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Field margin botanical diversity, composition and quality on intensively managed farming systems

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Abstract

Remaining semi-natural habitats are important refuges for farmland biodiversity, and field margins are one such habitat. Field margins consist of strips of herbaceous vegetation that are located between field boundary features such as hedgerows and the main grassland or arable field. However, little is known about their extent or ecological quality on intensively managed farmlands in Ireland. This lack of knowledge can only be addressed through the application of a standardised assessment methodology, which we developed and implemented in this study. A survey of field margins was conducted on 92 intensively managed farms, across three enterprise types (arable, beef and dairy farms) in Ireland. We describe the botanical composition and assess the ecological quality of field margins based on threshold levels of the percentage cover of positive, neutral and negative botanical indicator species that are predominantly informed by existing European Union (EU)-accepted methods for vegetation classification. Positive indicator species occurred in 77% of margins and had a mean cover of 10%. There was a high incidence of negative indicator species, occurring in 93% of margins with a mean cover of 55%. Using our quality appraisal system, 16% of field margins were of high or very high quality, and the majority (55%) were of low or very low quality. Compared to either arable or dairy farms, beef farms had a greater percentage of higher-quality margins, higher species richness and greater percentage of positive indicator species. Retaining areas of high-quality farmland habitat and enhancing those areas that have become ecologically degraded will be key to achieving the Common Agricultural Policy (CAP) objective of protecting landscapes and biodiversity. However, the implementation of appropriate management decisions requires effective evaluation of the current ecological condition of these habitats. Field margins are ubiquitous habitats in Irish farmlands and comprise a significant proportion of overall farmland habitat area. However, our results show that the majority in more intensively managed systems are in a botanically impoverished condition. Our standardised field margin quality assessment technique may offer an appropriate method of tracking change in habitat quality in response to conservation actions to improve habitat quality.

Keywords

Biodiversity • field margin • intensive farmland • results-based payments • semi-natural habitats

Introduction

Pressures from agricultural intensification and simplification have resulted in the loss of many semi-natural habitats, including semi-natural grasslands, which are estimated to have declined considerably in area over recent decades, for example, by approximately 90% in the lowlands of the UK since 1945 (Bullock *et al.*, 2011). As a result of land-use changes, and associated loss of habitat quantity and quality, the remaining semi-natural habitats (including field margins) within an agricultural setting are increasingly important refuges for biodiversity.

Field margins are strips of herbaceous vegetation located between the field boundary (e.g. hedgerow, drainage ditch, etc.) and the conventional cropped field, and can be found in both arable and grassland systems. This definition excludes margins found adjacent to natural watercourses, for example, riparian buffer strips (Borin *et al.*, 2010). Depending on their origin (naturally occurring or sown with a seed mix) and subsequent management, field margins can be a valuable resource within an agricultural landscape, providing many environmental and biodiversity benefits (Hackett & Lawrence, 2014). Compared to the adjacent cropped field, the conditions of reduced disturbance and limited inputs of fertilisers and pesticides in field margins can provide habitat for many plant and invertebrate species (Sheridan *et al.*, 2008; Fritch *et al.*,

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2011; Holland *et al.*, 2011) and the associated species that feed on them. They can act as refugia for species associated with semi-natural grasslands (Smart *et al.*, 2002) and woodland, and may harbour seeds of rare plant species within their seed bank (Asteraki *et al.*, 2004). They may also provide habitat for pollinators such as bees, butterflies and hoverflies (Holland *et al.*, 2015; Morrison *et al.*, 2017) and natural predators of crop pests, thus enhancing the potential for biocontrol within adjacent crops (Balzan & Moonen, 2014; Ó hUallacháin *et al.*, 2014; Fritch *et al.*, 2017). They can also have important roles as landscape dispersal corridors for species (Jobin *et al.*, 2001).

Recognising the ecological value of field margins, six European Member States (MS) afforded protection to these habitats, under their cross-compliance requirements (Belgium, Bulgaria, Germany, Spain, Malta, Slovakia) (EC, 2017). A number of MS have also included field margin measures within their agri-environment schemes, for example, Austria, Germany, Switzerland and the UK (Haaland et al., 2011). The 2013 Common Agricultural Policy (CAP) reform included the establishment of Ecological Focus Areas (EFA) on arable land to “safeguard and improve biodiversity on farms” (EC, 2013). Although 17 MS or regions chose to recognise field margins as EFA, (at the time of study) a number of countries did not, including the Republic of Ireland (hereafter referred to as Ireland) (EC, 2017). More recently (2021), Ireland has recognised the ecological value of field margins by including them in the Results-Based Environment Agri-Pilot Programme (REAP) (DAFM, 2021).

The management of field margins within arable systems for the benefit of biodiversity has received significant attention (for a comprehensive review see Hackett & Lawrence [2014]). In contrast, however, less attention has been paid to the quantity or quality of field margins within grassland systems or a comparison in the species composition of field margins between arable and grassland farms. Additionally, with a small number of exceptions (see Kleijn & Verbeek, 2000; Hovd & Skogen, 2005; Alignier, 2018) relatively few studies have investigated the ecological quality of field margins using botanical species as indicators to assess quality. However, inclusion of habitat quality assessment is intended to be an important component of future iterations of agri-environment policy (EC, 2020) as it seems that agri-environment measures which include a habitat quality component (e.g. results-based payments) are more likely to result in improved ecological condition and biodiversity value than those focusing exclusively on habitat quantity (Herzon *et al.*, 2018; O’Rourke & Finn, 2020).

In our recent study within Irish farming systems of higher management intensity, field margins were one of the more widely occurring semi-natural habitats, with at least one field margin (≥1 m wide) occurring on 73% of the 119 farms surveyed (Larkin *et al.*, 2019). Within the current study, we investigated the botanical species and community composition of field margins in the same cohort of intensively managed farms as in Larkin *et al.* (2019). We investigated “naturally occurring” (unsown) field margins adjacent to hedgerows in grassland and arable farmland systems from similar regions within Ireland. Here, we developed and implemented an assessment system to compare the conservation value of the field margin habitats. More specifically, we aimed to:

1. Describe the plant communities of field margins associated with intensively managed; arable, beef and dairy farms in the south and east of Ireland;
2. Compare the community composition of the field margin communities; and
3. Compare the relative nature conservation value of the field margins, using botanical indicators of conservation value.

Materials and methods

Farm selection

This study focused on intensively managed arable and grassland (grazed and mown) farms in Ireland. As an eligibility criterion, arable farms had to comprise >15 ha of arable land, and grassland farms had either a stocking rate of ≥ 1.5 livestock units/ha, or a nitrogen loading ≥ 170 kg N/ha per year *via* a derogation from the Nitrates Directive (91/676/EEC). Farms were selected with the assistance of local agricultural advisors and were focused primarily in the south and east of Ireland, coinciding with where intensive management is more prevalent (see Appendix A for a map of farm locations). A total of 92 farms (average [±s.e.] size 68 ha ± 4.0 ha) were selected across the three main farming systems: arable (n = 38), beef (n = 29) and dairy (n = 25).

Sampling field margin vegetation

Field margin vegetation on the selected farms was surveyed once between May and August in either 2015, 2016 or 2017. Field margins are very frequently adjacent to hedgerows, thus aerial imagery was used to identify every hedgerow within each farm, prior to farm visits. Six hedgerows were randomly selected from each farm and the vegetation of the field margins adjacent to these was assessed using quadrats. The length of each of the six randomly selected field margins (per farm) was measured and two, non-concurrent, randomly located 30-m strips per field margin were selected for study. Within each of the two 30-m strips, botanical composition (vascular plants and mosses) of the field margin vegetation was sampled using two 0.5 m × 0.5 m quadrats placed at both the 10-m and 20-m mark. This gave a total of four quadrats for each of the six selected field margins per farm (a total of 24 quadrats per farm).

Study farms were walked in their entirety and the width of representative points from all field margins present was measured from the base of the adjacent hedgerow to the crop edge (see Larkin, 2019). The mean width of field margins within study farms was 1 m; thus the 0.5 m × 0.5 m quadrat size was considered appropriate. Where possible, to reduce edge effects, quadrats were located in the centre of each margin and at a minimum of 0.25 m from the adjacent hedgerow; however, some margins were not wide enough for this to occur. Gateways and intersections with other hedgerows were excluded from the sampling area.

The percentage cover of all vascular and moss species rooted within each quadrat was recorded; thus, the total percentage coverage for a single quadrat could be >100%. Species nomenclature followed Stace (2010). Botanical species recorded within quadrats were assigned to 1 of 10 functional groups; 1) grasses, 2) forbs/wildflowers, 3) woody species, 4) ferns, 5) noxious weeds, 6) mosses, 7) invasive species, 8) horsetails, 9) rushes and 10) sedges. Percentage cover was also recorded for non-plant material (e.g. bare soil, stones) and unidentifiable plant materials (e.g. sprayed material, slurry-covered material).

Development of a habitat quality assessment for field margins

We aimed to estimate the ecological quality of each field margin using a standard approach, but to the best of our knowledge there is no available methodology to do this for plant communities of field margins. Many habitat assessment methodologies rely on the use of indicator species (Ruas *et al.*, 2021); thus, we developed an assessment method based on the percentage cover of positive and negative indicator species within each margin. The categorisation of species as positive, neutral or negative indicators of conservation value was largely informed by the indicator species lists of Annex I habitats from the Irish semi-natural grasslands survey (O'Neill *et al.*, 2013), as well as the ground flora lists in the Hedgerow Appraisal System (Foulkes *et al.*, 2013). A small number of additional species were included, based on the authors' experience of Irish field margin vegetation (see Table 1, with further explanation in Appendix B). De Cáceres and Legendre (2009) highlighted that indicator species should 1) reflect the biotic or abiotic state of the environment and 2) provide evidence for the impacts of environmental change. Thus, species included within the list of negative indicators are conventionally considered to be undesirable and indicative of low or unfavourable conservation status, for example, alien invasive (e.g. *Impatiens glandulifera* L.), non-native (e.g. *Geranium pyrenaicum* L.), noxious (e.g. *Cirsium arvense* L.), nutriphilous (e.g. *Galium aparine* L.) and so on. Direct evidence of unfavourable management was also included in this category (e.g. vegetation sprayed with pesticide or fertiliser, etc.) as was *Pteridium aquilinum* L. (see Appendix B). Further explanation of the allocation of species to either the positive or negative indicator groups is provided in Appendix B. All species recorded in this survey, their respective functional group and whether they were classed as a positive or negative indicator are listed in Appendix C.

The positive and negative indicator groups underpinned the assessment of field margin quality. The cumulative percentage cover of positive indicator species and the cumulative percentage cover of negative indicator species within a field margin were used to assign each field margin to a quality category (Table 2). As an example, for the habitat quality of a field margin in this study to be categorised as "very high", the sum of positive indicator species within that margin must be >20% cover and the sum of the negative indicator species must be <20% cover. The threshold values for percentage cover were chosen by the authors; however, this approach was very strongly informed by the assessment methodology of the conservation status of vegetation of Annex 1 grassland habitats (see O'Neill *et al.*, 2013). In general, that assessment methodology includes threshold proportions of nominated negative and positive indicator species as structural indicators to assess conservation status. Such approaches are also widely adopted in results-based payments for nature conservation status in semi-natural grassland communities (see O'Rourke & Finn, 2020).

Data analysis

Normality of all the botanical data was checked using the Shapiro–Wilk test. All data were non-normal; therefore, non-parametric tests were used for statistical analysis. Analysis of the data was undertaken at two spatial scales, that is, field margin and farm, where "field margin" refers to the absolute cover percentages from the four quadrats per field margin that were pooled and averaged, while "farm" refers to the absolute cover percentages from all quadrat data (n = 24) from each farm that was subsequently pooled and averaged. The number of species present per sampling unit (field margin and farm scales) was also analysed. Sampling effort was not uniform across the three enterprises; fewer margins were sampled from some farms and fewer farms were sampled from certain enterprises. To eliminate differences due to variation in sampling effort, a subset of the data "Margins (F23)" was created to standardise sampling effort across enterprises. The maximum number of field margins sampled per farm was six. The minimum number of farms representing any one enterprise with six field margins sampled was 23. Subsequently, the Margins (F23) subset consisted of 23 farms per enterprise with each farm containing six sampled field margins.

The R package "rich" (Rossi, 2011) was used to compare species richness for each enterprise. Mean overall species

Table 1: Sources of positive and negative indicator species

Positive indicator species	Negative indicator species
Foulkes *et al.* (2013) Appendix E	Species listed under S.I. No. 103/1939[1]
Herbaceous ground flora species list	Species listed under S.I. No. 194/1973[2]
Ferns and allies list	Ruderal species listed by Foulkes *et al.* (2013)
O'Neill *et al.* (2013) Appendix 1	Stokes *et al.* (2004)
Grassland 6210	Herbaceous species listed in Appendix 3
High-quality positive indicator species	Appendix 4 – *Aegopodium podagraria* L.
Positive indicator species	O'Neill *et al.* (2013) Appendix 1
Grassland 6230	Grassland 6210
High-quality species – calcareous	Negative indicator species
High-quality species – non-calcareous	Grassland 6230
General indicator species	Negative indicator species
Grassland 6410	Grassland 6410
High-quality positive indicator species	Negative indicator species
Positive indicator species	Grassland 6430
Grassland 6430	Negative indicator species
Positive indicator species	Grassland 6510
Grassland 6510	Negative indicator species
High-quality positive indicator species	Bare soil >20%
Positive indicator species	Any crop species >20% (excl. *Lolium perenne* L.)
Poa trivialis L. ≤20%	Vegetation covered in slurry
Poa pratensis L. ≤20%	Sprayed vegetation (excl. noxious weeds)
Phleum pratense L.	Any woody species >20%
Cynosurus cristatus L.	Grasses not listed in any of the above
	Elymus repens L.
	Bromus sterilis L.
	Phalaris canariensis L.
	Agrostis spp. >50%
	Holcus mollis L. >50%
	Lolium perenne L. >50%
	Epilobium sp. >20%

See Appendix B for further information.
[1]Irish Noxious Weeds Order of 1937 (S.I. No. 103/1937).
[2]Irish Noxious Weeds Order of 1973 (S.I. No. 194/1973).

Table 2: Criteria to assess the botanical quality of field margins. The five quality categories (ranging from very high to very low) are based on combinations of the percentage cover of positive and negative indicator species.

Very high	High	Acceptable	Low	Very Low
Positive >20%	Positive >10%			
Negative <20%	Negative <30%	Negative < 50%	Negative >50%	Negative >90%

richness and associated output was calculated using the function "rich" with 1,000 resamples. Mean overall species richness and mean number of species per sampling unit were compared among enterprises using the randomisation test "c2m" within the package "rich" with 1,000 randomisations. The percentage cover of species groups (both functional and indicator) at the margin level and the width of margins across enterprises were compared using Kruskal–Wallis rank sum tests and Dunn's test of multiple comparisons (with the "FSA" package [Ogle, 2018]) in R (R Core Team, 2018). All tests of significance were at $P < 0.05$.

The composition of positive indicator and negative indicator groups across the three enterprises (beef, dairy and arable) was compared at the farm scale using one-way analysis of similarity (ANOSIM) which uses the Bray–Curtis measure of similarity (untransformed data). These similarities were visualised using non-metric multidimensional scaling (nMDS) with 100 restarts to give the best goodness-of-fit. ANOSIM and nMDS analysis of data were undertaken using Primer 6 software, version 6.1.15 (Clarke & Gorley, 2006).

Results

Botanical richness of agricultural field margins

A total of 2,096 quadrats were sampled in 524 field margins across 92 farms. A total of 170 botanical species were recorded across the three enterprises (arable = 125, beef = 110 and dairy = 100) (a breakdown of samples analysed per sampling unit per enterprise can be seen in Appendix D, Table D1). A greater mean number of species were recorded from beef field margins (12.49 ± 0.37) (i.e. four quadrats pooled and averaged) compared to arable (8.63 ± 0.26; $P < 0.001$) and dairy (10.78 ± 0.34; $P < 0.001$) margins. Dairy field margins also contained more species compared to arable margins ($P < 0.001$). The mean number of species recorded per farm was 18 (± 0.6), 24 (± 0.7) and 19 (± 0.7) for arable, beef and dairy farms, respectively. The mean number of species recorded per farm did not differ between arable and dairy farms, and both were significantly lower than species richness recorded on beef farms ($P < 0.001$ for both comparisons). Mean species richness per margin did not differ significantly between the full ("Margin", $n = 524$) and reduced ("Margin(F23)", $n = 414$) data sets across enterprises (Table E1, Appendix E).

Botanical functional groups

Grass species accounted for the highest percentage cover of each field margin within each enterprise (Table 3). Grass species occurred in 97% of margins with a mean cover of 61.4% (± 1.38) across the three enterprises combined. With respect to grass cover, the dairy enterprise had a higher percentage cover than beef ($Z = 3.45$, $P < 0.001$) and arable ($Z = 7.96$, $P < 0.001$), while beef had a higher percentage cover than arable ($Z=4.42$, $P < 0.001$). Forb/wildflower species occurred in 98% of margins and comprised the second highest percentage cover within field margins, that is, 34.8% (± 1.26) across all enterprises combined. Arable margins contained a higher percentage of forb/wildflower species compared to both beef ($Z = 4.60$, $P < 0.001$) and dairy ($Z = 8.47$, $P < 0.001$) margins, with high abundances of negative indicators including *G. aparine*, *Heracleum sphondylium* L. and *Urtica dioica* L.. The percentage cover of herbaceous species reduced to 15%, 19% and 14% for arable, beef and dairy, respectively, when negative indicator species were removed from calculations.

Beef farms in our sample contained a greater percentage cover of forb/wildflower species within their field margins compared to dairy farms ($Z = 3.77$, $P < 0.001$). Dairy field margins contained a greater percentage cover of fern species compared to both arable ($Z = 2.16$, $P < 0.05$) and beef ($Z = 2.35$, $P < 0.05$) field margins. Lower percentage cover of moss was sampled from arable field margins compared to both beef ($Z = -6.13$, $P < 0.001$) and dairy ($Z = -6.34$, $P < 0.001$). With regard to noxious weeds, beef had a significantly greater cover than dairy ($Z = 2.50$, $P < 0.05$). There was a higher percentage cover of rushes in dairy margins compared to both beef ($Z = 2.29$, $P < 0.05$) and arable ($Z = 2.19$, $P < 0.05$) field margins.

Community composition

The ANOSIM highlighted significant differences in the composition of positive ($P < 0.001$, Global R=0.102) and negative ($P < 0.001$, Global R=0.208) indicator species among enterprises. Pairwise ANOSIM tests showed these differences, while significant, to be weak and that they occurred between arable and beef ($P < 0.001$, R = 0.096; $P < 0.001$, R = 0.178), arable and dairy ($P < 0.001$, R = 0.131; $P < 0.001$, R = 0.359) and beef and dairy ($P < 0.001$, R = 0.074; $P < 0.001$, R = 0.068) for positive and negative indicators, respectively. No distinct separation of enterprises could be determined with regard to both positive and negative indicator species composition, that is, a high percentage of margins from each enterprise plotted in a very tight cluster on an nMDS output with a random distribution of the remaining margins (mainly consisting of dairy and beef margins for negative indicators) around this central group (Figure 1).

Indicator groups

Species from the negative indicator group (see Appendix C for list of species) accounted for the highest percentage cover of each field margin from each enterprise (Tables 3 and 4). Negative indicator species occurred on 93% of margins surveyed, and had a mean cover of 55.4% (± 1.6) across the three enterprises combined. Arable field margins had a significantly higher percentage cover of negative indicator species compared to both beef ($Z = 9.41$, $P < 0.001$) and

Table 3: Mean percentage cover (± s.e.) and percentage frequency (% freq.) of occurrence of species groups, assessed from quadrat data, within field margins (arable *n* = 210; beef *n* = 164; dairy *n* = 150) recorded on 92 farms (arable *n* = 38; beef *n* = 29; dairy *n* = 25) across three enterprises

	Arable		Beef		Dairy	
Group	**Mean (± s.e) % cover per margin**	**% freq.**	**Mean (± s.e) % cover per margin**	**% freq.**	**Mean (± s.e) % cover per margin**	**% freq.**
Functional groups						
Grass***	48.8 ± 2.1[a]	93.3	64.5 ± 2.2[b]	100	75.8 ± 2.4[c]	98.7
Forb/wildflower***	46.9 ± 2.2[a]	98.6	31.8 ± 2.0[b]	97.6	21.1 ± 1.6[c]	97.3
Woody [ns]	18.8 ± 1.4	85.7	17.0 ± 1.4	90.2	16.0 ± 1.5	81.3
Fern*	3.1 ± 0.6[a]	25.2	2.5 ± 0.6[a]	25.0	3.7 ± 0.7[b]	37.3
Noxious weeds*	2.8 ± 0.5[ab]	30.9	3.9 ± 0.6[a]	39.6	3.0 ± 0.7[b]	26.0
Moss***	1.7 ± 0.5[a]	12.9	6.2 ± 0.9[b]	42.1	5.8 ± 0.9[b]	45.3
Invasive species[ns]	0.5 ± 0.3	1.4	0	0	<0.1 ± <0.1	1.3
Horsetail[ns]	0.5 ± 0.2	5.7	0.2 ± 0.1	4.3	<0.1 ± <0.1	2.0
Rushes*	<0.1 ± <0.1[a]	0.9	0.1 ± 0.1[a]	0.6	0.3 ± 0.1[b]	4.0
Sedges[ns]	<0.1 ± <0.1	0.5	<0.1± <0.1	0.6	0	0
Non-plant***	3.0 ± 0.7[a]	17.1	6.3 ± 0.9[b]	36.6	3.6 ± 0.7[c]	28.7
Unidentifiable***	6.9 ± 1.2[a]	20.5	3.3 ± 0.9[b]	9.1	1.8 ± 0.7[b]	6.7
Indicator groups						
Negative***	76.6 ± 2.2[a]	98.1	41.5 ± 2.5[b]	93.2	40.9 ± 2.6[b]	86.7
Positive***	7.9 ± 0.7[a]	65.2	14.3 ± 1.1[b]	89.0	8.9 ± 0.9[a]	79.3

Data were analysed at the field margin level, that is, four quadrats pooled and averaged per margin. "Unidentifiable" refers to plant material that could not be identified, for example, after being sprayed with herbicide.
*Denotes a significant difference ($P < 0.05$) and *** denotes a very highly significant difference ($P < 0.001$) in the percentage cover of this group between at least two enterprises (Kruskal–Wallis rank sum test). Species groups with "ns" indicates no significant difference between enterprises. Values that share letters in superscript ([a,b,c]) were not significantly different based on Dunn's test.

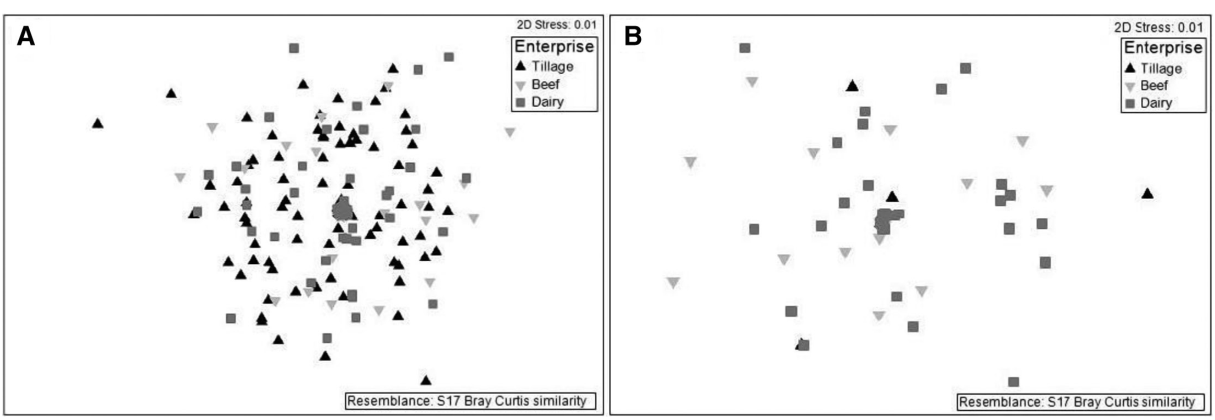

Figure 1. Non-metric multidimensional plot of A) positive indicator species and B) negative indicator species at the margins level (four quadrats pooled and averaged) per enterprise (arable *n* = 210; beef *n* = 164; and dairy *n* = 150). A very tight overlap of margins from all enterprises (especially arable in panel B) can be visualised at the centre of the plot with a random distribution of the remaining margins (from mainly beef and dairy enterprises in panel B) surrounding this central cluster.

dairy ($Z = 9.26$, $P < 0.001$) field margins. Positive indicator species were present in 77% of field margins surveyed and accounted for a mean of 10.2% (± 0.5) of the cover within field margins. Field margins on arable and dairy farms contained a significantly lower percentage cover of positive indicator species compared to beef farms (Table 3).

Table 4: Mean percentage cover (± s.e.) and percentage frequency (% freq.) of occurrence of the 10 most abundant species (by percentage cover) per enterprise, assessed from quadrat data, within field margins (arable *n* = 210; beef *n* = 164; dairy *n* = 150) recorded on 92 farms (arable *n* = 38; beef *n* = 29; dairy *n* = 25) across three enterprises

	Tillage		Beef		Dairy	
Species	**Abundance**	**Frequency (%)**	**Abundance**	**Frequency (%)**	**Abundance**	**Frequency (%)**
Cleavers	20.5 ± 1.5	87.1	R		R	
False oat grass	20.3 ± 1.6	71.9	15.9 ± 1.3	81.7	12.9 ± 1.3	76.7
Ivy	9.0 ± 1.1	61.4	8.4 ± 1.1	59.1	5.9 ± 0.8	52.0
Nettles	7.8 ± 0.9	53.8	7.9 ± 1.2	43.9	4.4 ± 1.1	34.0
Brambles	7.4 ± 0.9	58.6	7.1 ± 0.8	67.7	8.2 ± 1.1	54.7
Hogweed	7.3 ± 0.9	46.7	R		R	
Scutch	5.8 ± 0.8	38.1	R		R	
Sterile brome	5.3 ± 0.9	25.7	R		R	
Bent sp.	4.6 ± 0.6	43.8	8.2 ± 0.9	68.9	18.3 ± 1.4	88.7
Cocksfoot	3.9 ± 0.8	19.5	7.8 ± 0.9	59.8	13.0 ± 1.4	68.0
Yorkshire fog	R		10.5 ± 1.1	68.3	19.0 ± 1.6	76.7
Red fescue	R		7.0 ± 1.1	36.0	5.1 ± 0.8	34.0
Moss	R		6.2 ± 0.99	42.1	5.9 ± 0.9	45.3
Perennial ryegrass	R		5.0 ± 1.0	37.2	R	
Creeping buttercup	R		R		5.6 ± 0.8	13.3

Data were analysed at the field margin level, that is, four quadrats pooled and averaged per margin.
R denotes recorded but not ranked in the top 10 sp for that enterprise.

Assessment of field margin quality

Using the quality criteria proposed in this study, just over half of field margins assessed in this study (55%) were categorised as either low or very low quality (Figure 2). Twenty-nine percent of margins were of acceptable quality, while the remaining 16% were of high or very high quality. By enterprise, arable

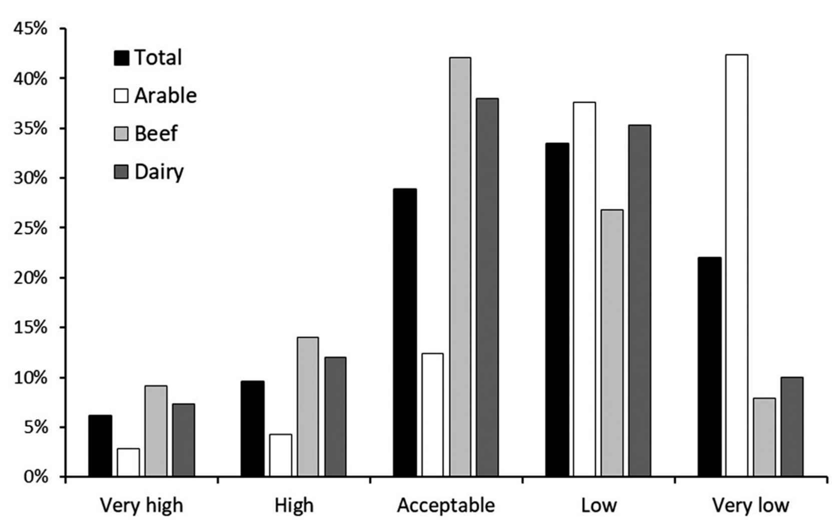

Figure 2. The distribution of sampled field margins across each quality grade (very high, high, acceptable, low, very low) for the three enterprises combined (total), and for each enterprise (arable, beef and dairy).

Table 5: Mean width (m) of 3,262 field margins surveyed across three enterprises (arable, beef and dairy) and the percentage of margins from each enterprise within each width range

	Arable	Beef	Dairy
No. of margins	1508	969	785
Mean width (m)*	0.99[a]	1.06[b]	0.88[a]
<0.5 (%)	26.72	21.57	20.76
0.5–1 (%)	43.17	41.18	58.73
1–2 (%)	23.87	28.69	19.23
2–3 (%)	4.71	7.12	<1
3–4 (%)	<1	1.24	<1
>4 (%)	<1	<1	<1

*Denotes a significant difference ($P < 0.05$) in this category between at least two enterprises (Kruskal–Wallis rank sum test; values that share letters in superscript ([a,b,c]) were not significantly different, assessed via a *post hoc* Dunn's test.

farms had the highest percentage of low- or very-low-quality margins (80%) compared to 35% of beef margins and 45% of dairy margins. Beef farms had the highest percentage of high- or very-high-quality margins (23%) compared to 7% of arable margins and 19% of dairy margins. Table F1 in Appendix F illustrates the application of the criteria to specific examples of field margins within each grading category of the assessment system and can be used in conjunction with Table 2 to show how margins were graded.

Field margin width

The mean width of field margins across the three enterprises combined was < 1.1 m (Table 5). Field margin widths on beef farms were significantly higher than those on either arable ($Z = 3.82$, $P < 0.001$) or dairy ($Z = 4.41$, $P < 0.001$) farms, but did not differ between dairy and arable farms.

Discussion

Field margins are ubiquitous features within the agricultural landscape, with Larkin *et al.* (2019) finding that they occurred on 73% of intensive farms surveyed. In the current study of vegetation composition, field margins were dominated (in abundance) by grass species and although forb/wildflower species occurred more frequently than grasses, forb/wildflower species were present in lower abundance. Negative indicator species (as classified in this study, Appendix C) occurred frequently and in high abundance, resulting in the majority of field margins (particularly those on arable farms) being categorised as low or very low quality. Field margins adjacent to arable crops contained fewer species than those adjacent to grassland systems, commensurate with results from previous studies (Hovd & Skogen, 2005).

The higher percentage cover of negative indicator species, lower species richness and hence lower ecological quality of margins on arable farms compared to grassland farms is not surprising. Although nutrient enrichment and herbicide drift can negatively impact the botanical composition of both arable and grassland field margins, in general, soil disturbance due to ploughing, sowing and harvesting tends to be higher on arable compared with grassland farms. This disturbance can alter community structure and ecosystem functioning and can promote encroachment of weedy, ruderal species (Hobbs & Huenneke, 1992) such as *C. arvense* and *Rumex crispus* L. (Foulkes *et al.*, 2013).

Field margins across all enterprises were strongly associated with negative indicator species

Field margins across all three enterprises were strongly associated with negative indicator species, culminating in the majority of the herbaceous species in arable margins being "undesirable" (indicative of low or unfavourable conservation status) (Tables 3 and 4). The presence of negative indicator (e.g. nitrophilous) and woody species within margins is reflective of management. High percentage cover (>20%) of negative indicator species (such as *G. aparine*, *U. dioica*) within a field margin can indicate nutrient enrichment arising from direct application, drift or run-off of nutrients from the adjacent crop. When soil fertility is high, botanical diversity is generally low and nitrogen input in particular, is very strongly associated with low plant species richness (Kleijn *et al.*, 2009). Tall and weedy species, such as those recorded from arable field margins in this study, and elsewhere, are promoted by lack of mowing (or lack of grazing) and can be an indicator of high nutrient levels (Hovd & Skogen, 2005). Margins in the current study were frequently very narrow (<0.5 m width), and their resulting high edge:area ratio makes them particularly vulnerable to impacts of agricultural activities in the adjacent fields, for example, slurry and fertiliser spreading.

Developing a methodology to assess the botanical quality of field margins

To our knowledge, there is currently no standard method to assess the ecological quality of field margins. Although there have been many investigations of field margins and linear landscape features, most use species richness or functional groupings of species to analyse change over space and/or time (e.g. Alignier, 2018; Vanneste *et al.*, 2020). However, use of species richness alone, especially in potentially disturbed habitats, can be an unreliable indicator of relative conservation value. In addition, although methods can be used to retrospectively gauge the relative conservation value of field margins, there is a need for practical, field-scale methods to assess the relative conservation value of individual field margins and to inform farm-scale management. For this reason, we devised and implemented a methodology based largely on adaptation of previously published Irish lists of indicator species (see Table 1 and Appendix B). The use of quantitative thresholds of positive and negative indicator species (e.g. Robertson & Jefferson, 2000; O'Neill *et al.*, 2013) (Table C1, Appendix C in this study) to guide habitat assessments is a key feature of EU monitoring of habitat quality, that is, Council Directive 92/43/EEC, Article 17 reporting (e.g. Ryle *et al.*, 2009; The Bat Conservation Trust, 2014). Assessments of the quality of semi-natural grasslands set thresholds of ≤5% and ≤10% cover, respectively, for certain negative indicator species within semi-natural grasslands (Robertson & Jefferson, 2000; O'Neill *et al.*, 2013).

The approach used here was based on simple and transparent quantitative criteria to broadly categorise the quality of field margins. These five categories (Table 2) span a very broad range of habitat quality from dominance by negative species, to dominance by a combination of positive and neutral species. Even within a single category, a wide variation in community structure is possible; for example, within the "acceptable" category, community composition can range from 49% negative indicator species and 51% positive indicator species, to 49% negative and 9% positive indicator species. As with any threshold-based approach, one can conceive of situations where a minor change can cause a transition from one category to another; in general, however, the breadth of the categories means that there needs to be a very substantial change in the species composition of the vegetation to cause a transition from one category to another. Given the robust nature of the categories, it is highly unlikely that a high-quality margin would be inadvertently classified as low quality, or *vice versa*. Overall, this method has considerable capacity to estimate the relative conservation value of field margin vegetation in intensively managed Irish farming systems, and the lessons learned and general principles applied in this study can help inform the design of similar approaches in other regions.

There are some caveats associated with the method proposed here.

First, we know of no other published methods for assessing the habitat quality of field margins against which results from this study can be compared. The method applied here can, however, be considered more robust than some other standard methods of community analysis. For example, neither ordinations nor species richness typically incorporate the degree of abundance of positive, neutral and negative indicator species that informs an assessment of habitat quality.

Second, the quality assessment in this study was applied in field margins within intensively managed systems. As the quality of field margins within extensively managed farms could be higher or indeed lower than those within intensively managed farms, an application of this method to field margins across farms of varying degrees of intensity would help to further test its validity. An application in more extensive and species-rich farming systems could usefully investigate whether the current categories are sufficient to discriminate among field margins with the highest levels of habitat quality.

Third, the indicator lists included here are based on grassland systems, and they probably do not fully represent the flora of arable margins. To address this and to identify possible rare and declining arable weeds overlooked by grassland indicator lists, we compared the list of neutral and negative indicators in our dataset, to a checklist of protected and threatened plant species for Ireland (Nelson *et al.*, 2019). No neutral/negative species in our dataset appeared on this checklist. In this study, negative indicator species dominated the flora of the arable field margins (mean cover of 76%, Table 3), with species that would be regarded as positive or neutral indicator species within arable field margins present in very low abundances (approximately 8% and 15% for positive and neutral indicators, respectively, Table 3). Thus, it is very likely that the conclusions in this study would differ little even if the positive indicator species were supplemented with a wider list of species characteristic of arable field margins. This is because 1) these species did not occur, and 2) in general, the dominance of negative species (Table 4) in our study determines that arable margins are of lower ecological condition, despite increases that might occur in the cover of additional positive species. More generally, for future surveys in areas with more botanically diverse field margins or different flora, if other species of high conservation value (arable or otherwise) occurred that are positive indicator species, there is no reason why they cannot be added to the list of species in Table 1, and incorporated into the assessment framework presented in Table 2.

Fourth, for the aforementioned reasons, the proposed assessment methodology and threshold criteria are provided for guidance. Clearly, it would be desirable to conduct a more extensive validation of the method across a wider range of landscape types and biogeographical regions. Nevertheless, the general principle of categorising species into positive, neutral and negative indicators of nature conservation value can be more widely applied. Similarly, the nature of the thresholds (in Table 2) can be more widely applied or incorporated into rapid assessment scorecards (to facilitate results-based payments [O'Rourke & Finn, 2020]), even if they need further validation and amendment to suit different biogeographical regions.

Management options for field margins

In the UK, management options for field margins constitute a considerable portion of agri-environment schemes (Vickery *et al.*, 2009) and are one of the primary AES habitat options designed to promote ecological intensification (McHugh *et al.*, 2022). Appropriate management options for field margins can vary, but management of soil nutrient status is a basic requirement that will determine the success of all other management options. Elevated soil nutrient status can give rise to competitive asymmetry, with a small number of nutrient-tolerant species dominating the sward; therefore, fertiliser and slurry inputs must be excluded from these habitats (Sheridan *et al.*, 2008). Approximately 77% of field margins in this study had at least one positive indicator present. For margins with a high percentage of negative or unwanted species and no opportunity for positive species establishment (despite these being readily available in the surrounding landscape), simple disturbance measures may be sufficient to facilitate the rejuvenation. However, where there is no seed source of positive (desirable) species, some method of re-establishment of margins involving rotavation and reseeding with a grass/wildflower mix may be appropriate as this can increase species diversity while reducing abundances of weed species (Sheridan *et al.*, 2008). However, reseeding will likely have a detrimental effect where rare species are present (Marshall, 2009) and should only be considered as a "last option". Where it is implemented, every effort should be made to ensure that the seed used is native and of local provenance. Management actions such as mowing or grazing regimes have been shown to control weed species without the need for field margin re-establishment (Smith *et al.*, 2010). Other actions could include fencing off margins where livestock access has caused poaching, and spot application of herbicide to noxious weeds. These actions will assist in achieving the biodiversity potential of field margins (Asteraki *et al.*, 2004; Sheridan *et al.*, 2009).

Conservation of field margins: looking to the future

One of the nine objectives of the CAP 2021-27 is to protect landscapes and biodiversity (EC, 2018). Conservation of both the quantity and quality of farmland habitats will be fundamental to achieving this objective. Field margins can play an important role in supporting farmland biodiversity and provision of associated ecosystem services. However, their ability to do this greatly depends on both their area and ecological condition. A related study showed that field margins are ubiquitous habitats in the Irish farmed landscape, and therefore have the potential to make a contribution in the order of 0.1–0.3% to farmland habitat area (Larkin *et al.*, 2019). However, this study showed that approximately half of the margins did not attain an "acceptable" level (<50% cover by negative indicator species). Rótches-Ribalta *et al.* (2020) found no correlation between quantity of farm habitats and quality of farm habitats. Looking to the future, this strongly suggests that as a priority for farm-scale responses, a greater focus is needed to improve the botanical quality of existing field margins rather than the establishment of new areas of field margin habitat. Although this study demonstrated low abundance of positive indicator species, their frequency of occurrence was relatively high (approximately 77% of margins, and in 100% of farms). Thus, as positive indicator species are already present in a high percentage of margins, management options that reduce competition from negative indicator species may be all that is needed to increase the abundance of positive indicator species (although this is dependent on soil nutrient status and management actions, see above).

A recent report by the European Court of Auditors highlighted that the European CAP has failed to halt the decline of biodiversity on farmland (ECA, 2020). In light of this report, and recommendations under the EU Green Deal (EC, 2019), there is high demand for improved effectiveness of environmental payments to achieve environmental goals. Results-based payments can be effective in targeting payments towards increased delivery of biodiversity benefits and incentivising increases in habitat quality (O'Rourke & Finn, 2020; Moran *et al.*, 2021). Looking to the future, a results-based approach could be considered that would link farmers' payments for biodiversity objectives to the quality of habitats; in this case, the higher the habitat quality of a field margin, the higher the payment received. Such an approach would better incentivise the improvement of low-quality habitats, and also better reward the supply of higher-quality habitats. The recent introduction of the REAP in Ireland has seen the inclusion of elements of field margin quality (e.g. cover of negative indicators within the field boundary, based on a more limited list of negative indicator species than in this study) within the wider assessment of its Grassland Scorecard. This approach could be further refined, based on the methodology presented in this study. Further development of such an approach is beyond the scope of the current study, and would require careful consideration of the objectives, indicators and transaction costs. Fundamental to such an approach, however, would be a method to assess the habitat quality of field margins. In principle, our assessment of habitat quality for field margins could help inform the threshold and target levels of habitat quality for incorporation into a results-based approach.

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Appendix A

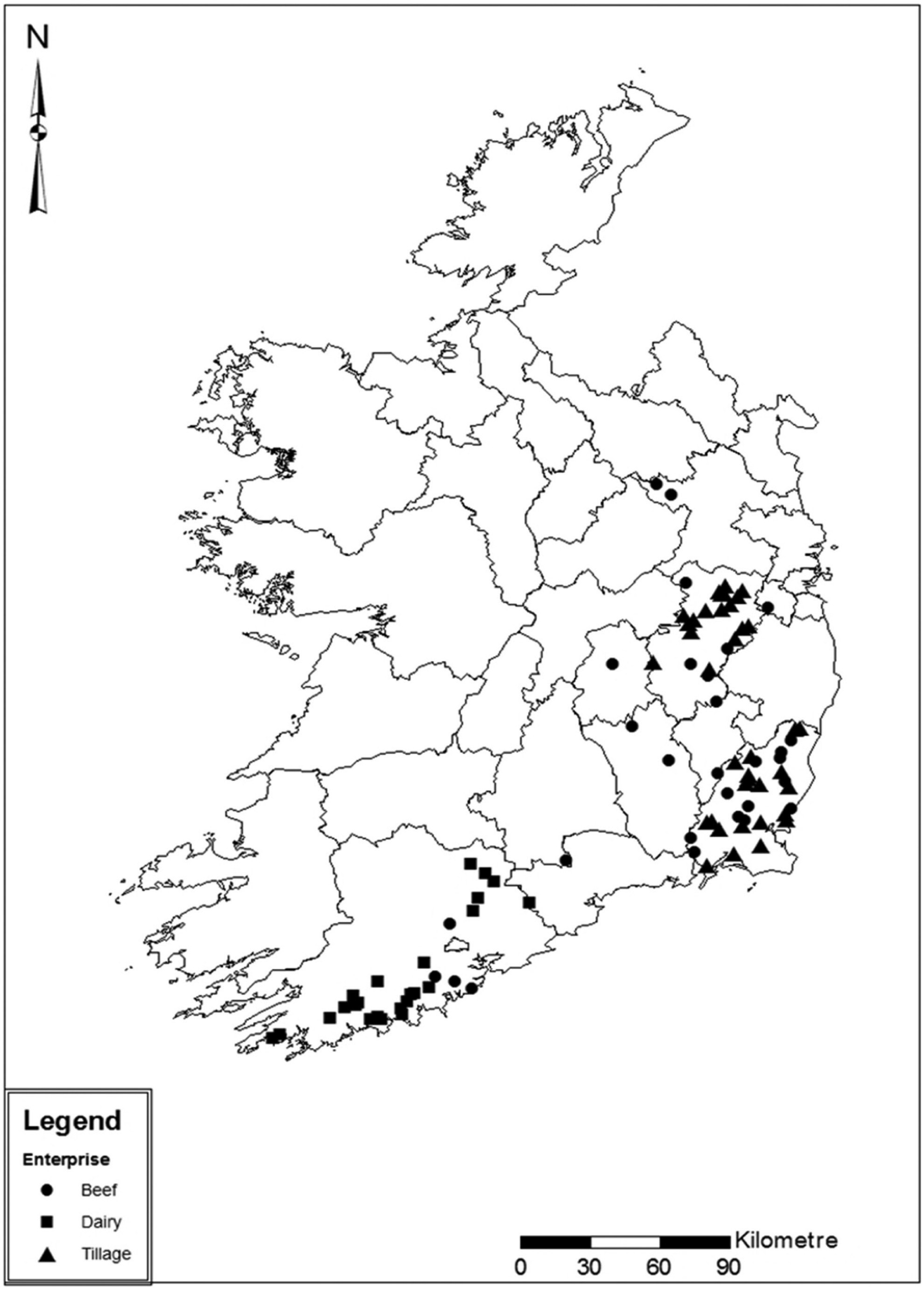

Figure A1. Map of Ireland showing the locations of all surveyed farms.

Appendix B: Positive and negative indicator species

The positive and negative indicator species lists were largely informed by the ground flora lists presented within the Hedgerow Appraisal System (Foulkes *et al.*, 2013) and the indicator species lists of Annex 1 habitats from the Irish semi-natural grasslands survey (O'Neill *et al.*, 2013). A small number of additional species were also included within these groups (Table 1). Species within the negative list demonstrated specific traits, for example, alien invasive (e.g. *I. glandulifera*), non-native (e.g. *G. pyrenaicum*), noxious weed (e.g. *C. arvense*), nutrient enrichment indicator (e.g. *G. aparine*) and so on, meaning they were assigned to this category. Signs of unfavourable management were also included in this category (e.g. sprayed material, etc.) as was *P. aquilinum*, a weed plant with very little biodiversity value (Purvis *et al.*, 2009), a problematic plant indicative of undergrazing, which has the potential to become invasive. *Pteridium aquilinum* produces very tall, large fronds and extensive accumulations of litter that impede the growth of low-growing species, in addition to containing toxins that deter herbivory and decomposition (Marrs *et al.*, 2000). It can, however, provide nesting habitat for queen bees; thus a threshold was placed on this species.

As field margins link hedgerows with the adjacent cropped land and can act as refugia for species associated with semi-natural grasslands (Smart *et al.*, 2002), positive indicator ground flora species from the Hedgerow Appraisal System (Foulkes *et al.*, 2013) and the Irish Semi-natural Grasslands Survey (O'Neill *et al.*, 2013) were assigned as positive indicator species within this study. Field margins can also act as refugia for arable weed species; however, a definitive list of positive arable weed species could not be ascertained. Nonetheless, a number of arable weed species were already included in both the hedgerow and semi-natural grassland lists (e.g. *Daucus carota, Lapsana communis, Vicia cracca, H. sphondylium*) and so it was decided to continue with these two sources alone for the purposes of this study without the addition of a specific arable weed species list.

To account for additional vascular plants of conservation concern (that may be associated with arable habitats), we compared the remaining plants recorded in our study (i.e. those classified as either neutral or negative) to a checklist of protected and threatened plant species for Ireland (Nelson *et al.*, 2019), (i.e. Floral Protection Order; Habitats Directive; Red List of Vascular Plants). None of the species classified as either neutral or negative in our classification was present on this checklist.

A number of grass species were, however, added to the positive indicator list (e.g. *Phleum pratense, Cynosurus cristatus*). As very few grasses were nominated within either the hedgerow (Foulkes *et al.*, 2013) or semi-natural grassland (O'Neill *et al.*, 2013) positive species' lists, additional grass species were required for the positive indicator species list for this study due to the fact that field margins provide suitable habitats to support grasses whose range has been restricted by intensive farming practices. All species recorded within this study and their associated groups are outlined in Appendix C, Table C1.

Some species listed within the negative indicator lists were only regarded as negative when their abundance value exceeded a threshold (i.e. 20% or 50% for some grasses), for example, *Dactylis glomerata, U. dioica, Hedera helix, Arrhenatherum elatius* and so on. For instance, a number of butterfly species use *U. dioica* as a larval food plant (e.g. peacock (*Aglais io*), small tortoiseshell (*Aglais urticae*), comma [*Polygonia c-album*]); however, this plant can also be a sign of high nutrient soil status (Tsiouris and Marshall, 1998) within the field margin when present in large abundances. Similarly, *D. glomerata* can provide overwintering habitat for carabid and staphylinid beetles (Meek *et al.*, 2002); however it is a competitive grass that can significantly reduce sward species diversity on fertile soils (Vickery *et al.*, 2009). While a number of *Epilobium* species were listed as positive indicator species for 6430 grassland (hydrophilous tall forb fringe communities of plains and of the montane to alpine levels) (O'Neill *et al.*, 2013), all *Epilobium* species were grouped together in this study and were regarded as a negative indicator species above a threshold abundance of 20% coverage. *Chamerion angustifolium* is included within the *Epilobium* grouping. This is justified within field margin habitats as the taller species such as *C. angustifolium* can shade out lower-growing species. Similarly, *H. sphondylium* is listed as a positive species for 6510 grassland (Lowland hay meadows) (O'Neill *et al.*, 2013). A 20% threshold was placed on *H. sphondylium*, whereby at 20% coverage or less it was included as a positive indicator but above 20% it was regarded as a negative indicator. *Heracleum sphondylium* was the only species that could be classified as either positive or negative, based on the cover. Justification for inclusion as a positive indicator is based on the fact that it is listed as a positive species for 6510 grassland (lowland hay meadows) (O'Neill *et al.*, 2013). De Cáceres and Legendre (2009) suggested that indicator species should be chosen if they could predict the diversity of other species, taxa or communities within an area. Thus, this study applied a threshold (above which *H. sphondylium* was considered negative) as taller species such as *H. sphondylium* within field margin habitats can dominate, and shade out lower-growing species.

Some other species within the positive species list were also only regarded as positive when their abundance was below a threshold value (20%). Above this value, they were classed as neutral within the grass category. The two species this refers to are *Poa trivialis* and *Poa pratensis*, which are both tall-growing species. *Poa pratensis* also has a creeping habit and can form dense mats. These traits can result in the exclusion of other species; thus a threshold level of 20% was allocated to both of these *Poa* species.

Signs of unfavourable management included within the negative indicator group include sprayed material, woody species > 20%, bare soil > 20% and material covered in slurry. Sprayed material and material covered in slurry indicate imprecise application of pesticide and fertiliser, respectively, onto the adjacent crop. Woody species encroachment from the adjacent hedgerow is a sign of lack of hedgerow management; however, as the recommended frequency of hedgerow management (at the time of study) was once every 3 yr (Teagasc, 2009), a threshold of 20% was applied to this category to allow for regrowth during maintenance periods. Bare soil within a field margin can be a sign of poaching from cattle and thus indicative of unfavourable management as the margin is improperly fenced away from the adjacent field. A threshold was set to this category as some bare soil can naturally occur within a field margin, for example, at the base of a tree. Additionally, most Irish solitary bees nest on bare ground or in south- or east-facing bare earth banks (All-Ireland Pollinator Plan, 2015–2020).

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Appendix C

Table C1: All species and non-plant material sampled from 92 farms (arable = 38, beef = 29, dairy = 25) and each species' respective grouping

Group	Species			
Forbs/wildflowers	*Achillea millefolium*	*Aegopodium podagraria* (N)	*Ajuga reptans* (P)	*Alliaria petiolata* (P)
	Allium ursinum (P)	*Anagallis arvensis*	*Angelica sylvestris* (P)	*Anthriscus sylvestris* (P)
	Apium nodiflorum	*Arctium minus*	*Arum maculatum* (P)	*Bellis perennis*
	Calystegia sepium ≤20%	*C. sepium* >20% (N)	*Cardamine flexuosa*	*Cardamine hirsuta*
	Cardamine pratensis	*Centaurea nigra* (P)	*Cerastium fontanum*	*Chrysosplenium oppositifolium* (P)
	Cirsium palustre	*Conopodium majus* (P)	*Convolvulus arvensis* ≤20%	*Daucus carota* (P)
	Digitalis purpurea (P)	*Epilobium* spp.≤20%	*Epilobium* spp.>20% (N)	*Euphrasia officinalis*
	Ficaria verna (P)	*Filipendula ulmaria* (P)	*Fragaria vesca* (P)	*Fumaria muralis*
	Galium aparine (N)	*Galium odoratum* (P)	*Galium verum* (P)	*Geranium pyrenaicum* (N)
	Geranium robertianum (P)	*Geranium* spp.	*Geum urbanum* (P)	*Glechoma hederacea* (P)
	Heracleum sphondylium ≤20% (P)	*H. sphondylium* >20% (N)	*Hyacinthoides non-scripta* (P)	*Hypericum humifusum*
	Hypochaeris radicata (P)	*Iris pseudacorus* (P)	*Lamium purpureum*	*Lapsana communis* (P)
	Lathyrus pratensis (P)	*Lotus corniculatus* (P)	*Lotus pedunculatus* (P)	*Lysimachia nemorum* (P)
	Matricaria discoidea (N)	*Medicago lupulina*	*Mentha aquatica* (P)	*Myosotis arvensis*
	Oxalis acetosella (P)	*Papaver rhoeas*	*Plantago lanceolata* (P)	*Plantago major*
	Potentilla anglica (P)	*Potentilla anserina*	*Potentilla erecta* (P)	*Potentilla reptans*
	Potentilla sterilis (P)	*Primula vulgaris* (P)	*Prunella vulgaris* (P)	*Ranunculus acris* (P)
	Ranunculus repens ≤20%	*Ranunculus repens* >20% (N)	*Raphanus raphanistrum* subsp. *raphanistrum*	*Rumex acetosa*
	Rumex acetosella	*Sagina procumbens*	*Senecio vulgaris*	*Sherardia arvensis*
	Sinapis arvensis	*Smyrnium olusatrum*	*Sonchus arvensis*	*Sonchus asper*
	Stachys palustris (P)	*Stachys sylvatica* (P)	*Stellaria graminea*	*Stellaria holostea* (P)
	Stellaria media	*Taraxacum* spp.	*Teucrium scorodonia*	*Torilis japonica*
	Trifolium pratense (P)	*Trifolium repens*	*Trifolium* spp.	*Tussilago farfara*
	Umbilicus rupestris	*Urtica dioica* ≤20%	*U. dioica* >20% (N)	*Veronica beccabunga*
	Veronica chamaedrys	*Veronica filiformis*	*Veronica hederifolia*	*Veronica persica*
	Veronica serpyllifolia	*Vicia sativa*	*Vicia cracca* (P)	*Vicia sepium*
	Viola arvensis	*Viola* spp. (P)	*Viola tricolor* subsp. *tricolor*	

Table C1: (continued)

Group	Species			
Woody species	*Acer pseudoplatanus*	*Corylus avellana*	*Crataegus monogyna*	*Fraxinus excelsior*
	Hedera helix ≤20%	*H. helix* >20% (N)	*Ilex aquifolium* ≤20%	*Ligustrum vulgare*
	Lonicera periclymenum	*Prunus avium*	Prunus spinosa ≤20%	Prunus spinosa >20% (N)
	Quercus spp.	*Rosa* spp.	*Rubus fruticosus agg.* ≤20%	*R. fruticosus agg.* >20% (N)
	Salix spp.	*Sambucus nigra*	*Solanum dulcamara (P)*	*Ulex* spp. ≤20%
	Ulex spp. *>20%* (N)	*Ulmus procera* ≤20%	*U. procera* >20% (N)	*Viburnum opulus*
Grasses	*Agrostis* spp. ≤50%	*Agrostis* spp. >50% (N)	*Alopecurus pratensis* (P)	*Anthoxanthum odoratum* (P)
	Arrhenatherum elatius ≤50%	*A. elatius* >50% (N)	*Avena sativa* ≤20%	*Brachypodium sylvaticum*
	Bromus sterilis (N)	*Cynosurus cristatus* (P)	*Dactylis glomerata* ≤50%	*Dactylis glomerata* >50% (N)
	Deschampsia cespitosa ≤20%	*Elytrigia repens* (N)	*Festuca rubra*	*Holcus lanatus* ≤50%
	H. lanatus >50% (N)	*Holcus mollis ≤50%*	*H. mollis* >50% (N)	*Hordeum vulgare* ≤20%
	Lolium multiflorum (N)	*Lolium perenne ≤50%*	*L. perenne* >50% (N)	*Phalaris arundinacea* (N)
	Phalaris canariensis (N)	*Phleum pratense* (P)	*Poa annua*	*Poa pratensis* ≤20% (P)
	P. pratensis >20%	*Poa* spp.	*Poa trivialis* ≤20% (P)	*P. trivialis* >20%
	Schedonorus arundinaceus ≤20%			
Noxious weeds	*Avena fatua* (N)	*Cirsium arvense* (N)	*Cirsium vulgare* (N)	*Rumex crispus* (N)
	Rumex obtusifolius (N)	*Senecio jacobaea* (N)		
Invasive	*Crocosmia x crocosmiiflora* (N)	*Impatiens glandulifera* (N)		
Horsetails	*Equisetum arvense*	*Equisetum fluviatile* (P)	*Equisetum sylvaticum* (P)	*Equisetum telmateia* (P)
Moss	All bryophytes			
Unidentifiable material	Slurry-covered material (N)	Sprayed material (N)		
Non-plant material	Bare soil ≤20%	Bare soil >20% (N)	Branches, leaves	Stones
Rushes	*Juncus bufonius*	*Juncus conglomeratus* (P)	*Juncus effusus*	
	Juncus spp.			
Sedges	*Carex* spp.			
Ferns	*Asplenium adiantum-nigrum*	*Asplenium scolopendrium* (P)	*Athyrium filix-femina* (P)	*Dryopteris filix-mas* (P)
	Polystichum setiferum (P)	*Pteridium aquilinum* ≤20%	*P. aquilinum* >20% (N)	

The letters in brackets after a species indicate whether this species was allocated to the positive (P) or negative (N) indicator group. All other species were classed as neutral species.

Appendix D

Table D1: The number of samples per sampling unit per enterprise

	Quadrat	Margin	Margin (F23)	Farm
Total	2096	524	414	92
Arable	840	210	138	38
Beef	656	164	138	29
Dairy	600	150	138	25

Appendix E

Table E1: Number of species recorded within the full ("Margin") and reduced ("Margin[23]") field margin sampling units per enterprise including the accumulated total for all enterprises combined

	Margin	Margin (F23)
Total	*n* = 524	*n* = 414
Total no. of species	170	156
Species richness (± s.e)	125 ± 1.3	125 ± 1.4
Species richness upper CI	127.8	127.6
Species richness lower CI	122.9	122.2
Arable	***n* = 210**	***n* = 138**
Total no. of species	125	96
Species richness (± s.e)	123 ± 2.1	121 ± 2.7
Species richness upper CI	127.2	126.6
Species richness lower CI	118.9	116.1
Beef	***n* = 164**	***n* = 138**
Total no. of species	110	102
Species richness (± s.e)	127 ± 2.1	127 ± 2.3
Species richness upper CI	131.67	131.63
Species richness lower CI	123.3	122.7
Dairy	***n* = 150**	***n* = 138**
Total no. of species	100	99
Species richness (± s.e)	126 ± 1.8	126 ± 1.9
Species richness upper CI	129.5	130.1
Species richness lower CI	122.5	122.5

Also included is the bias-corrected bootstrapped mean species richness calculated from 1,000 resamples and associated standard error and upper and lower confidence intervals. CI = confidence interval.

Appendix F

Table F1: Examples of field margins for each quality assessment category (very low, low, acceptable, high, very high) showing the percentage cover of each species surveyed per margin, the group each species represents (positive indicator, negative indicator, neutral) and the total percentage cover of each of the positive and indicator groups

F1a: Very low quality

Category	Neutral	Positive	Negative	Negative	Positive	Neutral	**Total Negative**	**Total Positive**
Species	*Agrostis* spp. ≤50%	*Anthriscus sylvestris*	Dead/sprayed material	*Galium aparine*	*Heracleum sphondylium* ≤20%	*Urtica dioica* ≤20%		
% cover	0.5	5	45	57.5	1.25	1.25	102.5	6.25

F1b: Low quality

Category	Neutral	Negative	Negative	Neutral	Positive	Positive	Neutral	Negative	**Total Negative**	**Total Positive**
Species	*Arrhenatherum elatius* ≤50%	*Cirsium arvense*	*G. aparine*	*Holcus lanatus* ≤50%	*Poa trivialis* ≤20%	*Polystichum setiferum*	*Rubus fruticosus agg.* ≤20%	*f* >20%		
% cover	18	5	40	1.25	2.5	22.5	5	35	80	25

F1c: Acceptable quality

Category	Neutral	Neutral	Negative	Neutral	Neutral	Neutral	Negative	**Total Negative**	**Total Positive**
Species	*Agrostis* spp. ≤50%	*A. elatius* ≤50%	*G. aparine*	*Hedera helix* ≤20%	*Holcus lanatus* ≤50%	*R. fruticosus agg.* ≤20%	*U. dioica* >20%		
% cover	20	30	6.25	15	21.25	17.50	27.5	33.75	0

F1d: High quality

Category	Neutral	Negative	Negative	Positive	Neutral	Neutral	Neutral	Neutral	**Total Negative**	**Total Positive**
Species	*A. elatius* ≤50%	*Bromus sterilis*	*Galium aparine*	*Heracleum sphondylium* ≤20%	*Poa annua*	*Pteridium aquilinum* <20%	*Rubus fruticosus agg.* ≤20%	*Stellaria media*		
% cover	40	2.5	12.5	11.25	25	10	3.75	3.75	15	11.25

F1e: Very high quality

Category	Neutral	Positive	Neutral	Neutral	Neutral	Positive	Neutral	Neutral	Positive	**Total Negative**	**Total Positive**
Species	*Agrostis* spp. ≤50%	*Anthoxanthum odoratum*	*Festuca rubra*	*Holcus lanatus* ≤50%	*Holcus mollis* ≤50%	*Lotus corniculatus*	*R. fruticosus agg.* ≤20%	*Trifolium repens*	*Viola* spp.		
% cover	43.75	47.5	2.5	7.5	2.5	0.12	14.25	0.5	0.5	0	48.12

Neutral refers to all species that are not classed as either positive indicator or negative indicator. Total Negative is the sum of the percentage cover of negative indicator species within a margin; for example, in Table F1a it is equal to the sum of dead/sprayed material (45%) and *Galium aparine* (57.5%); total positive is the sum of the percentage cover of positive indicator species within a margin; for example, in Table F1a it is equal to the sum of *Anthriscus sylvestris* (5%) and *Heracleum sphondylium* ≤20% (1.25%). Assignation of quality scores follow criteria outlined in Table 2, for example, the margin described in Table F1a is classed as very low quality because the sum of the negative indicator species is >90%.