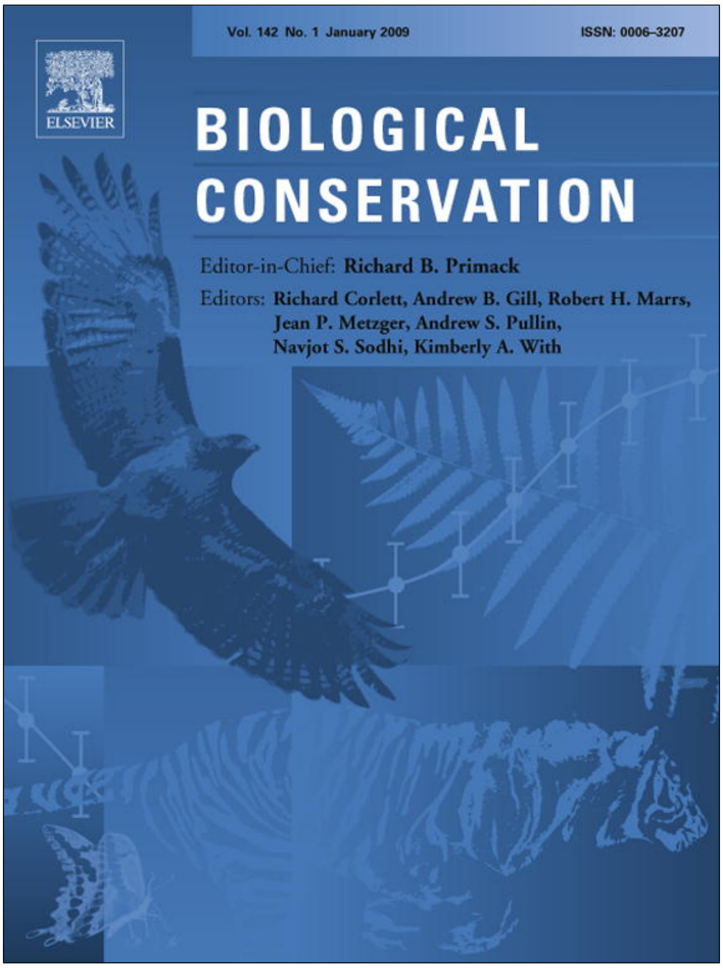
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Short communication

Arable weed decline in Northern France: Crop edges as refugia for weed conservation?

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ABSTRACT

The maintenance of biodiversity in agro-ecosystems is often viewed as an insurance against an uncertain future, yet, there is increasing evidence of biodiversity loss in agricultural landscapes. Here, we examined long term trends in the arable weed flora of North-East France by revisiting 158 arable fields initially surveyed in the 1970s. We assessed changes in species richness, density and frequency of occurrence in weed communities as well as for subgroups that are recognised for their conservation value. We also evaluated the importance of crop edges as potential refugia for the threatened arable weeds. Among the 121 species recorded in both surveys, 40% had significantly declined in frequency while 10% had significantly increased. At the field level, we recorded a 42% decline in species richness and a 67% decline in species density. Trends were comparable for weed species of particular conservation value. In the 2000s survey, crop edges harboured levels of weed diversity that were intermediate between those found in field cores in the 1970s and in the 2000s survey. Our results indicated that many species of conservation value had disappeared or seriously decreased in the field core but still persisted in the crop edge. The consequences of this general decline and possible conservation options are discussed in the light of the results.

1. Introduction

Recent emphasis has been put on enhancing the sustainability of agricultural landscapes through greater reliance on ecological goods and services (MEA, 2005). In this context, the maintenance of biodiversity is viewed as an important coping strategy or an insurance against agricultural risks in an uncertain future (Loreau et al., 2003; Jackson et al., 2007). Among the biota found in agro-ecosystems, arable weed species play an important role in supporting biological diversity, in particular as food resources of primary importance for birds and insects inhabiting farmlands (Hawes et al., 2003; Marshall et al., 2003; Gibbons et al., 2006). In Europe, there is increasing evidence of a general decline in arable weeds over the last decades (Andreasen et al., 1996; Sutcliffe and Kay, 2000; Preston et al., 2002; Hyvönen, 2007; Baessler and Klotz, 2006) likely to result from widespread changes in agriculture practices since the end of the second world war (Stoate et al., 2001).

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Practices detrimental to weeds are the widespread use of herbicides (Haas and Streibig, 1982; Hyvönen, 2007), the massive increase in fertilizer use and the introduction of crop varieties sown at high densities which increases competition for light (Bischoff and Mahn, 2000). In France, botanists have reported a drastic decline in the abundance and distribution of arable weeds as early as in the 1960s (Aymonin, 1962), but there has been no quantification of this process to this present day.

The conservation of weed species is somehow problematic as their optimal habitat, arable fields, are primarily devoted to crop production. Yet, many arable weeds also flourish in crop edges (Wilson and Aebischer, 1995) as these habitats combine higher light penetration and less intense chemical or mechanical perturbations (Kleijn and van der Voort, 1997). On the other hand, some species are more strongly linked to the field core area either because they have mimetic seeds and are sown with the crop or because they are unable to maintain in the margins where tall grasses exert high competitive pressure. The importance of crop edges for maintaining declining weed species is therefore largely unclear.

Here, we used long term data on the weed flora of 158 fields to quantify changes in the species richness, density and frequency of occurrence of weed species in field cores between 1970s and 2000s, as well as for listed species and species that are considered beneficial to other taxa in agro-ecosystems. In a second part, we assessed the relative contribution of the field core and the field edge to the maintenance of listed and beneficial species. The conservation of arable flora is discussed with particular attention to the potential contribution of crop edges for maintaining listed species and beneficial species.

2. Materials and methods

2.1. Study area

The sample consisted of 158 arable fields located within an area of 6000 km^2 (centroid 47.461°N, 4.805°E) in Côte d'Or (Burgundy), a typical intensive agricultural area devoted to cereal production. A first survey took place between 1968 and 1976 with each field sampled 3–7 times over at least three successive years, i.e. an overall crop rotation (sample size: $n = 755$). Field core and crop edge vegetation were surveyed in the same 158 fields in 2005 and in 2006 ($n = 315$, 1 missing field). Between the two surveys, spring barley cultivation has decreased in the area and has been replaced with winter barley and oilseed rape.

2.2. Vegetation sampling

In the 1970s and the 2000s surveys, field core vegetation was recorded in a 2000 m^2 area (40 * 50 m) located at least 20 m from the field boundary. Crop edge vegetation was recorded in a 50 m^2 area, i.e. a 50 m long line and 1 m wide (the outside edge next to the first crop row) parallel to the field core sample area. The density of each species was estimated by adapting a cover abundance method (Mueller-Dombois and Ellenberg, 1974) to arable crop fields, i.e. 5 classes (1: less than 1 individual/m^2; 2: 1–2 individuals/m^2; 3: 3–20 individuals/m^2; 4: 21–50 individuals/m^2; 5: more than 50 individuals/m^2).

2.3. Changes in overall species diversity and frequency

The regional species pool (γ-diversity) was compared between the two periods after adjusting sample size with a rarefaction method adjusted to the smallest sample size available for the 2000s survey ($n = 315$). Weed diversity at the field level (α-diversity) was assessed with species richness and weed density (mean value of cover abundance classes); changes between the two surveys were tested with a paired Wilcoxon-test.

Changes in the frequency of occurrence of individual species were assessed as follows. A single sample out of the 3–7 available was taken at random 100 times from the 1970s survey to obtain the (relative ranked) distribution of species frequency. Each species whose occurrence in the 2000s survey fell outside this distribution was considered to have changed status between the two surveys.

2.4. Conservation value of weed species

We assessed changes γ-diversity, α-diversity and frequency of occurrence (as described in the previous section) for species belonging to the national Archeophyt Weed National Red List (Aboucaya et al., 2000) (AWNRL species, see Appendix 1) which we assumed would have a conservation value *per se* (Türe and Böcük, 2008). We also assessed changes for the 12 'beneficial' species (Appendix 1) recognised as having the most potential biodiversity value for other trophic levels in agro-ecosystems and to be of least competitive ability (Storkey, 2006).

2.5. Ecological characterisation of weed communities

We derived from the weed community data three indicators of environmental conditions, the proportion of perennial species derived from Raunkier biological types (therophytes, geophytes sand hemicryptophytes) associated with intensity of mechanical disturbance associated to soil tillage (Zanin et al., 1997) and the mean cover-weighted Ellenberg Nitrogen and Light scores (Ellenberg et al., 1992) extensively used as indirect indicators of abiotic conditions (Diekmann, 2003), here the intensity of nitrogen fertilisation and the density of crop sowing. Indicator values were compared with a paired Wilcoxon signed ranked test.

3. Results

3.1. Changes in weed communities in field cores between 1970 and 2000

A total of 222 weed species were recorded during the two surveys. At the regional level, γ-diversity significantly decreased between the two surveys (Table 1). At the field level, both species richness and species density significantly decreased between the two surveys (Table 1). Increases in α-diversity

Table 1 – Comparison of (1) diversity indices for all weed species, AWNRL and beneficial species (mean and standard deviation) and (2) ecological characteristics of the flora found in field cores in the 1970s and in the 2000s.

		1970s	2000s	Test[a]
All weed species				
Regional species pool	(γ-Diversity)	165 (4.02)	155	$P < 0.05$
Field level	Species richness	16.6 (4.84)	9.28 (4.91)	$P < 0.01$
	Species density	61.5 (41.50)	20.2 (20.64)	$P < 0.01$
AWNRL species				
Regional species pool	(γ-Diversity)	23 (1.13)	18	$P < 0.05$
Field level	Species richness	1.68 (1.26)	0.74 (0.93)	$P < 0.01$
	Species density	6.10 (8.84)	1.00 (3.53)	$P < 0.01$
Beneficial species				
Regional species pool	(γ-Diversity)	12	12	
Field level	Species richness	3.59 (1.15)	2.15 (1.45)	$P < 0.01$
	Species density	15.47 (15.53)	5.47 (11.14)	$P < 0.01$
Ecological characterisation of weed communities				
	Perennial species (%)	20.30	11.97	$P < 0.01$
	Ellenberg-L score	6.58(0.14)	6.56 (0.28)	$P = 0.81$
	Ellenberg-N score	5.83(0.34)	6.16 (0.48)	$P < 0.01$

a Paired Wilcoxon signed-rank test.

were observed in 17 of the 158 fields while increases in species density were observed in 24 of the 158 fields.

Records show that 67 out of the 188 species recorded in the 1970s survey were not recorded in the 2000s survey while 34 species out of the 155 recorded in the 2000s survey were not recorded in the 1970s survey (see Appendix 1). Among the 121 species recorded in both surveys, 48 species have significantly decreased in frequency and 12 have significantly increased. The proportion of perennials species significantly decreased between the two surveys (Table 1). This resulted from a reduced representation of both geophytes (5.6% down to 3.7%) and hemicryptophytes (14.1% down to 8.5%). Ellenberg Nitrogen scores significantly increased between the two surveys while there was no significant change in the Ellenberg Light scores (Table 1).

We recorded 27 AWNRL species in either surveys, i.e. 26 in the 1970s and 18 in the 2000s. There was a significant decrease in the number and the density of AWNRL species (Table 1). Among the 17 AWNRL species recorded in both surveys, 7 species were observed with lower frequencies in the 2000s while only one increased. There was no evidence for a sharper decline of AWNRL species compared to other weeds (Khi2 = 4.47; $P = 0.11$). There was a significant decline in species richness and density for the 12 beneficial species (Table 1) not statistically different of trends observed for other weed species (Khi2 = 1.19; $P = 0.55$).

3.2. *Comparison between field cores and crop edges in the 2000s survey*

Overall species richness and richness in AWNRL species were significantly higher in crop edges than in the core area of fields while the opposite was true for beneficial species (Table 2).

Our records indicate that 23 species that have disappeared from the field cores between the 1970s and the 2000s surveys were still found in the crop edges in the 2000s survey. Crop edges populations were particularly important for decreasing species and/or AWNRL species as shown in Appendix 1. However, an important proportion of AWNRL species did not occur in crop edges at frequencies that were higher than in the field cores. The proportion of perennial species was significantly higher in the crop edges than in the field cores (Table 2). Crop edges harboured a greater proportion of both geophytes (9.8%) and hemicryptophytes species (17.5%). We found no significant differences between field cores and crop edges for species Ellenberg Nitrogen and Ellenberg Light scores (Table 2).

4. Discussion

The main results of the study were that: (1) between 1970s and 2000s, species richness and density sharply decreased at the field level while the total number of weed species at the regional scale only decreased slightly, (2) there was a general decline in the frequency of arable weeds between the two periods, both for rare archeophyt weeds and for the most common weeds, including beneficial species and, (3) in the 2000s survey, crop edges harboured levels of species diversity that were intermediate between those found in field cores in the 1970s and the 2000s survey, indicating that crop edges would buffer the decline and/or act as a refugia for species now disappeared in field cores.

4.1. *Quantification of the decline of the arable flora*

Studies focusing on arable weed flora decline are scarce and quantitative data are generally lacking to estimate the loss of diversity. Our study provides a quantitative estimate of the decline of arable flora, i.e. a 42% decline in the number of species per field and a 67% decrease in the mean species density per field between the 1970s and the 2000s survey. Although different sampling methods were used in other studies, comparable estimates were observed in Denmark

Table 2 – Comparison of (1) diversity indices for all weed species, AWNRL and beneficial species (mean and standard deviation) and (2) ecological characteristics of the flora found in field cores and crop edges.

		Field core	Crop edge	Test[a]
All weed species				
Regional species pool	(γ-Diversity)	155	194	
Field level	Species richness	9.28 (4.91)	12.16 (4.22)	$P < 0.01$
AWNRL species				
Regional species pool	(γ-Diversity)	18	16	
Field level	Species richness	0.74 (0.93)	0.98 (1.05)	$P < 0.01$
Beneficial species				
Regional species pool	(γ-Diversity)	12	12	
Field level	Species richness	2.15 (1.49)	1.85 (1.27)	$P < 0.01$
Ecological characterisation of weed communities				
	Perennial species (%)	11.97	27.31	$P < 0.01$
	Ellenberg-L score	6.56 (0.28)	6.59 (0.31)	$P = 0.13$
	Ellenberg-N score	6.16 (0.48)	6.13 (0.42)	$P = 0.25$

a Paired Wilcoxon signed-rank test.

between 1968 and 1990 (Andreasen et al., 1996) and Germany between 1953 and 2000 (Baessler and Klotz, 2006).

4.2. *Potential impacts of the decline of arable weeds*

We show a drastic decline in the density of the 12 common weed species recognised as beneficial in agro-ecosystems. Most of the weed species that are known to be very important for farmland birds or insects (Storkey, 2006), i.e. *Chenopodium album*, *Fallopia convolvulus*, *Polygonum aviculare*, *Polygonum persicaria*, *Sinapis arvensis* and *Stellaria media*, have significantly decreased over the last 30 years (Table 1 and Appendix 1). If we assume that green matter or seed production available in a field is proportional to the number of plant per m^2, our results would indicate that food availability for birds has declined by roughly two thirds in the last 30 years. This would support the often cited hypothesis that the loss of available resource is one of the main causes of farmland bird declines (e.g. Newton, 2004). Yet the decline of common weeds is not necessarily irreversible and changes in agricultural practices can lead to shifts in actual trends. Reduced herbicide use has indeed been linked to increases in the frequency of common weed species of trophic value to birds and invertebrates (Andreasen and Stryhn, 2008), although such regime is unlikely to allow the recovery of weed populations to the same level as before herbicide applications, at least in the first years (Hyvönen, 2007).

4.3. *Potential role of crop edges for the conservation of rare arable plants*

In this study, we wanted to assess the potential role of crop edges under no specific management prescription for maintaining arable weeds. Our results showed that these habitats maintained higher levels of species richness than field cores which confirms patterns reported for annual crops (Marshall, 1989; Wilson and Aebischer, 1995; Walker et al., 2007) and grasslands (Smart et al., 2002). Crop edges harboured 23 species that had become extinct from field core areas as well as a greater number of AWNRL species. This amounts to about 10% of the regional pool of weeds and 34% of the species that have become extinct within field cores. There may be several explanations to the current refugia role of crop edges. First, differences in species diversity and density might simply reflect the fact that soil seed bank density decreases from the crop edges to the centre of fields (Wilson and Aebischer, 1995). Second, crop edges are spatially better connected to external neighbouring sources of propagules (adjacent crop, field margin, and set-aside). Thirdly, and as shown in the present study, arable flora found in crop edges reflects a much lower degree of mechanical perturbations. Several species that disappeared in the field core area but remained in crop edges were perennial weed species adapted to slight mechanical soil perturbations with rhizomes, tubercle or bulbs. On the other hand, weed communities in field cores and crop edges seemed to indicate comparable conditions for nitrogen and for light (except for spring barley) hence the introduction of new *nitrophilous* weeds inside the field through crop edges and the inability of the most *oligotrophous* species of AWNRL to persist in the crop edges. This situation explains the success of no-fertiliser options for arable weed conservation in crop edges (Walker et al., 2007).

5. Conclusion

Conservation efforts usually focus on rare endemic (Schemske et al., 1994) or characteristic species (Bani et al., 2006). In this study, we show that the sharp decline of arable weeds is not restricted to rare species but affects similarly weed species that used to be very common in agricultural landscapes. This should be of major concern as it is difficult to conceive that abundant and widespread species do not affect ecosystem structure and functioning (Gaston and Fuller, 2007).

We also suggest that crop edges which are not under management prescriptions are unlikely to provide solutions for long term arable weed conservation as while they harbour more perennial species due to a lesser degree of mechanical perturbation, nitrogen and light conditions prevailing in crop edges are unsuitable for the declining *oligotrophous* and/or *heliophilous* species. Prescribing lower fertilisation levels should be efficient as high nitrogen concentrations in crop edges limit populations of threatened weeds and enhance the diffusion into the crops of the most *nitrophilous* weed species, which are also the most competitive species. This type of prescription might allow some species to persist in crop edges, while for the rarest species, *ex situ* conservation and local reintroduction in suitably managed crop edges may be more efficient.

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Appendix A. Supplementary material

Changes in species frequency and abundance between the 1970s and the 2000s and comparison between field cores and crop edges for all weed species, listed ANWRL species and beneficial species. Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2008.09.029.

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