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Responses of medium- and large-sized bird diversity to irrigation in dry cereal agroecosystems across spatial scales

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ABSTRACT

Conserving biological diversity under agriculture intensification is a global challenge given that the intensification process erodes biodiversity worldwide. Recently, efforts have begun to move towards conserving biodiversity in intensified farmland ecosystems, but there is little understanding of how some kinds of intensification (e.g., irrigation) affect biodiversity. We aimed to assess the responses of farmland bird diversity along an agricultural intensification gradient from dry to irrigation across spatial scales. We covered 10-km-survey transects by car to census medium- and large-sized farmland birds through a decreasing gradient of agricultural intensification ranging from irrigated to dry cereal farming systems in North-western Spain. We evaluated diversity of breeding and winter birds using different measures (species richness, abundance, and true Shannon diversity), and partitioning diversity into spatial components (α, β, and γ). We used turnover and variation partitioning to assess the variation in species composition. Changes from dry to irrigated farmland had no effects on (total) species richness, total abundance, and partitioning of farmland bird diversity in any season. However, irrigation led to changes in species composition, severely affecting open-habitat specialist species, most of which were threatened steppe birds. Beta(β)-diversity at landscape scale (between-transects) contributed to total diversity as much or more than β-diversity at regional scale (between-farming sub-areas with different degrees of intensification) in both seasons (i.e. spring and winter). Our study suggests a homogenization of the farmland bird community at regional scale driven by intensification. Promoting landscape-scale habitat heterogeneity could be an effective management measure to improve bird diversity in intensified farmland ecosystems, as long as requirements of open-habitat specialists are met.

1. Introduction

The process of agricultural intensification to increase crop yields (e.g., increase in irrigation, agrochemical use, mechanization, monoculturing, and overall cropped surface; Donald et al., 2001; Foley, 2005; Geiger et al., 2010) has reduced ecological heterogeneity (Benton et al., 2003) and the amount and quality of available habitats for species (Kleijn et al., 2011), eroding biodiversity and producing biotic homogenization (Donald et al., 2001; Smart et al., 2006; Kleijn et al., 2009). As a result, reconciling agricultural supply with biodiversity conservation is today one of the major challenges worldwide (Godfray et al., 2010; Phalan et al., 2011; Tscharntke et al., 2012).

Efforts to conserve biodiversity in intensive farmland ecosystems have recently begun through the implementation of either agri-environmental schemes (Kleijn et al., 2009, 2011; Sokos et al., 2013) or the development of new approaches that intend to increase food production in existing farmlands while minimizing environmental impact (e.g., sustainable intensification; Garnett et al., 2013). In the Mediterranean region, agricultural intensification through irrigation has been encouraged to increase production in dry areas. As consequence, the total irrigated area has almost doubled in the last decades representing over 20% of the arable land (Burke et al., 2011). In particular, large-scale conversion of dry extensive cereal systems into heavily irrigated areas has occurred (e.g., in Spain; MAGRAMA, 2013). However, detailed information on the environmental impact for some kinds of intensification such as irrigation in Mediterranean farmlands is still poor.

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Irrigation has significant adverse impacts on different components of farmland ecosystems including hydrology (e.g., overexploitation and depletion of groundwater, poor water quality, and altered natural hydrologic regimes; Moreno-Mateos et al., 2009a; Stoate et al., 2009; Martín-Queller et al., 2010), soils (e.g., salinization, high-nitrate concentration; Causapé et al., 2004a,b), wetland and aquatic biodiversity (Stoate et al., 2009; Robledano et al., 2010; Zacharias and Zamparas, 2010), and landscape complexity (i.e., landscape transformation by removing hedgerows and implementing artificial structures such as dams, pools, and channels for irrigation; Stoate et al., 2009). Nonetheless, these artificial structures can provide new aquatic habitats that benefit water-dependent biodiversity (Sánchez-Zapata et al., 2005; Moreno-Mateos et al., 2009b; Zacharias and Zamparas, 2010). Positive effects of irrigation on biodiversity have also been recently found for some terrestrial communities (i.e., butterfly diversity increases in irrigated farmlands; González-Estébanez et al., 2011). In contrast, several works suggest a negative impact of irrigation schemes on steppe birds (e.g., abundance of Lesser Kestrels, *Falco naumanni* Fleischer; Tella and Forero, 2000; De Frutos and Olea, 2008 see Brotons et al., 2004) and on other avian guilds (Díaz et al., 1993; Best et al., 1997; Laiolo, 2005; Meehan et al., 2010). Yet, the evidence available of the effects of irrigation on bird communities is still very poor, thereby limiting the management for biodiversity conservation and ecosystem services of these increasingly frequent irrigated agroecoystems.

Species richness (i.e., number of species) is one of the classic measures used to assess biodiversity responses to agricultural intensification (e.g., Flohre et al., 2011; Báldi et al., 2013). However, biodiversity measured as species richness alone might not respond sensitively to agricultural intensification (e.g., similar number of species among areas which harbor different species composition), and thus it has been proposed to use more than one diversity measure (Báldi et al., 2013). Using different measures of biological diversity may enable a better understanding of the impact of ecological disturbances on biodiversity, which could help to select better ecological indicators of anthropogenic disturbances such as agricultural intensification (Billeter et al., 2008). In addition, agriculture intensification involves different processes from field scale (e.g., increased agrochemical use on local fields) to farm and landscape scales (e.g., monoculture management or removal of natural and semi-natural habitats; Tscharntke et al., 2005; Flohre et al., 2011; Karp et al., 2012), thus altering the spatial heterogeneity of agricultural landscapes. Several studies have shown the importance of the use of multi-spatial scale procedures to study the response of biodiversity (e.g. bird species richness) to landscape spatial heterogeneity (Fahrig et al., 2011; Flohre et al., 2011; Concepción et al., 2012; Schindler et al., 2013). Accordingly, different spatial scales should be taken into account to better assess the impacts of agricultural intensification on the patterns and processes underlying biodiversity.

We are not aware of previous studies examining the responses of the farmland bird community to an agricultural intensification gradient via irrigation across spatial scales. Such a gradient could offer an appropriate framework to improve our understanding on farmland bird diversity responses to irrigation, and thus design more efficient conservation and management plans. Farmland birds are generally used as indicators to understand the impact of changes in agricultural intensification on biodiversity (Herrando et al., 2014; Morelli et al., 2014). Specifically, farmland birds can be classified in terms of use of habitat as specialist or generalist species (Julliard et al., 2006; Doxa et al., 2010). Specialist species associated with low-intensity dry farmed areas are steppe birds (Bota et al., 2005), many of which are species of high conservation value, particularly in Spain (Traba et al., 2006). From a conservation point of view, the most interesting bird species in vast low-intensity dry farmed areas are medium- to large-sized birds (unpublished results), which usually have large home ranges and are more mobile organisms. Censusing these species requires to cover large areas in a short time and car censuses have proved to be a suitable method (Bibby et al., 2000). Here we use different measures of diversity (i.e., species richness, abundance, and true Shannon diversity) to assess the response of medium- and large-sized, breeding and overwintering farmland birds to increasing agricultural intensification through irrigation in a Mediterranean farmland ecosystem. We consider different periods (i.e., breeding and overwintering) because (i) resident and migrant bird species may differ in their responses to agriculture intensification (Dänhardt et al., 2010) and (ii) the responses of resident species may change between seasons due to their ecological requirements (Seoane et al., 2013). The biodiversity partitioning approach (Crist et al., 2003; Jost, 2007) allows assessment of biodiversity at several spatial scales along a disturbance gradient (Jost et al., 2010; Paknia and Pfeiffer, 2011). Therefore, we partitioned the farmland bird diversity into spatial components (α-, β-, and γ-diversities) to analyze the effects of the agricultural intensification on the spatial variation of diversity. Finally, we examined the variation in species composition along the intensification gradient based on two measures of community structure: the species turnover (i.e., change in community composition) and the variation partitioning (i.e., the variation in community composition explained by environmental variables).

2. Methods

2.1. Study area

The study was carried out in a 1500 km^2 area in the province of León, NW Spain (5°31′W, 42°33′N; Fig. 1). The climate is Mediterranean with annual average temperature of 11.7 °C and mean annual rainfall of 486 mm (Penas et al., 1995). Arable farmland dominates the landscape (85% of the study area). Four adjacent farming sub-areas (Fig. 1) can be considered according to the degree of agricultural intensification in terms of irrigated surface, fallow surface, nitrogen inputs, and crop yields (see González-Estébanez et al., 2011 for further details): (i) a 300 km^2 area of very intensively managed agriculture featured with a conventional irrigation (i.e., gravity-fed system) for over 20 years (Irrigated hereafter); (ii) a 600 km^2 area of medium-intensity farming where a transition from extensive cereal dry system to modern irrigated crops (i.e., irrigated by sprinkler) is currently occurring (MAGRAMA, 2013, Mixed hereafter); (iii) a 300 km^2 area of low-intensity dry extensive agriculture (Dry hereafter); and (iv) a 300 km^2 area of low-intensity dry farming, protected as a Special Protection Area for birds since 2000 (MAGRAMA, 2014, SPA hereafter). In this latter sub-area, environmentally sensitive and sustainable farming practices are promoted (e.g., devoting 30% of farm area to fallow, cereal harvesting after July 10th; Oñate et al., 2007) to benefit threatened steppe birds. According to aerial photographs collected in 1956 (JCyL, 2013), the four adjacent farming sub-areas had historically similar farming based on low-intensity dry extensive agriculture.

2.2. Bird surveys and environmental data

We conducted car surveys to count medium- and large-sized diurnal birds (i.e., from the size of Lesser Kestrel, 26 cm in length, to the size of White Stork *Ciconia ciconia* L., 95 cm – the maximum size detected in surveys). To detect resident and migrant bird species, we carried out bird surveys during both the overwintering (February; winter hereafter) and the breeding (May; spring hereafter) seasons. We established five replicates of 10 km-survey