Research Article • DOI: 10.1515/ijafr-2016-0018 IJAFR • 55(2) • 2016 • 176-191

Irish Journal of Agricultural and Food Research

A comparison of grassland vegetation from three agri-environment conservation measures

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Abstract

Semi-natural grassland habitats have declined significantly throughout Europe. To halt the decline, grassland conservation measures have been included in most European agri-environment schemes. This is the first study to compare the botanical composition of grassland habitats managed under the Irish Agri-Environment Options Scheme (AEOS). Sixty fields on drystock pastoral farms in receipt of agri-environment payments for grassland conservation were surveyed, with 20 fields being enrolled in each of the following AEOS options: Traditional Hay Meadow (THM), Species-Rich Grassland (SRG) and Natura 2000 species-rich grassland (Natura). The vegetation quality of sites enrolled in the Natura measure was higher than the quality of those enrolled in the THM and SRG measures. Natura sites had the greatest species richness, with a mean >40 species per site, which included approximately 17 species indicative of high botanical quality. Traditional Hay Meadows sites had the lowest species richness (mean: 29 species per site) and were dominated by species associated with improved grassland. Some THM sites had good levels of botanical richness and were similar in composition to Natura sites, with some Natura sites having lower vegetation quality, more similar to that of THM sites. Species-Rich Grassland had botanical richness that was intermediate between THM and Natura sites. A thorough assessment of the effectiveness of these measures was confounded by a lack of quantitative objectives for the target community composition to be attained. We discuss limitations and potential opportunities regarding the design, targeting, implementation and cost-effectiveness of these agri-environment measures.

Keywords

agri-environment scheme • grassland botanical diversity • grassland conservation• high nature value farmland • semi-natural grassland

Introduction

The widespread decline in global biodiversity, including farmland biodiversity (Robinson and Sutherland, 2002; Tscharntke *et al*., 2005), represents a major conservation challenge (Butchart *et al*., 2010). Approximately 50% of all European species are dependent on agricultural practices (Kristensen, 2003; Stoate *et al*., 2009), and changes in farming practices (e.g. intensification/extensification of management techniques) can lead to the loss of priority habitats, including grassland habitats such as hay meadows, heathlands, moorlands, chalk and dry grasslands (Henle *et al*., 2008). Semi-natural grassland habitats act as a refuge for invertebrate, bird and mammal species (O'Neill *et al*., 2013). The intensification of grassland management (Poschlod and WallisDeVries, 2002), particularly through changes in reseeding and the frequency of new sward establishment (Ridding *et al*., 2015), grazing and forage systems (Kruess and Tscharntke, 2002), as well as nutrient inputs (Fuller, 1987), has resulted in the loss of a range of grassland habitats and their associated biodiversity (McMahon *et al*., 2010).

In Ireland, approximately 65% of the land area is dedicated to agricultural production (CSO, 2010; DAFM, 2013a), of which more than 90% is pasture and rough grazing land. Within Irish grassland systems, semi-natural grassland habitats have undergone a significant decline, similar to European trends (Fuller, 1987; Henle *et al*., 2008; Ridding *et al*., 2015). For example, of the semi-natural grassland sites recorded in Ireland in the 1970s, approximately 38% no longer supported semi-natural grassland communities by 1994 (Byrne, 1997). More recently (1990–2000), semi-natural grassland, heathlands, pastures and mixed farmlands have all decreased, while permanent pastures and arable land in particular have increased (EPA, 2003). In addition, Sheridan *et al*. (2011) found that the frequency of occurrence of semi-natural grasslands on farms in South-East Ireland was low, and these constituted <1.75% of the average farm area in their study. An evaluation of the status of habitats designated under the Habitats Directive found that all grassland habitats had a "poor" or "bad" conservation status in 2007 (NPWS, 2008), with no improvement by 2013

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(NPWS, 2013). Similarly, O'Neill *et al*. (2013) found that the assessment of overall condition for all five Annex 1 grassland habitats was "unfavourable–bad". The documented decline in the range and quality of semi-natural grassland habitats highlights the need for evidence-based and well-targeted conservation actions to address this decline.

Agri-environment schemes (AESs) were established (EU Agri-environmental Regulation [90/20788/EEC]) to promote management practices that are more ecological and environmentally beneficial (Kleijn and Sutherland, 2003). These schemes use public funds to pay for private actions by farmers, as a means of ensuring environmental public goods that are external to market systems (Finn and Ó hUallacháin, 2012). EU Member States are obliged to monitor and evaluate the environmental, agricultural and socioeconomic impacts of their agri-environment (AE) programmes (EC Regulation No. 746/96). Evaluation is also necessary to demonstrate value for money to taxpayers, as well as to avoid accusations of trade distortion. However, the effectiveness of AES as a tool to maintain and enhance farmland biodiversity has been questioned (Kleijn and Sutherland, 2003). This may be due to a variety of reasons, including deficiencies in relation to the design, targeting, monitoring, evaluation and flexibility of individual measures and overall schemes.

Considering the prominence of grasslands in Ireland, and the "bad" conservation status of the majority of designated grassland habitats (NPWS, 2013), it is not surprising that measures to address the conservation of grassland habitats have been included in all iterations of Ireland's AESs: the Rural Environment Protection Scheme (REPS, 1994–2014) and the Agri-Environment Options Scheme (AEOS, 2010–2018). The primary scheme in place during this study in 2013, AEOS, provided three specific AE grassland measures:

1. Traditional Hay Meadow (THM)
2. Species-Rich Grassland (SRG)
3. Grassland with a Natura 2000 designation, which formally received a Natura-based payment (Natura)

Grassland conservation measures are intended to represent a significant financial investment and policy instrument for protection of biodiversity in Ireland. The AE grassland measures were the three most popular measures in AEOS in 2013 (i.e. 51% of participants undertook SRG, 27% undertook THM and 19% undertook Natura measures on their farms) (L. O'Shea, DAFM, personal communication). High participation rates, coupled with payment rates of €314/ha for SRG and THM and €75/ha for Natura, have resulted in €19.25 million, €6.31 million and €3.03 million, respectively, being spent on these three measures in 2013. More recently, these measures (incorporating slight changes in eligibility and management criteria) have been included in the Green Low-Carbon Agri-environment Scheme (GLAS), the Irish AES launched in 2015.

Two basic requirements of successful conservation measures are that their environmental effectiveness is validated and that they are appropriately costed. The European Court of Auditors report (2011) on AE payments made the following recommendations:

1. AE expenditure should be more precisely targeted;
2. There should be a higher rate of EU contribution for sub-measures with higher environmental potential;
3. There should be a clear distinction between simple and more demanding AE sub-measures; and
4. Member States should be more proactive in managing AE payments.

This study compared the botanical species richness, abundance and community composition of grassland sites enrolled in three AE grassland measures. We sought to compare the variability in the botanical composition within grasslands undertaking the same management criteria (and thus in receipt of the same payment under AEOS) as well as the variability in botanical composition between grasslands undertaking different grassland measures (and thus receiving different payments). Greater understanding of the botanical composition and quality of grasslands in receipt of AE payments will help inform policymakers on the cost-effectiveness of existing management criteria, as well as helping to identify ways of revising existing measures to improve their cost-effectiveness.

Materials and methods

Site selection

Site selection was restricted to pastoral drystock farms participating in the AEOS and in receipt of payments for at least one of the three grassland options available under the scheme; THM, SRG, and grassland designated as Natura 2000 site (Natura). Thus, 20 sites representing each of the grassland options were randomly selected, resulting in a total of 60 sites (from counties Roscommon [20], Kildare [14], Longford [11], Laois [7], Offaly [6], and Mayo [2]). Information relating to the condition of the sites prior to entry to AEOS, or on whether the sites had been participants in previous AESs, was not available.

Each grassland measure in AEOS had specific management criteria (abbreviated details are provided in Table 1; additional details can be found in DAFM [2010]). The THM measure required applicants to identify at least three grass species other than *Lolium perenne* in the sward and specified that the land parcel must not have been cultivated for a minimum of eight years prior to entry into the scheme (DAFM, 2010).

Table 1. Classification and management prescriptions for Traditional Hay Meadow, Species-Rich Grassland and Natura grassland under the Agri-Environment Option Scheme (AEOS), summarised from DAFM (2010)

Classification and management prescription	Traditional Hay Meadow	Species-Rich Grassland	Natura
Eligibility	Three grass species present other than ryegrass	Five indicators from guidelines. <20% negative indicators	Designated as per Natura 2000 specifications
Cultivation	No cultivation in past 8 yr	No cultivation in past 8 yr	Cultivation must be avoided
Nitrogen	<30 kg/ha N	<30 kg/ha (N or P)	Traditional practices maintained, based on results of soil test
Phosphorus	–	<30 kg/ha (N or P)	Traditional practices maintained, based on results of soil test Phosphate level should be less than index 2
Closed period	By 15th April	N/A	N/A
Grazing/stocking rate	–	No specific details	Traditional grazing practices maintained
Mowing	After 15th July	After 15th July	–
Additional	Hay must be turned twice	No herbicides permitted. Spot treatment of noxious weeds permitted	No herbicides permitted. Spot treatment of noxious weeds permitted.
Payment rate	€314/ha	€314/ha	€75/ha

The SRG measure required the identification of indicator species as an eligibility criterion for participation and had similar cultivation requirements as for THM. Typically, no pesticides, chemical fertiliser, slurry or farmyard manure (beyond inputs from grazing animals) could be applied to SRG, with the exception being AEOS 3 (third iteration of the scheme; DAFM, 2013b) where up to 30 kg/ha of nitrogen (N) and/or phosphorus (P) could be applied. For THM, up to 30 kg/ha of N could be applied. Compliance with both THM and SRG measures required the continuation of "traditional" grazing practices (without further clarification as to what was considered traditional). THM and SRG had to be closed or cut at certain times of the year, and stocking rates and winter feeding were restricted. Payment rates for THM and SRG were €314/ha (up to a maximum of 10 ha).

Specifications for Natura grasslands were less explicit. Only designated Natura 2000 sites were eligible. Management prescriptions typically required that traditional management practices be maintained (Table 1; DAFM, 2010). The payment rate was €75/ha (maximum €4,000), and where this measure was selected, all Natura land had to be included (even if the total area of Natura land on the farm exceeded the area of land paid for).

Survey methods for grasslands

Grassland surveys were undertaken on each of the 60 sites between early May and August of 2013 and 2014. One field (site) per AE grassland measure was surveyed per farm. Where a farm had more than one field of any individual AE grassland measure, the largest field was selected. Seventeen farms had more than one AE grassland measure represented (THM and SRG: 8; SRG and Natura: 5; THM and Natura: 3; THM, SRG and Natura: 1), in which case, one field of each AE grassland measure was surveyed. Within each selected field, 20 quadrats (1 m × 1 m) were randomly located. To ensure that the full variability of plant species within the main area of the field was sampled, the quadrats were restricted in their location, i.e., they were (1) a minimum of 10 m apart and (2) a minimum of 10 m away from the base of hedgerows, other field boundaries or gateways. All vascular plants rooted within each quadrat were identified to species according to Stace (1997). Hybridisation of *Agrostis* species meant that the species were grouped as *Agrostis* spp. (refer Hubbard, 1984). Abundance values were assigned according to the Braun-Blanquet Scale (Braun-Blanquet *et al*., 1932). Data analysis techniques required that the Braun-Blanquet values be converted to actual percentage cover values. This was done by assigning a percentage score to the midpoint of each category (according to Wikum and Shanholtzer, 1978). The 20 quadrats per site were summed, and the mean value was used to calculate a mean percentage cover value for each species per site. To address the limitations with species richness metrics (Fleishman *et al*., 2006), both Shannon diversity index (H′) and effective species richness (expH′) (Jost, 2006) were calculated from the relative abundance data. Effective species richness represents the true diversity rather than an index of diversity; thus, a community with an effective richness of 2.0 is considered twice as diverse as a community with an effective richness of 1.0.

To assess the botanical quality of the sites, plant indicator species for high-quality grassland (hereafter, positive indicators) were based on the High Nature Value plant species list recommended by O'Neill *et al*. (2013). Negative indicator species (plants associated with Improved Agricultural

Grassland (GA1) which are considered negative when they exceed 10% cover; Fossitt, 2000) were also derived from O'Neill *et al*. (2013) and consisted of the species that were universal to the four occurring Annex 1 grassland habitats in the study (i.e. *Cirsium arvense, C. vulgare, L. perenne, Rumex obtusifolius, Senecio jacobaea, Trifolium repens* and *Urtica dioica*).

High soil nutrient levels are often associated with reduced botanical richness and the dominance of a few highly competitive species in the grassland (Kleijn *et al*., 2009). Soil was sampled at each field to measure the fertility and pH levels. Soil samples consisted of 20 pooled 10-cm-deep cores taken in a "W" formation across the sampled fields. These samples were air-dried and analysed for Morgan's available P, potassium (K), magnesium (Mg) and pH.

Data analysis

Data was checked for normality using Shapiro–Wilk test with PROC UNIVARIATE in SAS (SAS 9.3.1; SAS Institute Inc., Cary, NC, USA). A comparison of species richness, diversity and effective richness, along with the richness and mean percentage cover of taxonomic groups (i.e. herb, grass, shrub), between each AE grassland measure was undertaken with generalised linear modelling (GLM; normal distribution) and Kruskal–Wallis test (non-normal distribution) in SAS. Shrub cover data were used as a negative indicator of habitat quality; values were zero-inflated, so the data were log-transformed and Poisson distribution used. PROC GLM (normal distribution) and Kruskal–Wallis test (non-normal distribution) were used to analyse variations in P, K, Mg and pH concentrations in soils among each AE grassland measure and also to model correlations between P, K, Mg and pH concentrations and species richness, as well as the richness and relative abundance cover of different taxonomic groups.

Constrained and unconstrained approaches were used to analyse the data using PRIMER v6 and CANOCO 4.5 (CANOCO 4.5; Biometrics – Plant Research International, Wageningen, the Netherlands). Unconstrained analyses – non-metric multidimensional scaling (nMDS) – were used to test differences in the community composition between AE grassland measures. Differences in the botanical composition of the three AE grassland measures were calculated using "analysis of similarity" (ANOSIM) in PRIMER ANOSIM, which is an ANOVA-like analysis specifically developed for ecological data. Non-metric multidimensional scaling plots were produced to display differences in community composition between grassland measures.

Ordination analysis (using CANOCO 4.5) was used to investigate the relationship between plant species composition, AE grassland measure and sampled environmental variables. Detrended correspondence analysis (DCA) indicated that linear methods were most appropriate. Further analysis followed linear unconstrained principal components analysis (PCA) with passive projection of the AE grassland measure.

Results

A total of 143 higher plant species, consisting of 90 herb (including four weed species, as defined by the Noxious Weeds Act 1936), 25 grass, 14 woody, nine sedge, and five rush species were recorded in this study. No Red List plant species (Curtis and McGough, 1988) or Flora (Protection) Order (S.I. No. 356/2015) species were identified on any of the 60 sites. A full species list is provided in Appendix Table A.1.

Species richness, diversity and abundance cover

The greatest botanical species richness was found within the Natura grasslands, where 138 species were recorded, with an average (±SE) of 40.05 (±2.06) species per field. We recorded 103 species from the SRG fields, with an average of 33.50 (±1.79) species per field; moreover, 86 species were recorded from the THM, with an average of 29.05 (±1.60) species per field (Table 2). The highest species richness recorded was 59 species in a Natura site, with the lowest being 17 species in a THM site (Table 3). *Agrostis* spp. constituted the greatest cover for all AE grassland measures (Table 4).

Grasslands in the Natura measure were significantly ($P < 0.001$) more species rich than those in SRG and THM (Figure 1, Table 2). Species richness between SRG and THM was similar. The Shannon diversity ($P < 0.001$) and effective species richness ($P < 0.001$) differed significantly between the three AE grassland measures (Table 2). Natura sites were almost twice as diverse as THM sites, with SRG sites intermediate between the two.

Natura sites had a greater ($P < 0.001$) richness and relative cover of herbs than SRG and THM (Table 2). SRG and THM did not differ significantly for either herb richness or relative cover.

Traditional Hay Meadow sites had significantly greater relative cover of grass than SRG sites, which in turn had a significantly greater cover than Natura sites (Table 2). This was particularly evident in relation to relative cover of *L. perenne* ($P < 0.001$), with 6.5%, 3.9% and 1.1% recorded within THM, SRG and Natura sites, respectively. *L. perenne* was present in 95%, 70% and 25% of THM, SRG and Natura sites, respectively.

Habitat quality

Natura grasslands had a greater richness ($P < 0.001$) of positive indicator species than SRG and THM, both of which were similar (Figure 1, Table 3). The THM and SRG sites also

Table 2. Summary vegetation characteristics of the sampled sites in each of the three grassland measures of AEOS

	Traditional Hay Meadow	Species-Rich Grassland	Natura	$F_{2,57}$	P-value
Mean species richness	29.05 ± 1.60[a]	33.50 ± 1.79[a]	40.05 ± 2.06[b]	9.20	**< 0.001**
Shannon diversity (H′)	2.48 ± 0.07[a]	2.81 ± 0.07[a]	3.01 ± 0.05[b]	18.83	**< 0.001**
Effective species richness (expH′)	12.49 ± 0.87[a]	17.19 ± 1.03[b]	20.78 ± 0.98[c]	18.66	**< 0.001**
Herb richness	18.20 ± 1.32[a]	19.60 ± 1.37[a]	26.15 ± 1.26[b]	10.39	**< 0.001**
Herb cover (%)	37.73 ± 2.42[a]	38.63 ± 2.30[a]	47.06 ± 2.21[b]	4.97	**< 0.05**
Grass richness	10.15 ± 0.30	10.85 ± 0.44	9.80± 0.66	1.19	0.312
Grass cover (%)	59.87 ± 2.75[a]	50.03 ± 2.61[b]	37.25 ± 2.90[c]	16.87	**< 0.001**
Grass–sedge–rush richness	12.00 ± 0.52	13.85 ± 0.67	14.10 ± 0.86	2.74	0.073
Grass–sedge–rush cover (%)	62.24 ± 2.42[a]	61.22 ± 2.32[a]	52.24 ± 2.24[b]	5.58	**< 0.01**
Shrub richness	0.25 ± 0.20[a]	0.30 ± 0.73[a]	1.50 ± 0.51[b]	4.57	**< 0.05**
Shrub cover (%)	0.03 ± 0.03[a]	0.16 ± 0.11[b]	0.70 ± 0.42[b]	1.98	0.15

The table presents mean (± s.e.) richness and cover values of different vegetation categories. *F*-values and significance levels are from general linear models (normal data). Means with the same letter do not differ significantly from one another. Figures in bold indicate significance at $P < 0.05$.
s.e. = standard error of mean.

Table 3. Summary of positive and negative indicator species averaged across the sampled sites in each of the three grassland measures of AEOS

	Traditional Hay Meadow	Species-Rich Grassland	Natura
Mean species richness	29.05 ± 1.60[a]	33.50 ± 1.79[a]	40.05 ± 2.06[b]
Maximum species richness	47	54	59
Minimum species richness	17	21	27
Positive indicator richness	10.45 ± 0.92[a]	12.30 ± 1.04[a]	16.90 ± 1.04[b]
Negative indicator species relative cover (%)	13.60 ± 1.53[a]	14.07 ± 2.42[a]	4.90 ± 1.19[b]
Maximum cover (%)	20.68	45.11	17.13
Minimum cover (%)	0.94	6.34	0
Number of sites with either >10% cover by an individual negative indicator species or >20% cumulative cover of negative indicator species	10	9	1
Negative indicator species actual cover (%)	31.59 ± 3.78[a]	34.57 ± 5.60[a]	13.75 ± 3.30[b]
Maximum cover (%)	77.38	110.85	15.19
Minimum cover (%)	1.50	3.23	0
Number of sites with either >10% cover by an individual negative indicator species or >20% cumulative cover of negative indicator species	16	18	9

The table presents mean (± s.e.) of positive and negative indicator species. *F*-values and significance levels are from general linear models (normal data). Means with the same letter do not differ significantly from one another. Figures in bold indicate significance at $P < 0.05$.
Positive and negative indicator species are from O'Neill *et al*. (2013).

had a greater cover ($P < 0.001$) of negative indicator species than Natura sites (Table 3).

Soil samples from the three AE grassland measures did not differ in phosphorus ($P = 0.371$), magnesium ($P = 0.954$) and pH ($P = 0.266$) (Table 5). Potassium concentrations were higher ($P < 0.05$) on SRG and Natura sites than on THM sites (Table 5). There was no significant correlation between the soil data and the botanical community data for each AE grassland measure.

Table 4. Top 10 most abundant (% cover) and frequent (% occurrence) species across the sampled sites in each of the three grassland measures of AEOS

	Traditional Hay Meadow			Species-Rich Grassland			Natura		
	Rank	Cover	Frequency	Rank	Cover	Frequency	Rank	Cover	Frequency
Agrostis spp.	1	18.66	100	1	13.78	100	1	11.10	100
Ranunculus repens	2	9.61	100	7	5.15	100	6	3.07	85
Holcus lanatus	3	7.65	100	8	4.24	100	–	–	–
Poa trivialis	4	6.95	95	4	5.57	100	10	2.69	75
Lolium perenne	5	6.53	95	9	3.90	70	–	–	–
Trifolium repens	6	6.42	100	2	9.44	100	4	3.57	90
Anthoxanthum odoratum	7	6.12	80	5	5.54	100	2	4.41	90
Cynosurus cristus	8	4.52	85	3	7.40	100	3	3.59	70
Alopecurus pratensis	9	4.46	80	–	–	–	–	–	–
Trifolium pratense	10	3.66	85	–	–	–	–	–	–
Juncus effusus	–	–	–	6	5.28	85	–	–	–
Rumex acetosa	–	–	–	10	3.74	100	8	2.88	100
Filipendula ulmaria	–	–	–	–	–	–	5	3.36	85
Cardamine pratensis	–	–	–	–	–	–	7	3.02	95
Mentha aquatica	–	–	–	–	–	–	9	2.85	65

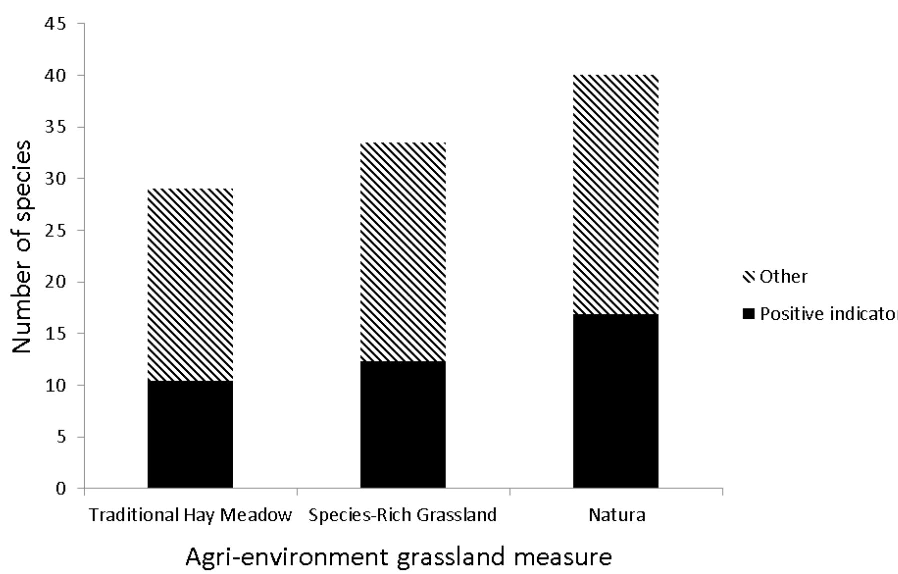

Figure 1. Average species richness and positive indicator richness for each agri-environment grassland measure.

Table 5. Comparison of soil nutrient levels (mean ± s.e.) between AE grassland measures

	Traditional Hay Meadow	Species-Rich Grassland	Natura
Potassium[1]	76.53 ± 9.74[a]	100.10 ± 7.89[b]	82.06 ± 6.30[ab]
Phosphorus[1]	5.92 ± 0.89	5.74 ± 1.18	6.12 ± 0.69
pH	5.74 ± 0.15	5.97± 0.16	6.11 ± 0.16
Magnesium	180.41 ± 26.29	188.12 ± 15.64	180.69 ± 20.86

Analysis was conducted using general linear models (normal) and Kruskal–Wallis test (non-normal).
[1]Kruskal–Wallis test (non-normal distribution).
Means with the same letter do not differ significantly from one another.
s.e. = standard error of mean.

Botanical community structure

There was a significant difference (global *R* = 0.281) in the botanical composition of the three AE grassland measures (based on ANOSIM in PRIMER). Pairwise comparisons showed a significant difference between SRG and THM (*R* = 0.215) and between SRG and Natura (*R* = 0.226). The most significant difference was between THM and Natura (*R* = 0.461).

When AE grassland measures were looked at individually, PCA and MDS analysis indicated that there was a close association between THM grassland and a number of grass species, in particular, grasses associated with improved pasture (e.g. *L. perenne*, *Agrostis* spp. and *Poa trivialis*; Table 4). Grasses were distinctly more closely associated with THM than with Natura grasslands, reflecting the results in Table 2. Natura grasslands were strongly associated with a number of herb species, especially those associated with semi-natural habitats (e.g. *Senecio aquaticus*, *Succisa pratensis*, *Mentha aquatica* and *Caltha palustris*). The community composition of SRG contained a combination of both grasses and herbs; moreover, it appeared to be intermediate in composition between the grass-dominated sward of the THM and the herb-rich sward of the Natura grassland. Species-Rich Grassland showed similar results as THM in grass species richness (Table 2); however, Figure 2 highlights that the grasses present in SRG (e.g. *Anthoxanthum odoratum*, *Festuca* spp.) are associated with low levels of nutrient inputs, in contrast to the grass species associated with THM grasslands.

The nMDS plot (Figure 3) shows that although there is a close association between the individual sites and certain plant species; there is also a certain level of overlap in community structure among the AE grassland measures. A majority of the THM sites were closely associated with species of improved grassland (as mentioned previously); however, some sites had a closer association with the botanical community of SRG grassland. Similarly, some Natura sites were closely associated with the plant communities of THM or SRG. The composition of the SRG sites is intermediate between those of THM and Natura.

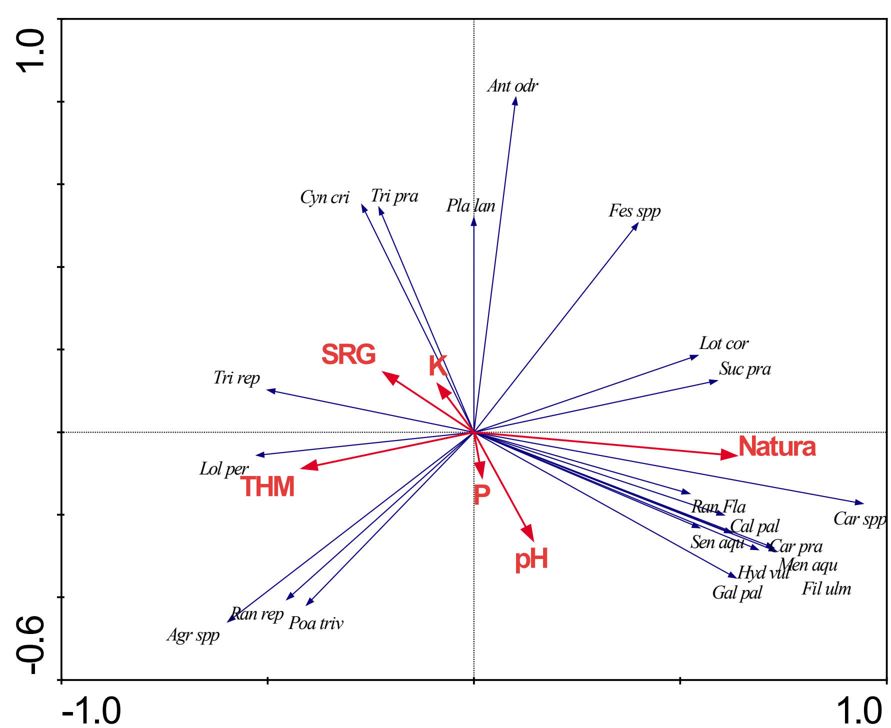

Figure 2. Principal component analysis biplots of grassland composition with passive projection of agri-environment grassland measures (Traditional Hay Meadow [THM], Species-Rich Grassland [SRG] and Natura) and the soil P, K and pH values.
Nominal variables are represented as centroids. The best fitting 20 species are shown. Species abbreviations are as follows: *Agr spp = Agrostis spp.; Ant odr = Anthoxanthum odoratum; Cal pal = Caltha palustris; Car pra = Cardamina pratensis; Car spp. = Carex spp.; Cyn cri = Cynosurus criststus; Fes spp. = Festuca spp.; Fil ulm = Filipendula ulmaria; Gal pal = Galium palustre; Hyd vul = Hydrocotyle vulgaris; Lol per = Lolium perenne; Lot cor = Lotus corniculatus; Men aqu = Mentha aquatic; Pla lan = Plantago lanceolata; Poa tri = Poa trivialis; Ran fla = Ranunculus flammula; Ran rep = Ranunculus repens; Sen aqu = Senecio aquaticus; Suc pra = Succisa pratensis; Tri pra = Trifolium pratense; Tri rep = Trifolium repens.*

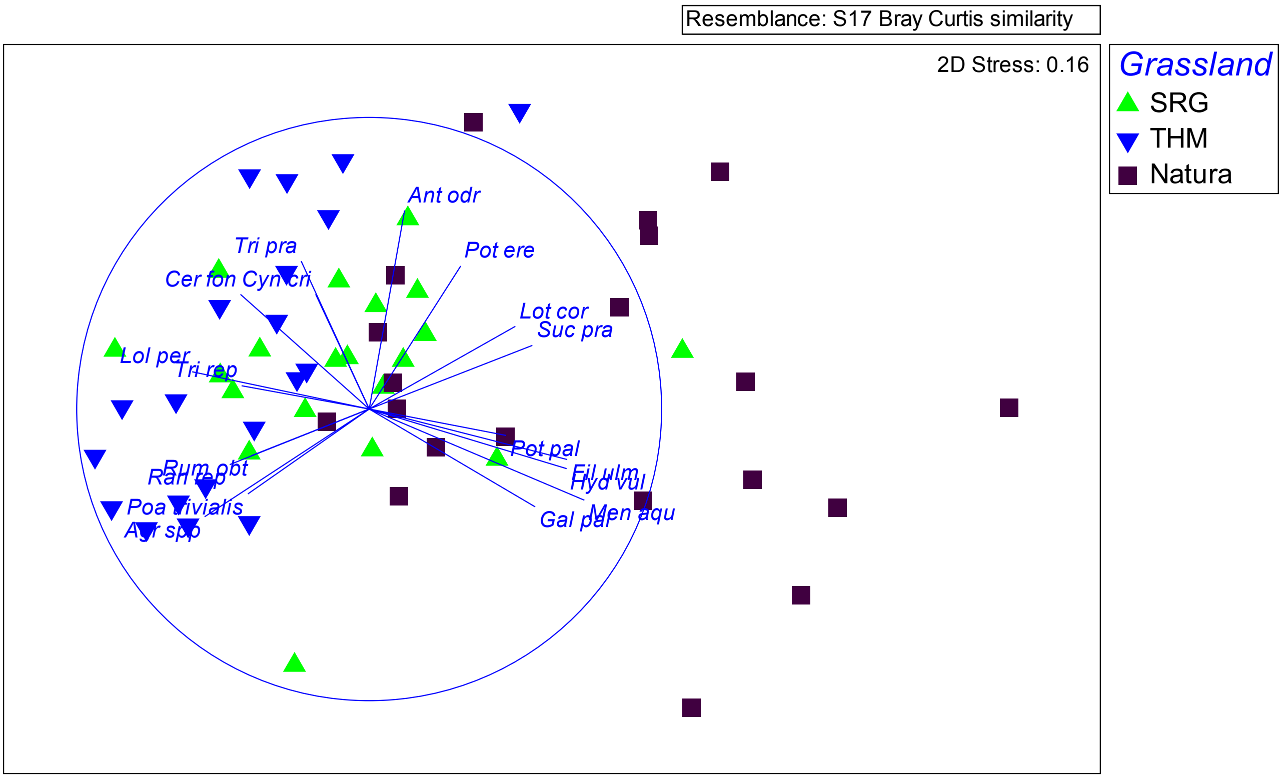

Figure 3. Non-metric multidimensional scaling plot of grassland composition and individual sample sites: Traditional Hay Meadow (THM) – triangle; Species-Rich Grassland (SRG) – inverted triangle; Natura grassland – solid square.
Species abbreviations are as follows: *Agr spp. = Agrostis spp.; Ant odr = Anthoxanthum odoratum; Cal pal = Caltha palustris; Car pra = Cardamina pratensis; Car spp. = Carex spp.; Cyn cri = Cynosurus criststus; Fes spp. = Festuca spp.; Fil ulm = Filipendula ulmaria; Gal pal = Galium palustre; Hyd vul = Hydrocotyle vulgaris; Lol per = Lolium perenne; Lot cor = Lotus corniculatus; Men aqu = Mentha aquatic; Pla lan = Plantago lanceolata; Poa tri = Poa trivialis; Ran fla = Ranunculus flammula; Ran rep = Ranunculus repens; Sen aqu = Senecio aquaticus; Suc pra = Succisa pratensis; Tri pra = Trifolium pratense; Tri rep = Trifolium repens.*

Discussion

Agri-environment schemes are an important policy mechanism for the protection of natural resources and provision of ecosystem services (Finn and Ó hUallacháin, 2012), with measures targeted at the conservation of semi-natural grasslands vital to the maintenance and enhancement of these habitats (Ridding *et al*., 2015). Considering that the majority of High Nature Value farmland is believed to be outside of Natura 2000 areas (Keenleyside *et al*., 2014; Walsh *et al*., 2015; Matin *et al*., 2016), there is a strong need for AE measures and nature conservation strategies that target species and habitats outside of designated protected areas (Jackson *et al*., 2009).

Design and management of AE grassland measures

The European Court of Auditors (2011) highlighted that to ensure the environmental effectiveness of AESs, schemes should be appropriately designed and managed, as well as including the provision of specific objectives, clear justification and having a good ability to assess the intended environmental objectives.

The objective of the THM measure under AEOS is not clearly specified through quantitative targets; however, we assume that it is similar to the objective for THM under REPS, i.e. "to encourage a grassland management system that results in a more diverse sward with an increase in flora and fauna". The lack of clarity in relation to a specific, measurable objective makes it difficult to determine whether objectives for THM are being achieved. In our study, THM sites had a relatively diverse sward, containing on average >10 species that indicated high-quality grassland. Some sites were very species rich; two sites had an average ≥40 species per field, including 18 indicator species of high-quality grassland. However, more than half of the THM sites had >30% cover of negative indicator species. A number of THM sites had reduced species richness (e.g. three sites had ≤20 species per field), with the cover and botanical communities resembling those of more agronomically productive swards. In the absence of specific, measurable objectives, it is difficult to conclude the extent to which this measure is effective.

The most stringent eligibility criterion for THM was that sites had to contain "at least three grass species (other than ryegrass)" (Table 1). Thus, e.g. sites containing a high cover (>10%) of negative indicator grass species (e.g. *Dactylis glomerata, Arrhenatherum elatius*; as in O'Neill *et al*., 2013), or grass species associated with improved agricultural grassland (e.g. *Holcus lantus*, *Phleum pratense*, *Poa annua;* as in Fossitt, 2000) would satisfy the eligibility criteria for THM in AEOS. Two sites in the current study had more than 72% and 76% cover of species associated with improved agricultural grassland (the GA1 grassland category in Fossitt, 2000), yet were fully compliant with the botanical eligibility criteria for THM in AEOS. A lack of stringent eligibility criteria could result in the fact that AE measures are not targeted to the sites with greatest environmental potential.

Effective AE measures require valid cause-and-effect relationships between the prescribed management practices and the intended outcomes. In a sample of European AESs, Primdahl *et al*. (2010) found that biodiversity measures were least likely to have evidence-based models of such cause-and-effect relationships. Under AEOS, the management specifications for THM, particularly where sites are relatively species poor, are unlikely to be sufficient to either enhance the species richness or encourage the establishment of positive indicator species (Bakker and Berendse, 1999; Fritch *et al*., 2011). The latest AES – GLAS (DAFM, 2015) – has introduced a further relaxation of THM management specifications, with permissible nitrogen application rates being increased from 30 (REPS and AEOS) to 40 kg N/ha (GLAS). With regard to SRG, permissible nitrogen application rates have increased from 0 (in REPS) to 30 (in AEOS) and 40 kg N/ha (in GLAS). Nitrogen application, even at low levels, is strongly associated with an increase in nitrophilus grasses, an increase in competition and ultimately an overall decline in species diversity (Kleijn *et al*., 2009; Bobbink *et al*., 2010; Bobbink and Hettelingh, 2011).

A lack of relevant and reliable management information is also problematic for some species-rich sites. The majority of surveyed Natura sites had a diverse botanical sward (Table 2), containing on average almost 17 positive indicator species for priority grasslands (e.g. *Dactylorhiza fuchsii*, *Mentha aquatica*, *Succisa pratensis* and *Galium palustre*). However, a small number of the surveyed Natura grasslands (Figure 3) had plant communities that were more closely related to THM swards or improved agricultural grassland. It is also concerning that 15% of Natura grassland sites had shrub and bracken cover exceeding the 5% threshold for designated habitats recommended by O'Neill *et al*. (2013). Considering the lack of clarity in relation to the objectives of the Natura measure and the lack of specific details in relation to management prescriptions (Table 1), this is not surprising. In the absence of specific management prescriptions, some farmers with Natura sites may be reluctant to undertake any management in these areas due to concerns that they might inadvertently be in violation of cross-compliance or Habitats Directive obligations. This lack of active management can lead to these grasslands becoming rank, losing botanical richness (and herb richness in particular), culminating in scrub encroachment. O'Neill *et al*. (2013) and Ridding *et al*. (2015) highlighted that abandonment, particularly of wet grasslands, was a problem, resulting in swards becoming rank, with negative implications for many insect and bird species.

Targeting and value for money

A key question for the design of AESs is: how to target participation and resources to those sites with the greatest environmental potential? Grassland conservation options were the most popular measures in AEOS at the time of the study (2013). Grassland measures were also the most popular options in GLAS, with Low Input Permanent Pastures (similar to SRG) being the most popular measure in Tranche 1, resulting in the participation target being met. This resulted in changes to Tranche 2 of GLAS, where the maximum permissible area for Low Input Permanent Pastures was reduced from 10 to 5 ha. It is understandable that there is a need to have participation targets and to avoid oversubscription to a reduced number of measures. However, where there is likelihood that a measure will be oversubscribed, there is an opportunity to target participation to those sites with the greatest environmental potential, as opposed to basing participation on a random selection. In this study, e.g. SRG sites that had only four positive indicator species were as likely to be included in AEOS as those with 24 positive indicator species. Where there is likely to be oversubscription, more targeted selection could prioritise entry of higher-quality sites by modifying the eligibility criteria; this would also help fulfil the recommendations of the European Court of Auditors that AE expenditure should be more precisely targeted.

Successful conservation measures should assess the environmental effectiveness of AESs and be appropriately costed. Where a number of measures are available to effectively achieve the same biodiversity objective, it is desirable that the most ecologically effective and least costly options are selected. The species richness and the richness of positive indicator species were greater (though not significantly so) on SRG sites compared to THM sites, yet payment rates (under both AEOS and GLAS) for both measures are the same. This suggests that the SRG measure provides better value for money than the THM measure in

terms of conservation of overall botanical richness.
The European Court of Auditors (2011) recommended higher payments for measures with higher environmental potential. The results in the current study found that Natura sites had significantly higher species richness, higher richness of positive indicator species and significantly lower cover of negative indicator species than either THM or SRG sites. Despite this, payment rates for Natura sites (€75/ha) were lower than those for THM and SRG (€314/ha). Farmers could select the THM or SRG measure for their Natura sites; however, this could potentially involve a change in the 'traditional' management of the Natura sites (e.g. a change in traditional grazing or mowing dates), with potential negative implications for biodiversity.

Payment by actions or payment by results?

Challenges lie in appropriately rewarding those sites that are delivering the greatest environmental benefit or, alternatively, incentivising site management to increase their provision of environmental benefits. We found high variability in the botanical composition between sites in the same measure and subject to the same management criteria (and thus in receipt of the same payment under AES). This highlights some of the limitations with AE measures that are based on payment by action. For example the current study identifies the contrasting situation of a THM site containing only five positive indicator species and >50% cover of negative indicator species being in receipt of the same payment rate (€314/ha) as a THM site with 19 positive indicator species and <10% cover of negative indicator species. A possible approach to address these challenges is to progress towards measures and schemes that are based on "payment by results", as opposed to "payment by action" (Schroeder *et al*., 2013). Payment-by-results approaches are based directly on the delivery of an ecosystem service; the more of the service that is provided, the higher the payment. They are more quantitative in their objectives, have measurable attributes that can be used to determine eligibility and – in turn – facilitate monitoring to assess effectiveness, and they also allow payment rates to be set in a more objective, transparent manner (refer Klimek *et al*., 2008; McGurn and Moran, 2013). They allow greater flexibility for farmers to innovate and achieve the environmental targets, resulting in greater uptake and a better working relationship with farmers because the payment rates are more transparent, with a reduced need for penalties (Klimek *et al*., 2008; Burton and Schwarz, 2013). However, there are some potential limitations associated with the payment by results approaches, particularly where delivery of positive results may be beyond the control of farmers (but this is less likely to be the case with measures for the conservation of grassland habitats) or when there are difficulties with developing lists of suitable indicator species. Nevertheless, evidence from the "Burren Farming for Conservation Programme" and further afield (Fleury *et al*., 2015; Russi *et al*., 2016) indicate that these limitations can be addressed (especially for grassland habitats) and that the benefits outweigh the limitations. Matzdorf *et al*. (2008) concluded that AE schemes could be improved by refocusing on a payment by result approach, as opposed to the more traditional payment by action method.

Conclusions

This study found significant differences in the species richness and botanical composition of grasslands enrolled in three different grassland conservation measures supported by AEOS. Compared to THM and SRG, Natura sites had significantly higher species richness, more positive indicator species and lower cover of negative indicator species. Despite this, Natura sites were in receipt of lower payment rates (per area) than THM and SRG.
The lack of clarity in relation to specific, measurable objectives makes it difficult to determine whether objectives for grassland measures are being achieved. Furthermore, the lack of a specific objective has resulted in relatively undemanding eligibility criteria for THM. This means that sites containing, for instance, a high cover of negative indicator grass species or grass species associated with improved agricultural grassland are eligible for inclusion. Even where compliance and participation are high, if a measure is not appropriately designed, it is unlikely to have the desired environmental benefits (Carlin *et al*., 2010; Ó hUallacháin and Finn, 2011). This is evident with THM, where despite the high compliance and participation rates, the relatively undemanding eligibility criteria in particular, coupled with under-researched management prescriptions, are unlikely to result in an increase in positive indicator species in swards where they do not currently exist. This is not to say that there are no biodiversity benefits associated with the measure, but rather the high rate of financial payment could be associated with a higher level of provision of environmental benefits.

Acknowledgements

This work was funded by Teagasc (The Irish Agriculture and Food Development Authority) under the Walsh Fellowship Scheme. We would like to acknowledge support from the Teagasc Advisory and two anonymous reviewers for comments on the manuscript. Finally, we would like to thank the farmers and landowners of the study sites.

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Appendix Table A.1. Presence and absence of botanical species within each AE grassland measure

Taxonomic group	Common name	Taxonomic name	THM	SRG	Natura
Grass	Bent grass##	*Agrostis spp*	*	*	*
Grass	Marsh foxtail	*Alopecurus geniculatus*	*	*	*
Grass	Meadow foxtail##	*Alopecurus pratensis*	*	*	*
Grass	Sweet vernal##	*Anthoxanthum odoratum*	*	*	*
Grass	False oat	*Arrhenatherum elatius*	*	*	*
Grass	Quaking grass##	*Briza media*	*	*	*
Grass	Soft brome	*Bromus hordeaceus*	*	*	*
Grass	Crested dogs tail	*Cynosurus cristatus*	*	*	*
Grass	Cocksfoot	*Dactylis glomerata*	*	*	*
Grass	Tufted hair grass	*Deschampsia cespitosa*		*	*
Grass	Couch	*Elytrigia repens*	*	*	*
Grass	Flote grass	*Glyceria fluitans*	*	*	*
Grass	Reed sweet- grass	*Glyceria maxima*			*
Grass	Downy oat grass##	*Helictotrichon pubescens*	*	*	*
Grass	Fescue##	*Festuca spp*	*	*	*
Grass	Yorkshire Fog	*Holcus lanatus*	*	*	*
Grass	Creeping soft grass	*Holcus mollis*	*		
Grass	Perennial ryegrass	*Lolium perenne*	*	*	*
Grass	Purple moor grass##	*Molinia caerulea*	*	*	*
Grass	Reed Canary grass	*Phalaris arundinacea*			*
Grass	Timothy**	*Phleum pratense*	*	*	*
Grass	Common reed	*Phragmites australis*	*	*	*
Grass	Annual meadow grass	*Poa annua*	*	*	*
Grass	Smooth meadow grass	*Poa pratensis*	*	*	*
Grass	Rough meadow grass	*Poa trivialis*	*	*	*
Sedge	Glaucous sedge##	*Carex flacca*	*	*	*
Sedge	Tawny sedge	*Carex hostiana*	*	*	*
Sedge	Oval sedge	*Carex ovalis*			*
Sedge	Tussock grass	*Carex paniculata*	*	*	*
Sedge	Flea sedge##	*Carex pulicaris*			*
Sedge	Yellow sedge##	*Carex viridula*		*	*
Sedge	Common cotton-grass	*Eriophorum angustifolium*		*	*
Sedge	Hare's-tail cotton-grass	*Eriophorum vaginatum*			*
Sedge	Deergrass	*Trichophorum cespitosum*	*		*
Rush	C. Spike rush	*Eleocharis palustris*		*	*
Rush	Sharp-flowered rush##	*Juncus acutiflorus*	*	*	*
Rush	Jointed rush##	*Juncus articulatus*	*	*	*
Rush	Soft rush	*Juncus effusus*	*	*	*
Rush	Hard rush	*Juncus inflexus*	*	*	*

Taxonomic group	Common name	Taxonomic name	THM	SRG	Natura
Herb	Yarrow	*Achillea millefolium*	*	*	*
Herb	Bugle	*Ajuga reptans*			*
Herb	Lady's mantle	*Alchemilla vulgaris*			*
Herb	Water-plantain	*Alisma plantago-aquatica*			*
Herb	Wild angelica	*Angelica sylvestris*		*	*
Herb	Fool's water-cress	*Apium nodiflorum*			*
Herb	Lesser water-plantain	*Baldellia ranunculoides*			*
Herb	Daisy	*Bellis perennis*	*	*	*
Herb	Marsh marigold##	*Caltha palustris*		*	*
Herb	Cuckoo-flower	*Cardamine pratensis*	*	*	*
Herb	Black Knapweed##	*Centaurea nigra*	*	*	*
Herb	Mouse ear	*Cerastium fontanum*	*	*	*
Herb	Meadow thistle##	*Cirsium dissectum*			*
Herb	Marsh thistle	*Cirsium palustre*	*	*	*
Herb	Pignut##	*Conopodium majus*	*		*
Herb	Hawksbeard spp	*Crepis spp*	*	*	*
Herb	Smooth hawksbeard##	*Crepis capillaris*	*	*	*
Herb	Common spotted orchid##	*Dactylorhiza fuchsii*	*	*	*
Herb	Wild carrot##	*Daucus carota*	*		*
Herb	Foxglove	*Digitalis purpurea*	*	*	*
Herb	Ferns	*Dryopteris spp*			*
Herb	Greater willowherb,	*Epilobium hirsutum*			*
Herb	Marsh willowherb,	*Epilobium palustre*		*	*
Herb	Willowherb	*Epilobium*	*	*	*
Herb	Eyebright##	*Euphrasia spp*	*		*
Herb	Meadow sweet##	*Filipendula ulmaria*	*	*	*
Herb	Cleaver	*Galium aparine*		*	*
Herb	Marsh bedstraw##	*Galium palustre*	*	*	*
Herb	Heath bedstraw##	*Galium saxatile*		*	*
Herb	Hogweed##	*Heracleum sphondylium*	*	*	*
Herb	Greater horsetail	*Equisetum telmateia*	*	*	*
Herb	Square stalked St John's Wort	*Hypericum tetrapterum*	*	*	*
Herb	Marsh pennywort##	*Hydrocotyle vulgaris*		*	*
Herb	Cats ear##	*Hypochaeris radicata*		*	*
Herb	Yellow Iris	*Iris pseudacorus*		*	*
Herb	Field scabious##	*Knautia arvensis*		*	*
Herb	Ox-eye daisy##	*Leucanthemum vulgare*		*	*
Herb	Ragged robin##	*Lychnis flos-cuculi*	*	*	*
Herb	Purple loosestrife	*Lythrum salicaria*			*
Herb	Pineapple weed	*Matricaria discoidea*	*	*	
Herb	Water mint##	*Mentha aquatica*		*	*
Herb	Bog bean	*Menyanthes trifoliata*			*

Taxonomic group	Common name	Taxonomic name	THM	SRG	Natura
Herb	Field forget-me-not	*Myosotis arvensis*	*	*	*
Herb	Water forget-me-not	*Myosotis scorpioides*			*
Herb	Water-cress	*Nasturtium officinale*			*
Herb	Grass of Parnassus	*Parnassia palustris*		*	*
Herb	Lousewort	*Pedicularis sylvatica*	*	*	*
Herb	Amphibious Bistort	*Persicaria amphibia*			*
Herb	Red leg	*Persicaria maculosa*	*	*	*
Herb	Common butterbur	*Petasites hybridus*		*	
Herb	Mouse ear Hawkweed[##]	*Pilosella officinarum*	*		*
Herb	Common butterwort	*Pinguicula vulgaris*			*
Herb	Ribwort plantain[##]	*Plantago lanceolata*	*	*	*
Herb	Greater plantain	*Plantago major*	*	*	*
Herb	Milkwort	*Polygala vulgaris*			*
Herb	Trailing tormentil[##]	*Pontentilla angelica*			*
Herb	Silverweed	*Potentilla anserina*	*	*	*
Herb	Tormentil[##]	*Potentilla erecta*	*	*	*
Herb	Marsh cinequefoil[##]	*Potentilla palustris*		*	*
Herb	Creeping cinquefoil	*Potentilla reptans*			*
Herb	Cowslip[##]	*Primula veris*	*	*	
Herb	Primrose[##]	*Primula vulgaris*		*	
Herb	Self-heal[##]	*Prunella vulgaris*	*	*	*
Herb	Bracken	*Pteridium aquilinum*		*	*
Herb	Meadow buttercup[##]	*Ranunculus acris*	*	*	*
Herb	Spearwort[##]	*Ranunculus flammula*	*	*	*
Herb	Creeping buttercup	*Ranunculus repens*	*	*	*
Herb	Yellow rattle[##]	*Rhinanthus minor*	*	*	*
Herb	Common sorrel	*Rumex acetosa*	*	*	*
Herb	Sheep sorrel	*Rumex acetosella*	*	*	*
Herb	Marsh ragwort	*Senecio aquaticus*		*	*
Herb	Marsh woundwort	*Stachys palustris*		*	*
Herb	Greater stitchwort	*Stellaria holostea*	*	*	*
Herb	Devil's-bit scabious[##]	*Succisa pratensis*		*	*
Herb	Dandelion	*Taraxacum officinale agg.*	*	*	*
Herb	Nettle	*Urtica dioica*	*	*	*
Herb	Water speedwell	*Veronica anagallis-aquatica*			*
Herb	Brooklime	*Veronica beccabunga*			*
Herb	Germander speedwell	*Veronica chamaedrys*	*	*	*
Herb	Thyme-leaved speedwell	*Veronica serpyllifolia*	*	*	*
Weed	Creeping thistle	*Cirsium arvense*	*	*	*
Weed	Spear thistle	*Cirsium vulgare*	*	*	*
Weed	Broadleaved dock	*Rumex obtusifolius*	*	*	*
Weed	Ragwort	*Senecio jacobaea*	*	*	*

Taxonomic group	Common name	Taxonomic name	THM	SRG	Natura
Legume	Meadow vetchling##	*Lathyrus pratensis*	*	*	*
Legume	Bird's-foot trefoil##	*Lotus corniculatus*	*	*	*
Legume	Black medic	*Medicago lupulina*	*	*	*
Legume	Red clover##	*Trifolium pratense*	*	*	*
Legume	White clover**	*Trifolium repens*	*	*	*
Legume	Tufted vetch##	*Vicia cracca*	*	*	*
Legume	Bush vetch	*Vicia sepium*	*		*
Legume	Beaked hawksbeard	*Crepis vesicaria*	*		
Shrub	Alder	*Alnus glutinosa*			*
Shrub	Heather	*Calluna vulgaris*	*		*
Shrub	Broom	*Cytisus scoparius*			*
Shrub	Bell heather	*Erica cinerea*	*		*
Shrub	Bog myrtle	*Myrica gale*		*	*
Shrub	Poplar	*Populus spp*			*
Shrub	Bramble	*Rubus fruticosus*	*	*	*
Shrub	Willow	*Salix spp*		*	*
Shrub	Bilberry	*Vaccinium myrtillus*	*		*
Shrub	Downy birch	*Betula pubescens*			*
Shrub	Hawthorn	*Crataegus monogyna*			*
Shrub	Hazel	*Corylus avellanna*		*	*
Shrub	Blackthorn	*Prunus spinosa*			*
Shrub	Pedunculate Oak	*Quercus robur*			*

##Plant indicator species for high-quality grassland based on the High Nature Value plant species list recommended by O'Neill *et al*. (2013).
**Negative indicator species (when they exceed 10% cover; Fossitt, 2000).