Article

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DOI: 10.3318/BIOE.2015.08

Change and causes of change in the vascular plant flora of Ireland: 1970-1999

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Abstract

The analysis of decadal change in regional floras has received fresh impetus in recent years with studies often detecting anthropogenic effects and biotic homogenization. Here we analyse the changing flora of the island of Ireland (i.e., both the Republic and Northern Ireland) using data derived from the New Atlas of the British Flora (Preston et al., 2002) to compare changing plant status from the previous national plant atlas of Perring and Walters (1962). We compare the number of 10 x 10 km grid squares occupied by individual plant species and enter these into a regression analysis. The null hypothesis assumes that all the species will be located on the line of best fit hence the resulting residuals are used as an Index of Change. This Index was entered into correlation analysis with independent environmental indicators to interpret the potential causes of any change. Despite some potential sampling bias in the data the findings point to several factors being implicated in change with eutrophication being a major correlate of change. This finding is discussed in relation to land use change and agricultural intensification over the period of the survey.

Key words: flora, change, Ellenberg, plants, eutrophication, acidification

INTRODUCTION

There is widespread concern about biodiversity loss due to contemporary pressures of land use, in Europe particularly that related to increased agricultural productivity and intensification due to EU farm subsidies since the 1970s (Skinner et al., 1997; Donald et al., 2001; Robinson and Sutherland, 2002). In Ireland, recent decades have seen increased pressures on the landscape, predominantly through agricultural intensification, urbanisation and peat and mineral extraction (EPA, 2000; Huyghe et al., 2014). Primary concerns resulting from these changes include increased surface water pollution, soil degradation, and increasing loss of remaining semi-natural habitats (Cabot, 1999).

Differing authorities provide slightly different estimates for the number of native plant species in the Republic: c. 900 according to United Nations (2014), 993 according to National Botanic Gardens (no date a), and 996 in the island of Ireland according Preston et al. (2002a). In the Republic, 11 plant species have gone extinct in recent times, seven species require immediate intervention, 52 are endangered, and a further 69 are vulnerable. A further 14 species are not considered to be threatened in the Republic but are listed as protected in Northern Ireland (Botanic Gardens, no date b). The Botanical Society of the British Isles (BSBI) set up a monitoring scheme to assess the status of the Irish flora in 1987-1988, and also to provide a more detailed means of monitoring change in the future (Rich et al., 2001). The results of a comparison between records collected by the BSBI Monitoring Scheme in Ireland and data published in the first Atlas (Perring and Walters, 1962) and other historical records were published by Rich and Woodruff (1996) and later by Rich et al. (2001). Significant changes were identified in at least 19% of the flora, with 11% showing declines and 8% showing an increase. These estimates lie in between those found in England, where at least 24% of the flora had changed and 12% was seen to have changed in Scotland (Rich and Woodruff, 1996). General trends included declines in species associated with calcareous grassland and with unimproved grassland as well as coastal species and arable weeds. This was accompanied by a significant increase in introduced species (Rich et al., 2001).

Although there have been few extinctions of plants at the national scale in either the UK or Ireland, analyses of regional records in the form of county floras on mainland Britain have demonstrated that there have been range contractions due to regional extirpations arising from factors such as habitat loss due to landscape modification (Walker and Preston, 2006). Analysing change in plant abundance and range extent over time received fresh impetus due to the development of a quantitative approach to measuring change (McCollin et al., 2000). This approach, which generates an Index of Change across a whole flora, has since been used to show change in regional floras in the UK, Belgium, the Netherlands, Switzerland, France amongst others (Preston et al., 2002a, Walker, 2003, van der Veken, 2004, Tamis et al., 2005, Stehlik et al., 2007, van Calster et al., 2008, van Landuyt et al., 2008).

The outstanding message from studies using this approach has been the extent to which regional floras have undergone biotic homogenization and the extent to which habitat loss and eutrophication have been implicated in such change. In this paper change in the flora of the island of Ireland are analysed (i.e., both Northern Ireland and Ireland combined) using data derived from Preston et al. (2002a) using a regression approach to investigate which species have changed in range size to the greatest extent, and to analyse the data with respect to potential factors correlated with overall change across the whole flora.

MATERIALS AND METHODS

Study Region

The study region encompasses the entire island of Ireland and plant data from the Republic and Northern Ireland are not treated separately. Much of the island is composed of agricultural land, with extensive upland heath and bog. The five commonest Corine land cover classes for the Republic in 2000 were pasture (51.4%), peat bog (16.1%), arable land (7.7%), agriculture with areas of natural vegetation (6.0%), and transitional woodland scrub (4.8%) and coniferous, broad-leaved, and mixed forest comprised 3.4%, 0.4% and 0.3%, respectively. The classes related to urbanisation, urban fabric (continuous and discontinuous), industrial and commercial, road and rail networks, sea ports, airports, mineral extraction sites, and construction, comprised 1.6% of the land cover in total (EPA, 2003).

Latest figures indicate forest covers 11% of the Republic (ITGA, 2012), 87% of which (9.6% by land cover) is comprised of plantations, the majority of which (9.2% by land cover) are dominated by conifers (MCPFE et al. 2007). The remainder of Ireland's forest cover is comprised semi-natural woodlands (Forest Service 2007). Native woodland, comprising semi-natural oak *Quercus* woodland often with birch *Betula* and holly *Ilex aquifolium*, covers only 1% of the Republic (Perrin and Daly, 2010; Perrin et al., 2008; Cross 2012). Areas of particular botanical interest include the rocky limestone grasslands of the Burren in Co Clare and the raised bogs concentrated in the midlands and west of the Republic. Ireland also has a number of rare or unique wetland habitats including turloughs, shingle beaches, coastal lagoons, maerl beds and machair (Otte, 2003).

Data Sources

Data recorded as pre-1970 in the New Atlas were used as the baseline for interpreting floristic change. These records were compiled largely from those collected in the survey period 1954-1960 for the original Atlas published by Perring and Walters (1962). These field records were supplemented by both historical and more recent records such as from county floras and natural history societies. As there were fewer botanists working on the field survey in Ireland during this period greater use was made of historical literature and herbarium records in compiling these data (Preston et al., 2002a).

Previous to the publication of the 1962 Atlas, plant distributions tended to be recorded at the scale of the Watsonian vice-county. The survey of the 1950s however was conducted at a scale of 10 x 10 km squares of the UK Ordnance Survey, an extension of the grid established by Webb (1955) to cover the UK. The 1954-1960 survey aimed to compile records and produce maps of the distributions of all vascular plant species present in the wild in Britain and Ireland. This included all native species and 'well established introductions'. In the analyses presented here, the recent data were taken from the 'New Atlas of the British and Irish Flora' (Preston et al., 2002a) based on records collected between the years 1987 and 1999 (although most of the fieldwork was done between 1996 and 1999). Over 1600 volunteer recorders carried out fieldwork while numerous other county recorders collated the records. The database was assembled at the Biological Records Centre at Monks Wood, England. Further details of the field methods and compilation of records may be found in Preston et al. (2002a).

Potential sources of bias that may arise while comparing the two data sets include the greater specific focus given to recording introduced and plantation species as well as hybrids and sub-species in the later survey. For this reason, a number of sub-species and hybrids were excluded from the analysis as the earlier records were seen to be incomplete (NB, see Preston et al. (2002b p. 36) for details of taxonomic coverage for a similar analysis for GB). Overall, these earlier records were based on far less thorough recording methods and were collected over a longer time-scale (i.e., from pre-1930 to 1970). They therefore probably do not provide such an accurate snapshot of the state of the flora as do the more recent records. Any such potential bias is taken into account in the regression approach used in this analysis (see below).

Other difficulties in interpretation relate to the fact that the extension of the British grid system to cover Ireland for the initial survey does not correspond to the current Irish grid. Data from the 1950s were converted to the new Irish grid in the 1970s, the system on which all subsequent recording has been based. This conversion was said to be good for one sixth of the 10 x 10km squares (hectads), acceptable for 2/3 and poor for one sixth (Rich et al., 2001). One result of this is that in some coastal regions, or hectads with little land, past records have been aggregated or shifted up or down a hectad on the distribution maps. However, as this analysis is concerned not with precise geographical locations but with overall distributions it is expected that this will not significantly affect the results.

One reason why Preston et al. (2002b) did not analyse the Irish data alongside that for the British were that the data sources were too varied with far more historical sources incorporated into the maps produced for Ireland. By analysing the data for Ireland independently however, and by looking for patterns of relative change in the flora, this difficulty may be largely overcome. Although the earlier records may be less than complete they still provide an important amalgamation of the historical records that are available on the status of the Irish flora in the years preceding 1970, thus provide an important baseline from which to measure changes in light of the more quantitative records that are available.

The species used in the analysis here were those that appear in the published *New Atlas* which is made up of all native and introduced species that are present in more than five hectads. This gave a total of 1511 species for Ireland, including 1035 natives, 327 neophytes, 122 archaeophytes, and 26 casuals. However, these figures should not be taken to represent the actual numbers of species present on the island as a substantial number of introductions and casual species have been excluded.

Data Analysis

Here, change in individual plant range extent is estimated in terms of a relative change in frequency between the two data sets using a regression approach (McCollin et al., 2000; Preston et al., 2002a; Telfer et al., 2002). Due to differences in recording effort and other perceived biases, two data sets from different time periods cannot normally be directly compared unless a correction factor is applied (e.g., Rich and Woodruff, 1996). Here, the standardised residuals from a linear regression are used to derive an Index of Change and allows for overall variation in recording effort (Preston et al., 2002a).

The data were analysed by directly comparing the number of hectads occupied by species in 2002 to the corresponding number in the 1970 Atlas. These data were log-transformed and entered into regression analysis and the standardised residuals were used as an Index of Change, those species above the line of best-fit being species being inferred to have increased and those below the line being inferred to have decreased. Each species has an

Index of Change relative to the whole flora and thereafter these are used as independent variables to investigate factors involved in change (after McCollin et al., 2000).

The influence of ecological and environmental factors were investigated using published indicator scores. Ellenberg scores calibrated for the UK were used for light (L), temperature (T), moisture (F), nitrogen (N), and soil reaction (R) (Ellenberg et al., 1991; Hill et al., 1999). Data relating to ecological characteristics such as seed weight and potential for lateral spread were taken from Grime et al. (1998) and Preston and Hill (1997). Commonest habitat type was defined by the major habitat given in Stace (2010) however in some cases the commonest terminal habitat defined by Grime et al. (1988) was used. Data relating to plant status as native or introduced (Neophyte or Archaeophyte) was taken directly from the *New Atlas* (Preston et al., 2002a) (Table 1).

The independent variables were also entered into a Principal Components Analysis (PCA) and the Index of Change was entered into Pearson's correlation analyses with the independent variable and the PC-scores. This was done using Pearson correlation and statistical significance recorded at the $p = 0.05$ level (2-tailed tests). ANOVA was used to test for differences in the Indexes of Change. All analyses were done using Minitab.

RESULTS

The relationship between the number of hectads in which plants were recorded pre-1970 and in 1987-1999 was very highly statistically significant ($r = 0.54$; $p << 0.001$, $n = 1510$). There was a highly significant statistical difference in the Change Index by status with Archaeophytes having decreased by the greatest extent ($F_{3, 1505} = 23.6$, $p << 0.001$)(Fig. 1). There was no significant difference in the Change Index for species categorised by the most common habitat types ($F_{13, 1495} = 0.86$, $p = 0.60$). A list of species and status of plants with the 100 highest and lowest Indexes of Change is presented in Appendix 1.

There was a very highly significant difference between the Change Indexes for the Major Biome categories with species belonging to the two broad categories, Wide-boreal and Wide-temperate, having significantly higher standardised residuals than the rest ($F_{8, 1215} = 9.96$; $p < 0.001$). The greatest decline was in the Boreal montane category.

The PCA generated three axes accounting for 64.6% of the variation (Table 1). Given the strength of the correlations with the original variables, these could be interpreted as a gradient relating increased canopy height to reduced floristic diversity (PC1), a gradient of increasing moisture with reduced acidity (PC2), and increased nutrient status and presence of seed bank with decreased lateral spread (PC3).

There were very highly statistically significant correlations of the Change Index for both Native species and Archaeophytes with Ellenberg's-N (Native: $r = 0.19$, $p < 0.001$ (Fig. 2); Archaeophytes: $r = 0.35$, $p < 0.001$) and Ellenberg's-F (Native: $r = 0.081$, $p < 0.05$; Archaeophytes: $r = 0.35$, $p < 0.001$). In addition, there were significant correlations for the Index of Change for Native species with Ellenberg's-L (negatively), Floristic Diversity (negatively), Canopy Height, Lateral Spread, and all three PCA axis scores (Table 2). The Change Index for Neophytes was correlated most strongly with Ellenberg's-R (negatively), but also with Ellenberg's-L (negatively) and Lateral Spread.

DISCUSSION

Due to the doubts expressed previously about the data available for Ireland, the species with the highest and lowest Change Indexes (and hence which are inferred to have increased or decreased the most, respectively) are listed in Appendix 1 and include many species which have been noted in similar analyses elsewhere. The lists of 100 species with the highest (the 'winners') and lowest (the 'losers') Change Indexes here coincide with 24 and 37 species cited in similar lists for England and Scotland (Rich and Woodruff, 1996) and for Britain (Preston et al., 2002b), respectively (Appendix 1). Assuming these coincidences add validity to the results here, what of the remaining species, do the changes in their frequencies represent reality or are they a result of sampling bias?

Of those species not noted in previous surveys, the list of 100 'losers' include *Melampyrum sylvaticum*, classified as globally endangered (IUCN, 2001) and nationally scarce in the UK, *Bromus commutatus*, an annual of unimproved damp meadows which has declined in the UK due to agricultural improvement (Preston et al., 2002a), *Matthiola sinuata*, a nationally scarce species in the UK and listed as Vulnerable (IUCN, 2001), as well as seven species listed in the Flora (Protection) Order 1999: *Saxifraga granulata*, lost from many localities in the UK due to habitat loss (Preston et al., 20002a), plus *Cephalanthera longifolia*, *Colchicum autumnale*, *Cryptogramma crispa*, *Hammarbya paludosa*, *Papaver hybridum*, *Pseudorchis albida*, Eighteen are listed as Critically Endangered, Endangered, or Vulnerable according to the list of endangered plants in Ireland (National Botanic Gardens, no date b).

The list of 'winners' include Daisy *Bellis perennis*, Ash *Fraxinus excelsior*, and Large-leaved Lime *Tilia platyphyllos* (Appendix 1). Either these species were under-recorded in previous surveys or greater vigilance was made to record these in later surveys. (NB. *T.*

platyphyllos is also in Preston et al.'s (2002b) list of 100 increasing species for mainland Britain.) With long-lived species such as trees increased vigilance is the obvious explanation. Accordingly, although recording bias may be present in these lists, it is suggested that such lists, if used judiciously, have the potential to highlight species of conservation concern.

Notwithstanding these concerns it is possible to interpret floristic change in terms of general trends of land use and management change. The most obvious of these relate to increased specialisation and intensification of agriculture which has been particularly marked in both Northern Ireland and the Republic since the 1970s driven by measures adopted under the European Common Agricultural Policy. Headage payments have led to dramatic increases in the densities of livestock in Ireland leading to concerns about the effects of over-grazing (DAHGI, 2002). As agriculture remains the main land use in terms of land area on the island of Ireland, these factors are all likely to have had significant effects on the island's flora.

Overall, there was little change in Native species and of Neophytes, but for Archaeophytes the mean Change Index indicates a decline (Fig. 1). Of the eight species in the list of Archaeophytes in the bottom 100 species (Appendix 1), all but two, *Fumaria densiflora* and *Papaver hybridum*, were not noted to have declined in previous surveys. (Similarly, of the 22 Neophytes in the list of 100 with the highest Index of Change, all but 10 have been cited as increasing in previous surveys (Appendix 1)). Most Archaeophytes are traditional arable weeds (Preston et al., 2002b, c), the decline of which had been noted in Ireland even before 1970 (Webb and Hodgson, 1968). The reasons for their decline are widely held to be associated with increased agricultural intensification, including fertiliser and herbicide use, as well as more effective seed cleaning techniques (Brady and Sheehy Skeffington, 1990;

Smart et al., 2003). This appears to be validated by the discovery of a number of arable weed species considered extinct in Ireland on the Aran Islands of the west coast of Galway (Curtis et al., 1988). Darnel *Lolium temulatum* and Cornflower *Centaurea cyanus* were found to persist as weeds of rye and oat crops on the islands. Darnel was also found to be thriving on thatched roofs made from locally harvested rye. As seed from these crops are collected and stored for use the following year, these plants are unlikely to be recent introductions to the islands, Rather, it is argued they survive due to traditional agricultural and cultural practices that persist in at least some areas of the Aran Islands. Historical records support the idea that these two species were once widespread and fully established throughout the Republic (Colgan and Scully, 1898; Praeger, 1901). It is thought that the system of small-scale crop rotation, the storage of seed over winter with minimal seed cleaning and little or no use of herbicides, provides a remnant of a habitat that was once common across Ireland. Other rare species noted as being established on the Aran Islands included Bristle oat *Avena strogosa* and Smooth brome *Bromus racemosus*, also both arable weeds.

One result that stands out in the analyses here is the significant correlation between the Change Index and Ellenberg's-N for Native species and Archaeophytes. Since Ellenberg's-N probably reflects the overall nutrient status of soil rather than just soil nitrogen (Hill and Carey, 1997), this relationship points to increased eutrophication of both the terrestrial and aquatic environment. Whilst it has long been acknowledged that eutrophication has been a factor involved in the degradation of the aquatic environment this has not been studied to the same depth in terrestrial environments (but see Keith et al., 2009). However, this trend has recently been detected for regional floras throughout northern Europe (e.g., Belgium: van der Veken et al., 2004; van Laduyt et al., 2008; northern France: van Calster et al., 2008, Northamptonshire, England: McCollin et al., 2000; UK: Preston et al., 2000a,b,c). Major factors accounting for this trend probably include the use of artificial fertilisers and other sources of nitrogen, phosphorus and ammonia from vehicle emissions and other agricultural sources (Stevens et al., 2010). For example, in Ireland overall nitrogen fertiliser consumption increased from 250,000 to 700,000 metric tonnes in the period 1970-1999 (DAHGI, 2002). Thus, it is posited that eutrophication of the environment has led to a shift towards vegetation of more nutrient-rich conditions.

The increase in more shade tolerant species indicated by the significant correlations of both Native species and Neophytes with Ellenberg's-L has similarly been reported in a number of studies (e.g., McCollin et al., 2000; Sutcliffe and Kay, 2000; Preston et al., 2002b,c,) though has not been reported for the island of Ireland. Rich et al. (2001) noted a decline in species of open grassland in the period 1960 – 1987/88, though this was not specifically related to the light demands of the species. In Britain, this trend was seen to be associated with the loss of grazed grassland in lowland southern England, the primary open habitats requiring full sun (Sutcliffe and Kay, 2000). In Ireland, while there has been a corresponding decline in the proportion of land used as permanent pasture, from 62% in 1970 to 48% in 1999, it remains a significant and widespread land use (DAHGI, 2002).

It might be assumed that the existence of grazed grassland would favour light-loving species that typically grow in open habitats. However, given the significant increase in nutrient availability and the frequent application of fertilisers and herbicides to pastoral land, it is likely that many smaller plants of open habitats are being lost in favour of more competitive species. As plants of open habitats also tend to be small and tolerant of nutrient-poor soils they would be negatively impacted by the use of herbicides that would lead to the production of dense, species-poor swards for grazing and for use as silage. This is supported by the correlation of the Change Index for Native species with PC1, a gradient relating canopy height to floristic diversity. I.e., the loss of Native species is associated with a change from low growth habitats with high floristic diversity to higher growth habitats with lower floristic diversity.

The destruction of Irish peat bogs has also been accelerated since the 1950s with the introduction of mechanised peat extraction. Although plants of wetland, bogs and mires did not show any relative declines, many of these species were under-recorded in the earlier survey (Preston et al., 2002a). For this reason the actual effects of drainage, over-grazing, and mechanised peat cutting on the flora of the bogs may be hidden. Peatlands once covered 17% of the land area of the Republic though less than a fifth of this now remains in a relatively untouched condition (Otte, 2003).

In the late 1980s, 30% of lowland bogs were found to be overgrazed, while almost 10% were found to be absolutely devoid of vegetation (Viney, 2003). The Irish Peatlands Council has also identified 50 sites of conservation importance that have been damaged by overgrazing (EPA, 2000). Again, sheep headage payments have contributed to over-stocking particularly in the west of the Ireland, though drainage and fertilisation for agricultural use have also led to the destruction of peatlands.

Plant species classed in the Wide-boreal and Wide-temperate biome categories appeared to have increased significantly compared to other groups. This finding is in contrast to the results in Britain where plants of Mediterranean and more southerly distributions were found to be increasing and species of arctic and boreal biomes were found to be decreasing (Preston et al., 2002 a,b,c). However, the Wide-temperate and Wide-boreal biome categories comprise the smallest groups of species in the Irish flora, representing only 33 and 15 species respectively, together accounting for only 3.1% of the flora. They tend to be fairly widely distributed across the island (e.g., *Poa annua*, *Potentilla sterilis* and *Taraxacum* agg) and may simply reflect increased observer effort to record common species.

The plants of the Wide-boreal elements are described as being ecologically heterogeneous, and a number such as *Equisetum arvense* and *Festuca rubra* can occur in a very wide range of habitats (Preston and Hill, 1997). Both of these species are also present almost throughout Ireland. However, although they are recorded in far fewer hectads in the original survey and therefore show a significant relative increase, both are accompanied by comments in the New Atlas suggesting that there has been no change in their overall distributions. This suggests that in relatively small groups of species such as these, a few cases of under-recording may have distorted the findings.

Despite this however, the species in these two major biome categories do have some characteristics that may have contributed to their relative success. In common with those of the Wide-boreal elements, species in the Wide-temperate elements tend to be common across Ireland, with many hectads containing at least 80% of its members (Preston and Hill, 1997). Similarly, they are described as species with 'broad ecological tolerances' and a number are common weeds, often occurring in disturbed habitats. It is possible that these species may enjoy a relative advantage over those with more specialised habitat requirements, particularly in the current context where changes in the cultural landscape have led to loss of many semi-natural and anthropogenic habitats. Aside from this however, there is little evidence to suggest the influence of climate change on floral composition in the island of Ireland.

CONCLUSIONS

Thompson and Jones (1999) suggested that in more sparsely populated countries such as Scotland or Ireland, the polarisation of the flora into 'winners' and 'losers' might be less apparent than in, say, England and western Europe generally. However, the results presented here suggest that some of the general trends found elsewhere are apparent in the island of Ireland, even allowing for potential biases in the database (see below). The decline of species typical of nutrient poor soils, taken together with land use changes, indicate a general trend towards intensification and specialisation.

As suspected by Preston et al. (2002a) it is likely that the data used in this analysis does include bias due to increased vigilance in more recent surveys combined with under-recording in earlier surveys. In terms of the approach used here, Botts et al. (2012) compared various methods to detect range size change (as applied to the South African Frog Atlas Project) and in comparison to observed data, they found that the correction factor method used by Rich and Woodruff (1996) was not only the most successful, but was considerably better than a regression-based approach used here. However, it should be noted that Rich and Woodruff's (1996) approach did not entirely control for bias since they went on to highlight species they considered might still be subject to potential bias, i.e., despite the method being supposed to correct for observer bias the authors still recognised that biases may still have been present. Here, there would have been little point in trying to compare results from the regression approach to the correction factor approach since both would have been subject to the same biases and there would be no independent data to verify the findings.

ACKNOWLEDGEMENTS

This paper uses data collected by hundreds of volunteers over many decades without which none of this would have been possible. Our thanks go to them all.

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Table 1. Explanation of ecological, habitat and dispersal variables used in analyses. Variables were taken from Preston and Hill (1997) and Grime et al. (1988).

Variable	Description	Categories
Ellenberg's - L	Light	scale from 1, species of deep shade, to 9, plants of full sun
Ellenberg's - T	Temperature	scale from 1, cold indicators found only in alpine zones, to 9, Mediterranean species
Ellenberg's - F	Soil moisture	arid land plants, 1, through to 9 (wetland plants) with categories 10 - 12 for water plants
Ellenberg's - N	Soil nitrogen	species with little requirement for soil nitrogen, 1, to 9, species with high requirements for soil nitrogen
Ellenberg's - R	Soil reaction	a gradient of soil acidity and lime content from 1, calcifuges, to 9 calcicoles
Floristic diversity	Mean no of species m^{-2}	1: $\leq$ 10 species; 2: 10.1-14.0 species; 3: 14.1-18.0 species; 4: 18.1-22.0 species; 5: > 22.0 species
Canopy height	Max height of canopy	1: foliage < 100 mm in height; 2: 101-299 mm; 3: 300-599 mm; 4: 600-999 mm; 5: 1.0-3.0 m; 6: 3.1-4.0 m; 7: 4.1-15.0m; 8: > 15.0 m
Lateral	Potential for lateral spread	1: therophytes (lateral spread exceedingly limited); 2: perennials with compact unbranched rhizomes or forming small tussocks; (diameter <100 mm); 3: perennials with rhizomes or tussocks (100-250 mm); 4: perennials (251-1000 mm); 5: perennials (>1000 mm)
Seedbank	Longevity of seed bank	1: most seed germinating shortly after being shed; 2: most seed persistent only until start of next growing season; 3: a small amount of seed persists in the soil but concentrations only high after seed shed; 4: large persistent seed bank throughout the year
Dispersule weight	Dry weight of seed, achene or other	1: too small to be measured easily; 2: $\leq$0.20 mg; 3: 0.21-0.50 mg; 4: 0.51-1.00 mg; 5: 1.01-2.00 mg; 6: 2.01-10.00 mg; 7: >10.00 mg

Table 1. PCA of independent variables. Factor loadings contributing most to each axis highlighted.

	PC1	PC2	PC3
Eigenvalue	2.83	1.65	1.34
% variance explained	31.4	18.3	14.9
Sum % variance	31.4	49.7	64.6
		Loadings	
Ellenberg-L	-0.37	-0.071	-0.13
Ellenberg-R	0.09	0.59	-0.34
Ellenberg-N	0.33	0.34	-0.51
Ellenberg-F	0.20	-0.47	-0.37
Floristic diversity	-0.43	0.33	0.12
Canopy height	0.45	0.093	-0.062
Lateral spread	0.38	-0.30	0.051
Seed bank	-0.30	-0.051	-0.50
Dispersule weight	0.30	0.33	0.45

Table 2. Correlations of Change Index for each of the three plant groups based on status against the independent variables. (Significance: *** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; all others not significant).

Variables	Native species	Neophytes	Archaeophytes
Ellenberg-L	-0.15***	-0.20**	-0.11
Ellenberg-R	-0.026	-0.034***	-0.14
Ellenberg-N	0.19***	0.098	0.35***
Ellenberg-F	0.081*	0.026	0.35***
Floristic diversity	-0.19***	-0.32	0.21
Canopy height	0.14*	-0.067	0.066
Lateral spread	0.21***	0.44*	0.003
Seed bank	0.03	-0.44	-0.20
Dispersule weight	0.049	-0.01	0.054
PC1	0.21***	0.13	-0.062
PC2	-0.16**	-0.096	-0.008
PC3	-0.14*	-0.14	-0.064

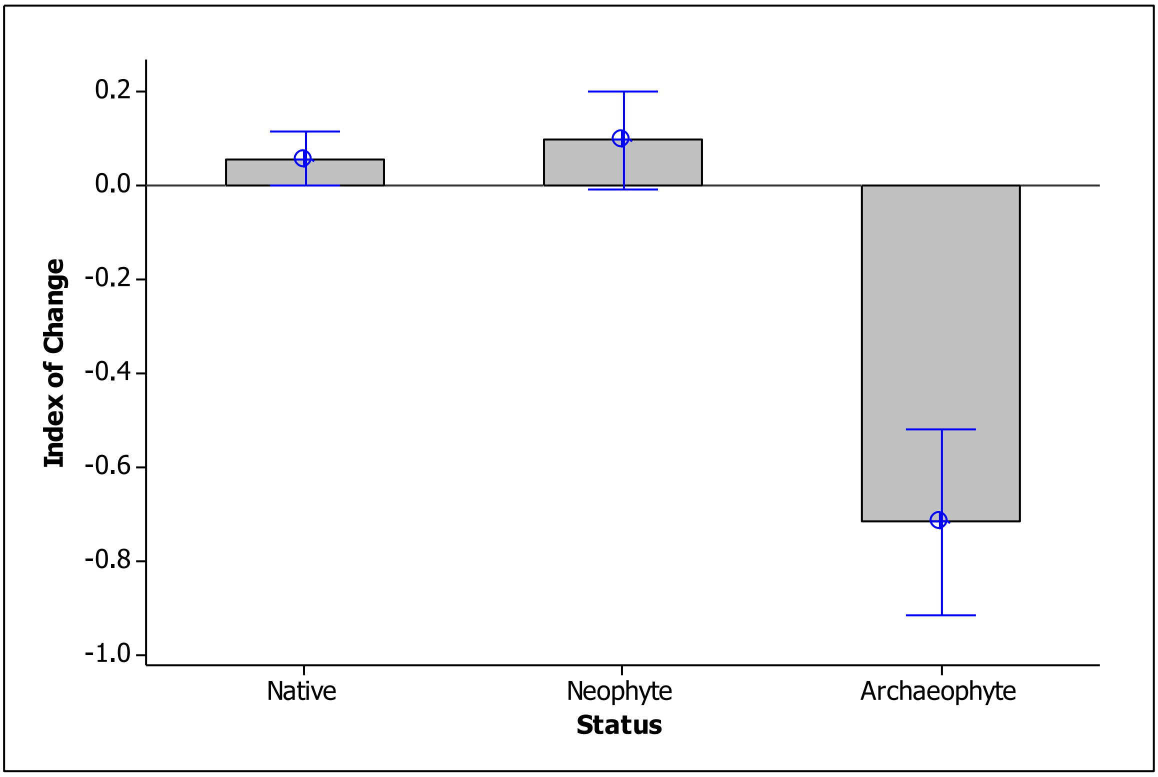

Fig. 1. Change Index by status (mean ± 95% confidence interval). Whilst Native species and Neophytes showed slight increases, Archaeophytes showed a large relative decrease.

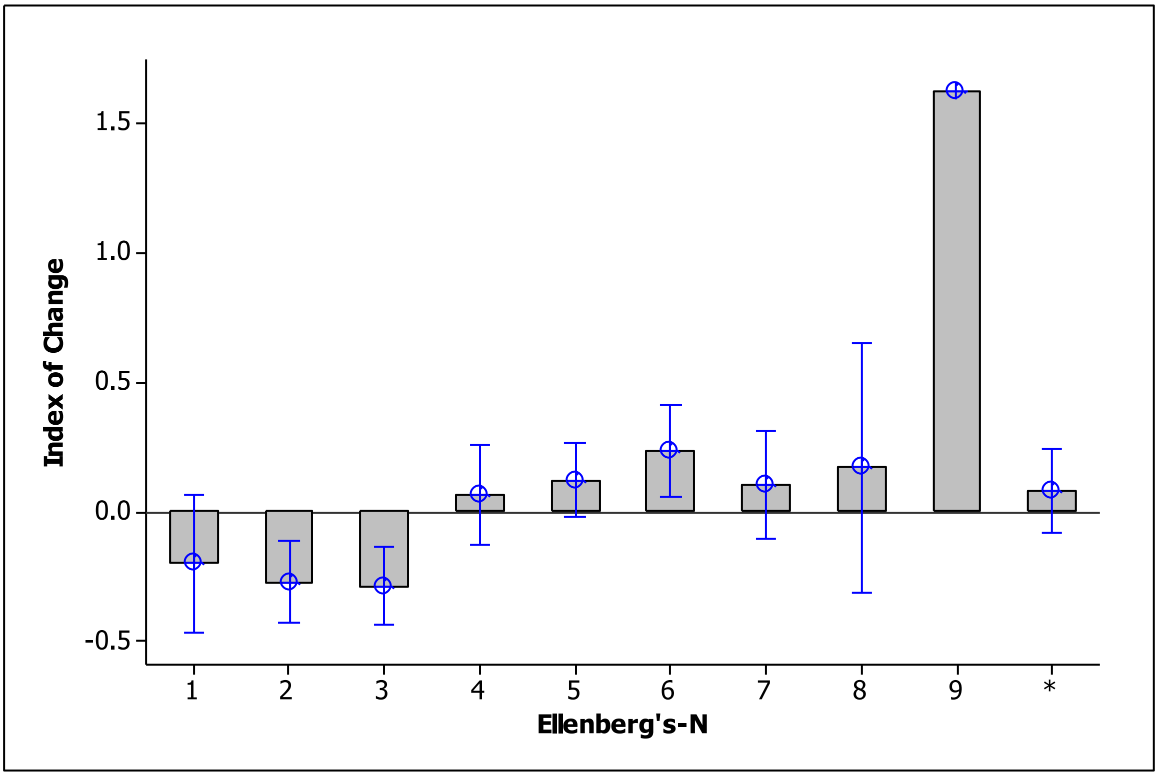

Figure 2. Change Index for Native species by Ellenberg-N (mean ± 95% confidence interval). There was a trend for species of nutrient-poor habitats to decline and species of nutrient-rich habitats to increase.

Appendix 1. List of 100 species with the a.) highest and b.) lowest Indexes of Change, respectively. Species also listed in a: Rich & Woodruff (1996) England; b: Rich & Woodruff (1996) Scotland; c: Preston et al. (2002b); d: a, b, c combined. FPO (1999) = Flora (Protection) Order, 1999 species; NBG b = endangered plants in Ireland (National Botanic Gardens, no date b): CE Critically Endangered, E Endangered, V Vulnerable.

a.)

Index	Species	Status	a	b	c	d
3.64	*Epibolium ciliatum*	Neophyte	1		1	1
3.24	*Lonicera nitida*	Neophyte	1			1
3.18	*Sorbus aucuparia*	Native				
3.14	*Picea sitchensis*	Neophyte				
2.71	*Triplospermum inodorum*	Archaeophyte				
2.66	*Pinus contorta*	Neophyte				
2.54	*Crataegus monogyna*	Native				
2.51	*Agrostis vinealis*	Native				
2.44	*Agrostis canina*	Native				
2.43	*Chamerion angustifolium*	Native				
2.40	*Plantago lanceolata*	Native				
2.34	*Dactylis glomerata*	Native				
2.31	*Veronica chamaedrys*	Native				
2.31	*Hyacinthoides hispanica*	Neophyte	1	1		1
2.31	*Geranium robertianum*	Native				
2.30	*Ribes sanguineum*	Neophyte	1	1		1
2.30	*Urtica dioica*	Native				
2.29	*Bellis perennis*	Native				
2.29	*Potentilla anserina*	Native				
2.28	*Filipendula ulmaria*	Native				
2.26	*Spartina anglica*	Native				
2.23	*Poa humilis*	Native				
2.20	*Ranunculus repens*	Native				
2.18	*Triplospermum maritimum*	Native				
2.14	*Rubus fruticosus* agg	Native				
2.12	*Potamogeton natans*	Native				
2.11	*Plantago major*	Native				
2.07	*Trifolium repens*	Native				
2.07	*Rorippa islandica*	Native				
2.07	*Trifolium pratense*	Native				
2.05	*Solanum tuberosum*	Neophyte				
2.03	*Spiraea salicifolia*	Neophyte				
2.03	*Holcus lanatus*	Native				
2.03	*Ribes rubrum*	Native	1	1		1
1.98	*Cirsium palustre*	Native				
1.97	*Gentiana verna*	Native				
1.96	*Juncus effusus*	Native		1		1
1.95	*Acer pseudoplatanus*	Neophyte	1			1
1.95	*Hedera helix*	Native				
1.92	*Fraxinus exelsior*	Native				
1.91	*Angelica sylvestris*	Native				
1.91	*Pteridium aquilinum*	Native				
1.90	*Ulex europaeus*	Native				
1.89	*Chamaecyparis lawsoniana*	Neophyte				

1.87	*Beta vulgaris maritima*	Native				
1.86	*Potentilla erecta*	Native				
1.85	*Ulmus minor*	Native				
1.85	*Phyllitis scolopendrium*	Native				
1.85	*Anthoxanthum odoratum*	Native		1		1
1.82	*Centaurea nigra*	Native				
1.82	*Agrostis stolonifera*	Native			1	1
1.82	*Taraxacum* agg.	Native				
1.81	*Galium aparine*	Native				
1.80	*Poa annua*	Native				
1.80	*Senecio jacobaea*	Native	1			1
1.77	*Leycesteria formosa*	Neophyte	1	1		1
1.76	*Ranunculus acris*	Native				
1.75	*Atriplex laciniata*	Native				
1.75	*Viola riviniana*	Native				
1.74	*Cirsium vulgare*	Native				
1.71	*Avena fatua*	Archaeophyte	1	1		1
1.71	*Lotus corniculatis*	Native				
1.70	*Festuca rubra* sens. lat.	Native	1	1	1	1
1.70	*Cirsium arvense*	Native				
1.69	*Prunus laurocerasus*	Neophyte			1	1
1.68	*Maticaria discoidea*	Neophyte	1			1
1.67	*Prunella vulgaris*	Native				
1.67	*Cotoneaster horizontalis*	Neophyte				
1.67	*Cardamine pratensis*	Native				
1.66	*Cerastium fontanum*	Native				
1.66	*Hypochaeris radicata*	Native				
1.64	*Festuca filiformis*	Native				
1.64	*Buddleja davidii*	Neophyte	1	1	1	1
1.64	*Galanthus nivalis*	Neophyte	1		1	1
1.64	*Larix kaemoferi*	Neophyte				
1.63	*Rosa micrantha*	Native				
1.62	*Rumex obtusifolius*	Native	1			1
1.62	*Potamogeton polygonifolius*	Native				
1.62	*Lunaria annua*	Neophyte				
1.61	*Daboecia cantabrica*	Native				
1.60	*Rubus spectabalis*	Neophyte				
1.60	*Eriophorum gracile*	Native				
1.60	*Leucojum aestivum*	Native			1	1
1.59	*Lolium perenne*	Native				
1.59	*Iris pseudocorus*	Native				
1.57	*Mentha aquatica*	Native				
1.57	*Vicia sepium*	Native				
1.56	*Galium palustre*	Native				
1.55	*Juniperus communis nana*	Native				
1.54	*Ranunculus flammula*	Native				
1.53	*Rumex acetosa*	Native				
1.52	*Achillea millefolium*	Native				
1.52	*Alnus glutinosa*	Native				
1.51	*Soleirolia soleirolii*	Neophyte	1		1	1
1.50	*Symphoricarpos albus*	Neophyte	1		1	1
1.49	*Dryopteris dilatata*	Native	1			1

1.49	*Ilex aquifolium*	Native				
1.47	*Oxalis stricta*	Neophyte				
1.47	*Festuca rubra juncea*	Native	1	1	1	1
1.47	*Tilia platyphyllos*	Native			1	1
		Totals	15	8	11	24

b.)

Index	Species	Status	a	b	c	d	FPO (1999)	NBG b
-3.43	*Scandix pecten-veneris*	Archaeophyte	1		1	2		
-3.28	*Marrubium vulgare*	Native	1		1	2		
-3.02	*Lepidium perfoliatum*	Neophyte						
-2.96	*Gymnocarpium dryopteris*	Native	1			1		E
-2.89	*Gnaphalium sylvaticum*	Native	1	1	1	3		V
-2.86	*Matthiola sinuata*	Native						
-2.81	*Saxifraga granulata*	Native					1	CE
-2.75	*Bromus commutatus*	Native						
-2.72	*Mentha pulegium*	Native	1			1	1	E
-2.69	*Scleranthus annuus*	Native	1		1	2	1	
-2.61	*Papaver hybridum*	Archaeophyte					1	CE
-2.55	*Acorus calamus*	Neophyte						
-2.48	*Valerianella rimosa*	Archaeophyte			1	1		
-2.48	*Althaea officinalis*	Native						
-2.47	*Alyssum alyssoides*	Neophyte			1	1		
-2.36	*Erophila majuscula*	Native						
-2.34	*Bromus lepidus*	Neophyte	1	1	1	3		
-2.31	*Filago vulgaris*	Native	1		1	2		
-2.27	*Asplenium onopteris*	Native						
-2.27	*Anaphalis margaritacea*	Neophyte						
-2.26	*Botrychium lunaria*	Native						
-2.24	*Cynosurus echinatus*	Neophyte			1	1		
-2.24	*Leonurus cardiaca*	Neophyte			1	1		
-2.19	*Salicornia euopaea*	Native						
-2.18	*Lycopodium clavatum*	Native	1			1		
-2.17	*Subularia aquatica*	Native	1	1		2		
-2.17	*Fumaria densiflora*	Archaeophyte						
-2.16	*Minuartia hybrida*	Native			1	1		
-2.15	*Melampyrum sylvaticum*	Native						E
-2.10	*Geranium sylvaticum*	Native						E
-2.10	*Rumex pulcher*	Native						
-2.10	*Bunias orientalis*	Neophyte						
-2.10	*Bupleurum subovatum*	Neophyte						
-2.09	*Sagina erecta*	Native						
-2.08	*Ranunculus parviflorus*	Native	1			1		
-2.08	*Dryopteris oreades*	Native						
-2.08	*Lactuca virosa*	Native						
-2.08	*Lathyrus aphaca*	Native	1		1	2		
-2.08	*Stellaria neglecta*	Native						
-2.08	*Thymus pulegioides*	Native						
-1.99	*Pastinaca sativa*	Native						
-1.99	*Campanula rapunculoides*	Neophyte			1	1		
-1.94	*Lolium temulentum*	Archaeophyte	1		1	2		E

-1.94	*Viola lutea*	Native							
-1.92	*Cephalanthera longifolia*	Native					1	E	
-1.91	*Agrostemma githago*	Archaeophyte	1			1			
-1.91	*Narcissus pseudonarcissus*	Neophyte							
-1.91	*Berteroa incana*	Neophyte							
-1.91	*Coriandrum sativum*	Neophyte	1			1			
-1.91	*Dianthus plumaris*	Neophyte							
-1.89	*Torilis nodosa*	Native	1			1			
-1.84	*Chaerophyllum temulum*	Native							
-1.84	*Cynoglossum officinale*	Native	1			1			
-1.81	*Spiranthes spiralis*	Native	1			1			
-1.81	*Pseudorchis albida*	Native					1	E	
-1.80	*Festuca arenaria*	Native							
-1.80	*Hornungia petraea*	Native							
-1.80	*Iberis amara*	Native			1	1			
-1.80	*Lotus glaber*	Native							
-1.80	*Scabiosa columbaria*	Native							
-1.80	*Silaum silaus*	Native							
-1.80	*Colchicum autumnale*	Native					1	CE	
-1.79	*Lithospermum arvense*	Archaeophyte	1	1	1	3			
-1.78	*Lithospermum officinale*	Native		1					
-1.77	*Salicornia fragilis*	Native							
-1.77	*Sempervivum tectorum*	Neophyte	1			1			
-1.76	*Reseda lutea*	Native							
-1.75	*Saxifraga rosacea rosacea*	Native							
-1.74	*Wahlenbergia hederacea*	Native	1			1			
-1.74	*Rhynchospora fusca*	Native							
-1.73	*Salicornia dolichostachya*	Native							
-1.71	*Pyrola minor*	Native							
-1.71	*Pyrola media*	Native			1	1		V	
-1.71	*Tragopogon porrifolius*	Neophyte							
-1.68	*Sisymbrium irio*	Neophyte							
-1.67	*Clinopodium vulgare*	Native							
-1.64	*Aruncus dioicus*	Neophyte							
-1.64	*Lonicera caprifolium*	Neophyte							
-1.64	*Malva parviflora*	Neophyte							
-1.64	*Oenothera stricta*	Neophyte							
-1.64	*Potentilla erecta*	Neophyte	1			1			
-1.64	*Symphytum grandiflorum*	Neophyte							
-1.64	*Vicia villosa*	Neophyte							
-1.64	*Sparganium natans*	Native							
-1.63	*Anagallis minima*	Native	1		1	2			
-1.63	*Anthriscus caucalis*	Native							
-1.62	*Bromus racemosus*	Native						V	
-1.60	*Cryptogramma crispa*	Native					1	V	
-1.60	*Agrimonia procera*	Native	1			1			
-1.59	*Saxifraga hirculus*	Native						CE	
-1.55	*Lycopodiella inundata*	Native		1		1	1	V	
-1.54	*Datura stramonium*	Neophyte							
-1.54	*Lathyrus hirsutus*	Neophyte							

-1.54	*Potentilla norvegica*	Neophyte			1	1		
-1.53	*Mentha suaveolens*	Native	1			1		
-1.53	*Nepeta cataria*	Archaeophyte			1	1		
-1.52	*Hammarbya paludosa*	Native					1	E
-1.51	*Stachys officinalis*	Native	1			1	1	E
-1.48	*Isoetes echinospora*	Native						
-1.48	*Plantago media*	Native						
		Totals	26	6	20	37		