (Aparicio 2008). Climatic conditions varied between study years; average precipitation in 2012 was 317 mm while in 2010 and 2011 precipitation was 961 and 998 mm respectively (unpublished data from San Rafael cooperative).

To determine whether the implementation of ground covers can act as an ecological trap for farmland birds we assessed the reproductive success of passerine birds over three years in seventeen olive groves with and without herbaceous ground cover in landscapes with contasting degrees of agricultural intensification (highly intensified landscapes, i.e. 'homogenous', vs less intensified landscapes, i.e. 'heterogeneous'). Thus, four types of olive groves were consideded:

groves with cover in homogeneous landscape, without cover in homogeneous ladscape, with cover in heterogeneous landscape and without cover in heterogeneous landscape. Herbaceous ground covers comprised annual species that are adapted to Mediterranean climates and set their seeds before the summer drought. Cover was present throughout the groves except immediately below tree crowns, which was kept plant-free by the application of contact and systemic herbicides. In the second half of May, ground covers were mowed and left on site. All of the olive orchards were in flat areas, were managed using convetional techniques, had trees >100 years old at a density of ~ 100 trees/ha, and were subjected to the same pruning schemes. On the slopes of Sierra Morena, to avoid the unduly influence of edge effects, surveyed olive groves were at least 300 m away from large natural vegetation remnants. Due to logistical constraints not all groves were sampled every year, but survey effort (number of olive trees sampled) was homogeneous across years (ANOVA, $F_{2,9}$=1.337, p=0.310) and grove types (with or without cover, in homogeneous or heterogeneous landscape; ANOVA, $F_{3,8}$=0.946, p=0.463**; Table S4.1**).

Study Species

Our study focused on breeding small-bird (passerine) communities of olive groves in Southern Spain (Castro-Caro et al. 2014a, in rev; **Table 4.1**). The most common breeding birds in our study area were three Cardueline finches that usually inhabit agro-ecosystems (Cramp and Perrins 1994): European Serin *Serinus serinus*, European Greenfinch *Carduelis chloris* and Common Linnet *Carduelis cannabina*. In our study area these species breed in olive orchards and place their nests on the outer branches of the olive trees, except the European Greenfich which nests on the inner parts of trees. The breeding season extends from March to late June and two clutches are usually laid. Both, incubation and the nestling period last on average 13 days. Cardueline finches have been described as opportunistic in their choice of foods, being able to feed on a wide variety of seeds, supplemented by insects, vegetable matter, and fruits (Newton 1967, Wiens and Johnston 1977). At the same time, they are considered specialized granivores, in that they are able to raise their nestlings almost exclusively on seeds (Borras et al. 2003, Valera et al. 2005). Analyses were conducted for all nests (including those for which bird species was unknown) and separately for these three species. For other species parallel analyses were not possible because nest density was too low (less than 10 nests per grove type). Only tree-nesting species are considered here; two species of ground-nesting birds (Crested larks *Galerida cristata* and Woodlarks *Lullula arborea*) occur in the studied olive groves at very low densities and were thus not included.

Table 4.1. Number of nests found for different species of songbirds in olive groves of southern Spain and nest densities (nests/ha; mean ± SE; bottom row), in two landscapes with contrasting degrees of agricultural intensification (homogeneous and heterogeneous), with and without herbaceous ground cover. From the total number of nests, those that were successful are indicated in brackets. Asterisks indicate the most abundant species for which separate analyses were conducted.

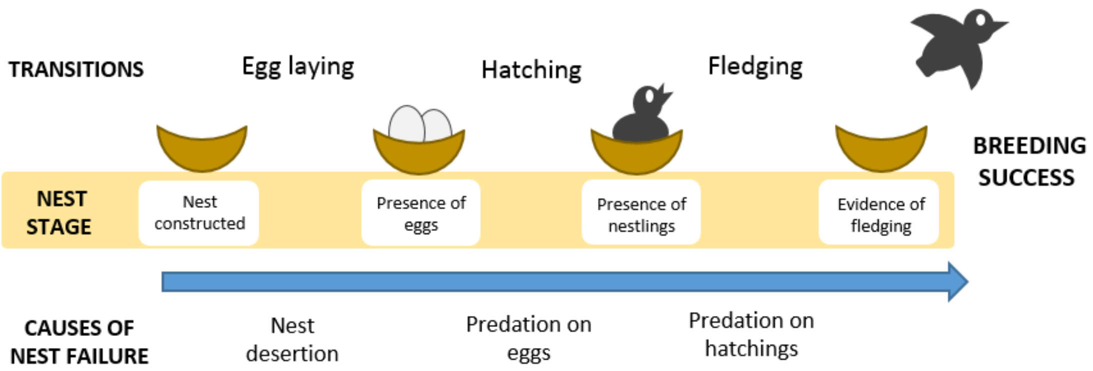
	Homogeneous landscape		**Heterogeneous landscape**		
	without ground cover	**with ground cover**	**without ground cover**	**with ground cover**	**Total**
*Carduelis cannabina**	34(9)	14(2)	26(4)	14(2)	88(17)
Carduelis carduelis	6(4)	1(0)	1(0)	2(1)	10(5)
*Carduelis chloris**	42(8)	65(15)	13(1)	76(8)	196(32)
Cyanopica cyana	0(0)	0(0)	15(2)	3(0)	18(2)
Fringilla coelebs	2(2)	3(1)	0(0)	0(0)	5(3)
Lanius senator	0(0)	15(0)	1(1)	30(12)	46(13)
*Serinus serinus**	66(31)	19(9)	106(31)	43(18)	234(89)
Sylvia melanocephala	4(1)	0(0)	0(0)	0(0)	4(1)
Turdus merula	0(0)	1(0)	0(0)	0(0)	1(0)
unknown	31(1)	28(0)	16(0)	43(2)	118(3)
Total	185(56)	146(27)	178(39)	211(43)	720(165)
Nest density (all species)	17.82±3.88	13.03±4.71	19.79±5.84	22.51±5.29	

Nest searching and monitoring

Nests were located by inspecting olive trees (Ralph et al. 1996) in groves of different types. Intensive nest searching and monitoring was conducted by the same observer (JCCC), between Mar 20 to Jun 25, 2010–2012. Nest densities in the olive groves were calculated as the number of nests per hectare, assuming a tree density of 100 trees per hectare.

Once located, nests were georreferenced using a hand-held GPS (Garmin e-Trex) and active nests were monitored every four days. To minimize disturbance to nests located in the highest part of the branches during monitoring and reduce the time spent on each nest, we used a small mirror attached to a long pole (Ralph et al. 1996). Nest monitoring data included nest stage (nest constructed, presence of eggs, presence of nestlings, and presence or evidence of fledging, i.e. faeces on the edges of the nest; **Figure 4.1**), bird species (if known) and if possible, laying and hatching date (Julian date), and clutch/brood size. When it was not possible to know the date of first egg and hatching of eggs, it was assumed that eggs were laid one every day, incubation lasted 13 days and nestling lasted 13 days on average. In the case of Woddchat Shrike *Lanius senator*, these figures were 14 and 14 days respectively (following Cramp and Perrins 1994). Probabilities of transition between different nest stages were defined as the proportion of nests in a particular stage given the number of nests in the previous stage: the probability of egg laying was defined as that of a (constructed) nest of having eggs, the probability of hatching as that of a nest having eggs of having nestlings, and the probability of fledging as that of nests having nestlings of showing presence of fledging. Overall breeding success was defined as the probability of a (constructed) nest to have one or more young fledged from it. Whenever possible, evidence of nest predation was also recorded (e.g. eggshell remains, nest disturbance) as well as evidence of nest success (e.g. faeces at the border of the nest; see); nest failure to predation cannot always be attributed with certainty, so our measure of predation represents a conservative estimate of nest predation rates at our study site.

	Egg laying	**Hatching**	**Fledging**
All species	47% (344/720)	58% (200/344)	83% (165/200)



Carduelis cannabina	47% (41/88)	54% (22/41)	77% (17/22)
Carduelis chloris	54% (106/196)	43% (46/106)	70% (32/46)
Serinus serinus	57% (133/234)	74% (98/133)	91% (89/98)

Figure 4.1. Nest stages identified in this study and associated transition probabilities for all species, and for the most common breeding songbirds in olive groves of southern Spain: *Carduelis cannabina*, *Carduelis chloris* and *Serinus serinus*.

Statistical analyses

Differences in nest density across the four olive grove types were assessed using Linear Mixed Effects Models (LMM), where nest density in each olive grove was the response variable, and year was included as a random factor. Differences in transition probabilities were modelled using Generalized Linear Mixed Effects Models (GLMM), where transitions (egg lying, hatching, fledging or overall nest success) were included as Bernouilli distributed response variables, and year and olive grove were included as crossed, non-nested random factors. For all models, the fixed effects included the interaction between the degree of landscape intensification (homogeneous vs heterogeneous landscape) and presence of ground cover. When the interaction was not significant, it was dropped from the final model to allow straightforward interpretation of independent term effects (Engqvist 2005). All analyses were conducted in R 3.1.0 (R Development Core Team 2014).

RESULTS

A total of 15,339 olive trees were surveyed over three breeding seasons, covering a total of 153.39 ha; 717 nests were recorded from at least 9 bird species (**Table 4.1**). Nest densities tended to be higher in heterogeneous landscapes (LMM, t=2.03, p=0.053) and did not differ between olive groves with and without herbaceous ground cover (LMM, t=0.16, p=0.876; **Table 4.1**).

Table 4.2. Summary of model results for overall success and each transition probability (egg laying, hatching and fledging) for all nests and for the three main breeding species separately. Only significant variables are shown, with direction of the effect indicated in brackets. $^{m.s.}$ Marginally significant. * Model could not be calculated because all nestlings fledged.

	All nests	*Carduelis cannabina*	*Serinus serinus*	*Carduelis chloris*
Overall success	--	--	Landscape heterogeneity (-)	Landscape heterogeneity (-) Cover (+)
Egg laying	Landscape heterogeneity (-)	Landscape heterogeneity (-)	Landscape heterogeneity (-)	Landscape heterogeneity (-) Cover (+)$^{m.s.}$
Hatching	Cover (-)	--	--	--
Fledging	Landscape*Cover	*	--	--

For those nests for which laying date was available (n=157), average laying dates for each year were 20-Apr-2010, 13-April-2011 and 7-May-2012. Overall nest success for all species was not affected by landscape type or the presence of ground cover (**Table 4.2; Table S4.2**). For *S. serinus* overall nest success was negatively affected by landscape heterogeneity (GLMM, z=-2.218, p=0.030), and for *C. chloris*, it was negatively affected by landscape heterogeneity (GLMM, z=-349.8, p=0.000) and positively affected by the presence of herbaceous cover (GLMM, z=160.5, p=0.000).

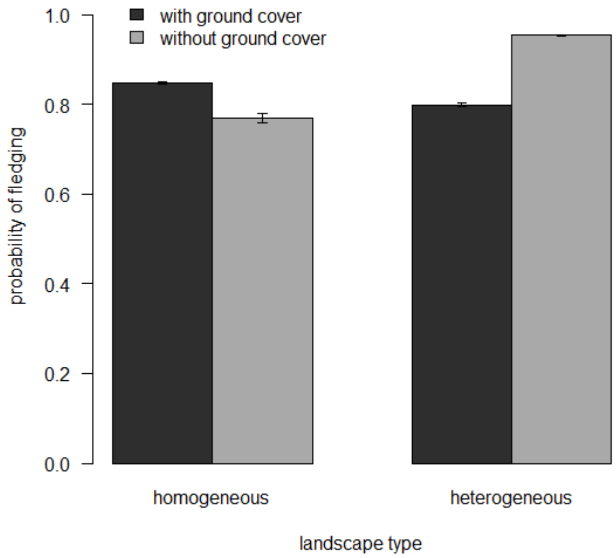


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Figure 4.2. Probability of fledging for all tree-nesting songbird species. Means and standard errors are shown.

The probability of egg laying, once a nest was constructed, was lower in heterogeneous landscapes for all species (GLMM, z=-2.336, p=0.019), and for the three most common breeding species *C. cannabina* (GLMM, z=-2.363, p=0.018), *S. serinus* (GLMM, z=-3.094, p=0.002) and *C. chloris* (GLMM, z=-2.385, p=0.017). In addition, for *C. chloris* there was a trend towards increased probabilities of egg laying in groves with herbaceous cover (GLMM, z=1.909, p=0.056).

The presence of herbaceous covers had a negative effect on the probability of hatching when all species were considered together (GLMM, z=-2.690, p=0.007; **Table 4.2**), but none of the species was affected when considered separately (**Table S4.2**).

Finally, the probability of success of nests containing nestlings was affected by ground covers differently in the two types of landscape (landscape*cover; GLMM, z=-2.088, p=0.037): in homogeneous landscapes the presence of ground covers increased the probability of nestlings to fledge, while in heterogeneous landscapes the probability of fledging was higher in olive groves without ground cover (**Figure 4.2**). In the case of *Carduelis cannabina* the model for the probability of fledging could not be calculated because of insufficient sampling size (22 nests with chicks, out of which 17 showed evidence of fledging). Neither *S. serinus* nor *C. chloris* were affected by landscape type or the presence of ground cover.

DISCUSSION

Our results suggest that the implementation of ground covers in olive groves of Southern Spain is not acting as an ecological trap for songbird communities, when considering all tree-nesting species together. Ground covers might be benefitial to the overall breeding success of some species (e.g., greenfinch *Carduelis chloris*), or differently affect particular steps of the breeding cycle, but their influence seems to be modulated by the degree of landscape intensification. Thus, herbaceous ground covers might be recommended as an AES in these systems.

Ground covers have shown to increase the abundance and diversity of songbird communities in olive groves (Muñoz-Cobo 2009, Castro-Caro et al. 2014a). However, concerns have been raised that these covers may act as ecological traps because they create apparently suitable habitats that are only available for a short period of time (before they are mowed) or that attract predators and consequently reduce prey species performance in these patches. For an AEM to act as an ecological trap two conditions need to be fulfilled: 1) AEM needs to provide a preferred habitat (i.e. increased nest densities should be found), and 2) fitness is decreased when animals utilize this AEM (i.e. breeding success is reduced). In our study none of these conditions was met: nest density was similar in olive groves with and without ground covers and, overall, there was no effect of ground cover on breeding success. Although ground covers promote the abundance and richness of passerine birds (Castro-Caro et al. 2014a), this may only reflect a preference of foraging birds that does not necessarily reflect the preferences for breeding. Other reasons, such as antipredator strategies, might be guiding the location and distribution of nests (Andersson and Wiklund 1978).

Overall breeding success of songbird species in olive groves found in the present study (22.9 % on average) is similar to other studies in agricultural lands. For instance, breeding success of greenfinch ranged between 12% and 24% in fruit orchards (Mroczkiewicz 1974, Kwiatkowska 1989). These low rates of breeding success are generally attributed to predation (Evans 2004, Castro-Caro et al. 2014b). In our study, 56.6% of nest failures (314 out of 555) could be unequivocally attributed to predation. The alteration of farmland ecosystems has created an environment in which prey populations might be more sensitive to predation (Evans 2004). Nest predation is the primary cause of nest losses for a wide range of bird species and it has probably contributed to the decline of passerine populations in landscapes heavily modified by agriculture and other human developments (Ricklefs 1969, Martin 1993, Schmidt and Whelan 1999). Studies have shown that the observed variations in patterns of nest predation throughout the breeding cycle are determined by the distribution, abundance or species composition of nest predators and their specific foraging behaviors in different landscapes and habitats (Martin 1987, Ricklefs 1989, Andrén 1995). For instance, some studies have reported higher survival rate during the incubation period (David 1994, Patterson and Best 1996, David 2003), whereas Winter (1999) found that survival of Dickcissel (*Spiza americana*) nests was lower during the incubation period and found no difference in egg and nestling survival in Henslow's Sparrows (*Ammodramus henslowii*). Survival rate during the breeding cycle likely depends on the composition of the predator community (i.e. predators relying primarily on visual instead of auditory cues) and parental behavior (e.g., increased activity of adults feeding young and nestlings begging for food; Halupka 1998). The lower survival rates during the incubation period in the studied olive groves may be due to the tree nest predator community being mainly comprised of small rodents (*Rattus sp*. and the garden dormouse *Eliomys quercinus*) and snakes (Castro-Caro et al. 2014b), which mainly rely on visual and olfatory cues when hunting.

Although we found that ground covers did not affect nest density or breeding success when considering all bird species together, for one of the most abundant breeding species, the European Greenfinch, ground covers had a positive effect. Cardueline finches have been described as opportunistic in their choice of foods, being able to feed on a wide variety of seeds and supplement their diets with insects, vegetable matter, and fruits (Newton 1967, Wiens and Johnston 1977). Greenfinch nestlings feed on a wide range of food types and show a more generalist diet than other cardueline species (Gil-Delgado et al. 2009). Ground covers can provide a diverse source of food items (Wilson et al. 1999, Vickery et al. 2009) and as a result, breeding success of species able to exploit these resources might be higher. In contrast, others cardueline finches (e.g., European Serin *Serinus serinus*, Citril Finch *Serinus citrinella* and crossbills *Loxia spp*.) can show a high degree of diet specialization during the breeding season (Valera et al. 2005). For example, 70% of the diet of adult Serins comprised seeds of only two species, with a single species (*Diplotaxis* spp.) accounting for more than half of the diet. In this species breeding success may be conditioned by the availability of its main food plant which may not necessarily occur in the ground covers. Ground covers are probably more crucial for ground nesters since they provide food and suitable cover to hide their nests (Norment 1993, DeLong 1995), while for tree nesting species ground covers are only determining the extent to which they provide food.

Although, there is a debate as to whether AES benefit common species primarily or rare and declining species, Castro-Caro et al. (2014a) showed that, in olive orchards in southern Spain, the presence of ground covers had a positive effect on some bird species with unfavourable conservation status in Europe (Birdlife International 2004); in particular, on two species of conservation concern (*Cercotrichas galactotes* and *Lanius senator*; respectively, endangered (EN) and Vulnerable (VU) in Spain (Madroño et al. 2004). Interestingly, in this study 45 out of 46 nests of *Lanius senator* were located in groves with ground cover (**Table 4.1**).

This study also suggests that interannual variation in weather conditions may be a constraint on nesting success. In the Mediterranean region average annual precipitation is 550 mm, which is concentrated mainly between November and April and characterized by an irregular distribution (Aparicio 2008). In 2012, the breeding season started with a severe drought (accumulated rainfall until 30 April was 254 mm, while for the same period in 2010 and 2011, accumulated rainfall was 823 and 805 mm respectively). This could explain the delayed laying date form mid April in previous years to May 7 in 2012. The lack of rainfall at the beginning of the breeding season in 2012, led to a weak development of ground cover and to a decrease in seed and arthropod production. We did not observe higher desertion rates or failure due to starvation probably because birds could feed on remaining seeds. However, reduced arthropod availability may affect feeding choices of opportunistic predators that can switch their diet to include other prey types (Schluter 1981). For instance, the garden dormouse *Eliomys quercinus* is an opportunistic species which mainly feeds on arthropods (Gosálbez 1987), but can also consume birds and small mammals when their main foods are scarce, and there are many reports which indicate that dormice can destroy bird nests (Juškaitis 1995, 2006; Koppmann-Rumpf et al. 2003, Gil-Delgado et al. 2009 Castro-Caro et al. 2014b). Therefore, as the availability of arthropods decreases, predation pressure on nests may increase.

In conclusion, we found no evidence that herbaceous ground covers are acting as an ecological trap for small birds in olive groves with varying degree of intensification. On the contrary, our study showed a positive effect of ground cover on the breeding success of some common breeding species such as the Greenfich. These effects may also extend to other species with broad diet spectrum. Therefore, given that olive groves with ground cover do not act as ecological traps and greatly promote biodiversity for foraging passerine birds, in addition to other associated benefits, e.g. agronomic benefits and soil erosion protection, the implementation of this AEM might be a suitable practice to promote biodiversity in Mediterranean olive groves. Nevertheless, the low breeding success rate found in this study suggests that nest predation is an important causal factor of the declines in farmland biodiversity. Studies on predator communities are needed to document the responses to spatial and temporal heterogeneity in resources (e.g., nests) in landscapes with different degree of intensification and also in years with different rainfall regimes, to help design effective measures to promote biodiversity in Mediterranean farmland systems.

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SUPPLEMENTARY MATERIALS

Table S4.1. Sampling effort across years and olive grove types. Acronyms correspond to different olive groves.

			Nr sampled olive trees		
olive grove	X	Y	2010	2011	2012
Heterogeneous landscape					
With cover					
ERM	388869.4	4212910.2	550	703	529
VIN	388213.8	4213914.8	438	262	392
DEH	386136.7	4209296.2	270	0	354
Without cover					
MOL	388200.6	4213568.1	350	654	458
PED	387113.1	4208521.0	148	553	627
LAG	388466.6	4213061.0	350	0	0
VER	388282.5	4209861.2	338	246	0
NAV	384178.7	4208845.4	105	0	0
Homogeneous landscape					
With cover					
CER	386183.2	4199704.9	477	0	746
EST	385195.0	4203407.4	613	956	0
LEO	381957.7	4200761.0	447	0	0
LEOCV	382275.5	4201354.5	0	544	0
MVIEJA	385344.9	4199058.8	0	0	427
Without cover					
LEOSD	382232.3	4200943.0	0	466	0
AIRSOL	386370.0	4202905.7	686	916	960
ANT	386169.7	4199887.2	605	0	0
PACOSD	389882.6	4207831.2	0	0	169
		Total	5377	5300	4662

Table S4.2. GLMM results for probabilities of overall success and each transition (egg laying, hatching and fledging) for all nests (A) and for the three main breeding species: *Carduelis cannabina* (B), *Serinus serinus* (C) and *Carduelis chloris* (D). In the case of *Carduelis cannabina* the model for the probability of fledging could not be calculated because of insufficient sample size.

	Variable	*Estimate (±SE)*	*z value*	*p-value*
A. All nests				
Overall success	Landscape heterogeneity	*-0.160 (±0.268)*	*-0.596*	*0.551*
	Cover	*-0.314 (±0.269)*	*-1.170*	*0.242*
Egg laying	Landscape heterogeneity	*-0.714 (±0.306)*	*-2.336*	*0.019*
	Cover	*0.194 (±0.305)*	*0.636*	*0.525*
Hatching	Landscape heterogeneity	*0.154 (±0.309)*	*0.496*	*0.620*
	Cover	*-0.803 (±0.298)*	*-2.690*	*0.007*
Fledging	Landscape heterogeneity	*2.045 (±0.900)*	*2.273*	*0.023*
	Cover	0.661 *(±0.671)*	0.985	0.325
	Landscape*Cover	-2.369 *(±1.135)*	-2.088	0.037
B. *Carduelis cannabina*				
Overall success	Landscape heterogeneity	*-0.499 (±0.563)*	*-0.886*	*0.375*
	Cover	*-0.478 (±0.628)*	*-0.762*	*0.446*
Egg laying	Landscape heterogeneity	*-1.115 (±0.472)*	*-2.363*	*0.018*
	Cover	*-0.757 (±0.519)*	*-1.459*	*0.145*
Hatching	Landscape heterogeneity	*-0.377 (±0.695)*	*-0.542*	*0.588*
	Cover	*-0.725 (±0.807)*	*-0.899*	*0.369*
C. *Serinus serinus*				
Overall success	Landscape heterogeneity	*-0.629 (±0.284)*	*-2.218*	*0.027*
	Cover	*0.377 (±0.311)*	*1.214*	*0.225*
Egg laying	Landscape heterogeneity	*-0.917 (±0.296)*	*-3.094*	*0.002*
	Cover	*0.331 (±0.321)*	*1.031*	*0.303*
Hatching	Landscape heterogeneity	*-0.333 (±0.414)*	*-0.804*	*0.421*
	Cover	*-0.011 (±0.448)*	*-0.025*	*0.980*
Fledging	Landscape heterogeneity	*0.776 (±0.750)*	*0.941*	0.301
	Cover	1.036 *(±1.101)*	0.941	0.347
D. *Carduelis chloris*				
Overall success	Landscape heterogeneity	*-1.163 (±0.003)*	*-349.8*	*0.000*
	Cover	*0.533 (±0.003)*	*160.5*	*0.000*
Egg laying	Landscape heterogeneity	*-1.336 (±0.560)*	*-2.385*	*0.017*
	Cover	*1.068 (±0.559)*	*1.909*	*0.056*
Hatching	Landscape heterogeneity	*-0.175 (±0.473)*	*-0.370*	*0.712*
	Cover	*-0.127 (±0.513)*	*-0.248*	*0.804*
Fledging	Landscape heterogeneity	*-1.357 (±0.962)*	*-1.410*	*0.158*
	Cover	0.182 *(±1.046)*	0.174	0.862

GENERAL DISCUSSION

AEMs in conventional olive groves: a new approach to assess their effectiveness

Olive farming is one of the predominant land-uses in the Mediterranean basin where 5 million ha are dedicated to this crop, with significant social, environmental and economic implications.

Over the last few decades agricultural intensification has led to a homogenization and simplification of farmland landscapes across Europe. This trend has been even stronger in the Mediterranean region where policies adopted at a national level aimed at the expansion of monocultures (De Graaff et al. 2010). The past olive oil subsidy regime, with payments based on amounts of oil produced, encouraged intensification and has led to adverse environmental effects (e.g. soil erosion, loss of biodiversity and water pollution). To halt this trend, in the 2003 reform of the Common Agricultual Policy (CAP), the subsidy system was decoupled from current production in an attempt to integrate production with environmental aspects. However, agro-environmental measures (AEM) of the CAP have been applied to olive farming in a very feeble way. Although all EU Member States have been obliged to implement agri-environment programmes since 1992, very few schemes have been targeted at olive farming, and these have failed to address the scale and range of environmental issues affecting the sector. The main emphasis has been on promoting organic production, an option taken up by a significant number of producers (~5%) due to the attractive subsidy, but which does not deal directly with issues such as soil erosion, habitat conservation or water use (Beaufoy 2001). Nevertheless, to prevent erosion and partly to fulfil the cross-compliance from 2003-CAP reform, many farmers started to implement herbaceous ground cover within crops and maintain small residual habitats like hedgerows. Both of these actions are, so far, the only AEM now in practice in conventional olive groves. As a result, there is a patchy configuration of the landscape with scattered ground-covered olive orchards and some hedgerows embedded in a bare-ground olive grove matrix. Ground covers and hedges are known to deliver benefits in terms of biodiversity in agro-ecosystems because they increase structural complexity of the habitats and provide resources for foraging birds (Wilson et al. 1999, Vickery et al. 2009). However, isolated patches of good quality habitat may attract birds as well as their predators, turning these orchards into a sink rather a source (Robertson and Hutto 2006).

This thesis has analysed the effectiveness of AEM in woody crops of the Mediterranean area. Previous studies have been conducted in temperate areas of Europe, and their management implications might not be transferrable to Mediterranean perennial crops. Using songbird communities as an indicator, I have analysed for the first time the effect of different AEM when applied in combination to perennial woody crops. The effectiveness of such measures was assessed using several criteria. In addition to traditional approaches comparing diversity indices of foraging birds (i.e. species richness and abundance) in areas with and without AEMs, I also took into account their breeding success to evaluate the potential role of AEM in agricultural fields as ecological traps.

My results show that ground covers and hedges consistently promote songbird diversity in Mediterranean olive groves. This is in accordance with the established patterns in other regions and crops (ground covers in vineyard Arlettaz et al. 2012, coffee Philpott et al. 2008, oil palm Jambari et al. 2012; and hedges in temperate areas of Europe Batary et al. 2010). In particular, hedges have been reported as important components of agricultural landscapes throughout the world because they increase the heterogeneity and resources within agricultural systems (Hinsley and Bellamy 2000, Manning et al. 2006). When applied in combination, hedges and ground covers show an independent, additive effect on the diversity of songbird communities. However, hedges seem to have a stronger effect in promoting bird diversity in olive agro-ecosystems. The positive relationship between landscape heterogeneity and bird species richness may be partially related to the process of landscape complementation (Dunning et al. 1992, Fuller et al. 2004, Myczko et al. 2013). For example, a range of farmland birds in Europe use different types of landscape elements for foraging and breeding and availability of these elements is critical for their persistence (Atkinson et al. 2002, Berg 2002, Fuller et al. 2004). Hedges can also provide key resources for birds, such as nesting and sheltering sites and food in agricultural areas (Hinsley and Bellamy 2000). Permanent crop systems provide predictable seasonal feeding resources; in the case of olive orchards, ripe olives represent a key food resource for large populations of wintering frugivorous birds from central and northern Europe (Rey 2011). In turn, hedges can provide complementary food resources all year long, even in summer (e.g. fleshy fruits produced by the false olive *Phillyrea angustifolia*), making olive orchards more similar to natural habitats in fruit diversity and phenology (Rey 2011). Hedges also increase the abundance of arthropods (Thomas and Marshall 1999, Pollard and Holland 2006), and invertebrate-feeding birds particularly benefit from the greater habitat diversity found in extensive farming management (Smith et al. 2010; this study).

On the other hand, unlike annual crops in temperate areas of Europe, this thesis suggests that in Mediterranean perennial farming systems the effect of ground covers on songbird abundance and richness is independent of the landscape context. That is, the effect of ground cover on songbird communities was equal in both landscape contexts. The interaction between AEMs and the sourronding landscape is still poorly understood. There is still a lack of knowledge about the thresholds along the landscape complexity gradient that determine this interaction, which is expected to differ among taxa, depending on their perception of landscape complexity and their dispersal ability (Concepción et al. 2008). For example, studies carried out in temperate areas of Europe considered 0-20 % cover of semi-natural habitat for simple landscapes and >20% cover for complex landscapes (Andrén 1994, Tscharntke et al. 2002); but how these thresholds apply to Mediterranean woody systems remains to be tested. Moreover, landscape structure does not always seem to influence the effectiveness of conservation initiatives on farmland (Brittain et al 2010). For instance, a recent meta-analysis by Batáry et al. 2010 shows that the moderating effects of landscape structure on conservation benefits differ between grasslands and arable lands and between functional groups. For species with reduced dispersal ability small-scale landscape heterogeneity might be more relevant, whereas in the case of highly mobile organisms like birds these thresholds might be found at larger scales, as they have the ability to locate and exploit places of high food provision, independently of landscape heterogeneity (Robinson and Sutherland 1999, Gonzalez-Varo 2010). An alternative explanation to this lack of interaction is the level of disturbance between farming systems (e.g. annual vs. perennial systems; Batáry at al. 2010). Perennial systems, as they do not need to be re-planted every year, provide more predictable resources. For example, in olive orchards ripe olives represent a key food resource for large populations of wintering frugivorous birds from central and northern Europe (Rey 2011). Perennial crops may foster more stable plant and animal communities (Foster et al. 2002) which prevents the establishment of plant and animal species from the surrounding landscape-wide species pool.

We found no evidence that olive groves with ground cover are acting as ecological traps, since songbirds did not preferentially breed in olive groves with ground cover. Also, for those birds breeding in areas with ground covers there was no hindrance in breeding success, so these patches of good quality habitat are not acting as a sink. Therefore, given that olive groves with ground cover do not act as ecological traps and greatly promote biodiversity for foraging passerine birds, in addition to other associated benefits, e.g. agronomic benefits and soil erosion protection, the implementation of this AEM might be a suitable practice to promote biodiversity in Mediterranean olive groves. Nevertheless, the overall low breeding success found in these agro-ecosystems, either with artificial or real nests, suggests that nest predation is an important causal factor of the declines in farmland biodiversity. Nest predation has been reported to be the primary cause of nest losses for a wide range of bird species and it has probably contributed to the decline of passerine populations in landscapes heavily modified by agriculture and other human developments (Ricklefs 1969, Martin 1993, Schmidt and Whelan 1999). Studies on predator communities are needed to document the responses to spatial and temporal heterogeneity in resources (e.g. nests) in landscapes with different degree of intensification to help design effective measures to promote biodiversity in Mediterranean farmland systems.

Future directions: Designing AEMs for olive groves

This thesis demonstrates that effective solutions to promote biodiversity in conventional olive groves are available and sometimes already in place. In most cases, relatively small changes in farming practices may be sufficient, such as the maintenance of hedges and ground covers on the soil. Both of these practices have been suggested to be the most cost-efficient measures in Mediterranean agro-ecosystems (Sokos et al. 2013). In the more intensive olive farming landscapes where hedges have been eliminated over the years and their creation might be hampered by the lack of space between orchards, ground covers could be used as an effective tool for delivering biodiversity. In turn, the creation and maintenace of hedges, in combination with the implementation of ground covers, would be the best option in extensive landscapes (Morelli 2013). Hence, different agri-environment schemes should be designed for different landscape types (Geiger et al. 2010). In addition, the present study demonstrates the greatest effect of hedges on songbird communities at shorter distances (<50 m), suggesting that measures should be directed towards the promotion of networks of hedges and natural vegetation remnants embedded in the olive grove matrix (e.g. hedgerows located between properties, as suggested by Rey 2011). A suitable network of hedges allows passerine birds to thrive in Mediterranean agricultural landscapes. Length (>0.5 km), width (2-5 m) and continuous native shrubs are some key elements of hedgerows where the conservation of small farmland birds is the aim (Rey 2011).

Furthermore, ground cover has been reported to be the most efficient tool to prevent soil erosion, which is the main environmental problem in the Mediterranean basin (Gómez et al. 2009). Besides their environmental benefits, ground covers can provide agronomic benefits by increasing soil fertility and water content, and activating soil microbial processes (Moreno et al. 2009). For instance, some studies suggest that with appropriate management ground covers may increase yield even in rainfed olive orchards due to the higher water availability in the soil compared to bare ground (Hernández et al. 2005). Although all these benefits have been well documented, most EU Member States have made very little effort in applying CAP environmental measures to olive farming, despite their considerable potential for reducing the environmental impacts and enhancing the conservation benefits of this land use (Beaufoy 2001).

Research in other regions has shown that these measures can integrate agricultural production with environmental protection (Sokos et al. 2013). However, the knowledge for biodiversity management in Mediterranean agroecosystems still has serious gaps. For instance, there is little information about species composition and the minimum area covered by ground covers to yield optimal biodiversity benefits with minimal agronomic costs. In our study ground cover comprises spontaneous herbaceous vegetation. Ground covers could also be sown (i.e. cover crops), generally using a single species or a mixture of a reduced number of species (2 species in most cases). Both types of covers are effective tool to control soil erosion (Gómez et al. 2009) but their consequences on the woody crop may differ. When sown, farmers usually implement monospecific ground covers comprising plants with shorter cycles that wither in early spring, in order to avoid competition for water between the sown ground cover and the crop without needing to mow. Spontaneous ground cover, that comprises a higher number of herbaceous species, may provide a wide variety of seeds in the bird breeding season. As demonstrated in this study, this will be especially benefitial for passerine birds with more generalist diets like the Greenfich (*Carduelis chloris*). For other carduleline finches with a highly specialized diet, like the European Serin (*Serinus serinus*), this type of ground covers may not provide its main food source and be less relevant for its breeding success.

Ground covers might also provide other agronomic services, such as pest control. The implementation of ground covers can promote certain plant species that favor the occurrence of natural enemies of pests (Paredes et al. 2013). For instance, in citrus orchards in Spain the effect of *Festuca arundinacea* ground cover on pest control of the red spider mite (*Tetranychus urticae*) was stronger, relative to multitaxa (naturally grown) spontaneous ground cover (Sá Argolo 2012). In apple orchards, Mathews et al. (2004) found that compost cover promoted the abundance and richness of ground-foraging generalist predators, but the predator effect on the target pest was lower compared to bare-ground cover because of a higher availability of alternative prey in the compost treatment. Similarly, ground covers may help reduce vertebrate damage to woody crops. For example, the implementation of cover crops in vineyards of Southern Spain, proved efficient to reduce rabbit damages, because rabbits would feed on the ground covers rather than on the vineyards (Barrio et al. 2012).

The efforts of modern society to preserve biodiversity in Mediterranean agroecosystems can be achieved in the frame of multifunctional agriculture. Research programmes should be implemented to improve our knowledge of the role of different agricultural practices in maintaining functional biodiversity as well as landscape properties in olive orchards. A detailed knowledge is needed of habitat structure, the occurrence of natural elements in the landscape, the connectivity of these elements, their function and their relationship to biodiversity. Future studies should involve experimental trials combining different ground cover settings that integrate environmental with agronomic aspects.

CONCLUSIONS AND RECOMMENDATIONS

1. Implementation of ground covers and maintenance and creation of hedgerows, two agri-environmental measures commonly implemented in olive groves, effectively promote bird diversity in conventional olive groves of Southern Spain.

2. Hedgerows efficiently increase the abundance and richness of passerine communities of olive groves, particularly that of insectivorous birds that use the orchards year round.

3. The effect of hedges on songbird communities was greater overshort distances (<50 m), suggesting that measures should be directed towards local efforts, including the promotion of networks of hedges and natural vegetation remnants embedded in the olive grove matrix.

4. In the absence of hedgerows, herbaceous ground covers consistently favour the abundance and richness of songbirds in olive groves.

5. When applied in combination hedges and to a lesser extent ground covers have positive additive effects on passerine communities in olive groves.

6. The landscape-dependent hypothesis might not apply to perennial agro-ecosystems such as olive groves in southern Spain; that is, the effectiveness of agri-environmental measures is independent of the complexity of the surrounding landscape.

7. In the olive groves in southern Spain, the presence of ground cover had a positive effect on rare birdspecies, such as the Rufous-talied scrub robin(*Cercotrichas galactotes*)and the Woodchat shrike(*Lanius senator*).

8. Nest predation was the major driver of nest losses both in artificial and real nests.

9. Nest predation rate was lower in olive groves with ground covers, where the structural complexity was higher.

10. Artificial nests placed on the ground were predated more frequently than those placed on trees regardless of the degree of habitat structural complexity (olive groves with ground cover vs bare ground).

11. Variations in patterns of nest predation in olive groves are determined by the distribution, abundance or species composition of nest predators and their specific foraging behaviors in different landscapes and habitats

12. There were no differences between olive groves with and without ground covers in terms of preference for breeding or nest success, suggesting that groves with ground covers are not acting as ecological trap.

13. Ground covers might be benefitial to the overall breeding success of some species, in particular for those with broad diet spectrum.

14. The implementation of herbaceous ground cover and the creation and maintenance of hedges can be recommended as a suitable practice to promote biodiversity in Mediterranean olive groves.

15. The creation and restoration of networks of hedges and natural vegetation remnants embedded in the olive grove matrix (e.g., hedgerows located between properties), in combination with the implementation of ground covers, would be the best option in extensive landscapes.

16. Ground covers can be used as an effective tool for delivering biodiversity in the more intensive landscapes, where hedges have been eliminated over the years and their creation is hampered by the lack of space between orchards.

CONCLUSIONES Y RECOMENDACIONES

1. El uso de cubiertas vegetales y, el mantenimiento y creación de setos, dos medidas agroambientales comúnmente usadas, promueven de forma efectiva la biodiversidad de aves en el olivar convencional del sur de España.

2. Los setos incrementaron notablemente la abundancia y riqueza de especies de las comunidades de paseriformes en el olivar, en concreto de las comunidades de insectívoros a lo largo del año.

3. El efecto de los setos sobre las comunidades de paseriformes fue mayor a cortas distancias (<50m), lo que sugiere que futuras directrices deberían orientarse hacia esfuerzos locales, incluyendo el fomento de una red de setos y restos de vegetación natural dentro de una matriz de olivar.

4. En ausencia de setos, las cubiertas vegetales consistentemente potenciaron la abundancia y riqueza de aves paseriformes en el olivar.

5. Cuando se aplican en combinación, setos y en menor medida las cubiertas vegetales tienen efectos aditivos positives en las comunidades de aves paseriformes en el olivar.

6. La hipótesis de de la “dependencia del paisaje” podría no ser aplicable a cultivos leñosos, como es el caso del olivar. Es decir, la eficacia de las medias agroambientales es independiente de la complejidad del paisaje.

7. En los Olivares del sur de España, la presencia de cubierta vegetal tuvo un efecto positivo sobre las especies poco comunes, como es el caso del Alzacola rojizo (*Cercotrichas galactotes*) y del Alcaudón común (*Lanius senator*).

8. La depredación de nidos fue la principal causa de la pérdida de nidos, ya sea nidos artificiales o reales.

9. La tasa de depredación de nidos fue más baja donde la complejidad estructural fue más alta, es decir, en los olivares con cubierta vegetal.

10. Los nidos artificiales de ubicados en suelo presentaron tasas de depredación más altas que los ubicados en árbol con independencia del grado de complejidad estructural del hábitat.

11. Las variaciones en los patrones de depredación de nidos están determinados por la composición de las especies de depredadoras de nidos y sus comportamientos específicos de forrajeo en diferentes paisajes y hábitats.

12. No hubo diferencias de preferencia a la hora de anidar ni en éxito reproductor entre olivares con o sin cubierta, lo cual sugiere que los olivares con cubierta no están actuando como trampas ecológicas.

13. Las cubiertas vegetales podrían ser beneficiosas para el éxito reproductor de algunas especies, sobre todo para aquellas con espectros de alimentación amplios.

14. La implementación de cubiertas vegetales y, la creación y mantenimiento de setos, puede ser recomendado como una práctica adecuada para favorecer la biodiversidad en los olivares.

15. La creación y restauración de una red de setos y restos de vegetación natural dentro de la matriz de olivar (setos en los linderos de las fincas), junto a la implementación de cubiertas vegetales, sería la mejor opción en paisajes más extensivos.

16. Las cubiertas vegetales pueden ser usadas como una efectiva herramienta para potenciar la biodiversidad en los paisajes más intensivos, donde los setos has sido eliminados a lo largo de los años y su creación se imposibilita por la falta de espacio entre las lindes de las fincas.

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