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Birds as suppliers of pest control in cider apple orchards: Avian biodiversity drivers and insectivory effect

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ABSTRACT

Making farming compatible with biodiversity conservation requires identifying the biodiversity drivers that operate in agricultural landscapes, while also addressing the role of biodiversity in ecosystem services. Such integrative information is, however, rare for specific biodiversity groups and services. Here, we focus on insectivorous birds in cider apple orchards in northern Spain, ascertaining the relationships between landscape- and orchard-scale features and bird biodiversity. We conducted field observations and experiments to estimate the potential of birds for controlling arthropod abundance and pest outbreaks in apple trees. Twenty-nine tree-dwelling, insectivorous bird species were observed during one year, inside and around cider apple orchards, with six abundant species representing a predictable core across sites and seasons. Bird abundance and richness increased with the availability of semi-natural woody habitats (hedgerows, remnant trees, and forest patches) both in the immediate neighborhood of the orchard and in the landscape within a 1-km radius of the orchard. Orchards with higher cover of apple tree canopy also harbored a greater abundance and richness of birds. Apple tree branches that were cage-excluded from birds and manually infested with aphids suffered increased shoot damage and aphid outbreak, compared to those that were aphid-infested but open to birds. Bird exclusion led to increased abundances of pest insects other than aphids, and also of other arthropods considered as natural enemies or mutualists of pests. Arthropod abundance was lower in those orchards showing higher abundances of insectivorous birds during spring and summer. Multi-scaled farming management, involving both within-field practices and regional land use schemes, should be considered in order to promote win–win scenarios in cider apple orchards, whereby species-rich assemblages of insectivorous birds provide effective pest control service.

1. Introduction

Agriculture intensification is jeopardizing biodiversity worldwide, due to the loss and the alteration of natural habitats (Tscharntke et al., 2005; Newbold et al., 2015). There is, nevertheless, a consensus on the potential compatibility between food security and biodiversity conservation (Fischer et al., 2006; Tscharntke et al., 2012a). In this sense, recent research suggests that some farming schemes can retain habitat conditions that promote biodiversity while still being productive (e.g. Clough et al., 2011; Cunningham et al., 2013). Moreover, local biodiversity may render benefits to crop yield through the provision of ecosystem services like pollination, nutrient cycling or pest control (e.g. Moonen and Barberi, 2008; Power, 2010). Thus, integrative research on how farming constricts or fosters biodiversity, and on the relationship between biodiversity and ecosystem services, would seem essential for achieving conservation-agriculture win–win solutions (Tscharntke et al., 2012a; Gonthier et al., 2014).

Birds represent a biodiversity group suitable for addressing the farming-conservation dilemma (e.g. Philpott et al., 2008; Rey, 2011). Birds worldwide are facing the effects of agricultural intensification (Donald et al., 2001; Bregman et al., 2014), suffering population declines and extinctions that affect both rare and common species (e.g. Phalan et al., 2011; Inger et al., 2015). Specifically, bird biodiversity is sensitive to small-scale habitat alterations that decrease the availability of protection, nesting or roosting sites, or food resources, both within fields (e.g. Castro-Caro et al., 2014; Philpott and Bichier 2012) and in their immediate surroundings (e.g. hedgerows or set-asides; Hiron et al., 2013; Garfinkel and Johnson, 2015). In addition, given the potential of birds to spill-over into crop fields from surrounding, sometimes distant, habitat patches (Tscharntke et al., 2008), a significant effect of landscape modifications on bird biodiversity is also to be expected in agroecosystems. For example, bird abundance has been

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shown to decrease in those crop fields at further distances from semi-natural habitats (Karp et al., 2013) or within landscapes with lower proportions of these habitats (Barbaro et al., 2017). Despite these findings, there is a lack of knowledge on how habitat alteration at multiple scales (from local field to landscape level) affects the different components of bird biodiversity (Fahrig et al., 2011; but see Clough et al., 2009).

Birds, thanks to their usually high functional diversity, are thought to supply generalist services of biological control in tropical and temperate agroecosystems (Whelan et al., 2008; Sekercioglu 2012), preying upon different types of arthropod pests, from sap feeders and leaf herbivores to frugivores and seed predators (e.g. Kellermann et al., 2008; Maas et al., 2013). The magnitude of this biocontrol service depends, first, on the occurrence of top-down trophic effects by which avian predation would decrease arthropod populations and crop plant damage (Mäntylä et al., 2011). These effects, usually addressed by experiments in which birds are precluded from accessing the arthropod pests naturally occurring on plants, may, however, be hindered due to a suppression of intraguild predation and the concomitant mesopredator release, i.e. the suppression of avian control on arthropods (e.g. spiders) that act as natural enemies of pests as well, hence potentially increasing predation on these pests (Martin et al., 2015; Maas et al., 2016). Second, avian biocontrol potential also relies on the ability of birds to buffer pest outbreaks, by means of numerical or functional responses to population expansive increases in specialist pests (Barbaro et al., 2013; Garfinkel and Johnson, 2015). Simulations of pest outbreaks, by the experimental addition of specific insects (e.g. Garfinkel and Johnson, 2015), should thus be combined with exclusion experiments that evaluate population changes in the whole arthropod community. What is more, these experimental estimations should be complemented with top-down assessments based on the correlated variability between bird biodiversity and arthropod abundance across observational gradients (Mäntylä et al., 2011; Barbaro et al., 2013).

In this work, we assess the role of birds as natural enemies of arthropod pests in the cider apple orchards of Asturias (N Spain), taking into account the local and landscape determinants of bird biodiversity. The environment-dependent potential of birds as pest predators has been suggested in tropical agroforestry (e.g. Perfecto et al., 2004; Karp et al., 2013), although the existence of such a pattern in temperate woody crops is still unclear, even given that seminal findings on avian biocontrol come from exactly this sort of agroecosystems (e.g. Atlegrim, 1989; Mols and Visser, 2002). Our study system is suitable for addressing this issue, given that Asturian apple orchards are highly variable in their management regimes and landscape contexts, and the pool of insectivorous birds in the Cantabrian region is among the richest in Europe (Tellería et al., 2008; Santos et al., 2014). Specifically, we seek to answer the following questions: 1) How large and diverse, in terms of abundance, richness and composition, are the assemblages of forest insectivorous birds within the apple orchards and in their immediate surroundings across seasons?; 2) How do bird abundance, richness and species composition relate to landscape structure and orchard features?; and 3) Are birds able to control the abundance of arthropod pests in apple orchards? We then translate the answers of these questions into multi-scaled management guidelines for promoting the ecosystem service by insectivorous birds.

2. Methods

2.1. Study system and sampling spatial design

Apple (*Malus* x *domestica* Borkh.) is the most important fruit crop in Asturias (Dapena et al., 2005). There, almost all apple crops are devoted to cider production, given the long-tradition of cider as a valuable product with a Protected Denomination of Origin status. The majority of cider apple orchards are traditional, with large trees grown on seedling rootstocks, but new orchards are semi-intensive, with trees growing on semi-dwarfing rootstocks. Apple plantations in Asturias are based on local cultivars that are tolerant to common apple diseases (scab, canker and powdery mildew). Among the arthropod pests present (Miñarro et al., 2011), the most prevalent is the codling moth (*Cydia pomonella* L.), which attacks the fruits. Also present are the rosy apple aphid (*Dysaphis plantaginea* Passerini) and the green apple aphid (*Aphis pomi* De Geer), which harm the shoots of young trees, and so may be of particular concern in new orchards. The apple blossom weevil (*Anthonomus pomorum* L.), which attacks blossom, is also a significant pest locally. The cultural tolerance of growers to pests and diseases is high in general, as aesthetical damage is not relevant for cider apples and thus pests are not perceived as severe threats to productivity. Consequently, the use of pesticides is not generalized and, when they are used it is often at low intensity, with spraying mainly done with narrow-spectrum insecticides against the codling moth or the rosy apple aphid and, more occasionally, the apple blossom weevil. The low degree of agricultural intensification in some orchards and in the surrounding landscape (see below) thus allows for a high diversity of arthropods within orchards, including, as well as crop pests, their natural enemies (e.g. spiders, earwigs, hoverfly larvae, predatory beetles) or mutualists (e.g. aphid-tending ants) (arro et al., 2010, 2011;).

Asturian cider apple orchards are relatively small (most cover between 0.5 and 4 ha) and are embedded in a highly variegated landscape (Fig. 1; Fig. A1), containing a fine-grained mosaic of orchards, livestock pastures, annual crops (e.g. corn), timber (eucalyptus) plantations, human infrastructures, and semi-natural woody vegetation patches, mostly temperate broad-leaved forest, riverine forest and heathland patches. At the small scale of their immediate neighborhoods, apple orchards are typically surrounded, either totally or partially, by natural woody vegetation in the form of hedgerows or small forest patches (Fig. 1; Fig. A1). Hedgerows are very heterogeneous in terms of height, width, number of vegetation strata, plant composition and age (Miñarro and Prida, 2013; Fig. A1B–C), and are scarcely managed by farmers, although trimming on the planted side happens occasionally. Apple orchards are frequently adjacent to small patches of semi-natural forests composed by the same coterie of woody species as hedgerows (Fig. A1D). Isolated, remnant trees are also found within and between orchards (Fig. A1E).

In early 2015, we chose 25 orchards for the sampling, located over a 600 km^2 study area in the central part of the cider apple region in Asturias, at altitudes from 10 to 385 m a.s.l. (Fig. 1A–B; see Table A1 for geographical details). Minimum distance between orchards was 1.2 km (Fig. 1B). Due to logistical problems, one of the early sites had to be discarded and replaced for a different orchard of similar characteristics in early spring 2016. Sites were chosen with the aim of representing a gradient of variability in the environmental conditions around orchards, based on preliminary surveys on the structure of surrounding landscapes and the features within orchards. In each orchard, we established a sampling station within the apple tree plantation, 25 m away from orchard edges, and delimited a 50-m radius circular plot around each sampling station (R50 plot, hereafter; Fig. 1C).

2.2. Landscape structure and orchard features

Landscape structure was quantifyied by means of a Geographic Information System of the study area (GIS, ArcGIS9.3) based on 1:5000-scale orthophotographs (2014). From there, a layer of cover was carefully digitized in order to include all semi-natural woody vegetation assumed to be suitable habitat for forest insectivorous birds (see below for the definition of this classification). This layer, therefore, included forest patches of variable size, hedgerows, and isolated trees within pastures, but excluded low-height heathland (scrubland) patches. We estimated the availability of semi-natural woody vegetation around each apple orchard, at the large scale, within a circular plot of 1-km radius centered on the sampling station (*prop. woody vegetation R1000*; Figs. 1B, D), and at the small scale, within the R50 plot (*prop. woody*