The structural classification of field boundaries in Mediterranean arable cropping systems allows the prediction of weed abundances in the boundary and in the adjacent crop

A CIRUJEDA*, G PARDO*, AI MARÍ*, J AIBAR†, Y PALLAVICINI‡, JL GONZÁLEZ-ANDÚJAR‡, J RECASENS§, XO SOLÉ-SENAN§

**Unidad de Sanidad Vegetal. Centro de Investigación y Tecnología Agroalimentaria de Aragón. Instituto Agroalimentario de Aragón-IA2 (CITA-Universidad de Zaragoza). Avda. Montañana 930; 50059 Zaragoza*
acirujeda@aragon.es. Tel.: (+34).976.71.63.22. Fax: (+34).976.71.63.35
†Escuela Politécnica Superior, Universidad de Zaragoza, Ctra. de Cuarte km 67, 22071 Huesca
‡Dep. de Protección de Cultivos, Instituto de Agricultura Sostenible (CSIC), Avda. Menéndez Pidal s/n, Campus Alameda del Obispo. 14004 Córdoba
§Dep. Hortofructicultura, Botànica i Jardineria. ETSEA. Agrotecnio. Universitat de Lleida. Avda. Alcalde Rovira Roure 191, 25198 Lleida

Received 15 September 2017
Revised version accepted 13 March 2019
Subject Editor: Camilla Moonen, Scuola Superiore Sant'Anna di Pisa, Italy

Running head: Structural classification of field boundaries

Correspondence: A. Cirujeda, Unidad de Sanidad Vegetal, Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA); Avda. Montañana 930, 50059 Zaragoza, Spain. Tel.: +34.976.71.63.00 ext. 2032. Fax.: +34.976.71.63.35; E-mail: acirujeda@aragon.es

Summary

Boundary structure can hinder or facilitate disturbance of the boundary vegetation by farming practices, such as herbicide and fertiliser drift and occasional cultivation; this may affect their potential role as a weed reservoir. It would be relevant for researchers, farmers and legislators to know if relationships exist between boundary structure and weed abundance and frequency in boundaries and adjacent fields. In this study, we present a classification of arable field boundaries based on five descriptors: presence of a bank, width, percentage cover of woody and evergreen perennials (WEP), presence of a stonewall and presence of trees. Five types of boundaries are identified, ranging from structurally simple ones (flat, narrow, dominated by annual species) to structurally complex ones (presence of a bank, more than 3 m wide, dominated by WEP). Data from three Spanish regions were used to validate this classification and the five boundary classes contained different plant communities. Structurally simple, flat and narrow boundaries contained many of the weed species found also in the field centre and with high abundance. More complex, wider boundaries with a slope and a WEP >60%, had a lower probability of hosting the main weeds present in the field centres. Assessment of weed frequency and abundance gave complementary information. The proposed classification of field boundaries may be easily used by farmers and allows adjustment of field margin management to risks posed by the field boundary, in terms of hosting common weeds of arable crops.

Keywords: field margins, bank, perennial species, width, multivariate analysis, non-metric multidimensional scaling (NMDS), functional traits, growth form.

Introduction

In the past five decades increased attention has been paid to the functionality of field margins and boundaries in arable fields, such as their role in reducing soil erosion, providing suitable habitats for biodiversity, or connecting semi-natural habitats in agricultural landscapes (Marshall & Moonen, 2002; Aavik & Liira., 2010). Although numerous studies have focused on their role in northern and central Europe, hardly any work has been conducted in southern Europe (but Cirujeda *et al*., 2007; Bassa *et al*., 2012, Morrison *et al*., 2017, Solé-Senan *et al*., 2017; Solé-Senan *et al*., 2018).

Boundaries are a strip of semi-natural vegetation surrounding arable fields that harbour a diverse plant spectrum (Marshall & Moonen, 2002). Although farmers mostly consider boundaries as a source of weeds, few empirical data support their perception (for the United Kingdom, Marshall, 1989; Marshall & Arnold, 1995; Germany, Mante & Gerowitt, 2009; Netherlands, Kleijn & Verbeek, 2000; and USA, Reberg-Horton *et al*., 2011). From an ecological point of view, weeds are plants that compete with the crop for resources, because they are able to withstand the specific disturbance intensity and frequency of the cropped field. Whether or not they thrive in the field boundary depends on the boundary disturbance regime and the weed niche width. In Spain, contradictory results on weed communities have been found: while Pallavicini *et al*. (2013) found weed species common to boundaries and their respective field centres, Cirujeda *et al*. (2013) described few harmful species with coincident occurance. These findings may be explained by differences in boundary structure. For example, flat boundaries are easily disturbed, while boundaries with a bank have more protected vegetation. Thus, vegetation in narrow boundaries without a bank is more prone to disturbance caused by farming practices, such as soil disturbance from machinery, and fertiliser and herbicide drift. This creates a habitat that is similar to in-field conditions that are more likely to host weeds (Schippers & Joenje, 2002; de Cauwer *et al*., 2008; Pallavicini *et al*., 2013). Conversely, lack of disturbance promotes growth of perennial species, preventing colonisation by annual species (Marshall, 2009), thus leading to contrasting species assemblages in boundaries and field centres (Marshall & Arnold, 1995; Hovd & Skogen, 2005; Aavik & Liira, 2010; Cirujeda *et al*., 2013). Although it has been reported that boundary vegetation is determined by management (Hovd & Skogen, 2005; de Cauwer *et al*., 2008; Reberg-Horton *et al*., 2011; Solé-Senan *et al*., 2018), some studies found that boundary structure, such as presence or absence of a bank and width, drives community composition (Hovt & Skogen, 2005; Schippers & Joenje, 2002). Schippers and Joenje (2002) suggested that wider boundaries host more diverse plant communities than narrower boundaries, because (1) wide boundaries buffer against agro-chemical drift, which is one of the major causes of diversity decline and homogenization, and (2) species number increases with increasing area. Similarly, Gove *et al*. (2007) found that abundance of plant species sensitive to herbicides increased in boundaries at a distance of between 2 and 4 m from the edge compared with those located between 0 and 2 m, because of the reduction in effects of herbicide drift.

Some arable plant species have become extremely rare due to increasing agricultural intensification (Fried *et al*., 2009). As a results, there are increasing concerns about the conservation status of these species in northern and central Europe and, consequently, conservation policies have been developed (Aboucaya *et al*., 2000). Concurrently, studies have increased awareness of the negative effects of agricultural intensification on these species in the Mediterranean area (Solé-Senan *et al*., 2014). The presence of rare arable plants is expected to be greater in boundaries with an intermediate level of complexity than in those subjected to regular cultivation (Fried *et al*., 2009). Likewise, an increase in abundance of perennial species is expected to decrease abundance of rare annual plants due to their inability to thrive in competitive habitats (Marshall, 2009).

Competitive plants are usually confined to boundaries that are less disturbed by farming practices than in the inner field (Kleijn & van der Voort, 1997). Despite this, ruderal species, which tend to be annual weeds in cultivated fields, are present in boundaries and we expect boundary structure to affect species composition of the plant communities. It is assumed that annual weeds thrive in structurally simple boundaries (narrow, with no bank and fewer perennial species), whereas they are expected to decrease in structurally complex boundaries (wider, presence of a bank with greater abundance of perennial species). Therefore, we expect a reduction in annual weed infestation with increasing boundary complexity. Our aims were to: (1) test a field boundary typology based on easily measurable descriptors to support farmers and future research, (2) describe weed and rare arable plant occurrence in boundaries and field centres, and (3) validate the typology with available data from Spain. Boundary typology should inform researchers, farmers, stakeholders and legislators about drivers of weed abundance in boundaries that potentially affect crop production and contribute towards managing boundaries under specific Agri-Environmental Schemes (AES) aimed at reducing weeds but enhancing rare arable plants when possible.

Material and methods

Study regions

The study was conducted in three different regions of Spain (Andalusia, Aragon and Catalonia) that encompass cereal production areas under rainfed conditions. The regions provide a gradient of boundary structural complexity. Environmental characteristics and farming practices applied in the fields of each region, as well as the number of fields surveyed per region, are summarised in Table S1.

Plant survey

Sampling was conducted in boundaries (B) and field centres (FC) of rainfed cereal fields between April and July (prior to harvest) from 2008 to 2012.

In Andalusia, boundaries were sampled from five quadrats of 1 x 1 m at 5 m intervals along a single transect, whereas in the field centre, one quadrat was positioned 25 m away from the boundary and then an additional four quadrats were positioned diagonally from the edge towards the centre of the field; plant species were identified and individuals were counted. In Aragon, boundaries were sampled using three rectangular quadrats that were as wide as the boundary and 2 m in length, and inner field sampling was generally done at a distance of 20 m from the boundary in three 2 x 2 m quadrats that were spaced by at least 10 m. In Catalonia, surveys were performed in the boundaries and in the field at 30 m from the boundaries along a single transect of five quadrats (1 x 5 m) that ran parallel to the edge at 10 m intervals. Total and species cover (%) were estimated in Aragon and Catalonia. When shrubs or trees were found, their projection on the soil was considered. Details of the sampling areas are provided in Table S1.

Field boundary descriptors

Data from Aragon and Catalonia were used to test the effect of the boundary structure and cover of woody and evergreen perennials (WEP) on boundary weed species composition and cover. Data from Andalusia were not considered, because of differences in sampling methodology. Occurrence of trees in boundaries was rare, so boundaries containing trees were considered as a separate boundary category as was the presence of stonewalls (SW), because although they provide a habitat for vegetation, plants on wall tops are not disturbed by cultivation, and fallen stones at the base trigger a widening of the boundary that reduces levels of farming disturbance and cultivation.

First, we tested the relationship between cover of weeds and perennial species (WEP) on weed seed germination. These species were selected following the criteria of de Bolós *et al.* (1990) and are listed in Table S2. The relationships between abundance of perennial vegetation and four main weed species *(Avena sterilis* L., *Bromus diandrus* Roth., *Lolium rigidum* Gaud. and *Papaver rhoeas* L.), which were selected following Cirujeda *et al*. (2011), were tested using linear regression, to establish a possible threshold of perennial species for the reduction in abundance of the target weed species.

Then, we used five descriptors to classify boundaries: (1) WEP cover, (2) boundary width, (3) presence of a bank, (4) presence of a stonewall and (5) presence of trees. Boundaries were classified into narrow (<3 m) or wide (>3 m), according to the results of Gove *et al*. (2007) who defined that a 4-m no-spray buffer zone renders the impacts of spray drift and fertiliser overspread as negligible, although a 2-m buffer yields considerable beneficial effects on vegetation. Consequently, 3 m was considered as a mean value to separate narrow from wide boundaries. Boundaries were also divided into flat or with presence of a bank (after Greaves and Marshall, 1987), because Hovd and Skogen (2005) considered slope a driver of boundary species assemblages and annual species abundance.

The importance of these five descriptors was checked using two redundancy analyses (RDA) in Canoco 5.0. (Smilauer & Leps, 2014) and allowed us to propose a classification of boundary typology. First, species composition data were constrained to boundary characteristics (presence of a bank, wide or narrow boundary, and WEP cover; Fig. 2), and then the effect of these environmental variables was on vegetation functional type, comprising common annual weeds (CW) (four main weeds described above), other annual plants (AP), rare arable plants (RAP) (see Solé-Senan *et al*., 2014), and herbaceous perennial species including hemicryptophytes and geophytes (HP) (Fig. S1). For both RDAs, significance of the explanatory boundary characteristics was tested using a Monte-Carlo permutation test (999 permutations).

Validation of the boundary classification

Boundary and adjacent field vegetation in the three regions was analysed, accounting for proposed boundary type, where the most frequent and most abundant species were identified for each boundary type. The same was done for the four main weeds sensu Cirujeda *et al*. (2011), plus *Phalaris minor* Retz. (González-Andújar & Saavedra, 2003) in Andalusia.

Statistical analysis

Mean species frequency, as a metric of species assemblage, among sampling points within a region was analysed, and a similarity matrix for each region using species frequency at each patch per sampling point was obtained with the Bray-Curtis dissimilarity index (see Legendre & Legendre, 1998). Each region was analysed separately to avoid the effect of species turnover between regions. This matrix was used in a non-metric multidimensional scaling (NMDS) analysis, as the most robust unconstrained ordination method in community ecology (Leps and Smilauer, 2007). Plant cover (Aragon and Catalonia) and density (Andalusia) values of each plot per position (B or FC) were averaged to obtain a single value per field and position. Because of differences in the plant survey between regions, separate NMDSs were conducted for each region. To explore patterns of species assemblages in relation to the position (B, FC), a hierarchical cluster based on Ward's criterion was conducted using the Bray-Curtis similarity matrix. Two cluster groups were selected to test whether the clustered plots share the two field positions, and the clustered groups were overlaid on the NMDS, with plot type (B or FC) as a factor. The labels of each habitat correspond to environmental factor "position" averages obtained after fitting to the ordination diagram ($P < 0.001$). The circles in the ordination represent 95% CIs of the three clustered groups.

Statistical analyses were carried out using R 2.8.1 (R Development Core Team, 2008) with the vegan package (Oksanen *et al*., 2013). Rare arable plants (Solé-Senan *et* *al*., 2014) were exclusively projected in the NMDS of Catalonia, because they were poorly represented in the fields of Aragon and Andalusia.

Results

Field boundary descriptors

Cover of *B. diandrus, L. rigidum, P. rhoeas* and *A. sterilis* and total cover of common weed species were negatively correlated with WEP cover (*P*<0.05 and below) (Fig. 1), showing a threshold of 66% perennial cover limited cover of weed flora to 2%.

Figure 1 near here

Effect of the descriptors on species functional type

The RDA showed that species composition (Fig. 2, Table 1) and functional type were explained by boundary characteristics (Fig. S1, Table 1). The common arable weeds (bold species in Fig. 2) were more likely to have a greater abundance/cover in flat and narrow boundaries, while presence of herbaceous perennials (HP) was related to boundaries wider than 3 m and with a bank; in contrast, presence of common weeds was related to flat and narrow boundaries (Fig. S1). The amount of variation explained in the RDA was greater for functional type (24.2%) (Table 1) than for species assemblages (12.5%) (Figure S1 and Table 1). WEP cover explained the greatest amount of variation in species assemblage, followed by the presence of a bank, whereas boundary width explained the least amount of variation. Presence of a bank explained a greater amount of variation in functional type than boundary width. There was no effect of stonewall, which are legally protected, on functional type or species assemblage (Table 1).

Table 1 and Figure 2 near here

The combination of the four descriptors led to the classification of boundaries into five categories of increasing complexity: flat and narrow boundaries with <60% WEP (type A); boundaries with a bank with <60% WEP (type B); boundaries with a bank with >60% WEP (type C); boundaries with a bank and trees in the boundary and >60% WEP in narrow or wide boundaries (type D) and vegetation strips next to a stonewall (type E) (Fig. 3). Flat and wide boundaries were not considered because they were not found in the study areas.

Figure 3 near here

Validation of the boundary classification

Common weeds

In the Andalusian boundaries, *L. rigidum* exceeded 50% frequency, which was even greater than in the nearby fields (Table 2). None of the four common weeds reached this frequency in the Aragonese boundaries. Conversely, in Catalonia, *B. diandrus*, *L. rigidum* and *P. rhoeas* exceeded 50% frequency in boundaries types A, B, C and D. However, mean abundance of these species tended to be greater in field centres than in the boundaries, especially for types A and D, and for some species in types B, C and E (Table 2). Despite frequency being high in many cases, abundance was <10% for all common weed species in all boundaries, except *B. diandrus* that tended to decrease in Aragon and Catalonia with increasing boundary complexity (Table 2). The troublesome species *B. diandrus* accounted for ≥10% abundance in boundary types A, C and E and *L. rigidum* in type A in Andalusia. *B diandrus* was more frequent in boundary types A, B and C than in the respective field centres, but decreased in importance in types D and E.

Table 2 near here

Plant categories

As defined by the classification criteria, WEP cover increased from categories A to D; in the Aragonese boundaries of types B to D (21.8, 66.0 and 70.5%, respectively) and for Catalonian boundaries of types A to D (12.1, 30.9, 68.5 and 73.0%, respectively). WEP cover in Andalusian boundaries of type A was 3.1% WEP and 26.2% in Catalonian boundaries of type E. Due to the increasing amount of WEP, the remaining plant categories were less abundant with increasing boundary complexity. Common weed abundance decreased with increasing boundary complexity in Catalonia and in Aragon (Table 3). The proportion of annual plants was greatest in boundaries of types A, B and E, and lowest in boundaries of types C and D, regardless of region. Proportion of herbaceous perennial species tended to be consistent in boundaries of types B, C and

D, but greater in Catalonian boundaries of types A and E (Table 3). The proportion of rare arable plants in Catalonian boundaries was greatest in boundary types E and B and lowest in the simplest boundaries of type A (Table 3).

Table 3 near here

Comparison of species in boundaries and field centres

In Andalusia, *Polygonum aviculare* L. was one of the four most frequent species in boundaries and field centres (Table S3). In Catalonia, *L. rigidum*, *P. rhoeas* and *Convolvulus arvensis* L. were the most frequent species in boundary type B and in FC of types A and B. Likewise, in boundary type C, *P. rhoeas* and *L. rigidum* were among the four most frequent species in B and FC, whereas *C. arvensis* appeared in boundaries and field centres of type D and *L. rigidum* in those of type E, and (Table 1). Thus, in Catalonia, similar common weed species were found in B and FC, especially in types A and B, but fewer coincident species were found in boundaries of type C, D and E. In Aragon, no coincident species were found among the four most frequent species between boundaries and field centres (Table 2), and in most cases, they were scarce or even absent in boundaries of types B, C and E.

In Andalusia the most frequent species in FC were *A. arvensis* and *C. arvensis.* In Catalonia, *L. rigidum* was the most frequent species in FC types A, B and E, whereas *P. rhoeas* and *C. arvensis* were the most frequent and most abundant species in FC type C and D. Exclusively in Aragon, *S. vermiculata* was the most frequent and abundant species irrespective of the boundary type (Tables S3, S4).

No single species of the four most abundant in boundaries and FC in any boundary type was among the most abundant species in B and FC in any of the three study areas (Supporting Information Table S4).

Community composition and field boundary typology

NMDS analysis showed differences in species assemblage depended on boundary type and field position, (B versus FC; Fig. 4). Each of the three NMDSs conducted revealed stress below 0.2, indicating a strong structure of community composition (Lefcheck, 2012).

In Andalusia (Fig. 4a) and Catalonia (Fig. 4c), neither B or FC type A differed, according to the ANOVA of the NMDS scores on axis 1. For the rest of the types, differences between species assemblages in boundaries, as well as differences between boundary types and their respective FC, were observed in each region. In Aragon, boundaries of type B differed from their respective FC and from boundaries of type C and E. Although the latter two were not significantly different from each other, they differed from their respective FC. In Catalonia, boundaries of type A differed from C, D and E; boundaries of type D and E differed from the others.

NMDS analyses (k = 2, non-metric fit: $r^2 = 0.921$, Fig.4a; k = 2, non-metric fit: $r^2 = 0.935$, Fig.4b; k = 2, non-metric fit: $r^2 = 0.947$, Fig.4c,) showed a clear distribution of the sites based on the floristic similarities of the boundaries and field centres. The stress of the three NMDS ranges between 0.17-0.21.

Discussion

Field boundary descriptors

Gerowitt and Heitefuss (1990) established the general economic threshold inside a cereal field at 5-10% cover for broad-leaved species. Similarly, the Integrated Pest Management guide published by the Spanish Ministry of Agriculture considers 2% as a general economic threshold in a cereal field for the common species or the sum of those species (MAAMA, 2015). According to regression analyses, a total weed density <2% would be achieved with >66% WEP cover (Fig. 1). For *B. diandrus*, which had the greatest cover in the boundaries, <2% abundance would be expected with 64% of WEP cover. However, the 2% requirement for weeds is intended for field centres, so considering this threshold for field boundaries is rather demanding. Consequently, a 60% WEP limit was chosen as a descriptor that is a measurable figure in field assessments. Boundaries that exceed this value would probably not harbour weeds at such densities, whereas those with < 60% WEP may be considered a potential weed reservoir.

As the presence of WEP is directly related to boundary management, the main requirement to achieve these figures is to avoid boundary soil disturbance to enable establishment of perennial species.

Field boundary typology

Our study is the first to propose a typology of boundaries in arable fields in the European Mediterranean area. The wide range of boundary types influenced species assemblages (Figs. 1, 2), indicating that this typology provides a more complete description of boundary structure than a classification based on vegetation physiognomy, such as from woodlands to ruderal vegetation (Marshall & Moonen, 2002).

Influence of typology on most frequent and most abundant species

In Catalonia, increasing boundary complexity led to increasing differences in the most frequent and abundant species. This trend confirms that the proposed typology may be useful for predicting the occurrence of weed species in boundaries. Boundary narrowness suggests that both herbicide and fertilizer drift are greater under these circumstances. Likewise, we found that, among the most prominent species, structurally complex boundaries contained a pool of perennial species from the surrounding patches of natural vegetation. The results clearly relate main weeds with structurally more simple boundaries, confirming the initial hypothesis.

While some weeds were recorded from all five boundary types, the subset of the common weeds was more abundant in the most structurally simple, with the exception of *B. diandrus* that exceeded 10% cover in several boundary types. This finding partially confirms the common concern that this problematic species is in hosted in structurally simple boundaries (Pallavicini *et al*., 2013); however, Kleijn and Verbeek (2000) and Marshall and Arnold (1995) stated that problematic weeds are barely present in boundaries, probably because they studied more complex structures than Pallavicini *et al*. (2013). Agricultural intensification tends to cause a reduction in plant diversity in boundaries (Kleijn & Verbeek, 2000; Gove *et al*., 2007; Solé-Senan *et al*., 2014; Solé-Senan *et al.*, 2018), where vegetation composition is more influenced by fertilisers than by herbicides (Marshall & Moonen, 2002). This finding is corroborated in our study by the presence and abundance values of nitrophilous species, such as *Glebionis coronaria* (L.) Cass. ex Spach., *P. aviculare*, *B. diandrus* and *A. clavatus*, in boundary types A and B. As type A includes the narrowest boundaries, the impact of fertiliser drift may contribute to the persistence of these eutrophication-tolerant species (Robinson &

Sutherland, 2002). Therefore, differences found in species assemblages reflected differences in disturbance and nutrient regime among boundary types.

Our study shows the positive effects of perennial species (in boundaries of types C, D and E) by reducing annual weed seedling recruitment. For example, grasses such as *L. spartium*, *B. phoenicoides* and *D. glomerata* are effective in excluding weeds, as suggested by Critchley *et al*. (2006), but these species may impact negatively on rare arable plant populations (Marshall, 2009). The NMDS analysis showed that rare plants were more common in boundaries of types B and E, but seldom found in the FCs; despite the association between these weeds and crops, they probably did not meet the appropriate conditions to establish due to contemporary use of fertilisers and herbicides, and sowing cereals at high density. In contrast, these rare plant species were more abundant in boundaries, probably due to disturbance regimes. Thus, whereas fields were historic sources of these species, boundaries now represent resource sinks.

Our results do not differ from other studies that revealed significant associations between the presence and amount of perennial species and species assemblages in boundaries (Le Coeur *et al*., 2002). Moreover, boundaries tended to be wider in other studies and, therefore, were less affected by disturbance than the narrow boundaries that are typical of those around Spanish cereal fields. The lack of disturbance by soil cultivation or cutting and mowing promotes the presence of perennial species, but not of annuals (Smith *et al*., 2010).

Salsola vermiculata was among the most frequent and abundant species in the Aragonese boundaries, only. In Aragon, no species overlap was found among the four most frequent and abundant weeds in boundaries and field centres of any of the five boundary types analysed (S3, S4), suggesting that conditions in Aragonese cereal fields and their boundaries are profoundly different. Yet, *L. rigidum* was the most frequent and abundant species in the field centres of Catalonia, demonstrating a uniform weed flora inside the fields.

The results of the NMDS demonstrate that more complex boundaries are not only related to a lower abundance of common weeds in the boundaries, but also in the FCs, reflecting basic agronomic objectives. Therefore, the proposed boundary classification is useful to predict the risk of weed appearance in the boundaries and possibly also in the FCs.

Although no differences between floristic composition of B and FC in Andalusia were found (see the strong intersection between the centroids of the cluster groups), in general, Bs of Aragon and Catalonia differ from their respective FCs. This difference between regions reflects the fact all the sampled boundaries in Andalusia were classified as Type A, whereas in Aragon and Catalonia there was a mix of boundary types.

As expected, weed composition in the Aragonese FC was more diverse, probably due to lower levels of agricultural intensification than in Catalonia. Accordingly, FC type A from Catalonia contained the greatest weed abundance, reflecting the more intensive agricultural management of these fields.

Species frequency and abundance data were complementary, and we recommend the assessment of both in future work, because we found the most abundant species in Aragon and Catalonia boundaries were mostly non-weed species (except *B. sterilis* in boundaries of types A and C and *A. fatua* in boundaries type A in Catalonia). Thus, the focus on most frequent species results in a more negative perception of the weed problem, whereas recording abundance shows that different species grow in both environments (B, FC) of boundaries classified as types B, C, D and E.

Boundary management is determined by boundary type

Disturbance, which promotes more annual species (which are often weeds) and fewer perennials (Schippers & Joenje, 2002; de Cauwer *et al*., 2008), should be avoided if the aim is to prevent weed invasions in boundaries. If field management cannot be changed, structural elements, such as presence of a bank, increasing width, and presence of stonewalls, contribute to the limitation of vegetation disturbance. Cultivation or mowing and removing cuttings in newly established boundaries to reduce weeds, as suggested by de Cauwer *et al*. (2008), cannot be conducted in boundaries on banks or on stonewalls, and grazing is limited by presence of a bank; however, agronomic practices conducted inside the field may reach the boundary, especially when a bank is absent or boundaries are narrow. If boundary structure hinders machinery access and soil cultivation, levels of disturbance, such as soil tillage, fertiliser and herbicide drift, will be lower in boundary habitats than in the field centre (Schmitz *et al*., 2014). Boundary width and presence of a bank determine the likelihood of management operations and, thus, the presence of weeds in boundaries. Unfortunately, few studies take into account boundary structure with or instead of landscape structure descriptors (but see Marshall & Arnold, 1995; Aavik & Liira, 2010), possibly because much research is conducted in quite homogeneous boundary types. Therefore, we recommend that researchers include descriptors as proposed in this work (but see Kleijn & Verbeek 2000; Reberg-Horton *et al*., 2011) that are easy to measure, facilitate comparison between studies and improve Agri-Environmental Schemes focused on the promotion of boundaries, without increasing the risk of problem weeds that may invade nearby fields. This approach would allow the combination of environmental and production goals.

Acknowledgements

We thank S. Murillo and R. Gurrucharri (Government of Aragon) for their help in choosing the boundaries and FEDER funds and the Spanish Ministry of Economy and Competitiveness for supporting this work (Projects AGL2007-60828, AGL2010-22084-C02-02 and AGL2012-33736). YP was supported by an FPI (Spanish Ministry of Economy and Competitiveness) scholarship. XS was supported by a UdL (Universitat de Lleida) scholarship. Thanks to J. Torra, A. Royo and J.A. Conesa in the field surveys. Finally, we thank the reviewers, subject editor and EiC for useful improvements of the MS.

References

AAVIK T & LIIRA J (2010) Quantifying the effect of organic farming, field boundary type and landscape structure on the vegetation of field boundaries. *Agriculture, Ecosystems and Environment* **135**, 178-186.

ABOUCAYA A, JAUZEIN P, VINCIGUERRA L & VIREVAIRE M (2000) *Plan National d'Action pour la conservation des plantes messicoles*. Rapport final. Direction de la Nature et des Paysages. Ministère de l'Aménagement du Territoire et de l'Environnement. Available at: http://messicoles.org/files/fichierressource_Aboucaya_2000_rapportplannational.pdf (last accessed 13th June 2018).

BASSA M, CHAMORRO L, JOSÉ-MARIA L, BLANCO-MORENO JM & SANS FX (2012) Factors affecting plant species richness in field boundaries in the Mediterranean region. *Biodiversity and Conservation* **21**, 1101-1114.

De BOLÓS O, VIGO J, MASALLES & NINOT JM (1990) *Flora Manual del Països Catalans* (ed. Pòrtic). Barcelona, Spain.

De CAUWER B, REHEUL D, NIJS I & MILBAU A (2008) Management of newly established field margins on nutrient-rich soil to reduce weed spread and seed rain into adjacent crops**.** *Weed Research* **48**, 102–112.

CIRUJEDA A, AIBAR J & ZARAGOZA C (2011) Remarkable changes of weed species in Spanish cereal fields from 1976 to 2007. *Agronomy for Sustainable Development* **31**, 675-688.

CIRUJEDA A, LANGA E, MURILLO S, CAMARERO JJ & ZARAGOZA C (2007) Estudio de la composición y cobertura de la vegetación en franjas entre cultivos de diferentes edades. In: *Proceedings of the 2007 Congress of the Spanish Weed Society* (J Mansilla, A Artigao, JA Monreal, editors) (7-9 November, Albacete, Spain). 155-158. Albacete, Spain.

CIRUJEDA A, MARÍ A, MURILLO S, AIBAR J & ZARAGOZA C (2013) La flora en los márgenes internos no supone una amenaza para los campos colindantes en zonas cerealistas de Aragón. In: *Proceedings of the 2013 Congress of the Spanish Weed Society* (JM Osca, D Gómez de Barreda, V Castell, N Pascual, editors) (5-7 November 2013, Valencia, Spain). 269-273. Valencia, Spain.

CRITCHLEY CNR, FOWBERT JA, SHERWOOD AJ & PYWELL RF (2006) Vegetation development of sown grass margins in arable fields under a countrywide agri-environment scheme. *Biological Conservation* **132**, 1-11.

Le COEUR D, BAUDRY J, BUREL F & THENAIL C (2002) Why and how we should study field boundary biodiversity in an agrarian landscape context. *Agriculture, Ecosystems and Environment* **87**, 23-40.

FRIED G, PETIT S, DESSAINT F & REBOUD X (2009) Arable weed decline in Northern France: crop edges as refugia for weed conservation? *Biological Conservation*, 142, 238-243.

GEROWITT B, HEITEFUSS R (1990) Weed economic thresholds in cereals in the Federal Republic of Germany. *Crop Protection* 9, 323-331.

GONZÁLEZ-ANDÚJAR JL & SAAVEDRA M (2003) Spatial distribution of annual grass weed populations in winter cereals. *Crop Protection* **22**, 629-633.

GOVE B, POWER SA, BUCKLEY GP & GHAZOUL J (2007) Effects of herbicide spray drift and fertilizer overspread on selected species of woodland ground flora: comparison between short-term and long-term impact assessments and field surveys. *Journal of Applied Ecology* **44**, 374-384.

GREAVES MP & MARSHALL JP (1987) Field margins: definitions and statistics. Monograph No 35, Field Margins. British Crop Protection Council.

HOVD H & SKOGEN A (2005) Plant species in arable field margins and road verges of central Norway. *Agriculture Ecosystems & Environment* **110**, 257-265.

KLEIJN D, van der VOORT LAC (1997) Conservation headlands for rare arable weeds: The effects of fertilizer application and light penetration on plant growth. *Biological Conservation* **81**, 57-67.

KLEIJN D & VERBEEK M (2000) Factors affecting the species composition of arable field boundary vegetation. *Journal of Applied Ecology* **37**, 256-266.

LEFCHECK, J (2012) *NMDS tutorial in R.* Available at: https://jonlefcheck.net/2012/10/24/nmds-tutorial-in-r (last accessed 04th July 2018).

LEGENDRE P & LEGENDRE L (1998) Numerical Ecology, 2nd English edition. Elsevier; Amsterdam, The Netherlands.

LEPS J & SMILAUER P (2007) Subjectively sampled vegetation data: don't throw out the baby with the bath water. *Folia Geobotanica* **42**, 169-178.

MAAMA (Ministerio de Agricultura, Alimentación y Medio Ambiente) (2015) *Guía de Gestión Integrada de Plagas. Cereales de Invierno*. Available at: http://www.magrama.gob.es/es/agricultura/temas/sanidad-vegetal/productos-fitosanitarios/guias-gestion-plagas/ (last accessed 13th June 2018) (page 169).

MANTE J & GEROWITT B (2009) Learning from farmers' needs: Identifying obstacles to the successful implementation of field margin measures in intensive arable regions. *Landscape and Urban Planning* **93**, 229-237.

MARSHALL EJP (1989) Distribution patterns of plants associated with arable field edges. *Journal of Applied Ecology* **26**, 247-257.

MARSHALL EJP & ARNOLD GM (1995) Factors affecting field weed and field margin flora on a farm in Essex, UK. *Landscape and Urban Planning* **31**, 205-216.

MARSHALL EJP (2009) The impact of landscape structure and sown grass margin strips on weed assemblages in arable crops and their boundaries. *Weed Research* **49**, 107-115.

MARSHALL EJP & MOONEN AC (2002) Field margins in northern Europe: their functions and interactions with agriculture. *Agriculture, Ecosystems and Environment* **89**, 5-21.

MORRISON J, HERNÁNDEZ PLAZA E, IZQUIERDO J & GONZÁLEZ-ANDÚJAR JL (2017). The role of field margins in supporting wild bees in Mediterranean cereal agroecosystems: Which biotic and abiotic factors are important? *Agriculture, Ecosystems & Environment* **247**, 216-224.

OKSANEN J, BLANCHET FG, KINDT R, LEGENDRE P, MINCHIN PR, O'HARA RB, SIMPSON GL, SOLYMOS P, STENVENS MHH, WAGNER H (2013) vegan: Community Ecology Package. R package version 2.0-10. Available at: http://CRAN.R-project. org/package=vegan (last accessed 26th June 2017).

PALLAVICINI Y, BASTIDA F, PUJADAS A, IZQUIERDO J & GONZÁLEZ-ANDÚJAR JL (2013) Comparación de la riqueza y la composición de especies arvenses entre los diferentes hábitats de los cultivos cerealistas. In: *Proceedings of the 2013 Congress of the Spanish Weed Society* (JM Osca, D Gómez de Barreda, V Castell, N Pascual, editors) (5-7 November 2013, Valencia, Spain). 195-198. Valencia, Spain.

R DEVELOPMENT CORE TEAM (2008) *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.

REBERG-HORTON SC, MUELLER JP, MELLAGE SJ, CREAMER NG, BROWNIE C, BELL M & BURTON MG (2011) Influence of field margin type on weed species richness and abundance in conventional crop fields. *Renewable Agriculture and Food Systems* **26**, 127-136.

ROBINSON RA & SUTHERLAND WJ (2002) Post-war changes in arable farming and biodiversity in Great Britain. *Journal of Applied Ecology* **39**, 157–176.

SCHIPPERS P & JOENJE W (2002) Modelling the effect of fertiliser, mowing, disturbance and width on the biodiversity of plant communities of field boundaries. *Agriculture Ecosystems & Environment* **93**, 351-365.

SCHMITZ J, SCHAFER K & BRUHL CA (2014) Agrochemicals in field margins – Field evaluation of plant reproduction effects. *Agriculture Ecosystems & Environment* **189**, 82-91.

SMITH H, FEBER RE, MORECROFT MD, TAYLOR ME & MACDONALD DW (2010) Short-term successional change does not predict long-term conservation value of managed arable field margins. *Biological Conservation* **143**, 813–822.

SOLÉ-SENAN XO, JUÁREZ-ESCARIO A, CONESA JA, TORRA J, ROYO-ESNAL A & RECASENS J (2014) Plant diversity in Mediterranean cereal fields: unravelling the effect of landscape complexity on rare arable plants. *Agriculture, Ecosystems and Environment* **185**, 221-230.

SOLÉ-SENAN XO, JUÁREZ-ESCARIO A, ROBLEÑO I, CONESA JA, & RECASENS J (2017) Using the response-effect trait framework to disentangle the effects of agricultural intensification on the provision of ecosystem services by Mediterranean arable plants. *Agriculture, Ecosystems and Environment* **247**, 255-264.

SOLÉ-SENAN XO, JUÁREZ-ESCARIO A, CONESA JA & RECASENS J (2018) Plant species, functional assemblages and partitioning of diversity in a Mediterranean agricultural mosaic landscape. *Agriculture, Ecosystems and Environment* **256**, 163-172.

SMILAUER P & LEPS J (2014) *Multivariate Analysis of Ecological Data using Canoco 5*, second edition. Cambridge University Press, United Kingdom.

Supporting Information

Additional supporting information may be found in the online version of this article:

Fig. S1 RDA analysis showing the effect of boundary width, presence of a bank and of stonewalls in species distribution of the Aragonese and Catalonian surveys, grouping the species into the five selected annual main weeds (CW), other annual plants (AP), rare arable plants (RAP), herbaceous perennials (hemicryptophytes and geophytes) (HP) and woody and evergreen perennials (WEP). >3m: boundaries wider than 3m; <3m: boundaries narrower than 3m; bank: boundaries forming a bank; flat: boundaries without forming a bank.

Table S1. Environmental characteristics and boundary and crop management data

Table S2. List of the species included in the group of woody and evergreen perennials (WEP) following Bolós et al. (1990). The plants were selected because of their functional trait of covering the soil and offering shade all year round so that some non-woody species are also included (e.g. *Aphyllantes monspeliensis*). Names in bold refer to trees.

Table S3. The four most frequent species in boundaries and in field centres in three Spanish regions. Frequency (%) / mean abundance (%) considered only when found. [1]: abundance of plants m^{-2}; [2]: abundance in % soil cover. a) Most frequent species in boundaries, b) in inner fields. Boundaries (B), field centres (FC). Bold figures indicate the highest values.

Table S4. Data for the four most abundant species in boundaries (B) and field centres (FC) in three Spanish regions. Frequency (%) / mean abundance (%) considered only when found. [1]: abundance of plants m^{-2}; [2]: abundance in % soil cover. a) Most abundant species in the FMs, b) in the FCs. Bold figures indicate the highest values.

Figure legends

Fig. 1 Points and regression lines relating the percentage of plant cover of the common weeds *Avena sterilis, Bromus diandrus, Lolium rigidum* and *Papaver rhoeas* and the sum of all four weeds with the percentage of plant cover of woody and evergreen perennials in the boundaries. Weed sum=15.794-0.2085x, R^2=0.132, P<0.001; *Avena sterilis*=2.185-0.0318x, R^2=0.0236, P=0.03; *Bromus diandrus*=8.6233-0.1036x, R^2=0.0587, P<0.001; *Papaver rhoeas*=2.349-0.0353x, R^2=0.0657, P<0.001; *Lolium rigidum*=2.6361-0.0377x, R^2=0.0312, P=0.012. Data from Aragon and Catalonia pooled together.

Fig. 2 Biplot of the RDA of species assemblages as response variables and descriptors as explanatory variables. Species with abundance >20% are shown, where ALYSIM: *Allyssum simplex*, ANACLA: *Anacyclus clavatus*, AVESTE: *Avena sterilis*, BRAPHO: *Brachipodium phoenicoides*, BRARET: *B. retusum*, BRODIA: *Promus diandrus*, BRORUB: *B. rubens*, CIRARV: *Cirsium arvensis*, CONARV: *Convolvulus arvensis*, DACGLO: *Dactylis glomerata*, DIPERU: *Diplotaxis erucoides*, ELYREP: *Elymus repens*, FILPYR: *Filago pyramidata*, FUMOFF: *Fumaria officinialis*, GALAPA: *Galium aparine*, HORMUR: *Hordeum murinum*, LACSER. *Lactuca serriola*, LAMAMP: *Lamium amplexicaule*, LOLRIG: *Lolium rigidum*, LYGSPA: *Lygeum spartum*, MANSAL: *Mantisalca salmantica*, PAPRHO: *Papaver rhoeas*, PHAMIN: *Phalaris minor*, SALVEM: *Salsola vermiculata*, SONTEN: *Sonchus tenerrimus*, TORNOD*: Torilis nodosa* and VICPER: *Vicia peregrina*. Species in bold are main weeds. >3m: boundaries wider than 3m; <3m: boundaries narrower than 3m; bank: boundaries forming a bank; flat: boundaries without forming a bank.

Fig. 3 Field boundary classification diagram and description.

Fig. 4 NMDS ordination diagram of species compositional data regarding region, field position and boundary type. Centroids of cluster groups are shown with continuous lines for boundaries, discontinuous lines for field centres whereas (+) correspond to the averages obtained after fitting each position onto the ordination ($P < 0.001$). FC: field centre, B: boundary.

Table 1. Monte-Carlo permutation test on the explanatory variables from the RDA analyses.

	Species assamblages			Functional types		
	Explains %	F-value	p-value	Explains %	F-value	p-value
% WEP	11.9	26.8	0.001	-	-	-
Flat	2.9	5.9	0.001	16.5	28.1	0.001
Bank	2.9	5.9	0.001	16.5	28.1	0.001
> 3m	2.4	5	0.001	7.6	12.7	0.001
< 3m	2.1	4.2	0.002	6.3	10	0.001
SW	0.6	1.1	0.291	4.5	7	0.056

SW: Stonewall

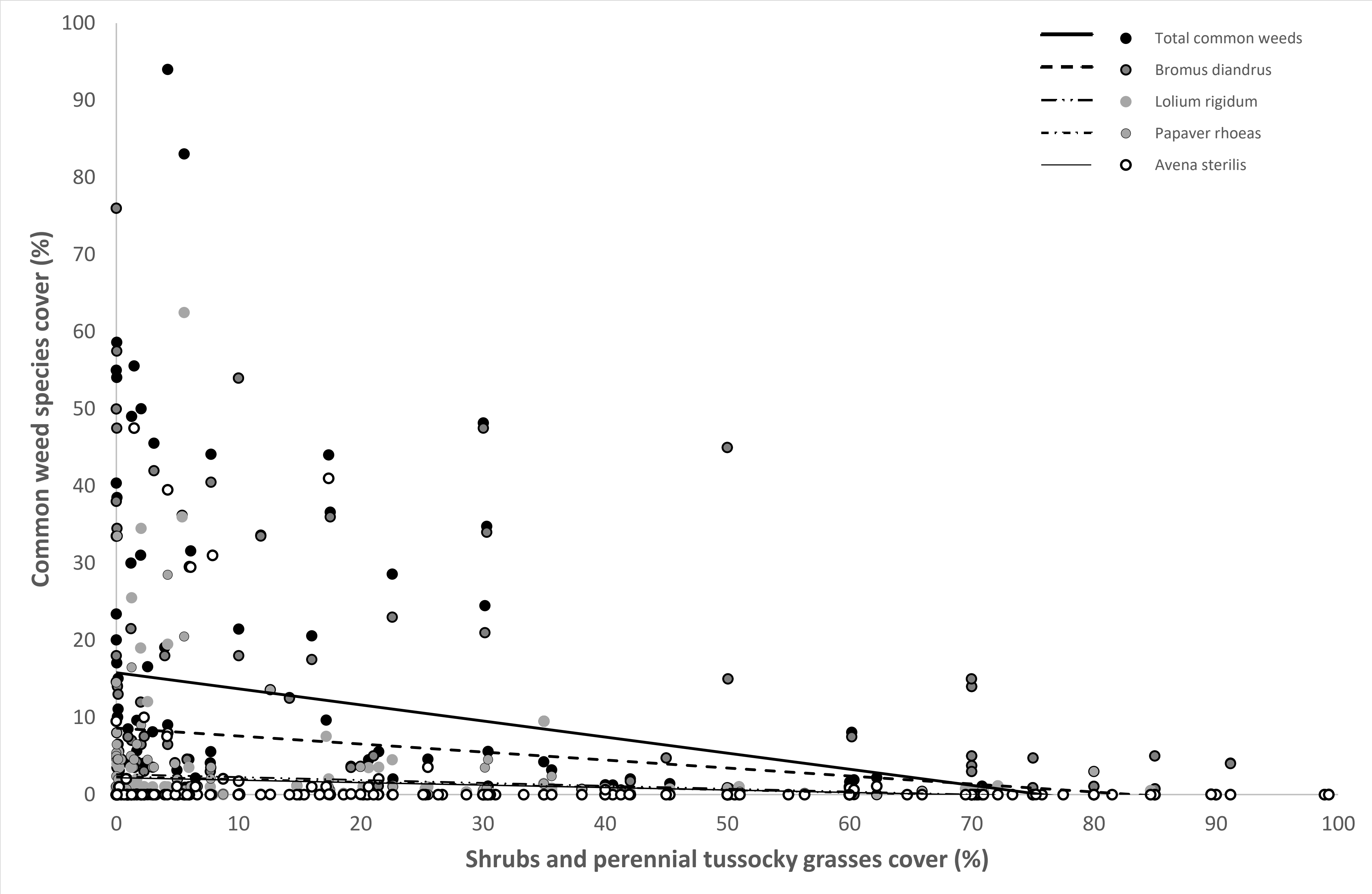
% WEP: woody and evergreen perennials.

Table 2. Common arable weed frequency (%) / mean abundance in the boundaries (B) and field centers (FC) in three Spanish regions. In bold highest values for each species per region and boundary type. Species selected following [1]González-Andújar and Saavedra (2003), [2]following Cirujeda *et al.* (2011).

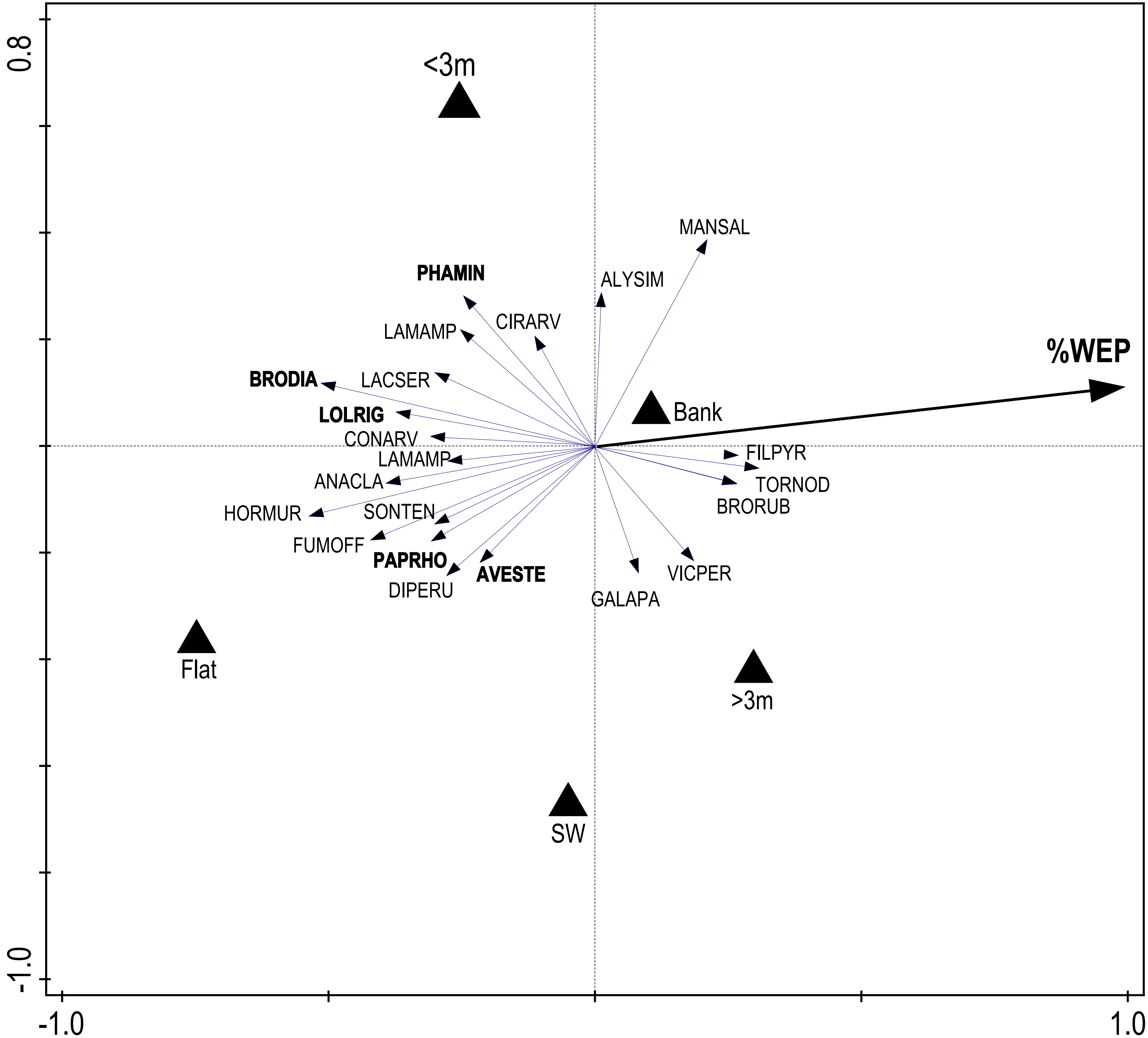
		Andalusia[1] (abundance in plants m^{-2})		Aragon[2] (abundance in % plant cover)		Catalonia[2] (abundance in % plant cover)	
		B	FC	B	FC	B	FC
Type A	*Avena sterilis*	**48/5**	44/3	-	-	**44**/13	31/**30**
	Bromus diandrus	-	-	-	-	**75**/10	25/**39**
	Lolium rigidum	**87/13**	30/8	-	-	**87**/10	81/**22**
	Papaver rhoeas	**27/2**	26/1	-	-	**81/11**	75/3
	Phalaris minor	**39/4**	35/1	-	-	-	-
	Mean	**50/6**	34/3	-	-	**72**/11	53/**24**
Type B	*A. sterilis*	-	-	**8/1.0**	3/1	**30**/6	20/6
	B. diandrus	-	-	**41/27**	3/0.4	**80/7**	20/0.1
	L. rigidum	-	-	30/0.6	**68/2**	**80**/0.3	70/**6**
	P. rhoeas	-	-	**30/2**	8/1	**65**/1	55/**4**
	Mean	-	-	**27/8**	21/1	**64**/4	41/4
Type C	*A. sterilis*	-	-	**3/10**	-	**27**/8	18/**14**
	B. diandrus	-	-	**30**/6	15/**12**	**91/12**	23/2
	L. rigidum	-	-	30/2	**64/3**	**91/6**	77/4
	P. rhoeas	-	-	15/2	**24/3**	**100**/2	91/**6**
	Mean	-	-	20/5	**26**/5	77/7	52/7
Type D	*A. sterilis*	-	-	**7/1**	-	60/2	60/10
	B. diandrus	-	-	**30**/6	7/**9**	**50**/0.04	-
	L. rigidum	-	-	20/1	**45/3**	**60**/1	40/**32**
	P. rhoeas	-	-	**16**/1	9/**3**	**60/1**	40/0.1
	Mean	-	-	**18**/2	15/**4**	**58**/1	35/**11**
Type E	*A. sterilis*	-	-	-	-	**39**/6	22/**19**
	B. diandrus	-	-	-	-	**44/13**	22/1
	L. rigidum	-	-	-	-	**94**/0.2	83/7
	P. rhoeas	-	-	-	-	44/**2**	**61**/0.2
	Mean	-	-	-	-	**55**/5	47/7

Table 3. Abundance of functional plant groups across the five boundary types in the three studied regions in Spain. CW: Common weeds (*A. sterilis*, *B. diandrus*, *L. rigidum*, *P. rhoeas*, *P. minor*); AP: annual plants; RAP: rare arable plants; HP: herbaceous perennial species (hemicryptophytes and geophytes). Woody and evergreen perennials were excluded in the calculations because they form part of the criteria for boundary type definition.

		Andalusia (plants m^{-2})	Aragon (% soil cover)	Catalonia (% soil cover)
Boundary type A	CW	6.3	-	11.5
	AP	83.1	-	61.3
	RAP	-	-	0.1
	HP	7.5	-	15.0
Boundary type B	CW	-	4.4	8.2
	AP	-	66.5	51.6
	RAP	-	-	5.0
	HP	-	7.3	4.3
Boundary type C	CW	-	5.1	7.3
	AP	-	20.7	16.8
	RAP	-	-	2.0
	HP	-	8.2	5.4
Boundary type D	CW	-	2.3	1.4
	AP	-	21.4	18.7
	RAP	-	-	0.8
	HP	-	5.8	5.9
Boundary type E	CW	-	-	5.1
	AP	-	-	51.1
	RAP	-	-	5.9
	HP	-	-	11.7



Total common weeds
Bromus diandrus
Lolium rigidum
Papaver rhoeas
Avena sterilis
Common weed species cover (%)
Shrubs and perennial tussocky grasses cover (%)
0
10
20
30
40
50
60
70
80
90
100



0.8
-1.0
-1.0
1.0
<3m
MANSAL
ALYSIM
PHAMIN
CIRARV
LAMAMP
%WEP
BRODIA
LACSER
Bank
LOLRIG
CONARV
LAMAMP
FILPYR
ANACLA
TORNOD
BRORUB
HORMUR
SONTEN
FUMOFF
PAPRHO
AVESTE
VICPER
DIPERU
GALAPA
Flat
>3m
SW

%WEP <60% / >60%	SLOPE FLAT or BANK	WIDTH <3m >3m	TREE	STONE WALL	FINAL STRUCTURE
<60%	FLAT	<3m	NO	NO	**TYPE A** 
<60%	BANK	<3m or>3m	NO	NO	**TYPE B** 
>60%	BANK	<3m or >3m	NO	NO	**TYPE C** 
>60%	BANK	<3m or >3m	YES	NO	**TYPE D** 
–	–	–	NO/YES	YES	**TYPE E** 

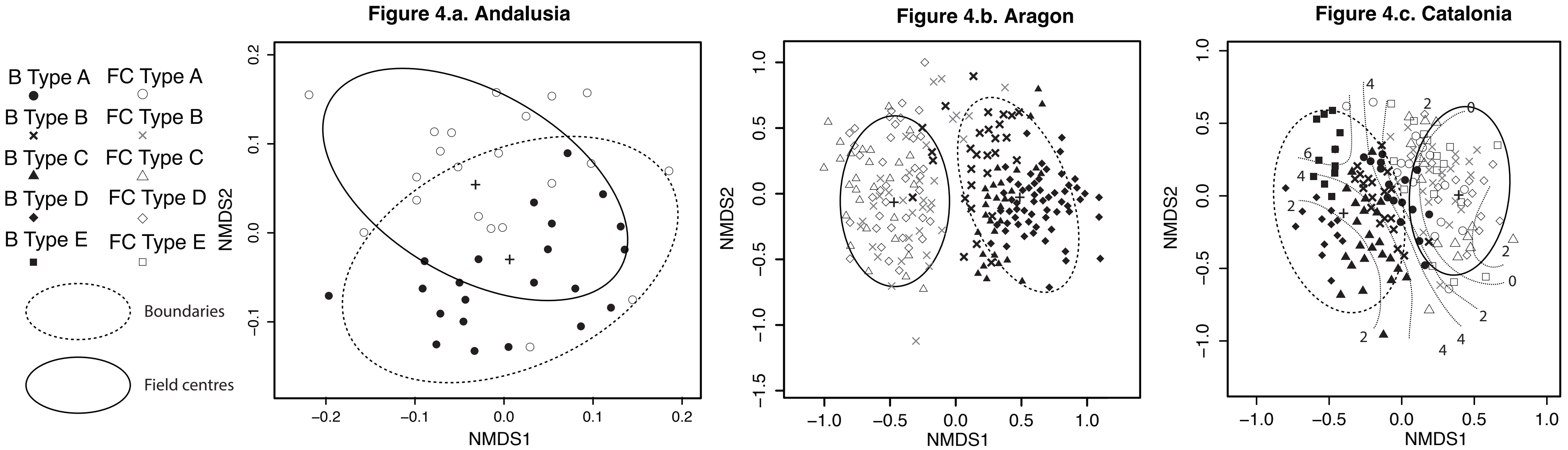


Figure 4.a. Andalusia
Figure 4.b. Aragon
Figure 4.c. Catalonia
B Type A
B Type B
B Type C
B Type D
B Type E
FC Type A
FC Type B
FC Type C
FC Type D
FC Type E
Boundaries
Field centres
NMDS1
NMDS2

Table S1. Environmental characteristics and boundary and crop management data

Sampling information	Andalusia	Aragon	Catalonia
Sampling years	2010 and 2011	2011 and 2012	2008
Sampling period	April and May	April and May	May to July
Sampled boundaries and fields	23	120	90
Environmental characteristics			
Altitude (m a.s.l.)	28-675	212-587	250-950
Mean rainfall (mm)[1]	534	318	370-560
Boundary descriptors			
Boundary width (m)	1.5 ± 1.29 [0.3-5.8]	2.8 ± 1.03 [1.0-6.0]	Field boundaries were classified into narrower or wider than 3m
Boundary height (m)	0.5 ± 0.23 [0.1-0.9]	1.1 ± 0.52 [0.3-2.5]	Data not available
Slope (%)	Flat	7.7 ± 4.98 [0-23.4]	Flat, steep
Position of the boundary	Outer borders and between-field	Between-field	Outer borders and between-field
Boundary and field crop management			
Boundary age	Unknown, irregular, but intensively managed	Probably more than 20	Probably more than 20
Herbicide use in the field	Usually graminicides	Usually auxinic herbicide in spring	Usually graminicides in winter and dicotyledoneous control in spring
Fertilizer use in the field	Annual or split into two applications	Annual or split into two applications	Annual or split into two applications
Burning / mowing / grazing / herbicide on the boundary?	Sporadic cultivation	No management and sporadic sheep grazing	No management and sporadic sheep grazing
Landscape indicators			
Forest or natural vegetation is abundant nearby (% soil cover)[2]	30-50	50-80	5-80

[1]Source: Agencia Estatal de Meteorología (1971-2000).

[2]Percentage cover was calculated drawing a circle on the aerial photograph of 1 km radius and calculating the percentage cover using the software gvsig v.1.12.0.

Table S2. List of the species included in the group of shrubs and perennial tussocky grasses following Bolós et al. (1990). The plants were selected because of their functional trait of covering the soil and offering shade all year round so that some non-woody species are also included (e.g. *Aphyllantes monspeliensis*). Names in bold refer to trees.

Woody and evergreen perennials	Perennial grasses
Alyssum montanum	*Agrostis stolonifera*
Aphyllantes monspeliensis	*Arrhenatherum elatius*
Argyrolobium zanonii	*Avenula pratensis*
Artemisia campestris subsp. *glutinosa*	*Brachypodium phoenicoides*
Artemisia herba-alba	*Brachypodium retusum*
Asparagus acutifolius	*Dactylis glomerata*
Astragalus incanus	*Elymus hispidus*
Atractylis humilis	*Elymus pungens*
Biscutella laevigata	*Elymus repens*
Bupleurum fruticescens	*Festuca ovina*
Celtis australis	*Festuca rubra*
Centaurea alba	*Koeleria vallesiana*
Centaurea aspera	*Lygeum spartum*
Centaurea linifolia	*Melica ciliata* subsp. *magnolii*
Cephalaria leucantha	*Oryzopsis miliacea*
Cistus albidus	*Phragmites australis*
Cistus clusii	*Poa bulbosa*
Clematis flammula	*Poa nemoralis*
Clematis vitalba	*Poa pratensis*
Coronilla minima subsp. *minima*	*Poa trivialis*
Crataegus monogyna	*Scirpus holoschoemus*
Dianthus pungens	*Stipa offneri*
Dorycnium hirsutum	
Dorycnium pentaphyllum	
Euphorbia amygdaloides	
Euphorbia characias	
Fraxinus angustifolia	
Genista biflora	
Genista cinerea	
Genista hispanica	
Genista scorpius	
Hedera helix	
Hedysarum boveanum subsp. *europaeum*	
Helianthemum apenninum subsp. *pilosum*	
Helianthemum nummularium subsp. *tomentosum*	
Helianthemum oelandicum	
Helianthemum origanifolium	
Inula viscosa	
Jasminum fruticans	
Kochia scoparia	
Limonium hibericum	
Linum narbonense	
Linum tenuifolium subsp. *suffruticosum*	
Lithospermum fruticosum	

Marrubium vulgare
Olea europaea
Ononis natrix
Ononis pusilla
Ononis spinosa
Ononis tridentata
Osyris alba
Pistacea terebinthus
Plantago albicans
Plantago sempervirens
Prunus dulcis
Prunus mahaleb
Prunus spinosa
Quercus coccifera
Quercus faginea
Quercus ilex* subsp. *ballota
Quercus subpyrenaica
Rhamnus alaternus
Rhamnus lycioides
Rhamnus saxatilis
Rosa canina
Rosmarinus officinalis
Rubia tinctorum
Rubus caesius
Rubus ulmifolius
Rubus x *assurgens*
Ruta montana
Salsola vermiculata
Salvia officinalis subsp. *lavandulifolia*
Sambucus nigra
Santolina chamaecyparissus
Satureja montana
Sedum album
Sedum sediforme
Sideritis hirsuta
Sideritis spinulosa subsp. *ilicifolia*
Solanum dulcamara
Teucrium polium
Thymelaea tinctoria
Thymus serpyllum subsp. *fontqueri*
Thymus vulgaris subsp. *palearensis*
Thymus vulgaris subsp. *vulgaris*
Ulmus minor
Vitis vinifera

Table S3. The four most frequent species in boundaries and in field centres in three Spanish regions. Frequency (%) / mean abundance (%) considered only when found. [1]: abundance of plants m^{-2}; [2]: abundance in % soil cover. Most frequent species in a) boundaries, and b) in the field centre. Boundaries (B), field centres (FC). Bold figures indicate the highest values.

		Andalusia[1]			Aragon[2]			Catalonia[2]		
			B	FC		B	FC		B	FC
Type A		*Lolium rigidum*	**87**/**13**	30/8				*L. rigidum*	**88**/10	81/**22**
		Glebionis coronaria	**65**/**9**	4/2				*Papaver rhoeas*	**81**/**11**	75/3
	a)	*Sonchus oleraceous*	**65**/1	30/**43**	-			*C. arvensis*	**81**/1	63/1
		Polygonum aviculare	**62**/**13**	61/8				*Bromus diandrus*	**75**/10	25/**39**
		Anagallis arvensis	57/4	**65**/**6**				*L. rigidum*	**88**/10	81/**22**
		Convolvulus arvensis	35/5	**65**/5				*P. rhoeas*	**81**/**11**	75/3
	b)	*Pulicaria paludosa*	48/7	**57**/**12**	**-**			*C. arvensis*	**81**/1	63/1
		P. aviculare	**62**/**13**	61/8				*Polygonum aviculare*	44/1	**56**/**3**
Type B					*Salsola vermiculata*	**51**/**33**	5/0.2	*B. diandrus*	**80**/**7**	20/0.1
					Sonchus oleraceus	**49**/**1**	14/0.3	*L. rigidum*	**80**/0.3	70/**6**
	a)	-			*Bromus rubens*	**46**/**6**	5/0.4	*P. rhoeas*	**65**/1	55/**4**
					Anacyclus clavatus	**43**/**5**	27/0.6	*C. arvensis*	**60**/**2**	50/1
					L. rigidum	21/1	**46**/**3**	*P. aviculare*	10/1	**75**/1
					C. arvensis	7/1	**46**/**2**	*L. rigidum*	**80**/0.3	70/**6**
	b)	-			*Salsola kali*	16/**3**	**39**/2	*P. rhoeas*	**65**/1	55/**4**
					Euphorbia serrata	2/1	**34**/**5**	*C. arvensis*	**60**/**2**	50/1

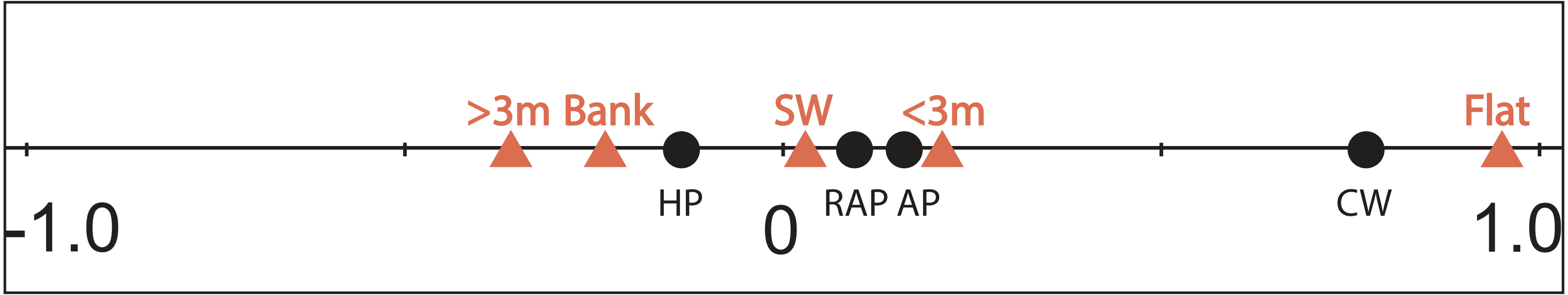
Table S3. (cont)

		Andalusia[1]	B	FC	Aragon[2]	B	FC	Catalonia[2]	B	FC
Type C					*Salsola vermiculata*	**70**/**37**	0/0	*P. rhoeas*	**100**/2	91/**6**
					Phalaris minor	**55**/**3**	0/0	*L. rigidum*	**91**/**6**	77/4
	a)	-			*B. rubens*	**46**/**4**	0/0	*B. diandrus*	**91**/**12**	23/2
					Mantisalca salmantica	**46**/**2**	0/0	*C. arvensis*	73/**2**	**77**/1
					L. rigidum	30/2	**64**/**3**	*P. rhoeas*	**100**/2	91/**6**
					C. arvensis	15/1	**46**/**2**	*L. rigidum*	**91**/**6**	77/4
	b)	-			*Diplotaxis erucoides*	9/1	**33**/**5**	*C. arvensis*	73/**2**	**77**/1
					Salsola kali	3/**20**	**27**/2	*P. aviculare*	41/1	**46**/1
Type D					*S. vermiculata*	**98**/**42**	5/0.2	*C. arvensis*	80/0.3	80/**1**
					T. nodosa	**55**/**2**	0/0	*Brachypodium phoenicoides*	**60**/**32**	0/0
	a)	-			*P. minor*	**48**/**4**	2/0.2	*D. glomerata*	**60**/**5**	0/0
					Dactylis glomerata	**46**/**9**	0/0	*Genista scorpius*	**60**/**2**	0/0
					L. rigidum	21/1	**46**/**3**	*C. arvensis*	80/0.3	80/**1**
					E. serrata	7/1	**46**/**2**	*P. aviculare*	40/0.3	**60**/**2**
	b)	-			*C. arvensis*	16/3	**39**/2	*A. sterilis*	60/2	60/**10**
					Chondrilla juncea	2/1	**34**/**5**	*L. rigidum*	**60**/1	40/**32**
Type E								*L. rigidum*	**94**/0.2	83/**7**
								S. oleraceus	**72**/**0.1**	28/0
	a)	-			-			*C. arvensis*	61/1	61/1
								Hordeum murinum	**56**/**8**	6/0.04
								L. rigidum	**94**/0.2	83/**7**
								P. rhoeas	44/**2**	**61**/0.2
	b)	-			-			*C. arvensis*	61/1	61/1
								F. officinalis	**56**/**2**	39/0.3

Table S4. Data for the four most abundant species in boundaries (B) and field centres (FC) in three Spanish regions. Frequency (%) / mean abundance (%) considered only when found. [1]: abundance of plants m^{-2}; [2]: abundance in % soil cover. Most abundant species in a) boundaries, and b) in the field centre. Bold figures indicate the highest values.

	Andalusia[1]			Aragon[2]			Catalonia[2]		
		B	FC		B	FC		B	FC
Type A	*Atriplex prostrata*	**507**/**4**	0/0				*Elymus repens*	**6**/**24**	0/0
	Echinochloa colonum	**168**/**4**	0/0				*Bromus sterilis*	**25**/**21**	0/0
a)	*Lythrum acutangulum*	**77**/7	116/**13**	-			*Bromus tectorum*	**6**/**16**	0/0
	Torilis glomerata	**73**/**3**	0/0				*Avena fatua*	**44**/**14**	19/0
	Juncus hybridus	**124**/4	30/4				*Hordeum murinum*	**31**/12	13/**44**
	Elminthotheca echioides	**120**/17	5/17				*Bromus diandrus*	**75**/10	25/**39**
b)	*Lythrum acutangulum*	**116**/**13**	77/9	-			*Avena sterilis*	**44**/13	31/**30**
	Juncus bufonius	**89**/**22**	21/13				*Lolium rigidum*	**88**/10	81/**22**
Type B				*Vulpia ciliata*	**5**/**34**	0/0	*E. repens*	**10**/**23**	0/0
				Salsola vermiculata	**51**/**33**	5/0.2	*Brachypodium phoenicoides*	**50**/**16**	0/0
a)	-			*B. diandrus*	**41**/**27**	3/0.4	*Poa bulbosa*	**5**/**16**	0/0
				Santolina chamaecyparissus	**14**/**20**	0/0	*Kochia scoparia*	10/**15**	**15**/0.1
				Descurainia sophia	**14**/2	3/**9**	*Cynodon dactylon*	**30**/8	10/**29**
				Vicia peregrina	11/1	11/**6**	*K. scoparia*	10/**15**	**15**/7
b)	-			*Chondrilla juncea*	3/0.2	**32**/**4**	*A. sterilis*	**30**/6	20/6
				Malcolmia africana	14/1	**16**/**3**	*L. rigidum*	**80**/0.3	70/**6**
Type C				*S. vermiculata*	**70**/**37**	0/0	*B. sterilis*	**18**/**15**	0/0
				Elymus repens	**42**/**34**	0/0	*Elymus pungens*	**14**/**14**	0/0
a)	-			*Lygeum spartium*	**39**/**31**	0/0	*Rubus ulmifolius*	**9**/**13**	5/1
				Brachypodium retusum	**24**/**29**	0/0	*Satureja montana*	**5**/**12**	0/0

		V. peregrina	**18**/1	15/**12**	*A. sterilis*	**27**/8	18/**14**
		B. diandrus	**30**/6	15/**12**	*A. fatua*	**14**/2	14/**6**
b)	-	*D. sophia*	6/1	**12**/**9**	*P. rhoeas*	**100**/2	91/**6**
		Chondrilla juncea	3/1	**21**/**5**	*P. aviculare*	9/2	**14**/**5**
Type E		*S. vermiculata*	**98**/**42**	5/0.2	*Brachypodium phoenicoides*	**60**/**32**	0/0
		Atriplex halimus	**11**/**37**	2/3	*Rosmarinus officinalis*	**10**/**27**	0/0
a)	-	*L. spartium*	**39**/**25**	0/0	*Elymus pungens*	**50**/**24**	0/0
		Rosmarinus officinialis	**4**/**22**	0/0	*Brachypodium retusum*	**30**/**18**	0/0
		Diplotaxis virgata	**9**/0.7	2/**11**	*L. rigidum*	**70**/1	40/**32**
		Hirschfeldia incana	0/0	**2**/**10**	*A. sterilis*	**70**/2	60/**10**
b)	-	*Vicia peregrina*	**21**/1	9/**10**	*Polygonum bellardi*	10/0	10/**5**
		B. diandrus	**30**/7	7/**9**	*P. aviculare*	40/0.3	**60**/**2**
Type D					*Rubus caesius*	**6**/**39**	0/0
					S. vermiculata	**33**/**38**	6/0
a)	-	-			*Scorpiurus muricatus*	**6**/**15**	0/0
					Arrenatherum elatium	**6**/**15**	0/0
					A. sterilis	**39**/6	22/**19**
					B. sterilis	**22**/6	6/**13**
b)	-	-			*L. rigidum*	**94**/0.2	83/**7**
					Xanthium strumarium	**6**/0	6/**7**


>3m Bank
SW
<3m
Flat
HP
RAP AP
CW
-1.0
0
1.0