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Plant diversity in Mediterranean cereal fields: Unraveling the effect of landscape complexity on rare arable plants

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ABSTRACT

Landscape complexity is thought to increase plant diversity in Mediterranean dryland cereal fields, although this assumption has not been tested specifically for rare arable plants (RAP). Standardized landscape metrics may help elucidate efforts to enhance RAP conservation. Our paper evaluates the impact of the surrounding landscape on the plant diversity and species composition for both total species and rare arable plants (RAP) at three contrasted field positions (boundary – first metre of non-cultivated habitat surrounding a field-, edge – first metre of cultivated habitat adjacent to the boundary- and centre) in 90 conventional cereal fields in 45 landscapes (2 fields per landscape) over three regions in the NE Iberian Peninsula (15 landscapes per region). Total species richness (S) and Shannon diversity (H') were partitioned into α- and β-components. β-Components accounted the maximum contribution to the total diversity. $S\alpha_{\text{landscape}}$ – species richness within-landscape and $H'\alpha_{\text{landscape}}$ – Shannon diversity within-landscape of total species and $S\alpha_{\text{landscape}}$ of RAP were higher in structurally complex landscapes than in simple ones. The positive effect of landscape complexity on the $\alpha_{\text{landscape}}$ diversity was highest at the boundary for total species but at the edge for RAP. Two subsets of RAP, G1 and G2, were identified according to their response to landscape metrics gradients. G1 and G2 were assembled in complex and simplified landscapes, respectively. Landscape metrics explained the highest variation in species composition at the boundary and the edge for total species and exclusively at the edge for RAP. Moreover, the variation in species composition explained by landscape metrics was higher for RAP than for total species. Thus, RAP assemblages in arable fields are greatly influenced by processes operating at the landscape scale which may filter plant species. Our study provided a formal framework to help policy makers identify landscape configurations that most benefit plant conservation policies. As a depleted species pool may prevent the re-assembly of RAP, agri-environmental schemes targeting landscapes with useful structural elements supporting diversity may increase populations of RAP. Low-input farming practices at the edge of the arable fields in complex landscapes are expected to be the best cost-effective methods for enhancing RAP.

1. Introduction

Arable plants are among the most endangered plant species in Europe (Storkey et al., 2012) as a result of increased land-use intensity and decreased landscape complexity in agricultural landscapes over the last few decades (Tscharntke et al., 2005; Van Calster et al., 2008). In particular, a set of arable plants which tend to be less tolerant to fertilizer and herbicides has become extremely rare and threatened (Kleijn and vanderVoort, 1997; Fried et al., 2009; Storkey et al., 2012). The conservation status of these rare arable plants (RAP) is increasingly raising concerns in Europe and, as a consequence, the number of RAP included in conservation polices has therefore increased (Aboucaya et al., 2000; Byfield and Wilson, 2005).

To counteract impacts of farming practices on agricultural landscapes, the European Union has developed the agri-environmental schemes (AES). The effectiveness of AES on the conservation of plant diversity in the Mediterranean area has been constrained by the shared effects of landscape complexity and land-use intensity (Concepcion et al., 2008). Landscape complexity plays a crucial role in dryland Mediterranean cereal areas, which harbor high levels of plant diversity (Holzner and Immonen, 1982) and large populations of RAP of European conservation concern (Kleijn et al., 2011), and are characterized by low rainfall (<500 mm/year) and low crop yields (<3000 kg/ha). Farming practices are mainly conventional, based on the use of herbicides and fertilizers (López-Bellido, 1992).

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In this scenario, landscape complexity is expected to play a preeminent role in supporting RAP because their persistence will depend on their ability to colonize a suitable habitat in the surrounding landscape.

The relationship between species diversity and landscape complexity is controversial. Complex landscapes have been reported to benefit plant diversity because they offer more habitat heterogeneity than simple landscapes (Gabriel et al., 2005; Roschewitz et al., 2005; Concepcion et al., 2012). However, some authors have pointed out that the effect of the surrounding landscape on plant diversity occurs only at local scale, within a radius of 500 m (Marshall, 2009; Gaba et al., 2010). Many studies have shown that the degree of landscape complexity affects exclusively the outer positions of the field, i.e., boundaries and edges, with no effects in the centre (Weibull et al., 2003; Jose-Maria et al., 2010). Additionally, complex landscapes contain higher perimeter-area ratios of patches and therefore more boundaries and sharp edges to provide refuge for plants (Gabriel et al., 2005; Gaba et al., 2010; Bassa et al., 2011), especially those most sensitive to conventional farming practices (Smart et al., 2002; Fried et al., 2009). Therefore, fields surrounded by structurally complex landscapes are expected to harbor plant communities with a higher diversity of RAP than simplified ones.

Although some studies on the relationship of plant diversity and landscape complexity in Mediterranean systems have been conducted recently (Concepcion et al., 2008, 2012; Jose-Maria et al., 2010; Armengot et al., 2011; Bassa et al., 2011), they have not focused on RAP. Identifying sites where RAP remain is essential to ensure their conservation through sustainable management. We hypothesize that RAP are more abundant at boundaries and edges of the fields and that landscape complexity provides safe havens for species of conservation concern. Structural complexity is expected to sustain plant populations and reduce their risk of local extinction. Thus, the use of landscape structure indicators such as the presence of arable lands, fields with sharp edges, and linear features of natural vegetation may help to elucidate the effect of landscape complexity on species diversity and community composition at boundaries, edges and the centres of the fields and to estimate, particularly, their importance for the maintenance of RAP. We used the additive diversity partitioning method (Lande, 1996), such that $\gamma = \alpha + \beta$, to divide the diversity in α-diversity within-landscape ($\alpha_{landscape}$), between-landscape β-diversity ($\beta_{landscape}$) and between-region β-diversity (β_{region}) for each location in field (boundary, edge and field centre) and for two diversity measures: species richness (S) and Shannon diversity (H'). Additionally, as diversity measures are usually large invariant to changes in species composition, we also focused on species assemblages. Our aims were to (i) examine whether changes occurred in the α- and β-components of S and H' of total species and RAP depended on the field position (boundary, edge and field centre) at two spatial scales (landscape and region), (ii) analyse the effect of landscape complexity on the within-landscape component ($\alpha_{landscape}$) of S and H' of total species and RAP from the boundary to the field centre and (iii) determine whether total species and RAP assemblages are equally affected by a gradient of landscape complexity. This information is essential to allow policy makers to develop guidelines for conserving plant diversity and particularly enhance RAP in the Mediterranean area.

2. Materials and methods

2.1. Study area and landscape structure characterization

The study was conducted in 2008 in three regions (Noguera, Segarra and Pallars Jussà) within a dryland area of the eastern Ebro Valley, in Catalonia, in the NE Iberian Peninsula. We have chosen these three regions because of three main reasons, namely; (1) they are representative of the traditional management of cereal in dryland areas, (2) they provide a gradient of landscape complexity and (3) they have not suffered any relevant landscape transformation in the last century. Regional environmental characteristics and farming practices applied in the fields are summarized in Table A.1. Landscape is characterized by mosaics of small arable fields, almond and olive groves interspersed with patches of natural vegetation. In each region, we selected 15 localities along a gradient of complexity ranging from simple landscapes with a high percentage of arable land (95%) to complex landscapes with a low percentage of arable land (5%). All landscapes were at least 5 km (from centre to centre) away from each other. At each locality two fields which were representative of the landscape (i.e., as similar as possible in terms of shape and area to that of most of the fields within the locality or landscape) were randomly selected. The two fields were not adjacent but were close in proximity to ensure similar abiotic conditions. Georeferenced aerial photographs (ICC, 2008) were digitalized and classified as natural vegetation or arable patches in a circular buffer area of 1 km radius around the two focal fields using a geographical information system (ESRI, 2006). Natural vegetation included forestry and shrubby patches and linear elements such as hedgerows. Arable patches included cereal fields, almond groves and olive groves, and man-made structures. There was no east–west or north–south gradient of landscape complexity, as *XY*-coordinates of the localities do not correlate with landscape context (*X*-coordinates vs. percentage of natural vegetation: $\rho = 0.03$, $P = 0.83$; *Y*-coordinates vs. percentage of natural vegetation: $\rho = 0.15$, $P = 0.32$). Afterwards, landscape structure was characterized by a set of landscape metrics widely used in landscape ecology (McGarigal and Marks, 1994) which are summarized in Table A.2:

Percentage of natural vegetation (hereafter PER_{NV}*).*

*Total length of perimeter of arable patches (*TLAP*)*, which is the sum of the lengths of the perimeters of all of the arable patches.

Perimeter-area ratios of the natural vegetation (PA_{NV}*) and arable (*PA_{ARA}*)* patches, which are the weighted perimeter-area ratios of each patch for each type (natural vegetation or arable lands).

Shape index of natural vegetation (SI_{NV}*) and arable (*SI_{ARA}*) patches*, which reflect the compactness of each patch. The minimum value is 1 and the index increases as the shape of the patch becomes more convoluted and dendritic. The shape index is computed as follows:

$$SI_{patch} = \frac{p}{2(\pi a)^{-1/2}}$$

where p is the length of the perimeter and a is the area of one patch of each type. The SI of each local landscape was calculated as follows:

$$SI_{NV/ARA} = \frac{\Sigma_{ij} SI_{patch\, i}}{a_i/A_i}$$

where a_i is the area of one patch and A_i is the sum of the areas of all of the patches.

2.2. Plant data sampling

Plant surveys were conducted before harvest, between May and July 2008. As plants are not homogenously distributed over the field (Wilson and Aebischer, 1995), the surveys were performed at three different positions: (a) the boundary, which is the first metre of non-cultivated habitat surrounding a field, (b) the edge, which encompasses the metre of cultivated habitat that is adjacent to the boundary, and (c) the field centre, 50 m from the