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Using the response-effect trait framework to disentangle the effects of agricultural intensification on the provision of ecosystem services by Mediterranean arable plants☆

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ABSTRACT

Agricultural intensification structures arable plant communities, including shifts in species assemblages and trait distributions, which affect the provision of ecosystem services. We used a response-effect trait framework to characterize the impact of agricultural intensification on two ecosystem services delivered by arable plants to pollinator and non-pollinator insects and birds. Agricultural intensification was characterized by field position as a gradient of the impact of crop management at field scale and the surrounding landscape heterogeneity, which can be divided into compositional and configurational heterogeneity. Shifts in functional assemblages of response and effect traits were analyzed by multivariate analyses, whereas changes in single trait metrics were analyzed by mixed-model effects. At field scale, we found a trade-off between ruderal and competitive species. The contrasting disturbance regime from boundaries to inner-fields overflows the potential shifts in functional assemblages both for response and effect traits due to the gradient of landscape heterogeneity. Conversely, some response and effect single trait metrics changed along gradients of landscape heterogeneity. We thus propose a response-effect trait framework to capture functional relationships along different trophic levels. Compositional heterogeneity affected traits linked to the provision of suitable habitat for insects and birds, whereas configurational heterogeneity affected traits linked to pollination. Incorporating this framework into decision-making processes may help to focus conservation efforts on maintaining the delivery of ecosystem services.

1. Introduction

Agricultural intensification is causing species loss across many trophic groups with potential effects on the provision of ecosystem services within agroecosystems (hereafter ESs) (Storkey et al., 2013). Causes of such phenomenon are increasing land-use disturbance regimes from boundaries to inner-fields (José-María et al., 2010), as well as the decline of landscape heterogeneity (Tscharntke et al., 2005). Landscape heterogeneity is influenced by the presence of patches of semi-natural and agricultural habitats (referred to as compositional heterogeneity), and their arrangement and shape (better known as configurational heterogeneity) (Fahrig et al., 2011). Increased compositional heterogeneity promotes more niches to support more species, whereas increased configurational heterogeneity promotes connectivity between patches, edge and mass effects for biodiversity along boundary networks (Fahrig et al., 2011). Studies focusing on compositional (José-María et al., 2010; Solé-Senan et al., 2014) and configurational heterogeneity in agricultural areas (Solé-Senan et al., 2014; Fahrig et al., 2015; Rotchés-Ribalta et al., 2015) suggest that landscape heterogeneity increases species richness and diversity in arable plant communities and promotes species persistence. Moreover, its positive effects on plant community composition are higher at boundaries than in inner-fields (José-María et al., 2010; Solé-Senan et al., 2014).

Plant community composition stems from the responses of plant functional traits to environmental filters here considered as abiotic factors, which prevent species establishment or persistence in a particular location (Violle et al., 2007). Environmental filters include land-use changes, field size increase and the increase of nitrogen and

pesticide inputs, which may affect the structure and composition of arable plant communities differently. The use of plant traits has been demonstrated as useful in disentangling the delivery of ESs (Lavorel et al., 2013; Storkey et al., 2013; Robleño et al., 2017), increasing awareness of the negative impacts of diversity loss on the ecosystem functioning, stability and sustainability (Wood et al., 2015). Therefore, nature conservation vision has shifted from targeting species to focusing on ecosystem properties. In this scenario, shifts in functional trait distributions of arable plants caused by the increasing use of nitrogen and pesticides and landscape simplification need to be quantified (Lavorel et al., 2013). Such quantification can be addressed using two metrics (Ricotta and Moretti, 2011): (1) functional diversity using Rao's quadratic entropy (hereafter Q); and (2) community-weighted mean (hereafter CWM). Q is used to test the complementary resource use hypothesis (Tilman et al., 1996) and with a higher Q among species within a community reflects higher diversity of resource strategies, and consequently, a more complete exploitation of resources than in less functionally diverse communities, thus improving ecosystem functioning. Q reveals patterns of trait over- or under-dispersion, compared to a random expectation. On the other hand, CWM is used to test the mass ratio hypothesis (Grime, 1998), assuming that the dominant traits in a community exert the greatest effect on ecosystem functions.

Agricultural intensification has promoted a decline in pollinators (Holzschuh et al., 2006; Bretagnolle and Gaba, 2015; Holland et al., 2015; Martins et al., 2015; Nayak et al., 2015; Perovic et al., 2015), non-pollinator arthropods (Kormann et al., 2015; Rouabah et al., 2015) and bird populations (Diaz et al., 1990). Likewise, it has been demonstrated that linkages among plant traits to those species (Ricou et al., 2014; Moretti et al., 2013; Diaz, 1990) are responsible for the delivery of ESs. In this context, the response-effect trait framework has been identified as a useful tool for predicting the impact of environmental changes on ecosystem services delivery in multi-trophic systems (Lavorel et al., 2013). This framework integrates plant traits, divided into driver response traits (DRs) that govern how plants respond to different environmental filters, and trophic effect traits (TEs) that determine how plants affect their environment (Lavorel and Garnier, 2002). There is agreement that TEs influence other trophic levels linked to trophic response traits (TRs) (e.g. floral traits to pollinator traits, seed traits to bird traits). Finally, the framework identifies functional effect traits (FEs) of the consumer community that drive ESs. The functional trait approach has been successfully used in studies focusing on grasslands under different management regimes to quantify trade-offs and synergies between plant traits and grasshopper traits (Moretti et al., 2013), as well as in arable communities to quantify relationships between crop management, plant and invertebrate traits that can potentially provide ESs to farmland birds (Storkey et al., 2013). However, neither Moretti et al. (2013) nor Storkey et al. (2013) have focused on the role of landscape heterogeneity in modulating plant functional traits. Concurrently, it has been suggested that agricultural intensification in the Mediterranean area increases the dominance of some response traits of non-woody (Armengot et al., 2016) and wind-pollinated species (José-María et al., 2011), promotes for tall, heavy-seeded and early-flowering species (Guerrero et al., 2014), and enhances plants with high SLA (Hernández Plaza et al., 2015). Conversely, Fried et al. (2012) found that under recurrent disturbances, short plants with small seeds are promoted. Yet, these studies have not focused on a functional trait approach aimed at disentangling the impact of shifts of these response traits to other trophic levels.

Our study represents the first attempt to analyze the effect of agricultural intensification on ESs, both at field and landscape-scale in the Mediterranean area, by integrating plant functional traits in a response-trait framework. By using functional traits, we address the recent call of Wood et al. (2015) for the application of functional approaches in agriculture to investigate the impact of agricultural intensification on ESs. Considering the different levels of disturbance regimes within an arable field along pre-defined field positions, we hypothesized that

landscape heterogeneity may help to counteract the negative impact of such disturbances on the functional composition of arable plant communities. Furthermore, we expect functional diversity of plant communities to display different responses to compositional and configurational landscape heterogeneity. Increasing compositional heterogeneity is expected to provide suitable habitats for biodiversity since it may offer more resources to specialized organisms. In contrast, increasing configurational heterogeneity is expected to enhance pollination as semi-natural habitats acting as boundaries benefit pollinator populations. The study was based on two measures of landscape heterogeneity and three different positions at field scale −boundaries, inner-edges and inner-fields- to evaluate their effects on (i) functional diversity (using Rao's quadratic entropy) and (ii) functional dominance on Mediterranean arable plants (using the community-weighted mean). Our research was aimed at identifying trade-offs in functional traits of arable plant communities which could suggest different ecological strategies, analyzing the extent to which functional assemblages and single trait metrics of DRs and TEs vary along environmental gradients (landscape heterogeneity and field positions), and proposing a response-effect trait framework for mapping the impact of agricultural intensification on pollination and the provision of suitable habitat for farmland biodiversity at field and landscape scales.

2. Materials and methods

2.1. Study area

The study was conducted in a dryland cereal area in Catalonia, in the northeastern Iberian peninsula (41°35′-42°11′N; 0°35′-1°21′E) of 4500 km². Study sites were composed of rain-fed barley fields interspersed with patches of Mediterranean woodlands of *Quercus ilex* L. and *Quercus faginea* Lam. We selected forty-five localities, defined by a circular buffer area of 1-km radius, along a gradient of landscape heterogeneity ranging from very simple landscapes with a high percentage of arable lands (95%), to complex landscapes with a lower percentage of arable lands (5%). A strong relationship between landscape heterogeneity and plant species richness and diversity in a 1 km buffer area has been previously highlighted (Solé-Senan et al., 2014). Landscapes were at a distance of at least 5 km (centre to centre) from each other. Two fields of barley with similar size and shape were selected at each landscape as study sites, since field size is known to affect weed richness and diversity (Gaba et al., 2010). Environmental characteristics and farming practises applied in the fields are described in Supplementary Appendix A.

2.2. Landscape heterogeneity

At each locality, compositional landscape heterogeneity was characterized by the percentage of natural vegetation (PER$_{NV}$) (José-María et al., 2010), whereas configurational landscape heterogeneity was characterized by the perimeter-area ratio of arable patches (PA$_{ARA}$) (Perović et al., 2015). While PER$_{NV}$ was computed by summing the proportion of areas not devoted to agriculture, PA$_{ARA}$ was calculated as follows:

$$PA_{ARA} = \sum_{i=1}^{m} P_i / \sum_{i=1}^{m} A_i$$

where P is the perimeter, A is the arable patch area, i the patch number and m the number of patches in the landscape buffer. The two metrics presented a wide range of values along localities (Spearman's Correlation coefficient of mean values: PER$_{NV}$ − PA$_{ARA}$: $\rho = 0.14$; $p > 0.05$). Landscape metrics were calculated using GIS-Software (ESRI, 2006).

2.3. Plant surveys

Plant surveys were carried out between May and July 2008. As