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Arable weed decline in Northeast Spain: Does organic farming recover functional biodiversity?

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ABSTRACT

The comparison of the frequency, richness and weed cover of total species and functional groups of weeds, including those of interest for birds, pollinators and other invertebrates, and the subset of segetal and rare species from the 1950s to the present, has allowed to detect the consequences of the agricultural intensification in Catalonia (NE Spain) at regional and field scales. We analyzed field plots of conventionally managed cereal fields of the periods 1953–88 and 1996–99 while cereal fields assessed in the period 2005–07 were organic and conventionally managed. Our results indicate a remarkable reduction in weed frequency (58%), species richness (47%) and total weed cover (69%) from the 1953–1988 to 2005–2007 periods. The diminishing species richness was observed in species that are important for birds, pollinators and other invertebrates, but the most drastic decline was observed in the segetal and rare species subsets (75% and 87%, respectively). In current organic crops, the frequency, richness and total weed cover per relevé are significantly higher than in conventional crops, especially for those groups of species that are interesting for fauna and for segetal (more than twice) and rare species (4-fold). Nevertheless, the increase in arable weeds by current organic management is still insufficient to recover the highest plant biodiversity values that were observed before the widespread agricultural intensification in Catalonia.

1. Introduction

A decline of species richness and abundance of arable weeds in the last decades in relation to agricultural intensification has occurred at regional and field scales (Andreasen et al., 1996; Hyvönen et al., 2003; Baessler and Klotz, 2006; Meyer et al., 2013; Storkey et al., 2012; Richner et al., 2015). The high application rates of chemical herbicides and fertilizers, use of commercial seeds and the monoculture of species or varieties, or the transformation of marginal arable land into grasslands or forests are the main factors that have reduced weed diversity in arable fields (Robinson and Sutherland, 2002; Roschewitz et al., 2005; Hyvönen, 2007; José-María and Sans, 2011). Moreover, the accumulative effects of these high-intensive farming practices are the main drivers that have led to the decrease or disappearance of the segetal flora (a subset of the arable weeds that thrive almost exclusively in cereal fields and that are characteristic species of arable crops) in different European countries (Andreasen et al., 1996; Sutcliffe and Kay, 2000; Baessler and Klotz, 2006; Fuchs and Saacke, 2006; Fried et al., 2009; José-María et al., 2010; Meyer et al., 2013). A meta-study on arable species in Central Europe showed a reduction of species per field of 20–50% for the period between 1950 and 1990 (Albrecht and Bachthaler, 1990), and recently Richner et al. (2015) remarked that changes in agricultural practices have dramatically altered the arable flora of Europe since the Second World War.

The role of weeds is manifold. From an agronomic point of view, they represent a major problem for farmers because of the yield losses that are associated with their presence. Moreover, the decrease in weed diversity has dramatically affected the associated food web and, in turn, the provision of agronomic ecosystem services such as biological pest control and pollination (Robinson and Sutherland, 2002; Marshall et al., 2003). In addition, arable flora provide food and shelter for a wide variety of farmland fauna. Thus, agricultural intensification may reduce functional weeds such as interesting flora for several groups of fauna, including birds (Campbell and Cooke, 1997; Wilson et al., 1999; Marshall et al., 2001, 2003), pollinators (Biesmeijer et al., 2006; Kremen et al., 2002; Potts et al., 2010; Henriksen and Langer, 2013) and other invertebrates such as phytophagous insects and plant pests (Marshall et al., 2001, 2003).

Organic farming has been addressed as an environmental-friendly set of practices that can counter the negative effects of

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agricultural intensification and the decline of biodiversity in agricultural landscapes (Rahmann, 2011). Some comparative studies among organic and conventionally managed systems have shown that weed biodiversity is enhanced in the former (Hole et al., 2005; Roschewitz et al., 2005; Armengot et al., 2012; Gibson et al., 2007; Kleijn et al., 2009). It is also widely acknowledged that less intensive farming practices such as those used in organic farming systems tend to benefit the richness and diversity of segetal flora (Van Elsen, 2000; Fuchs and Saacke, 2006; Romero et al., 2008; José-María et al., 2010) as well as the occurrence of rare arable weeds (Romero et al., 2008). Furthermore, the biodiversity of birds and invertebrates (Hyvönen, 2007), particularly insect pollinators (Holzschuh et al., 2007, 2008), have also benefited from organic farming systems.

The present paper analyses the weed diversity in dry cereal winter crops in Catalonia (Spain) from 458 floristic phytosociological relevés (field plots) surveyed between 1953 and 2007. We have also compared data from organic and conventional cereal field plots that were surveyed during the period 2005–2007 to ascertain to what extent organic farming may recover the current biodiversity decline that is related to agricultural intensification. Changes in the assemblages of weed communities considering segetal and rare species and the functional role of weed species, assessed as the proportion of important weeds for birds, pollinators and phytophagous insects, were also evaluated.

We addressed the following questions: (1) Has weed diversity been reduced in cereal crops of Catalonia throughout the last five decades by agricultural intensification, including the segetal and rare flora and the interesting weeds for birds, insect pollinators and other invertebrates? (2) If this weed diversity depletion has occurred, to what extent has organic farming influenced the recovery of plant biodiversity in current cereal crops and especially in segetal and rare species and in the aforementioned weed functional biodiversity groups?

2. Material and methods

2.1. Data sources and plant surveys

We analysed 458 floristic field plots (Braun-Blanquet method) of non-irrigated cereal crops in central Catalonia (NE Iberian Peninsula) from 1953 to 2007. Most of the field plots (439) were carried out by the authors in different survey periods: 51, 84 and 294 sampled plots in 1983–1988, 1996–1999 and 2005–2007, respectively. In the latest survey 218 and 76 field plots were performed in conventional and in organically managed cereal crops, respectively; differences in the number of samples were related to the lower availability of organic farms in the studied area.

As we did not resampled the same field in the following periods to first period (1953–1988) in any case, we understand that this sampling design is resampling of localities or parts of the territory. Some locations were resampled in the posterior periods to 1953–1988 within an area comprising approximately 5×5 km, in some cases a 10×10 km area depending on the presence of arable land.

All of the field plots were carried out from May to June (before crop harvest) primarily in commercial crops of winter barley

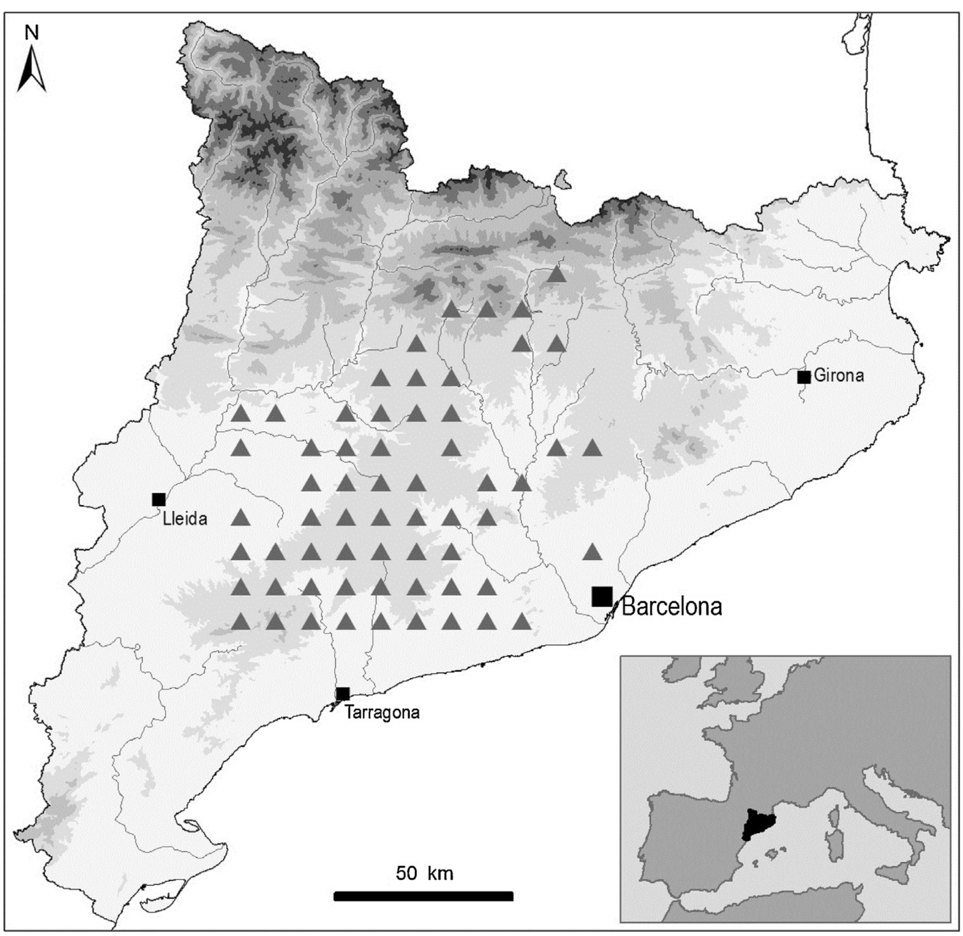

Fig. 1. The surveyed area in Central Catalonia (NE Iberian Peninsula) in the 1953–88, 1996–99 and 2005–07 periods. Symbols indicate the 10×10 km UTM grid areas in which field plots were performed.

(*Hordeum vulgare* and *H. distichon*) and winter wheat (*Triticum aestivum*) and in a lower proportion in oats (*Avena sativa*) and rye (*Secale cereale*). In each field we surveyed an area of 20 × 5 m a few meters distant from the field margin to avoid edge effects (Wilson and Aebischer, 1995; Romero et al., 2008). The nomenclature of the plant species follows that of de Bolòs et al. (2005). The lower number of field plots before the 1990s was supplied by gathering published relevés from the Vegetation Data Base in the Biodiversity Data Base of Catalonia (Font, 2011). We selected 29 relevés from a wider subset of cereal fields data that were included in the alliance *Roemerion hybridae* Br.-Bl. ex Rivas Martínez et al., 1999, and whose localities were coincident or near our own field plots (up to 10 km) in the later periods. We rejected database field plots for which the surveyed areas were lower than 80–100 m^2, those different from cereal crops, those dated other than May or June, and those with a percentage of total weed cover that was greater than 40%. We checked samples from the database for details of methods to avoid artifacts (including taxonomical concepts).

The study was conducted in a predominantly non-irrigated cereal area in central Catalonia (provinces of Tarragona, Lleida and Barcelona), which covered approximately 120 × 100 km extending from 41° 15′ to 42° 10′ N and from 0° 51′ to 2° 2′ E (Fig. 1). The climate is Mediterranean with mean annual temperatures that range from 12 to 15.2 °C and mean annual precipitation that ranges from 400 to 738 mm (Ninyerola et al., 2005). The altitude ranges from 120 to 855 m above sea level (mean ± ES: 513.2 ± 9.2 m), and the soils are mainly basic, clayish and loamy.

While the data set before 2005 came from conventionally managed cereal fields, the farming management of cereal fields for the 2005–2007 period was assessed by interviewing farmers and by consulting the database of the Organism of the Organic Farming Control in Catalonia (The Catalan Council of Organic Farming Production) (CCPAE, 2005, [CCPAE, 2005]2007). All of the organic fields were organically managed since at least 1996 following the European regulations on organic farming (European Union, 2007). The conventional management of the sampled fields in 1996–1999 was recorded during the field samplings based on visual evidence of herbicide use. Nevertheless, in our own field plots from the 1983–1988 period and those from the database (1953–1988), this information was not available. However, the number of organic cereal fields before the 1990s was negligible.

2.2. Data analysis

Before the data analyses, all of the 458 field plots were split into temporal groups according to four scenarios: (1) the first period 1953–88 (80 field plots) prior to agricultural intensification since Ticó (2004) and Faostat (2011) have indicated that in Spain, and especially in Catalonia, the increasing in the use of herbicides and chemical fertilisers occurred in the 1990s, at least 12 years later than other temperate countries; (2) the 1996–99 period (84 field plots) during the increase of agricultural intensification; (3) conventional crops in the 2005–07 period (218 field plots), representing the current situation and (4) current organic crops in the 2005–07 period (76 field plots).

Braun-Blanquet indexes of species cover (r, + 1, 2, 3, 4 and 5) were transformed to percentage cover following a ground cover scale with the following intervals: 0–1, 1–5, 5–10, 10–25, 25–50, 50–75 and 75–100%. The mean of each interval was used as the absolute species cover (Baessler and Klotz, 2006). From each relevé we evaluated the species richness as the species number per relevé and the total absolute weed cover as the sum of the absolute cover values of all individual weed species. The mean of the specific cover in each scenario was also calculated.

Additionally, the frequencies of the individual species were calculated for each scenario as the ratio of the number of field plots (fields) where the species was recorded and the total number of field plots in each scenario. To evaluate the species diversity and dominance in the weed community, Shannon–Wiener's and Simpson's diversity indexes (H' and D) and Pielou's evenness index (J') were calculated from relative specific covers in each relevé for every scenario. The H′ and D diversity and J' evenness indexes were calculated as $H' = -\sum p_i \ln p_i$, $D = -\sum p_i^2$ and $J' = H'/H'_{max}$, respectively. p_i is the cover of species i in the weed community relative to the total cover of all species. H' is a maximum when all species (S) are represented by the same cover, that is, when there is a perfectly even distribution of abundances ($H'_{max} = \ln S$).

The analysis of changes of the subset of segetal and rare species was carried out according to de Bolòs et al. (2005). Segetal weeds correspond to species that are almost exclusively thriving in dryland cereal fields in Catalonia and that are also characteristic of the phytosociological order *Centaureetalia cyani* Tüxen ex von Rochow 1951 and alliance *R. hybridae* Br.-Bl. ex Rivas Martínez et al., 1999 (Romero et al., 2008), while rare species corresponded

Table 1
Total species and species number in each subset of weeds in three different periods or managements (conventional and organic) from 458 field plots in dry cereal crops in Central Catalonia.

Period	1953–1988	1996–1999	2005–2007		2005–2007
Management			Conventional		Organic
N field plots	80	84	80 Rarefacted data[a]	218 Sampled data	76
Total species	260	176	102.1 ± 6.2	(144)	117
N Families/genera	34/145	33/113	23/87	(31/96)	25/99
Segetals[b]	75 (28%)	36 (14%)	17.5 ± 1.9 (17.1%)	(27) (16%)	26 (23%)
Rare species[b]	90 (34%)	45 (13%)	11.7 ± 2.4 (1.1%)	(26) (11%)	26 (20%)
Birds (i)	206	165	91.2 ± 5.6	(125)	106
Birds (ii)	169	116	63.8 ± 4.0	(89)	77
Pollinators (i)	202	140	79.1 ± 4.9	(107)	91
Other invertebrates (i)	35	22	17.4 ± 1.1	(20)	15
Other invertebrates (ii)	11	8	7.3 ± 0.5	(8)	7
Dicots	220	154	89.9 ± 1.4	(126)	102
Grasses	35	17	12.2 ± 1.5	(17)	14

[a] Rarefacted data: mean ± SD.
[b] Segetals correspond to characteristic species of *Centaureetalia cyani* order and *Roemerion hybridae* alliance; rare species follow the classification of rare, very rare and extremely rare species in the Catalan Countries (de Bolòs et al., 2005); (i) and (ii) indicate important and very important species for pollinators (Romero et al., 2008) and other invertebrates and birds, respectively (following Marshall et al., 2001, 2003 and Wilson et al., 1999).

to the rare (r), very rare (rr) or extremely rare (rrr) categories of rarity established in Catalonia (de Bolòs et al., 2005). In addition, to assess weeds that are interesting to birds we followed the weeds important to farmland bird diet *sensu* Campbell and Cooke (1997), Wilson et al. (1999) and Marshall et al. (2001, 2003). Likewise, to assess the weeds with a potential ability to support phytophagous insects we followed the list of weeds important to invertebrate diet *sensu* Marshall et al. (2001, 2003). Finally, information on weeds interesting to insect pollinators was extracted from Romero et al. (2008).

The frequency of each species at a regional scale among the scenarios was compared using the Pearson-Chi^2 statistic. Differences in the mean number of species, absolute specific cover and the mean total weed cover per relevé among the four scenarios were carried out by ANOVA-One factor analyses. Equally, the mean number and mean total cover of the segetal and rare species and species interesting for invertebrates, birds and pollinators per relevé among the four scenarios were determined by ANOVA-One factor analyses. Species richness was square root transformed to achieve the homocedasticity of residuals. Data were analyzed by a Kruskal–Wallis (K–W) analysis when the variances were not homogeneous by the Levene test. ANOVA, K–W and Chi^2 analyses were performed using the SPSS statistics package (SPSS, 2009).

Because the set of conventional field plots in the 2005–07 period was larger (218) than the other scenarios, we calculate the expected number of species (±S.D.) for 80 fields (i.e., a common simple size to all scenarios) in the entire sampling and in each species subset at regional scale by means of the function speccacum from R package Vegan (Oksanen et al., 2012), using the exact method developed by Ugland et al. (2003). In addition, the average of 1000 permutations by Montecarlo analyses by randomly resampling in groups of 80 field plots using Pop-Tools 3.2.3 (Hood, 2010) was used to calculate the species richness, total species cover and the mean specific cover at field scale (Baessler and Klotz, 2006).

3. Results

3.1. Overview

The total weed taxa recorded in all field plots was 346, belonging to 186 genera and 42 families. Seventy five percent of the weeds (260 species in 145 genera) were sampled in the 1953–88 period, while only 176 and 165 species were recorded in the 1996–99 and 2005–07 periods, respectively. In the latter period, 117 species were identified in organic fields and 102 in conventional fields after the data rarefaction (Table 1). The average of weed species richness per relevé decreased significantly from 1953–1988 (22.4 species) to 2005–2007. However, the species richness was significantly greater in the organic cereal fields (14.6 species) compared to the conventional fields (9.1 species) from 2005–2007 (Table 2). The average of the total weed cover per relevé was also significantly higher in 1953–88 than in the last two periods. From 2005–07, the total weed cover in the organic fields was higher than in the conventional fields (Table 2). Thus, the mean of the weed species number per relevé was reduced by 28% and 47% from the 1953–88 period to the 1996–99 and 2005–07 periods, respectively, and the mean total cover diminished by 52% and 69% from the 1953–88 period to the 1996–99 and 2005–07 periods, respectively.

The mean values of Shannon's diversity index (H) and Pielou's evenness (J) per relevé were significantly higher in the 1953–88 period and decreased over time. The Shannon's diversity index was higher in the organic crops than in the conventional crops in 2005–07 (all ANOVA and K–W analyses with a significance of $p < 0.001$), but the evenness was not. The mean of the Simpson's dominance index (D) values were generally low in all of the periods, and it was higher in 1953–88 and 1996–99 than in 2005–07 (Table 2).

3.2. Segetal and rare species

The proportion of segetal and rare species (hereafter abbreviated as S and R respectively) decreased over time at the regional scale. A total of 81 segetal and 114 rare species were recorded in all of the surveys, and most of those species (90% of S and 79% of R species) were observed in the 1953–88 period, in contrast to only 21.6% and 10.3% of the S and R species, respectively, in the conventional crops in 2005–07 (Table 1).

At the field scale the mean (±SE) number of S species per relevé diminished significantly from 6.5 ± 0.3 species in the 1953–88 period to 0.9 ± 0.1 species per relevé in the conventional 2005–07 crops (Fig. 2(A)). Additionally, the number of R species per relevé diminished significantly from 4.3 ± 0.2 in 1953–88 to 0.2 ± 0.04 species in the conventional crops from the 2005–07 period. In contrast, organic crops had significantly greater S (2.3 ± 0.0) and R species richness (1.0 ± 0.1) than those for conventional crops (Fig. 2(A)). The abundance (mean total cover) of the S and R species declined in a similar pattern in all of the scenarios (Fig. 2(A)). All of the ANOVA and K–W analyses were significant with $p \leq 0.001$ in each comparison.

3.3. Weed frequency

The weed frequency, which was assessed as the proportion of field plots (fields) where each species was present in each scenario, ranged from 1–91%. Generally, the average of the weed frequency was significantly higher in organic (12.5%) than in conventional crops (6.1%) for the 2005–2007 period, while values in the earliest periods were intermediate (9% and 8.5% in 1996–99 and 1953–1988, respectively, $F = 7.05$; 3 d.f.; $p < 0.001$). Only 5 species were present in more than the 50% of the field plots in 1953–88, 1990–96 and conventional crops in 2005–07, respectively, and 7 species in organic crops in the 2005–07 period (see details in

Table 2
Mean (± SE.) species richness and total species cover and Shannon–Wiener's diversity index (H), Pieolou's evenness index (J) and Simpson's dominance index (D) for three different periods and managements (conventional and organic) from 458 field plots in dry cereal crops in central Catalonia.

Period	1953–1988	1996–1999	2005–2007	
Management			Conventional	Organic
Species richness	22.38 ± 0.81 (8–40) a	16.2 ± 0.70 (1–34) b	9.1 ± 0.33 (0-25) c	14.6 ± 0.61 (5–30) b
Total species cover	62.1 ± 3.18 (16.6–138.7) a	29.7 ± 2.89 (0.3–133.1) b	14.8 ± 2.22 (0.1–110.3) b	23.4 ± 1.33 (0.7–89.7) bc
Shannon–Wiener (H')	3.05 ± 0.06 a	2.47 ± 0.08 b	1.70 ± 0.05 d	1.97 ± 0.07 c
Evenness (J)	0.69 ± 0.01 a	0.65 ± 0.01 ab	0.60 ± 0.01 bc	0.52 ± 0.02 c
Simpson (D)	0.19 ± 0.01 b	0.26 ± 0.014 b	0.39 ± 0.001 a	0.39 ± 0.02 a

Different letters among the periods and managements indicate significant differences by a Tukey test (all ANOVA analyses with a significance of $p < 0.001$). The minimum and maximum values are indicated in the parentheses.

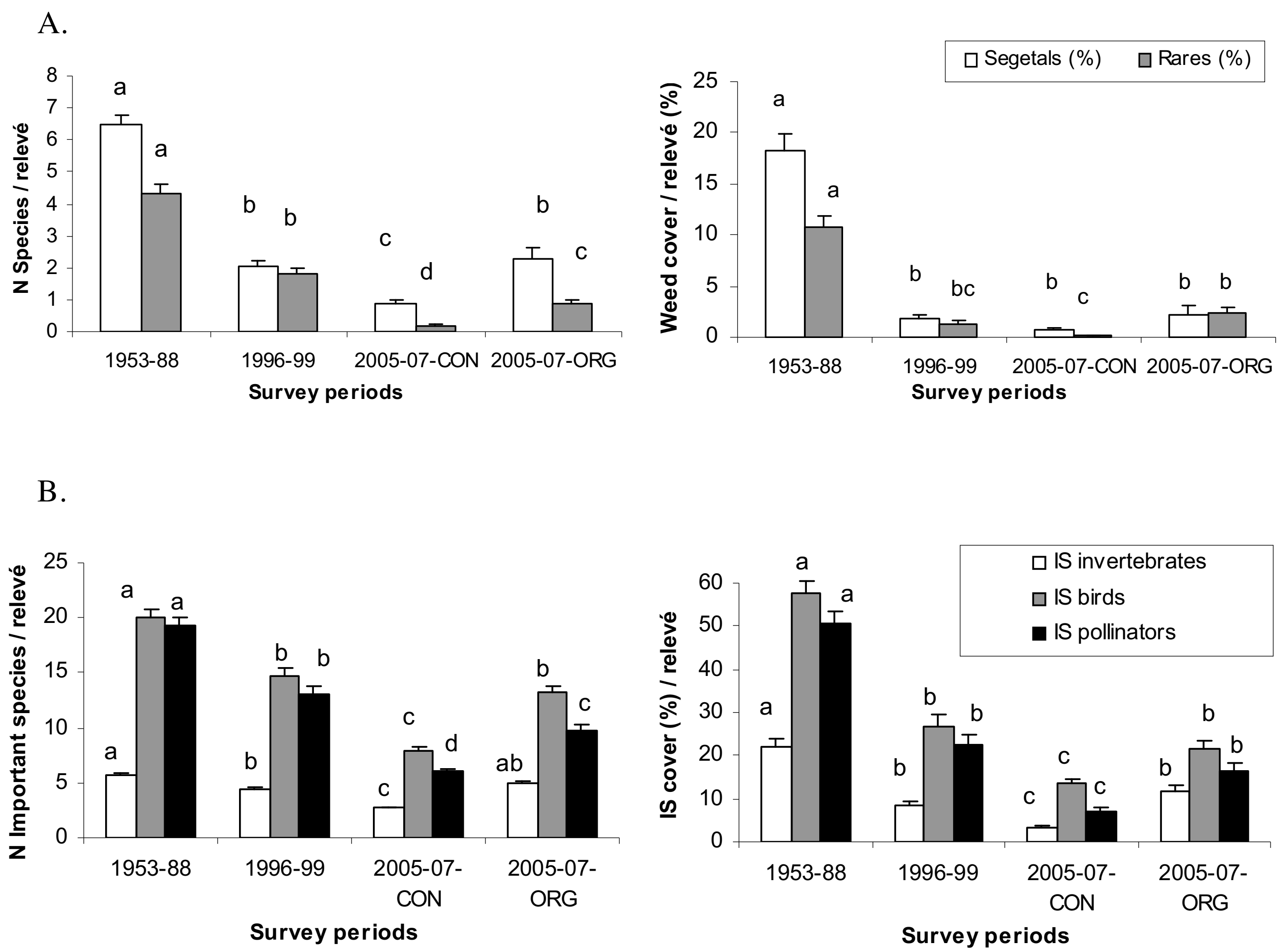

Fig. 2. Mean (±SE) number of species per field plot (relevé) (left) and mean of total weed cover (%) per field plot (right) of segetal and rare species (A) and important species (IS) for birds, pollinators and other invertebrates (B) in cereal crops from different surveyed periods in Catalonia, Spain. CON and ORG indicate conventional and organic management, respectively. For each item, bars with different letters indicate significant differences among survey periods by a Tukey test ($p < 0.001$).

Supplementary information). *Lolium rigidum*, *Convolvulus arvensis*, *Papaver rhoeas* and *Polygonum aviculare* were the most frequent species from the 1950s to the 2005–07 period in Catalonia. *Cirsium arvense* was very frequent in the 1953–88 period and in the current (2005–07) organic crops. In this scenario C*henopodium album* was also very frequent In contrast, *Avena sterilis* began to be very frequent from the 1990s to currently (Supplementary information). Contrary to these highly frequent species, the majority of the species had a very low frequent in each scenario, with a presence of less than the 5% of the field plots (4 fields) that accounted for up to 74% of the species in the 2005–07 conventional crops, 66% and 63% in the 1953–88 and 1996–99 periods, respectively, and up to 52% of the species in the 2005–07 organic crops ($\chi^2 = 16.02$; 3 d.f.; $p = 0.001$).

On average, most of the species (78%) decreased in frequency from 1953–88 to 2005–07; in contrast, 4.8% maintained their frequency, and 17% increased in frequency. From those groups, up to 19 species significantly increased their frequency in the conventional 2005-07 crops, including *A. sterilis, B. diandrus, B. sterilis, Galium aparine*, *L. rigidum* and *Polygonum convolvulus*. In contrast, up to 35 species significantly increased their frequency in organic crops: *A. sterilis, L. rigidum,* and *P. convolvulus* but also *C. album, C. vulvaria, P. aviculare, Medicago sativa,* segetals *Anchusa italica* and *Centaurea cyanus* and rare species *Matricaria recutita*, *Kochia scoparia*, and *Asperugo procumbens*.

Overall, the segetal species were significantly more frequent in 1953–88 and in organic crops in 2005–07 (9.4% and 9.1% of the surveyed fields; i.e., 7.5 and 7.3 fields, respectively) than in the 1996–99 period and 2005–07 conventional crops (6.1% and 3.5%; i.e., 4.8 and 2.8 fields, respectively; $F = 3.28$; 3 d.f.; $p = 0.022$). The mean frequency of rare species fields was significantly higher in 1953–88 (5.1%), organic crops in 2005–07 (4.8% of the fields) and 1996–99 (3.7%) than in current conventional fields (1.1% of the rare species; $F = 5.15$; 3 d.f.; $p = 0.002$).

Some *S* species such as *Lithospermum arvense, Hypecoum procumbens, Coronilla scorpioides* and *Lathyrus cicera* and some SR species such as *Papaver hybridum* and *Roemeria hybrida* were relatively frequent in the 1953–88 period but diminished considerably over time. As many as 113 species (42% of the total weeds in the 1953–88 period) were no longer detected in the latest surveyed periods. Most of the species that had disappeared were segetals (as many as 35 species) or rare species (as many as 52 species) are considered to be very rare (such as *F. vallantii, Papaver dubium,* and *Vaccaria hispanica*) or extremely rare (such as *Torilis leptophylla*) in Catalonia, following de Bolòs et al. (2005).

In contrast, 6 and 11 species exclusively appeared in organic crops and in organic and field plots from the 1950–1980 period, respectively; most of those species were S or R weeds: *A. italica*, *Astragalus sesameus*, *Bifora testiculata*, *Neslia paniculata* subsp. *Thracica* and *Ranunculus arvensis* (see Supplementary information).

3.4. Specific cover

The specific cover, assessed as the absolute abundance of each species in the relevé, from 1950s to the current crops by 80% and by 69% in the conventional and organic 2005–07 crops, respectively. The mean specific weed cover was significantly higher (almost twice) in field plots from 1953–88 (0.25%), 1996–99 (0.21%) and organic 2005–07 crops (0.19%) than in conventional 2005–07 crops (0.10%) ($F = 8.2$; 3 d.f.; $p < 0.001$). However, only as many as 27 several species, including *S Coronilla scorpioides, Erucastrum nasturtiifolium, Lathyrus aphaca, Lithospermum arvense, Scandix pecten-veneris* and *Vicia peregrina*, *R* species *Alyssum simplex* and *Vicia hybrida*, and SR *Papaver hybridum* and *Rapistrum rugosum* had significantly higher specific covers in the 1950–1980 than in the other periods. In contrast, only *Calendula arvensis* and *Bromus diandrus* significantly increased in abundance in the 2005–07 organic and conventional crops, respectively (see the Supplementary information).

3.5. Functional diversity: species interesting to birds, pollinators and other invertebrates

Analyses at the regional scale revealed a general reduction over time in grasses and all families of dicotyledonous, including those families and species that are interesting to fauna (Table 1). At the field scale, the mean number of important weeds for birds, pollinators and other invertebrates significantly diminished by 60%, 69% and 52%, respectively, and in mean total abundances (77%, 86% and 85%, respectively) from the 1953–88 period to the 2005–07 period in conventional crops (Fig. 2(B)). The proportion of dicotyledonous was significantly higher in the 1953–88 period (90.2%) and in the 2005–07 organic crops (83.6%) than in 1996–99 (44.1%) and conventional 2005–07 field plots (66.1%). Most of the dicotyledonous abundant families such as *Brassicaceae* and *Caryophyllaceae* (very important families for birds), *Fabaceae* (important for birds) and also *Papaveraceae, Rubiaceae* and *Primulaceae* were better represented in the number of species and total weed cover per relevé in the 1953–88 period than in the other scenarios (Fig. 3). In contrast, the richness and abundance per relevé in *Chenopodiaceae* and *Polygonaceae (*very important families for birds), *Lamiaceae* and *Asteraceae* (important for birds) and also *Ranunculaceae* were significantly higher in organic crops than in the other scenarios, whereas *Euphorbiaceae*, *Boraginaceae, Umbeliferae*, and *Convolvulaceae* had higher richnesses and abundances in both the current organic and the 1953–88 field plots (Fig. 3). Conversely, the proportion of the number of grasses (very important for birds) per relevé was significantly higher in conventional crops (31.3%) and in field plots from 1996–99 (27.7%) than in organic 2005–07 crops (16.3%) and those higher in field plots from the 1953–88 period (4.1%).

Organic crops in 2005–07 had a higher mean richness and abundance per relevé of interesting weeds for the mentioned taxa than those in conventional crops (Fig. 2(B)). Thus, the organic field plots of 2005–07 had the highest proportions of important species for these groups; i.e., 90.1% and 68% of the species were important and very important species for birds, respectively, and 34% and 21% of the species were important and very important species for phytophagous insects, respectively. Nevertheless the highest proportion of important species for pollinators (86%) was observed in the 1950–88 period. All of the ANOVA analyses were significant with $p \leq 0.001$ in each comparison.

4. Discussion

The comparison of the weed communities in Catalonia (NE Iberian Peninsula) from the 1950s to the present reflects the reduction of the weed flora, especially for segetal and rare arable weeds that thrive almost exclusively in arable habitats, and the decline in the abundance of functional groups including those that are important for birds, pollinators and other invertebrates.

At the regional scale, 160 species belonging to 58 genera and 11 families contributed to the decline of weed species richness in the past five decades. This depletion in weed biodiversity has notably affected the subset of segetal and rare species, which have contributed 76% and 87% of the losses, respectively. Moreover, the reduction in dicotyledonous is associated with the severe decline

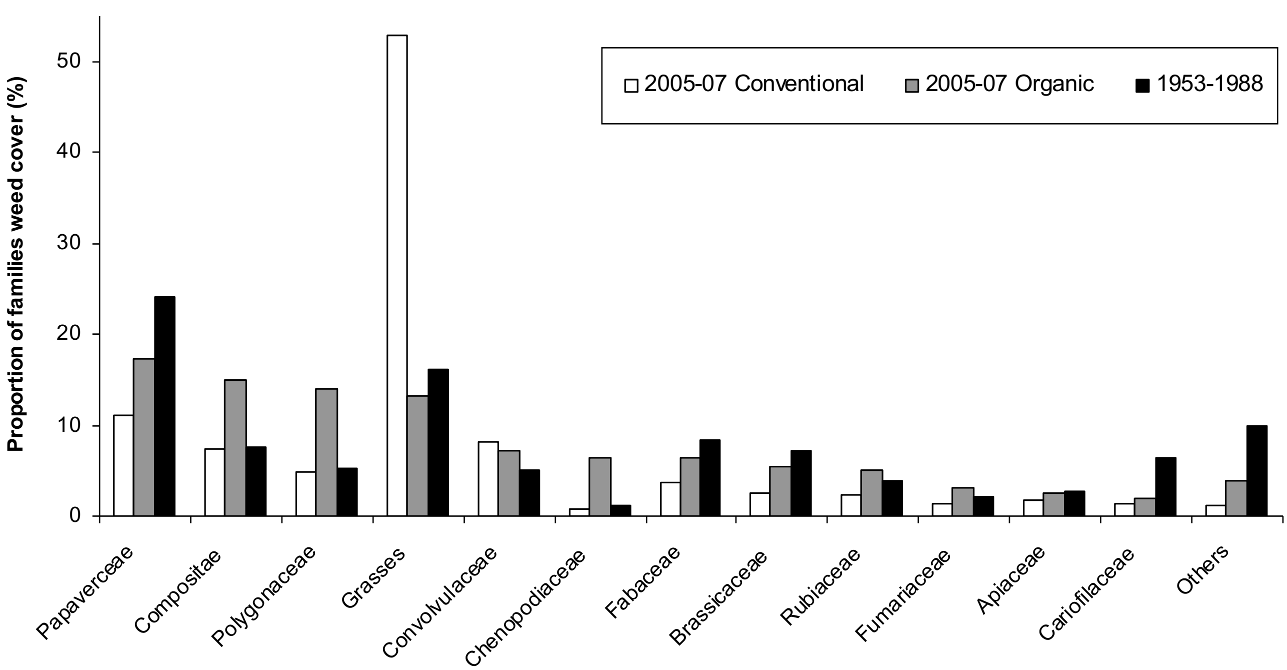

Fig. 3. Relative importance of the 12 most abundant families, assessed as the total percentage cover of species belonging to each, in cereal fields of central Catalonia (NE Iberian Peninsula) during the different study periods.

of species that are important for birds, pollinators and other invertebrates (56%, 75% and 50%, respectively).

At the field scale, the reduction in weed richness and abundance (59% and 76%, respectively) from the 1950s–1980s to current conventional crops was higher than the tendencies observed in Germany by Baessler and Klotz (2006) and those observed in France by Fried et al. (2009), but not as the severe reduction reported by Meyer et al. (2013) in Central Germany (a mean richness loss of 65%). The dramatic decline of weed biodiversity in Catalonia has been probably related with the sharp rise in the use of herbicides and chemical fertilisers occurred in the 1990s in Spain, that was at least 12 years later than other temperate countries as a result of the joining the European Union (Ticó, 2004).

The significant differences in diversity indexes also reflect changes in the weed community structure among the periods (contrary to results of Cirujeda et al., 2011). The decrease of Shannon–Wiener's diversity index (H') over time is related to the strong decline of species richness and, to a lesser extent, to the increase of the inequality in the relative abundances of species. The increase in the dominance of a few species in contemporary cereal crops compared to the oldest ones is also supported by the increasing pattern of Simpson's index values. *L. rigidum*, *P. rhoeas*, *C. arvensis* and *P. aviculare* have been the most frequent and abundant weeds from the 1950–1980s to the current time in conventional crops. They have also been recorded as some of the most noxious species in other survey studies in Catalonia (Recasens et al., 1996; Romero et al., 2008) and the first two weeds are considered to be the two worst weeds in the nearby Spanish region of Aragón (Cirujeda et al., 2011). In contrast, *B. diandrus* and *A. sterilis* have become noxious weeds from the 1990s to the current conventional crops. We have observed that the practice of monoculture is widely used in in conventional fields in Catalonia. The higher abundance of grasses in conventional fields in relation to organic fields could be explained both by the herbicide resistance of grasses due to the repetitive herbicide applications and the shorter (or lack of) rotation system (Meyer et al., 2013).

4.1. Segetal and rare species

As was hypothesized, the decline in weeds significantly affected the subset of segetal and rare species. The number, frequency and abundance of the segetal species of cereal crops in Catalonia has diminished over time. The *S* and *R* groups have experienced a very drastic reduction in biodiversity for the number of species at the regional scale (76% and 87%, respectively, from the 1953–88 period to the conventional field plots of 2005–07); therefore, their rarity has increased over time. For example, *A. githago* or *V. hispanica* were considered to be noxious weeds in Spain in the 1980s (Kuc et al., 2003) and have been considerably reduced or have even disappeared from recent cereal crops in central Catalonia. In central and northwest Europe, a large number of segetal species have become extinct, are threatened or have become rare due to the impact of crop management and land use (Storkey et al., 2012). The effects of herbicides and monoculture and the competitiveness of crop species soils highly fertilised by synthetic nitrogen inputs may have led to poor growth conditions for those species. The lack of vigour in some segetal species compare to more nitrophilous and competitive weeds in fertilised environments consequently may reduce the taxa survival and fecundities, which could decrease their preservation in soil seed banks (Baessler and Klotz, 2006). Fortunately, the situation in organic fields is less dramatic for segetals (Fuchs and Saacke, 2006). Generally, current organic farming practices may allow a relatively large number of segetal or rare weeds, which was the case prior to agricultural intensification (Hyvönen, 2007).

4.2. Functional diversity: species interesting to birds and pollinators and other invertebrates

Our data confirm the reduction in the richness and abundance of important weeds for birds, pollinators and other invertebrates at the field and the regional scales (for instance, a reduction in weed species richness of 56%, 75% and 50%, respectively) from the 1950s to recent conventional crops. The four most abundant families, *Poaceae*, *Papaveraceae*, *Asteraceae* and *Polygonaceae*, which account for 62% of the total weeds on average per scenario, constitute a pool of very important species for birds. Even the 12 most abundant families in each scenario, which account for an average of 87% of the total weed cover, belong to very important families for birds (with the exception of *Convolvulaceae* and *Fumariaceae)*. The dramatic loss of weed biodiversity in recent decades has altered the provision of important ecosystem services (e.g., provision of food and shelter for birds, pollinators and other invertebrates such as phytophagous insects) that adversely affect negatively the persistence of the populations of these taxa (Wilson et al., 1999; Marshall et al., 2001, 2003; Fried et al., 2009).

4.3. Organic farming

Organic farming in the Mediterranean study area generally displays lower levels of land use intensity than conventional farming and has been characterized by rotation practices and a lack of herbicide use for a considerable number of years. Our results support findings that organic management allowed a recovery in the number, abundance and frequency of species. The significant increase in the mean species frequency in organic crops can be explained primarily by the rotation practices in organic farming (Rotchés-Ribalta et al., 2014) but also by the utilisation of own seeds or seeds from other organic farmers to set sown (José-María et al., 2010). The translocation of weeds among fields and territories yearly from seeds from the previous year has the potential to increase the frequency, number and abundance of weeds in organic arable fields (Kuc et al., 2003; Chamorro et al., 2012).

Several dicot families have increased richness and abundance in organic crops in contrast to conventional crops, including important weeds for birds such as *Fabaceae*, *Asteraceae*, *Chenopodiaceae*, *Polygonaceae* and *Ranunculaceae* (Campbell and Cooke, 1997; Wilson et al., 1999; Marshall et al., 2001, 2003; Holland et al., 2006). Despite conventional crops displayed a greater abundance of grasses (52%) than that for organic crops, it was insufficient to elevate richness or abundance of the important species for birds. Organic management in current arable crops has enhanced weed richness for species interesting for birds, pollinators and other invertebrates by a factor of 1.7, 1.6 and 1.8, respectively, and in the weed abundance by a factor of 1.6, 2.4 and 3.6, respectively, over conventional crops. Nevertheless, organic farming in Catalonia has not entirely recovered the decline in weeds caused by agriculture intensification from the 1950–1980s, although their friendly environmental practices have aided a restoration of the flora that have disappeared in most of the current arable fields, which is also the case in some temperate regions of Europe (Hyvönen, 2007).

We suggest adopting adequate field managements with well-friendly practices which enhance the conservation of segetal and rare species as are referred in Rotchés-Ribalta et al. (2014) since the transition to organic farming is not accepted by the most of the farmers nowadays. We can also propose other strategies of species conservation such as the field bands next to margins avoiding the use of chemical fertilization and herbicides at the first few meters (edges) next to the field boundaries (José-María et al., 2013), although farmers should be funded for this proposals. Finally, different implied actors (farmers, governmental organisations, scientists and land managers) should discuss about the establishment of special protected fields or territories of high biodiversity of arable weeds and fauna in extensive cereal landscapes in Catalonia, as was presented by Meyer et al. (2010) in Germany.

5. Conclusions

Weed biodiversity in dry cereal lands in Catalonia (NE Iberian Peninsula) has decreased in the past five decades. The frequency and abundance of groups of weeds that are functionally important for birds, pollinators and other invertebrates and the subsets of segetal flora, rare arable species and dicots in general have also decreased, whereas the frequency and abundance of grasses have increased. This work also confirms the benefits of organic farming on biodiversity, in terms of the maintenance and restoration of the local floristic richness and abundance in cereal fields, including segetal and rare species, in relation to conventional crops. Organic management also changed the weed community structure and, in consequence, the function of the agroecosystem because organic crops can sustain a higher biodiversity of species and families that are interesting for birds, pollinators and other invertebrates, which may boost the recovery of such fauna in arable Mediterranean landscapes.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2015.11.027.

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