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Selecting appropriate plant indicator species for Result-Based Agri-Environment Payments schemes

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ABSTRACT

Agri-Environment Schemes (AES) have long been implemented across Europe to incentivise farmers to alter their management practices to improve biodiversity and water, air and soil quality. However, the cost-effectiveness of traditional action-based schemes has been questioned, and Result-Based Payment (RBP) schemes have been recommended as an alternative. To evaluate the effectiveness of management actions, RBP approaches often rely on indicator species to monitor changes in environmental conditions. The selection of appropriate indicator species for RBP follows several steps and criteria. One of the mentioned criteria is that the species should react to the farmer's management choices. Thus, the main objective of this study is to understand how existing lists of indicator plant species (aimed at assessing ecological integrity of grasslands and hedgerows in Ireland) are suitable for RBP schemes, by assessing how different environmental and management variables are related to the presence of the plant species selected. Extensive field surveys were conducted to assess the presence and cover of indicator species in grasslands and hedgerows in two study regions in Ireland. The indicator plant species occurrence and diversity (species richness and Simpson's Diversity Index) were correlated with *variables within farmers' control* and *variables outside farmers' control*. Results showed that grassland indicator species occurrence and diversity was mainly related to grassland semi-naturalness and to the diversity of habitats existing on the farm – both variables within farmers' control – and thus were appropriate indicators for assessing the effectiveness of management and suitable for use in RBP schemes. Conversely, the occurrence and diversity of hedgerow indicator species was not strongly related to any of the explanatory variables, making them unsuitable for use in a RBP scheme. For a RBP scheme targeted at hedgerows, clear objectives will need to be established and the farmers' management choices need to be better linked to the selected indicator species. The selection of indicator species needs to undergo scientific scrutiny to develop fair results assessments as shown by the results of this study. The analyses conducted highlight the importance of testing if the species react to the farmers' management choices and should be a key methodological step before final indicator species lists are implemented in RBP schemes. Recommendations for results assessments in RBP approaches are discussed based on the results of this study.

1. Introduction

The European countryside is an anthropogenic landscape, where extensive farming activities have created a large number of habitats of conservation importance, such as meadows and pastures (Sutherland, 2004; Halada et al., 2011; Bengtsson et al., 2019), that harbour a wide range of Europe's biodiversity adapted to these managed habitats (Mayer et al., 2018). However, in recent decades, large scale agricultural intensification and specialisation of agricultural practices have been associated with a loss of biodiversity (e.g. Chamberlain et al., 2000;

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Benton et al., 2003; Emmerson et al., 2016), negative effects on water and soil quality (Berka et al., 2001; Liiri et al., 2012), increases in flood risk (Rogger et al., 2017) and in greenhouse gases emissions (Muhammed et al., 2018).

Consequently, many current European nature conservation programs and funding are directed at halting the on-going loss of farmland biodiversity and associated ecosystem services (Latacz-Lohmann and Hodge, 2003; Lefebvre et al., 2012; Batáry et al., 2015). In particular, voluntary Agri-Environment Schemes (AES) were implemented under Reg. EC/2078/92 in all EU member-states, in an attempt to incentivise farmers to alter their management practices (e.g. EC, 2005). However, AES have been criticised for failing to raise environmental standards (Kleijn and Sutherland, 2003; Whittingham, 2007; Finn and Ó hUallacháin, 2011; European Court of Auditors, 2011, 2020) and have therefore become the subject of growing demand to be more cost-effective (Schroeder, 2013; Ansell et al., 2016; Cullen et al., 2018).

Most AES implemented are 'action-oriented' payments – meaning that farmers are paid for the delivery of land management practices (Burton and Schwarz, 2013). In recent years, especially in Europe, the recommendation for Results-Based Payments (RBP) approaches to be included in AES has increased (e.g. Herzon et al., 2018; O' Rourke and Finn, 2020). Several pilot schemes have been implemented with positive results highlighted amongst researchers, project implementers and farmers (Magda et al., 2015; Nitsch, 2014; Russi et al., 2016; Chaplin et al., 2019; synthesis of examples in Europe by Allen et al., 2014; O' Rourke and Finn, 2020).

Criticism of RBP is linked to the difficulty of transforming pilot or regional approaches into national-scale schemes, and to uncertainties of the influence of external factors (beyond the farmers' control) on expected environmental results (Derissen and Quaas, 2013; Burton and Schwarz, 2013; Herzon et al., 2018; Bartkowski et al., 2019). Nonetheless, studies show that farmers can influence biodiversity and associated ecosystem services positively by managing or creating semi-natural habitats in farmland, many of which (e.g. farmland habitat heterogeneity, grassy margins) correlate with increased biodiversity levels (e.g. Alison et al., 2017; Stoeckli et al., 2017).

Most assessment methodologies within RBP rely on parameters associated with indicator species, such as their richness and/or cover (e.g. Bertke et al., 2008; Underwood, 2014; Magda et al., 2015; Bartkowski et al., 2019; Keep et al., 2019; Tasser et al., 2019). These indicator species are expected to be strongly related to the quality of a particular habitat, to a specific ecosystem service, or to the presence of species of conservation interest (e.g. birds, butterflies) (e.g. Wittig et al., 2006; Matzdorf et al., 2008; Siddig et al., 2016; Byrne et al., 2018).

The advantages associated with sampling only a small set of species, as opposed to the entire community, have led to numerous scientific publications and to the development of statistical methods for identifying indicator species (e.g. Dufrêne & Legendre, 1997; Nielsen et al., 2007). Species should be chosen as indicators if they consistently (i) *reflect the biotic or abiotic state of the environment; (ii) provide evidence for the impacts of environmental change*; or *(iii) predict the diversity of other species, taxa or communities within an area* (in De Cáceres and Legendre, 2009 pp. 3566). In addition, they should be easily observable and amenable to sampling. For this reason, plants are often used as indicators in habitat assessments (Brunbjerg et al., 2018; Tasser et al., 2019). In a RBP context, Burton and Schwarz (2013), Keenleyside et al. (2014) and Maher et al. (2018) listed several conditions and factors to take into consideration when selecting indicator species. They should be easy to identify (after training) by non-specialists; should not conflict with agricultural goals; should reflect the effort of participating farmers (i.e. the cover of the positive indicator plants should remain constant, or increase, with improved ecological condition).

One of the main arguments against the use of indicator species is that other factors (such as disease, competition or predation), unrelated to the *in situ* degradation of ecological integrity, may affect the populations status of the indicator species (Carignan and Villard, 2001). Furthermore, abiotic variables (e.g. soil type (Löbel et al., 2006)), landscape structure, connectivity or the degree of habitat isolation may also influence plant diversity and community composition (Walz, 2011). These landscape factors, and some abiotic factors affecting plant species and diversity are normally outside of farmers' control (depending on farm size and scale of operation), even if their management practices are the most desirable to meet conservation targets.

Therefore, for the development of fair RBP schemes, plant indicator species should reflect successful achievement of environmental objectives, and their presence/abundance has to be mainly influenced by farmers' management and not by landscape or abiotic factors (Keenleyside et al., 2014). In interviews conducted by Matzdorf and Lorenz (2010) farmers often mentioned the importance of well-defined indicators and thresholds as preconditions for their participation in RBP schemes.

Wittig et al. (2006) provide a schematic process for the selection of indicators which include testing the relationships between indicator species with total species richness and rare species presence, and conducting identification tests with the farmers before a final list of indicators is implemented. Similarly, Kaiser et al. (2009) proposed a multi-staged drafting of a list of indicators for a result-oriented AES that was later revised by Kaiser et al. (2019) and introduces the idea of a weighted indicator species lists.

However, scientific research focused on the relationships between the selected plant indicator species and environmental variables that are outside of farmers' control in comparison to variables that are within farmers control is, to our knowledge, rarely conducted (or unpublished) in existing RBP schemes**.** Thus, another step should precede the final list compilation: ensuring that variables related to farm setting and that factors beyond farmers' control (e.g. altitude, landscape structure and connectivity) are not significantly affecting the indicator species presence; or if they are, they should be appropriately factored in the results assessments. Even if the plant species are proven to be related to the proposed environmental targets, this additional step is essential to guarantee that RBP schemes will be implemented justly.

The present study aims to understand how plant indicator species for two common agricultural habitats (grasslands and hedgerows) are affected by potential explanatory variables and assess how farmers' management variables are related to their presence. The explanatory variables are separated into two main groups: variables that are outside of farmers' control and variables that are within farmers' control.

Grasslands and hedgerows are amongst the most important and ubiquitous farmland ecosystems in Ireland and Europe. Consequently, both habitats have been targeted for conservation and quality improvement under AES (Batáry et al., 2015; Montgomery et al., 2020). In Ireland, plant indicator species lists are already in use for assessing the quality of both grasslands and hedgerows. The list of plant indicator species developed for grasslands aims to assess the ecological integrity of Irish semi-natural grasslands (O' Neill et al., 2013) and this list was adapted specifically for RBP pilot schemes (Maher et al., 2018; McLoughlin, 2018); in contrast the hedgerow plant species list (proposed by Foulkes et al. 2013) has not been used in any RBP scheme so far, but was developed to assess the ecological value of hedgerows more broadly: the species selected are supposed to be indicators of hedgerow management (if the species are deliberately or incidentally allowed to grow; cutting regimes), age or origin (e.g. *derived from scrub, old or ancient woodland*; in Foulkes et al., 2013). Notwithstanding, these differences in the rationale for the development of these lists, their suitability for RBP approaches will be tested in this study.

2. Methodology

2.1. Study sites and farm selection

Two contrasting regions were selected in Ireland for this study (Co. Sligo in the north-west and Co. Wexford in the south-east), so that the climatic variation of the country could be taken into account. The mean annual temperature and precipitation in the Co. Sligo region are 9.6 °C and 1260 mm respectively and in the Co. Wexford region are 9.8 °C and 840 mm respectively (https://www.met.ie/, accessed 26/02/2019). The study areas corresponded to two selected sub-catchments (delimited by Irish Environmental Protection Agency, 2015) of 135.3 km^2 in Co. Sligo and of 248.06 km^2 in Co. Wexford (Fig. 1).

The study aimed to cover a gradient of farming intensities; thus farms were categorized into intensive, intermediate and extensive farms, using a whole farm nature value score (Boyle et al., 2015). The nature value score considers the farm stocking rate, the proportion of improved grasslands and a visual assessment of size of fields and boundaries. Intensive farms (n = 9 in Co. Sligo and n = 10 in Co. Wexford) were considered to be those with a score < 3.5; intermediate (n = 9 in Co. Sligo and n = 8 in Co. Wexford) with a score between 3.5 and 5; and extensive farms (n = 9 in both Co. Sligo and Co. Wexford) with a score > 5. A total of 54 farms were surveyed, covering a total area of 2,236 ha (968 ha in intensive, 727 ha in intermediate and 541 ha in extensive farms).

2.2. Indicator species and quality assessments of grasslands and hedgerows

The plant indicator species lists tested in this study were adapted from Maher et al. (2018) for grasslands and Foulkes et al. (2013) for hedgerows. Some species/genera are grouped within the grassland list and considered as an *aggregate* of species. The grassland indicator species list includes a total of 32 positive and 3 negative taxa (Table S1 in Supplementary Materials (SM)). Positive indicator species are expected to occur in extensively managed grasslands, semi-natural grasslands, providing an indication of their ecological integrity; negative indicators reflect the use of fertilizers and intensification of the grasslands. The hedgerow indicator species list has a total of 71 to 72 positive indicator taxa, in addition to 22 to 23 negative taxa (Ivy is considered a negative species when it exceeds a certain cover (>25%)) (complete list in Table S2 in SM).

Irish habitat assessment methodologies (O' Neill et al., 2013; Maher et al., 2018 for grasslands; Foulkes et al., 2013 for hedgerows) were adapted to produce Rapid Assessment Cards (RACs) (Rotchés-Ribalta et al., 2021) so that variables related to management (e.g. poaching and grazing levels) and ecological conditions (e.g. cover of bryophytes and lichens) could be assessed while the indicator species were surveyed in grasslands and hedgerows (see Figure S1, S2a & b in SM).

One parcel representative of the overall farm intensity category was sampled on each farm. Each parcel was comprised of several fields (2 to 5 fields) and all linear features surrounding them. The fields included in a parcel could belong to the same habitat type (e.g. only grasslands) or to different habitats (e.g. grassland, scrubland area, tillage field). The linear features dividing the fields and bordering the parcel could also vary (e.g. stonewalls, drainage ditches, hedgerows). All grasslands and hedgerows existing in the parcel were surveyed for indicator species presence and cover, management variables and ecological conditions using the RACs. All the habitat types existing in the parcel were recorded.

Grasslands were surveyed by walking a "W" shaped route (Maher et al., 2018). Hedgerow surveys were conducted along a 30 m transect in each hedgerow. If a hedgerow was of sufficient length (i.e. > 80 m), two 30 m surveys separated by at least 5 m were conducted, following Foulkes et al. (2013). The data from the two 30 m hedgerow transects were later grouped, taking into consideration the dominant categorical characteristics of the hedgerow and by averaging the covers of floristic variables.

Fields were categorised into one of the following grassland types: improved GA1, semi-improved GSi, semi-natural GS, and transition to semi-natural grasslands (from heathland). This classification relates to the ecological integrity of the grassland as a result of management

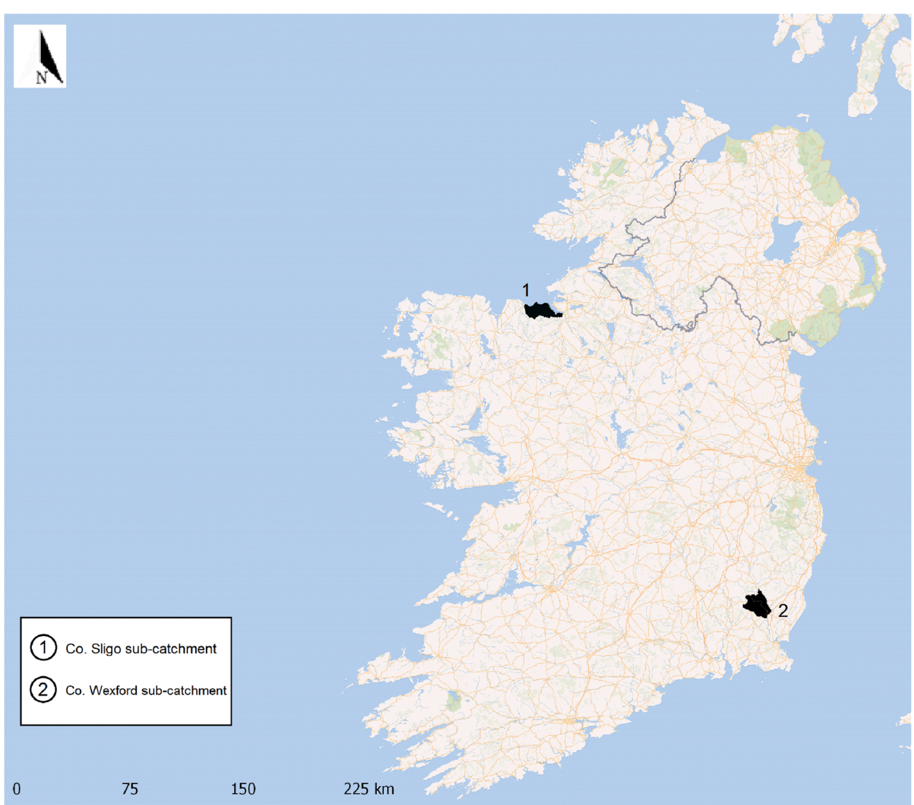

Fig. 1. Location of the study areas (1 – Co. Sligo sub-catchment; 2 – Co. Wexford sub-catchment).

(livestock units, nutrient inputs, reseeding) and follows Fossitt (2000), Sullivan et al. (2010), Devaney et al. (2013) and O' Neill et al. (2013) and has also been adopted by Tasser et al. (2019). Indicator species data were arranged according to grassland types existing in each parcel. When more than one field of a particular grassland type was present in a parcel, the cover value (DAFOR scale) of the indicator species was determined as the median cover between those fields.

All surveyed hedgerows were scored for structural condition (ranging from 0- Unfavourable to 3- Highly favourable) given that provides an indication of how hedgerows have been managed by the farmer (cutting regimes, livestock pressure). The structural condition score was calculated using the criteria present in Table S3 (SM). Indicator species data were grouped according to structural condition: when more than one structural condition score was present in the parcel, the cover of the indicator species for that particular structural condition category was determined as the median cover.

Separate species occurrence matrices were created for grasslands and hedgerows using cover data for all indicator species recorded (positive and negative) per grassland type/parcel and hedgerow structural condition score/parcel. Four response variables were also considered for further statistical analyses: grassland positive indicator species richness; hedgerow positive indicator species richness; Simpson's Diversity Index for grasslands positive indicators; and Simpson's Diversity Index for hedgerows positive indicators.

2.3. *Explanatory variables selection and statistical analyses*

Potential explanatory variables were gathered from generated habitat maps, from the field surveys and online geodatabases. Habitat mapping was undertaken for both sub-catchments on ArcGIS.10.5 (ESRI, 2016) following the Irish national habitat classification (Fossitt, 2000) and Smith et al. (2011) mapping guidelines. The two maps were ground-truthed using the data obtained from farm habitat surveys (Rotchés-Ribalta et al., 2021), Google Street View (Carlier and Moran, 2019) and by confirming the classification on the ground of randomly selected polygons and linear features.

Co-linearity between the explanatory variables was investigated trough Spearman correlations analyses. When correlation between two explanatory variables was greater than $|r| > 0.7$ (Dormann et al., 2012) one of them was discarded and the one with more ecological relevance was kept (i.e. reported as having influence on vegetation). Spearman correlation analyses were conducted in R 3.5.2.

All variables considered are listed in Table S4 from SM and a description of how each variable was obtained and determined is available. Table S4 also shows to which habitat (grassland and/or hedgerows) each variable was considered relevant. Average/median values and range for all initially compiled explanatory variables are shown in Tables S5 and S6.

The variables were separated into a) variables that are outside the farmers' control; b) variables within the farmers' control; and c) other parcel level variables.

Variables considered outside the farmers' control included: soil drainage class; altitude; landscape connectivity metrics (obtained from a Morphological Spatial Pattern Analysis (MSPA) in GuidosToolbox software (Vogt and Riitters, 2017)); percentage of semi-natural linear features within 500 m buffer from the parcel; percentage of semi-natural areas within 500 m buffer from the parcel; distance to nearest semi-natural grassland. Variables within the farmers' control included: grassland type; vegetation structure; grazing and poaching levels; cover of bare ground; cover of plant litter; fence presence separating fields from hedgerows; hedgerow height and width; hedgerow gaps presence, shape/profile, basal density and heterogeneity; hedgerow structural condition score; hedgerow type; Shannon Diversity Index of areal habitats; Shannon Diversity Index of linear habitats; area of the fields; length of hedgerows (see also Table S7 in the SM to consult which habitats were considered as semi-natural habitats).

Other parcel level variables included floristic variables surveyed with the grasslands RAC, such as: bryophytes cover; lichens cover; cover of bracken; cover of negative indicator species; number of negative indicator species. And floristic variables surveyed with the hedgerows RAC, such as: cover of woodland species; cover of scrub species; cover of ground flora; cover of ferns; cover of deadwood; ground cover of bryophytes; cover of epiphytic bryophytes; ground cover of lichens; cover of epiphytic lichens; cover of negative indicators; number of negative indicators.

2.3.1. *Indicator species occurrence*

The indicator species occurrence matrices (in DAFOR scale cover values) were modelled against a second matrix with the potential explanatory variables. To select the appropriate ordination method an exploratory analysis of the data was conducted in PC-ORD 7.08. (McCune and Grace, 2002), by analysing Dust Bunny Indices (McCune and Root, 2015). Because Dust Bunny Indices were higher than 0.85 for both matrices, ordination methods that assume normality of the data were not considered.

A strong effect of both rare and dominant species was apparent when visually investigating the dominance curves and tables derived from the species matrices. Therefore, species with a number of occurrences inferior or equal to 2 were considered to be a "chance" effect and not representative of the ecological trends sampled (Lawesson, 2000) and therefore removed. The data were transformed in both matrices to reduce the effect of very dominant species (general relativisation). Outliers that could have a strong effect in the analyses (with standard deviations > 2.0) were also removed from the matrices, when an inappropriate classification and/or exceptional ecological conditions were obvious.

An NMS (Nonmetric Multidimensional Scaling) ordination analysis (Kruskal, 1964; Mather, 1976) was conducted for both grassland and hedgerow indicator species. The analyses were performed with PC-ORD, 7.08. This ordination analysis method does not quantify the effects of categorical variables in the models; however, the relation of each categorical variable with the axes and species can be investigated using overlays in the ordination graphs (McCune and Grace, 2002).

2.3.2. *Models for richness of positive indicators species and Simpson's Diversity Index*

The effect of the selected explanatory variables on the Simpson's Diversity Index and species richness of positive indicators (for both grasslands and hedgerows) was further explored. The four diversity variables were tested for normality by analyzing the histogram, qq-plots and performing Shapiro-Wilk normality tests. These variables were fitted against the explanatory variables using Linear Regression Models (LM) and Generalized Linear Models (GLM). GLM's (with Poisson distribution) were developed for the species richness response variables (count data). For each response variable, two different models were developed: i) models with only variables within farmers' control and other parcel variables (type 1 models); and ii) models with variables outside farmers' control included as predictors in the first iteration of the model (type 2 models). All models were developed in R (v.3.5.2) (R Development Core Team, 2013).

A modified version of the stepAIC() function from the R package MASS (Venables and Ripley, 2002) was used for model selection. This modified function uses the AICc (Akaike's corrected information criterion) rather than AIC to select the predictor to add at each step (Read et al., 2018). The model selection was set for both "backward" and "forward" selection. An additional backward elimination approach was later conducted to find the most parsimonious model - the least significant effect that does not meet the significance level of p-values > 0.05 was removed (Hong and Mitchell, 2007). The process was repeated until no other effect in the model met the specified level for removal (Faraway, 2002; Bursac et al., 2008). The effect of the potential interaction between grassland type, vegetation structure and grazing levels was included as a predictor in the grassland models.

For the evaluation of the models regression fit the AIC and adjusted R^2 values were considered. For GLMs, an adjusted pseudo-R^2 was applied to measure and understand the explanatory power of the model, following Guisan and Zimmermann (2000) equation. Multicollinearity was tested by assessing the variance inflation factor (VIF) and was considered problematic if the VIF values exceeded 4 (The Pennsylvania State University, 2018). The LMs residuals were examined for normality and GLMs were tested for overdispersion (Bolker et al., 2009). To support the previous analyses, LMs assumptions were tested with the gvlma.lm (Pena and Slate, 2006) function. This function evaluates the LMs skewness, kurtosis, link function suitability and heteroscedasticity, performing a global validation of the linear models assumptions. Outliers' analyses were performed with the outlierTest function (Fox and Weisberg, 2019).

To understand if there were significant differences between the two types of models fitted to the four explanatory variables (type 1 versus type 2) the anova() function with a likelihood ratio test was used.

LMs provided the best model results for both the grasslands response variables. However, the best model fitted to the species richness were LMs with square-root transformed data.

2.3.3. Indicator species analysis for hedgerows

An indicator species analysis was applied to find positive indicator taxa significantly related to hedgerows of "Highly favourable" structural condition. This sub-set of relevant taxa was determined with the R function 'multipatt' (numbers of random permutations = 2000; duleg = TRUE) (De Cáceres and Jansen, 2013). This function calculates the IndVal index, originally described by Dufrêne and Legendre (1997). The IndVal index was determined from the hedgerows species matrix and the corresponding structural condition of each hedgerow. This analysis returns the positive indicators of "Highly favourable" and the following coefficients: A: the probability for occurrence of a given species to coincide with the hedgerow in which it was found to be in "Highly favourable" condition; B: the probability of finding the species in the hedgerow belonging to the "Highly favourable" score; and Stat: the average between A and B representing the indicator value of the species (De Cáceres and Jansen, 2013).

The results obtained for the ordination analysis and models fitted to the hedgerow diversity variables (see Results section) motivated this complementary analysis. It is a methodological suggestion for improving the scientific basis of results evaluation methods within a RBP context (in line with Birkhofer et al., 2018 proposal) and to improve the suitability of the indicator species list for conservation targets.

It can be argued that it would be enough to simply assess and reward the structural condition, however, the species identity is important: good structural condition in a hedgerow can also be obtained with invasive/exotic species, thus native species presence should be included as a desired/complementary goal. Furthermore, best structural condition might only be achieved after years (due to plant species growth time) and by weighting the presence and abundance of specific taxa a positive signal is given to the farmer.

3. Results

Grasslands and hedgerows accounted for the most frequent habitats present in the farms surveyed: a total of 159 grassland fields (mean of 3.6 fields per parcel) and 454 hedgerows (mean of 8.4 hedgerows per parcel) were surveyed. For the grasslands, a mean (SE) of 4.84 (±0.49) positive indicators per field (min = 1 species; max = 19 species) was obtained. The most common positive indicators were *Rumex acetosa* Linn and *Cirsium palustre* (L.) Scop. whilst the most common negative indicator species was the aggregate *Cirsium arvense* (L.) Scop., *C. vulgare* (Savi) Ten. The mean (SE) Simpson's Diversity Index was 0.562 (±0.046) (min = 0; max = 0.933).

For hedgerows, a mean (SE) of 9.10 (±0.32) indicator species per hedgerow (min = 3 species; max = 20 species) was recorded. The most common positive indicators were *Rubus* spp. and *Crataegus monogyna* Jacq.; the most common negative indicators was the aggregated *C. arvense., C. vulgare*, *Rumex obtusifolius* L., *R. Crispus* L. and *Urtica dioica* L.(nutrient rich species). The mean (SE) value of the Simpson's Diversity Index was 0.762 (±0.015; min = 0; max = 0.928).

3.1. Indicator species composition

3.1.1. Grasslands

An NMS ordination with three axes explained 83% of the species distribution, with axis 1 representing a "naturalness gradient", separating improved grasslands from other grassland types of more extensive management. The best NMS solution (for 29 indicator species and a total of 60 plots) had a final stress value of 13.65. According to McCune and Grace (2002), most ecological community data sets will have solutions between 10 and 20, and values that are in the lower half of this range are considered satisfactory.

Axis 1 explained 51% of the species distribution and correlates positively with diversity of indicator species (D), the cover of bryophytes on site, the semi-natural ratio for fields, and the parcel diversity of areal habitats; it correlates negatively with "negative" indicator species and with the distance to semi-natural pastures (Fig. 2, Table 1). Variables related to management (within farmers' control) were more correlated with axis 1. In the NMS plotting options the categorical variable grassland type was included and it is possible to confirm a gradient of semi-naturalness of grassland type which is related to axis 1 (Fig. 2). Axis 2 represented a weak management gradient (influence of bare ground) accounting for 19% of the species distribution in the ordination space. Finally, axis 3 represented an altitudinal gradient and explained 12% of the species distribution in the oridnation space. Positive and negative indicator species correlated as expected with the "naturalness gradient", axis 1 (see Table S8 in SM). Some positive indicators were more related than others to altitude, and therefore, to parcel setting, whilst negative indicators are mostly correlated with management variables. Higher values of the Simpson's Diversity Index (abbreviated to D in Fig. 2) were correlated with most positive indicator species assessed and occurred in farms with larger proportions and diversity of semi-natural areas. Conversely, an inverse relationship between cover and number of negative indicators and the Simpson's Diversity Index was evident.

As altitude was the variable that has biggest correlation with axis 3 it is possible to verify that only a few species are influenced significantly by this variable. Given that axes 2 and 3 have a low explanatory power, the NMS graph is not displayed for these two axes together since interpretation would be highly uncertain.

3.1.2. Hedgerows

An NMS ordination with three axes explained 78% of the species distribution in the ordination space, with axis 1 explaining 27% of the variance and correlating negatively with the cover of woodland species and the Simpson's Diversity Index (D). It correlates positively with altitude and with the cover of ferns (Pearson's r = 0.263). Most parcel level floristic variables were correlated with axis 2 (axis that explains biggest percentage of variation – 29%), showing the highest correlation values with the Simpson's Diversity Index (abbreviated to D in Fig. 3) and altitude. It had its strongest positive correlations with the percentage of "Islets" (a structural connectivity variable – see Table S4 in SM) and the cover of ferns (Table 2, Fig. 3). Axis 3 explained 23% of species distribution in the ordination space, being positively correlated with the Simpson's Diversity Index (D) and Parcel's Shannon Diversity Index (areal); and negatively correlated with the cover of bare ground (Pearson's r = 0.268). A high number of hedgerows of better structural condition (structural condition score of 3) were associated with higher values of Simpson's Diversity Index (D), cover of woodland species and cover of epiphytic bryophytes (Fig. 3). However, structural condition scores of 0, 1 and 2 are randomly distributed in the ordination space and,

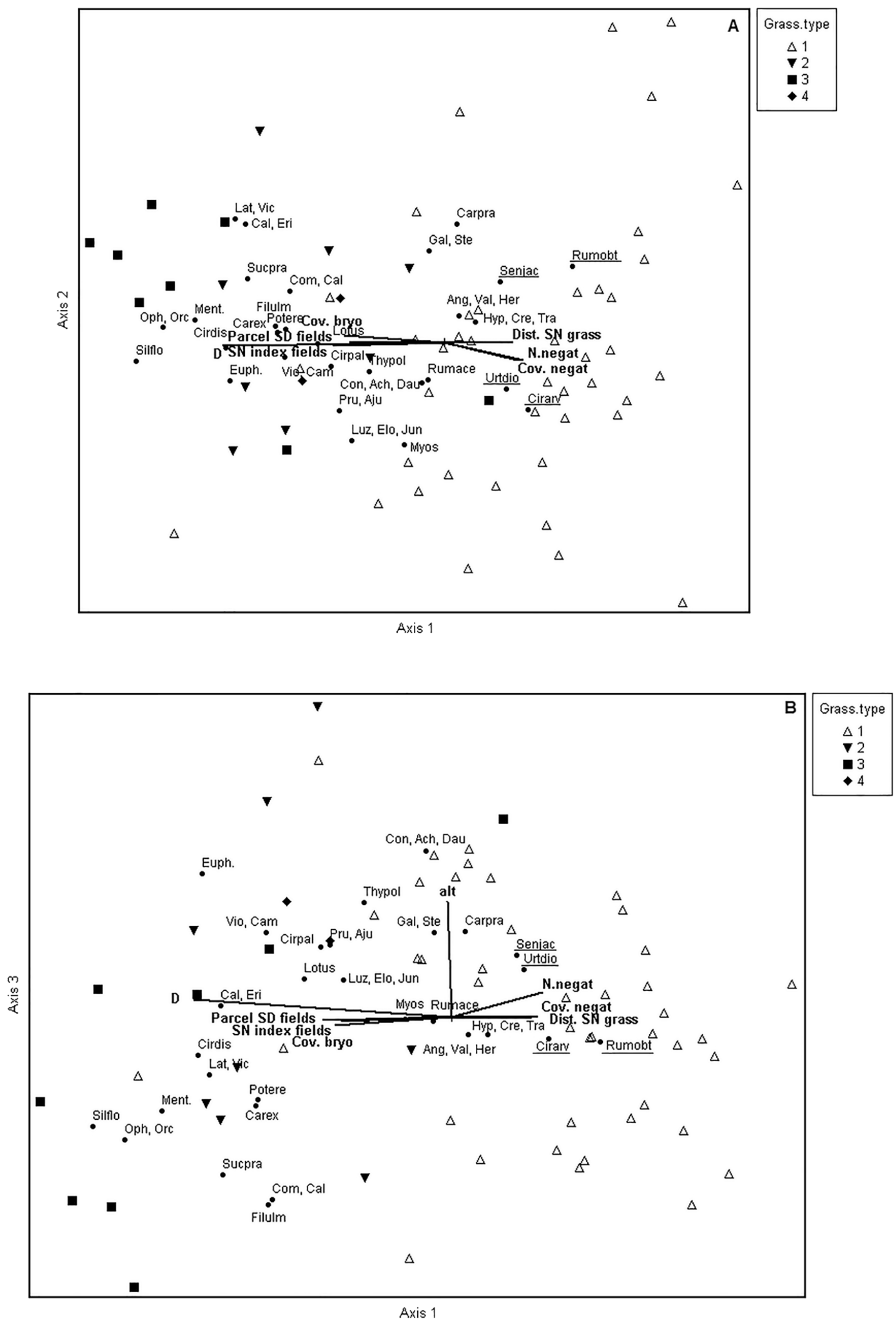

Fig. 2. NMS ordination plots showing the relationship between indicator species composition and environmental variables in relation to NMS axes (grasslands). Only species that have correlations above |0.300| are identified (dots). Graph A: Axis 1 plotted against Axis 2; Graph B: Axis 1 plotted against Axis 3. Legend for "Grass.type": improved grasslands = 1; semi-improved grasslands = 2; semi-natural grasslands = 3; transition to semi-natural grasslands = 4. Species names can be consulted in Table S1 in the Supplementary Materials and Table S9 shows all correlation values between species and ordination axes. Negative indicator species are underlined.

thus, do not related with the indicator species occurrence and explanatory variables.

Most of the variables controlled by the farmer were categorical variables, and their distribution was not associated with particular species or axes, indicating that variables within farmers' control were poorly related to indicator species surveyed. Few positive indicator species showed strong correlations with the ordination axes, however most of them were correlated negatively with axis 1 and 2 and thus positively with the cover of woodland species, the Simpson's Diversity Index (D) and most parcel level floristic variables (except with the cover of ferns). The species belonging to the genus *Rubus* had, however, a positive correlation with both axis 1 and axis 2.

Despite the high cumulative explanatory value, the stress value obtained for this NMS solution (17.04) can be misleading when interpreting the results (McCune and Grace, 2002). All correlation results obtained between the explanatory variables and each axis can be further investigated in Table S10 from the SM.

3.2. Models for Simpson's Diversity Index and positive indicator species richness.

Determinants of grasslands Simpson's Diversity Index: results of models comparison via ANOVA showed that the LM where the variables considered outside of farmers' control were introduced as explanatory variables (type 2 model) was significantly better than the model where only variables within farmers' control and other parcel variables were considered (type 1 model) (see Table 3). In both models the type of grassland and the Parcel's Shannon Diversity Index of habitats (areal) had a positive effect on the grasslands Simpson's Diversity Index. However, altitude and the soils drainage class also correlate with this

Table 1
NMS results for grasslands – Pearson correlation values of grasslands' explanatory variables with Ordination Axes. Correlation values above 0.300 or below −0.300 are highlighted in bold. Variables within farmers control are highlighted in italics.

	Axis 1	Axis 2	Axis 3
Variables	**Pearson's r**	**Pearson's r**	**Pearson's r**
Cover of bryophytes	**0.556**	−0.156	−0.152
Cover of bare ground	−0.271	**−0.317**	−0.001
Cover of negative species	**−0.473**	0.240	0.008
Number of negative species	**−0.489**	0.237	0.071
Percentage of SN habitats in a 500 m buffer	**0.365**	−0.057	−0.123
Semi-Natural Ratio (fields)	**0.585**	−0.091	0.087
Distance to semi-natural pastures	**−0.458**	0.058	0.065
Altitude	0.106	0.238	**−0.553**
Parcel Shannon Diversity Index of habitats (areal)	**0.542**	0.033	0.104
Simpson's Diversity Index (D)	**0.828**	−0.087	−0.219

response variable. Nonetheless, the multiple and adjusted R^2 values had only slight increments when both these variables emerged as significant.

The type 1 model did not meet the criteria of residuals normality (Shapiro-test: W = 0.935, p-value = 0.003) whilst the type 2 model did (Shapiro-test: W = 0.980, p-value = 0.440). However, results of the Global Validation of Linear Model Assumptions (gvlma) showed that for the type 1 model linearity, heteroscedasticity and assumption of normality – (skewness and kurtosis) were all acceptable and only the link function assumptions were not satisfied; In turn, the results of this analysis for the type 2 model, showed that the link function assumptions and assumption of model linearity were not met.

Determinants of grassland positive indicator species richness: positive indicator species richness was positively related to the diversity of habitats in the parcel, to the type of grassland and to bryophyte cover. The only significant negative predictive relationship in this model was with cover of plant litter. The variables that have larger contribution to the model were all regarded as within farmers' control. No difference between the models (type 1 versus type 2) were detected, since the same predictors emerged as significant when variables outside the farmers' control were considered (Table 3). The model residuals were shown to be normal (Shapiro-test: W = 0.989, p-value = 0.877) and all the Global Validation of Linear Model Assumptions were met.

Determinants of hedgerows Simpson's Diversity Index: The final model obtained where variables outside farmers' control were considered outperformed the best model where only variables within farmers' control and other parcel variables were considered (Table 4). The height, heterogeneity, basal density score and grazing levels of hedgerows were the significant variables within the farmers' control that were related to the Simpson's Diversity Index. The first three variables were used to calculate the structural condition of the hedgerow; however, the variable structural condition score did not emerge in itself as a significant variable. Most significant variables can be related, to some extent, with the farmers' management since they are parcel level variables (cover of ground flora; cover of bare ground; cover of deadwood; cover of ground bryophytes). Farm setting (soil drainage class) and isolation of hedgerows (percentage of Islets) also appeared to have an effect on the Simpson's Diversity Index. The results of the Global Validation of Linear Model showed that none of the assumptions were met and the model residuals were not normal (Shapiro-test: W = 0.931, p-value = 4.763e−05). Data transformations did not improve model performance.

Determinants of hedgerows positive indicator species richness: Again, the type 2 outperformed the type 1 model (higher multiple and adjusted R^2) but not significantly (ANOVA results in Table 4). This second model, where variables outside farmers' control were considered as predictors, indicates that farm surrounding (percentage of semi-natural areas in a 500 m buffer) and connectivity (percentage of branches and bridges)

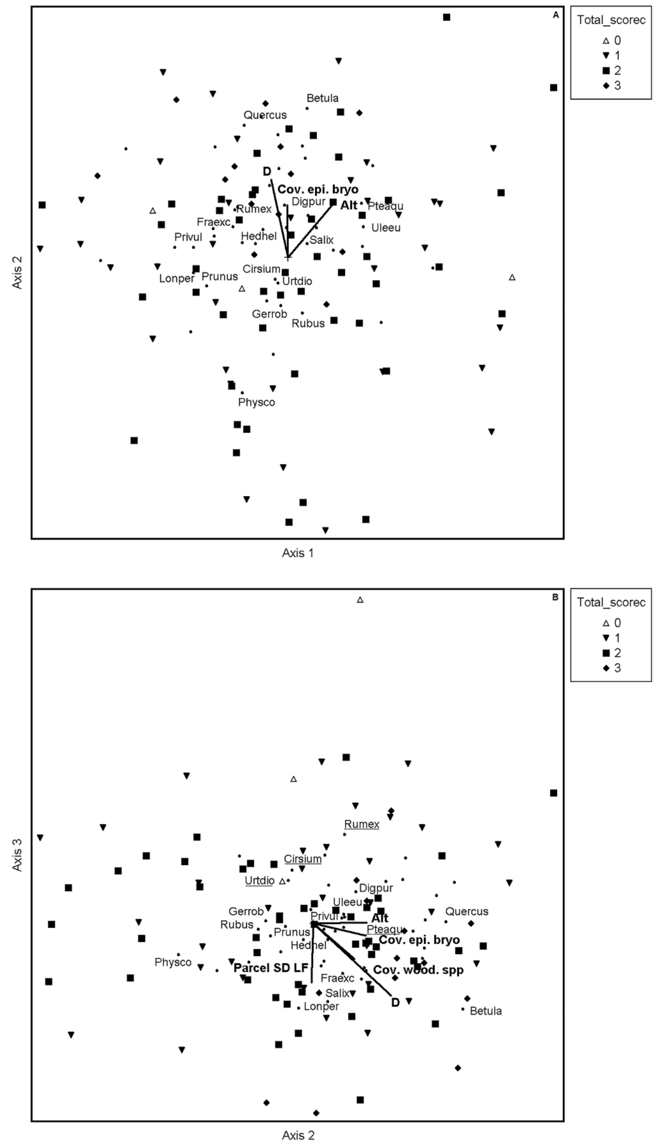

Fig. 3. NMS ordination plots showing the relationship between species and environmental variables in relation to NMS axes (hedgerows). Only species that have correlations above |0.300| are identified (dots). Graph A: Axis 1 plotted against Axis 2; Graph B: Axis 2 plotted against Axis 3. Legend for "Structural condition score" (Total_scorec): unfavourable = 0; adequate = 1; favourable = 2; highly favourable = 3. Species names can be consulted in Table S2 in the Supplementary Materials and Table S11 shows all correlation values between species and ordination axes. Negative indicator species are underlined.

explain the observed richness of hedgerows positive indicator species. Furthermore, results of the Global Validation of Linear Model show that most assumption were not met, thus interpretations of the results are not exhaustive and conclusive.

In summary, both grassland diversity variables were mainly affected by variables within farmers' control, followed by other parcel level variables. However, results from the models fitted to the Simpson's Diversity Index, showed that there was a small but significant effect of the parcel setting in the relative abundance of positive indicators species, which is in line with the results of the ordination analysis – altitude was correlated with axis 3 and thus with some of the positive indicators cover. The soil drainage class of the farm parcel, a variable outside farmers' control, also emerged as significantly correlated with the Simpson's Diversity Index. However, the species richness of positive indicators did not seem to be affected by parcel setting (altitude and soil

Table 2
NMS results for hedgerows – Pearson correlation values of hedgerows' explanatory variables with Ordination Axes. Correlation values above 0.300 or below −0.300 are highlighted in bold. Variables within farmers' control are highlighted in italics.

	Axis 1	Axis 2	Axis 3
Variables	**Pearson's r**	**Pearson's r**	**Pearson's r**
Simpson's Diversity Index (D)	−0.288	**−0.551**	**0.533**
Cover of woodland species	**−0.340**	**−0.408**	**0.339**
Cover of scrub species	0.034	**0.306**	0.074
Cover of ferns	0.263	**−0.376**	**0.311**
Cover of plant litter	0.199	**−0.318**	−0.043
Cover of epiphytic bryophyte	−0.059	**−0.450**	0.211
Cover of epiphytic lichens	−0.164	**−0.368**	0.088
Parcel Shannon Diversity Index of habitats (areal)	0.114	0.085	**0.458**
Parcel Shannon Diversity Index of habitats (LF)	−0.123	**−0.334**	0.212
Altitude	**0.422**	**−0.470**	−0.075
% of Islets - tall woody MSPA results	−0.233	**0.341**	0.000

Table 3
Summary of results for LMs fitted to the Simpson's Diversity Index and positive indicators species richness (grasslands) and model type comparison (type 1 versus type 2). Significance levels: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. Variables within farmers' control are highlighted in bold.

Response variable	Significant variables according to model type	Mult. R^2 Adj. R^2 AIC	ANOVA results Pr(>Chi)
Grassland Simpson's Diversity Index	Type 1 model **Grassland type** = 0.166 *** **Parcel Shannon Diversity Index of habitats (areal)** = 0.357 **	Mult. R^2 = 0.419 Adj. R^2 = 0.388 AIC = 26.140	**Pr(>Chi) 0.011***
	Type 2 model **Grassland type** = 0.140 ** Altitude = 0.001* **Parcel Shannon Diversity Index of habitats (areal)** = 0.298** Soil drainage class = −0.102*	Mult. R^2 = 0.468 Adj. R^2 = 0.429 AIC = 21.858	
Grassland species richness of positive indicators	Type 1 model **Grassland type** = 0.435*** Cover of bryophytes = 0.019** **Cover of plant litter** = −0.018 * **Parcel Shannon Diversity Index of habitats (areal)** = 0.522**	Mult. R^2 = 0.613 Adj. R^2 = 0.585 AIC = 79.742	**Same model was obtained (no differences)**
	Type 2 model **Grassland type** = 0.435*** Cover of bryophytes = 0.019** **Cover of plant litter** = −0.018 * **Parcel Shannon Diversity Index of habitats (areal)** = 0.522**	Mult. R^2 = 0.613, Adj. R^2 = 0.585 AIC = 79.742	

Table 4
Summary of results for LMs fitted to the Simpson's Diversity Index and positive indicators species richness (hedgerows) and model type comparison (type 1 versus type 2). Significance levels: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. Variables within farmers' control are highlighted in bold.

Response variable	Significant variables according to model type	Mult. R2 Adj. R2 AIC	ANOVA results Pr(>Chi)
Hedgerow Simpson's Diversity Index	Type 1 model **Height (score)** = 0.073*** **Basal density (score)** = −0.047** **Heterogeneity (score)** = 0.054* Cover of ground flora = −0.199** Cover of bareground = −0.201*	Mult. R^2 = = 0.389 Adj. R^2 = 0.357 AIC = −134.8	**Pr(>Chi) 0.0231***
	Type 2 model **Height (score)** = 0.073*** **Heterogeneity (score)** = 0.054* Cover of ground flora = −0.199** Cover of bareground = −0.229* Cover of deadwood = −0.881* Cover of groundbryophytes = 0.409* **Grazing levels** = 0.054* Soil drainageclass = −0.036* % of Islets (woody MSPA) = −0.038*	Mult. R^2 = 0.456 Adj. R^2 = 0.403 AIC = −136.93	
Hedgerow species richness of positive indicators	Type 1 model **Score structural condition** = −0.295 **Hedge type** = 0.114* **Height (score)** = 0.254** Cover of scrubs = 0.624** Cover of ferns = 1.126*	Mult. R^2 = 0.183 Adj. R^2 = 0.140 AIC = 196.75	**Pr(>Chi) 0.108 (no differences)**
	Type 2 model **Height (score)** = 0.249*** **Parcel Shannon Diversity Index of habitats (areal)** = 0.575* **SN ratio fields** = −0.728* % SN habitats in 500m buffer = 1.090* % of bridges (woody MSPA) = 0.242* % of branches (woody MSPA) = 0.324*	Mult. R^2 = 0.204 Adj. R^2 = 0.154 AIC = 196.37	

drainage class) or even regional differences (Co. Wexford and Co. Sligo). The hedgerow models showed a poor fit of the explanatory variables to variables characterizing indicator species diversity, especially considering the high number of variables that emerged as significant in both models. Thus, interpretations are tentative and not conclusive.

3.3. Indicator species analysis results for hedgerows

A total of eight native taxa were significantly ($p < 0.05$) correlated with "Highly favourable" structural condition scores**,** these include: *Salix* spp. *(S. caprea, S. cinerea, S. pentandra, S .triandra)* (A = 0.698; B = 0.518; Stat = 0.602); *Crataegus monogyna* (A = 0.396; B = 0.852; Stat = 0.581); *Fraxinus excelsior* (A = 0.436; B = 0.518; Stat = 0.475); *Alnus glutinosa* (A = 0.749; B = 0.222; Stat = 0.408); *Betula pendula* and *B. pubescens* (A = 0.765; B = 0.148; Stat = 0.408); *Populus nigra* and

P. tremula (A = 0.743; B = 0.148; Stat = 0.332); *Quercus petraea* and *Q. robur* (A = 0.639; B = 0.148; Stat = 0.308) and *Ulmus glabra* and *U. procera* (A = 0.769; B = 0.074; Stat = 0.332).

4. Discussion and conclusions

4.1. Farmers management strongly influenced grassland indicator species

Ordination results for the grasslands indicator species showed an interpretable pattern of indicator species occurrence, with most significant explanatory variables related to management and parcel condition (grassland type, semi-naturalness ratio of the parcel, Parcel Shannon Diversity Index of areal habitats). It is important to highlight that some positive indicators, even the most commonly surveyed species (*R. acetosa* and *C. palustre*) were present in some intensively managed grasslands (see NMS results), which might indicate that reseeding, fertiliser inputs and weed topping – typical management practices aimed to increase grasslands productivity in Ireland (White et al., 2019) – were never applied in an very intensive way in some of these surveyed grasslands. Keeping these species might be important as they can provide a first signal of reduction of fertilisers input, reseeding frequency or weed topping. Therefore, the list of indicators allows assessing a semi-naturalness gradient of grasslands and thus gradual transitions can be rewarded within a RBP context. NMS results also showed that the proximity to other fields of semi-natural grassland had an effect (to a smaller degree) on some positive indicator species, which is in line with Brose (2001) observations. This small effect can be explained, at least in part, by the dispersal of semi-natural grassland species by wind or other vectors such as farm machinery or livestock (Gil-Tena et al., 2013).

LM results showed that soil type (soil drainage class) and altitude were correlated with the Simpson's Diversity Index, but not with the species richness of positive indicators. Similar results were reported by Yeboah et al. (2016) for soil drainage class effects on vegetation diversity variables, with this variable having a higher correlation with evenness than with species richness. The effect of altitude on some species occurrence (see NMS results) and Simpson's Diversity Index are not necessarily surprising given the farm type distribution in Ireland. Gardiner and Radford (1980) highlight that farms in mountain and hill slopes face limitations related to high altitude (e.g. shallow soil depths, wetness, and inaccessibility) and that the farming systems in these areas usually consist of extensive grazing with low productivity levels.

The Parcel Shannon Diversity Index of areal habitats consistently emerged as an explanatory variable and reflects farmers' management choices with regard to the presence of areas of different habitat types. This result is line with findings by Brose (2001) and Martin et al. (2020), where habitat heterogeneity also emerged as the most reliable variable for predicting plant species richness and other taxonomic groups abundances.

Higher values of cover of plant litter showed a negative correlation with the species richness of positive indicator and this variable is also related to farmers' management choices. Regular and extensive grazing has been highlighted as a necessary tool to maintain the valuable grassland plant community and associated biodiversity (Hansson and Fogelfors, 2000; Rook and Tallowin, 2003). Thus, our results also indicate that some level of grazing with plant litter removal can be important for a higher diversity of positive indicators.

From the range of floristic explanatory variables (e.g. cover of bracken, cover of lichens, cover of bryophytes) introduced in the ordination analysis and on both models, the only one that consistently emerged as significant (and positive) was the cover of bryophytes. The competitive effect between vascular plant species and bryophytes reported in some studies (e.g. Löbel et al., 2006) or the hump-back relationship commonly described between these two plant groups (Grace, 1999) was not fully observed in this study. The higher cover of bryophytes observed in species-rich grasslands might be related to lower nutrient inputs (Kleijn et al., 2009; Boch et al., 2018) and more open vegetation which allow for both taxonomic groups to coexist without the competitive effects being obvious. However, we cannot state that indicator species richness is affected by bryophytes cover, rather it is more likely that there is a correlation between these two groups due to management choices and that only half of the hump-back relationship was observed.

In summary, the results indicate that the occurrence of indicator species and related diversity variables for grasslands is easily explained by variables mainly associated with parcel management. This supports the observation from other studies that farmers' management can indeed positively influence biodiversity (Stoeckli et al., 2017; Tasser et al., 2019). Therefore, assessing the positive indicator species richness in a RBP can provide a fair way of assessing both the quality of grasslands and farmers efforts for achieving the targets. Furthermore, the present indicator species list has the potential to be utilised in national-scale schemes, since most species seemed to react primarily to disturbances at fine spatial scales (Carignan and Villard, 2001) and land-use intensity (Tasser et al., 2019), and not so much to landscape variables. However, since other soil properties, besides the soil drainage class, can influence plant communities (e.g. Critchley et al., 2002; Venterink et al., 2003; Löbel et al., 2006; Devaney et al., 2013) and some areas might have exceptional climatic and floristic characteristics (e.g. islands), further research may be important for refining the current species list (but is unlikely to invalidate it) for certain regions.

4.2. Management variables were poorly related to hedgerow indicator species

Higher values of structural condition were inversely related to the richness of positive indicators in the fitted LM, indicating that the species list is not necessarily related to desirable structural conditions and to hedgerow management. These results were somehow divergent with the NMS obtained, where hedgerows with higher structural condition values (3) were associated with higher diversity of indicator species (higher values of Simpson's Diversity Index): thus, the hedgerows with higher scores of structural condition are not necessarily equivalent to hedgerows with higher species richness, but seemed more related to the presence of tree species and higher values of Simpson's Diversity Index. In fact, most hedgerows surveyed, even those more species rich, fell between values of 1 and 2 in terms of structural condition, and are randomly distributed along the NMS plots. These results are in line with what Larkin (2019) found for the majority of hedgerows on more intensively managed land in Ireland.

What emerges from the NMS and models results is an overall poor explanatory power of all selected predictors of hedgerows indicator species richness and diversity. Nonetheless, the effect of the farmers' management on the species occurrence and richness seems to be more directly suggested by the significant variables height, cover of woodland species and heterogeneity, where farmers' choices on the frequency and degree of hedgerows cutting are probably reflected. Vanneste et al. (2020) also found that forest specialists' richness in hedgerows was associated to tree cover, tree height and the proportion of forests in the surrounding landscape. However, the authors verified that generalist species richness was negatively affected by tree height. The indicator species list tested in the present study is comprised of both specialists and generalists, which might explain the high stress value of the NMS results and the poor LM and GLM fit. The most common species surveyed and with higher covers were *Rubus spp*. and *Crataegus monogyna* as reported by Sullivan et al. (2013), which are considered generalist species. Even if a general relativisation was performed before running the ordination analysis, these generalist species might still had a strong effect in the results.

Some landscape variables related to connectivity seem to have a weak effect on the indicators presence and abundance as seen in the ordination and models results. There is evidence that hedgerows may function as potential corridors for woodland herb species between forest patches (e.g. Wehling and Diekmann, 2009; Vanneste et al., 2020), thus the results might show this effect to a small degree, since hedgerows that are isolated (Islets) seemed to have lower diversity of positive indicators. In turn, bridges and branches (hedgerows connected to a woodland patch) seemed to have a positive relationship with positive indicators richness. It can be argued that farmers can increase connectivity of hedgerows and that these variables (connectivity variables) are within the farmers' control, however, this is only true if the property contains woodland areas, which is not commonly the case (see Rotchés-Ribalta et al., 2021).

Altitude, a significant variable in the ordination results, was correlated to region, and can be interpreted as representative of different management behaviors in the two sub-catchments. The Co. Wexford sub-catchment is characterized by more intensive agricultural systems, with more improved grasslands and a higher proportion of arable land compared to the Co. Sligo sub-catchment (Rotchés-Ribalta et al., 2021). However, in the statistical analyses conducted the variable related to field intensification (i.e. semi-naturalness ratio of fields) did not have any effect on hedgerows indicator species composition. In fact, in the work conducted by Rotchés-Ribalta et al. (2021) for the same study regions, the habitat quality of hedgerows and treelines in extensive farms of Co. Sligo was higher than in intensive farms, whilst the opposite was seen in Co.Wexford. This might indicate existing differences in hedgerows management regimes between the regions (e.g. cutting frequency). Thus, even in more intensive landscapes there is potential to retain semi-natural habitat quality through appropriate management of field boundaries and even more intensively managed farms can have the highest frequency of species rich hedgerows (see Sullivan et al., 2013). Nonetheless, it cannot be excluded that altitude *per se* can be affecting indicator species occurrence, and since this variable is outside farmers' control, species that have high correlation with altitude should be removed from the indicator species list.

In general, management variables had a poor relationship with the indicator species (low interpretability of both NMS and regression models) which indicates an inadequacy of the current species indicator list for wider use in a RBP scheme. One of the main criticisms of RBP in terms of practicability is the risk of implementing monitoring programmes that are too sophisticated and complex (Bartkowsi et al., 2018) with quality indicators that do not respond to management or are inappropriate for the defined objectives. Indicator species should then be *easily identified by farmers and paying agency representatives* and need to *occur consistently in target farmland habitats* (Keenleyside et al., 2014; Byrne et al., 2018). Thus such a long list of indicators imposes a challenge for botanical non-specialists (Birkhofer et al., 2018), and, additionally, some of the species listed were never found in this study.

Indicator species analysis identified a sub-set of eight species that are correlated with a higher structural condition score, resulting in a shorter and more targeted list of relevant taxa for structural condition. Good structural condition can be promoted by management choices (e.g. cutting regimes, gaps removal) by the farmer and is identified as an important hedgerow attribute for biodiversity (Graham et al., 2018; Volpato et al., 2019; Montgomery et al., 2020) so this new sub-set of relevant taxa, coupled with a rapid assessment of structural conditions, could be incorporated in future assessments. Nonetheless, different objectives in addition to structural condition can be targeted, such as the value for pollinators, the value for pest control or for carbon sequestration. In fact, Carlier et al. (2019) tested how hedgerow structure (also adapted from Foulkes et al., 2013) affected several bat species in Ireland and concluded that different structural conditions affect species differently. The structural characteristic of hedgerows also seems to contribute differently to dipteran abundance and diversity (Ahmed et al., 2021). Therefore, other indicator species from the initial list that do not correlate with structural condition might correlate with other environmental targets, which were not assessed in this study.

Well-designed RBP schemes are of particular importance to improve and reward hedgerows quality: hedgerows account for the highest percentage of semi-natural linear habitats in both study regions, and across Europe (Lecq et al., 2017; Montgomery et al., 2020; Rotchés-Ribalta et al., 2021; Larkin, 2019); are managed by farmers to prevent their expansion into adjacent fields (Baudry et al., 2000); high quality hedgerows play a key role as forage resources for pollinators and pest control invertebrates principally in more intensely managed landscapes (Garratt et al., 2017) and have an overall high value for biodiversity, by acting as corridors for fauna (e.g. Coulthard et al., 2016) and by maintaining species that otherwise could not exist in agricultural landscapes (Baudry et al., 2000).

4.3. Recommendations for Results-Based Payments

The popularity of RBP is growing and the incorporation of this approach within AES is likely to increase in the next round of the CAP (Pe'er et al., 2020), however, hastened designs of results assessments and conservation objectives might risk their superior cost-effectiveness. Hence, as demonstrated in this study, it is important to test the relation of indicator species with the environmental targets and understand the real influence of management choices and of variables that are outside farmers' control to develop fair RBP schemes.

The present study shows the importance of conducting extensive surveying of the habitats targeted, in different climatic/regional settings to determine whether management choices emerge as determinants of indicators species occurrence and diversity. It contributes with a methodological proposal to be conducted prior to the implementation of a definite indicator species list for Results-Based assessments, which is particularly relevant for an evidence-based roll out of RBP in European policy. Other works (e.g. Wittig et al., 2006; Matzdorf et al., 2008; Kaiser et al., 2009, 2019) provide guidance for selecting plant indicator species from an expanded checklist; however, they never explore how variables outside of famers' control are influencing indicator species occurrence and diversity.

The grasslands list tested in this study was based on a previous pilot scheme (RBAPS) (with some alterations) and was developed to reflect the overall biodiversity value of grasslands (Maher et al., 2018; McLoughlin, 2018). From the results obtained the list has proven to be related to the environmental targets and mainly influenced by farmers' management even in two contrasting regions in Ireland (Co. Sligo and Co. Wexford). Therefore, the use of the grassland indicator species list in an Irish National RBP scheme will likely reward the quality of semi-natural grasslands and account for gradients of intensification.

On the other hand, the hedgerows list was developed as part of a wider monitoring assessment of hedgerows conditions (Foulkes et al., 2013) and not designed specifically for RBP requirements. Perhaps not unexpectedly therefore, it does not seem to reflect easy-to-capture management choices. For a RBP scheme targeted at hedgerows, clearer objectives (e.g. structural condition related to particular conservation species targets, pest control, pollinators and/or carbon sequestration) will need to be established and the farmers' role in meeting those objectives needs to be better linked to the selected results indicators.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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