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Development of a scoring method to identify important areas of plant diversity in Ireland

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Abstract

In the face of accelerating biodiversity loss it is more important than ever to identify important areas of biodiversity and target limited resources for conservation. We developed a method to identify areas of important plant diversity using known species' distributions and evaluations of the species importance. We collated distribution records of vascular plants and developed a scoring method of spatial prioritisation to assign conservation value to the island of Ireland at the hectad scale (10km × 10km) and at the tetrad scale (2km × 2km) for two counties where sufficient data were available. Each plant species was assigned a species conservation value based on both its conservation status and distribution in Ireland. For each cell, the species conservation values within the cell were summed, thereby differentiating between areas of high and low conservation value across the landscape. Areas with high conservation value represent the most important areas for plant conservation.

The protected area cover and the number of species present in these important areas were also examined by first defining threshold values using two different criteria. Species representation was high in the important areas; the identified important areas of plant diversity maintained high representation of species of conservation concern and achieved high species representation overall, requiring a low number of sites (<8%) to do so. The coincidence of protected areas and important areas for plant diversity was found to be low and while some important areas of plant diversity might benefit from the general protection afforded by these areas, our research highlights the need for conservation outside of protected areas.

Keywords

plant distribution, plant diversity, conservation priorities, protected areas.

Introduction

A critical global loss of biodiversity has occurred in recent history and is accelerating (Johnson et al., 2017). Recent assessments in Ireland have found that many important habitats have unfavourable conservation status (NPWS 2013) and Ireland has committed to the protection of biodiversity in line with international agreements (CBD 2010; European Commission 2011) which are reflected in national biodiversity strategies and policy (DCHG 2017; DAERA 2017). A variety of pressures on biodiversity have been identified including land drainage and burning, pollution, invasive species, nutrient enrichment, over- and under-grazing, land-abandonment, excessive grazing by wild deer, rural development, urbanisation, and afforestation (DAHG 2014; JNCC 2014). Information on the location of important areas of biodiversity is necessary to apply practical solutions (Kukkala & Moilanen, 2013) such as improved spatial planning, control of the introduction and spread of invasive alien species, maintenance of water and air quality, and the conservation of protected areas (JNCC 2014). However, the implementation of solutions first requires knowledge of where conservation actions should be applied. Since resources available for such actions are often limited there is a need to devise methods for the identification of the most important areas so that limited resources can be targeted effectively (Margules & Pressey, 2000; Rodrigues et al., 2000).

The identification of important areas for conservation must be based on the value of their biodiversity (Abellán et al., 2005) and so identification methods often rely on the spatial distribution of relevant components of biodiversity such as species distribution and habitat condition, or threats (Moilanen et al., 2009). Various methods have been employed to select important areas of biodiversity. One class of methods uses the experience of relevant experts to identify areas for conservation; although these are often subject to the biases associated with experts' uneven knowledge and personal experience (Cowling et al., 2003). Criteria-based identification methods apply threshold requirements (such as the number of species present) and have been applied to globally important sites such as Important Bird Areas (IBA) (Brown et al., 1995), Important Plant Areas (IPA) (Plantlife 2016), Key Biodiversity Areas (KBA) (Eken et al., 2004), and biodiversity hotspots (Myers et al., 2000).

To date, in Ireland, just four sites have been identified as IPAs in Northern Ireland (Plantlife 2016). Using these international criteria results in a very limited selection of important sites for plant diversity in Ireland. The internationally-agreed selection criteria in the IPA identification process includes the presence of significant populations of threatened wild plants, threatened habitats, and a high diversity of wild plants (e.g. Plantlife 2016). That so few sites met the criteria for IPAs in Northern Ireland may indicate that, in the context of Ireland, the criteria for IPA selection are too strict for selection of sites at the sub-national level, especially when Ireland has few endemic (Rich et al., 2008) or globally threatened vascular plant species. While this methodology is reasonable at a European scale, it doesn't help Irish institutions to identify priority sites for plant conservation. Many methods to identify important areas for conservation are intended to identify areas that meet strict requirements (Williams et al., 2004) or attain near-optimal solutions for conservation targets (Watts et al., 2009). Such approaches can be useful, but they have also been criticised. In reserve selection, for example, they do not provide information on the conservation value of land beyond the identified areas, and fail to recognise that non-reserve areas also contribute to the biodiversity of a landscape (Edwards et al., 2010; Willis et al., 2012).

An alternative 'scoring method' (Ferrier & Wintle 2009) can be used to assign value to sites based on a set of user-assigned criteria and values, thereby providing information on the conservation value of all sites. If necessary, sites can later be separated into classes of conservation importance (Burgess et al., 2006; Türe & Böcuk 2010) or ranked in order of conservation value and the highest ranking sites selected as the most important (Abellán et al., 2005; Blasi et al., 2011). The set of highest ranking sites can also be assessed for representation (the extent to which natural features, such as species, occur within a set of sites (Cabeza & Moilanen, 2001)), an important aspect of spatial conservation planning (Albuquerque et al., 2013; Armenteras et al., 2003; Pliscoff & Fuentes-Castillo 2011; Rodrigues et al., 2004). A key requirement of the selection of priority areas for biodiversity conservation is that they should be representative of the biodiversity of the region in which they are located (Margules et al., 2002). In addition to considering species representation, the effectiveness of protected areas in providing protection to important sites is one aspect of protected area performance (Geldmann et al., 2015). A key requirement of the selection of priority areas for biodiversity conservation is that they should be representative of the biodiversity of the region in which they are located (Margules et al., 2002). In addition to considering species representation, the effectiveness of protected areas in providing protection to important sites is one aspect of protected area performance (Geldmann et al., 2015). A recent examination of the protected area cover of locations containing important plant species in Ireland showed that many locations do not coincide with protected areas (Walsh et al., 2015). Knowledge of the level of coincidence of protected area cover with important areas of plant diversity is essential to inform whether and where conservation priorities occur outside of protected areas. In this study, we investigate an alternative method to IPAs for identification of priority conservation areas. Here, we develop and implement a measure of species representation and conservation status of species to identify important areas of plant diversity.

The objectives of this study were to:

1. Develop a scoring method that used the cumulative conservation values of species recorded within a grid cell to assign a cell conservation value.
2. Apply the scoring method to study areas comprising the island of Ireland (hectad scale) and Counties Fermanagh and Waterford (tetrad scale).
3. Compare two methods to define a threshold level of cell conservation value, and use the threshold values to prioritise candidate cells that comprise important areas of plant diversity.
4. Assess the degree of representation of species achieved by the two methods and compare to the minimum number of sites required for full species representation, identified using linear programming.
5. Examine the degree of overlap between protected areas and the candidate cells that comprised important areas of plant diversity.

This study was not intended to provide a definitive mapping of important areas of plant diversity but instead consists of an exploratory exercise with preliminary results based on available data. We discuss the implications of the important areas of plant diversity within the context of plant conservation in Ireland.

Material and methods

The island of Ireland is located to the west of the European mainland and has a temperate, oceanic climate. The island is divided into two political entities; the Republic of Ireland and Northern Ireland. Fermanagh is the westernmost county of Northern Ireland and Waterford lies on the southern coast of the Republic of Ireland (Figure 1).

Hectad-scale distribution records of vascular plant species were provided by the Botanical Society of Britain and Ireland (BSBI) the Northern Ireland Environment Agency (Hunter & Wright 2011) and the National Parks and Wildlife Service of Ireland (NPWS 2012). The distribution data for these species categories covered 997 of the 1014 (98%) hectads in the island of Ireland. Records from 1987 onwards were considered for both the hectad- and tetrad-scale analysis as this date coincides with a major survey by the BSBI. Two counties in Ireland, Fermanagh and Waterford, have finer-scale plant records (2km × 2km). Although likely to share some plant records the tetrad-scale records were not derived from the hectad-scale data and should therefore be considered to be separate datasets. The distribution data covered 526 of the 541 tetrads (97%) in County Fermanagh, and 544 of the 551 tetrads (99%) in County Waterford. Data were analysed for all of Ireland (hectad scale) and separately for both Counties Waterford and Fermanagh (both at tetrad scale).

A scoring method for the identification of important areas of plant diversity

The goal of our research was to develop an objective scoring method to identify important areas of plant diversity in Ireland. We identified these through comparison of assigned conservation values of grid cells that were derived from the summed Species Conservation Values of plant species recorded from a cell (see Table A1 for glossary and Figure A1 for a schematic of the workflow). The Species Conservation Value for each species was calculated as the product of a Species Conservation Weight and a Species Distribution Value. The calculation of these values is explained further in the following sections.

Species Conservation Weight

All plant species were assigned to one of four categories that reflected their relative conservation importance, in decreasing order of priority; (1) Species of conservation concern (SCC), (2) Annex I habitat indicator species (Annex 1), (3) Semi-natural habitat indicator species (Semi-natural), and (4) native species (native). These categories reflect national lists of species conservation status (as previously determined and agreed by relevant experts) (see Supplementary Information for further details). Each species was assigned to one exclusive category, and the numbers of species in each category are shown in Table 1. Each species was assigned a numerical value defined as the Species Conservation Weight that reflects the relative conservation importance of the species. The scoring method used species weights of SCC = 1000, Annex I = 100, Semi-natural = 10, native = 1 (Table A2) to increase the influence of the SCC group on cell values. The representation of the SCC group was found to be too low with other values (e.g. SCC = 4, Annex I = 3, Semi-natural = 2, and native = 1; from Walsh, 2016).

Plant species distribution value

The second component of the Species Conservation Value is the Species Distribution Value. This was calculated for each species by examining their distribution at the hectad scale for the island of Ireland (from records from 1987 to 2014). A percentage value for each species was calculated by dividing the number of hectads in which species occurred in by the total number of hectads that contained plant species records (n = 997). This percentage value was used to assign each species to one of six categories of distribution (Table 2). Species with a more limited distribution are more vulnerable than those with a widespread distribution and were assigned a higher ordinal value. Although the hectad-scale data appear to show complete coverage across Ireland, in reality the scale of the data masks the underlying patchiness of the distribution records, as has been identified at the tetrad scale in Ireland (Walsh et al., 2015). For this reason, indicative broad categories of species distribution were used within the scoring method rather than relying on actual percentage values.

Assigning cell conservation values

Each Cell Conservation Value was calculated as the sum of the Species Conservation Values for each of the plant species that were recorded in the cell. Each species contributed a single Species Conservation Value to the Cell Conservation Value regardless of the number of times that species occurred in the cell, or any measure of its abundance. Cell Conservation Values were assigned to each grid cell both for hectad-scale data for the island of Ireland and for tetrad-scale data in Counties Waterford and Fermanagh. The Species of Conservation Concern category contains different species in the Republic of Ireland and Northern Ireland and cell conservation values were calculated separately for each of these areas. The two areas were later combined and the highest value for overlapping cells was retained.

The primary output of the scoring method was a cell conservation value for grid cells across Ireland, Fermanagh, and Waterford. The number of species in each cell will vary between study areas and scales; therefore the numerical conservation values will only reflect the relative conservation value within and not between study areas (Table 3). The cell values in each area were therefore rescaled to a common 0 to 1 range and mapped for each area using a stretched colour symbology to display the spatial range of conservation value. This allowed a visual comparison of conservation values between scales and study areas (Figures 1 - 3).

Selection of sets of cells that comprise important areas of plant diversity

The scoring method assigns cell conservation values, and cells with high values are interpreted as representing the most important areas for plant diversity. However, the definition of a minimum set of grid cells that comprise important areas of plant diversity is not possible until a threshold value is used to differentiate between cells that exceed some threshold value and cells that do not. We compared two approaches to define such a threshold. The first selected the highest ranking 17% of cells, reflecting the Aichi targets of the Convention on Biological Diversity for 17% of important biodiversity areas to be under protection (CBD 2017).

The second approach selected a minimum number of cells in which all (or a high proportion of) species are represented. In the second approach, cells were ranked in order of decreasing cell conservation value and the number of species present was plotted against number of cells until all of the Species of Conservation Concern were represented. Segmented regression (Toms & Esperance 2003) was used to locate critical thresholds ('breakpoints') in the resulting species accumulation curve. The second breakpoint marking the transition from moderate to low inclusion of species was chosen as the defining line for a set number of high value cells. This provided an objective method to identify a threshold, and thus identify a set of cells in which species representation was optimised. Segmented regression was conducted using R statistical software (Version 3.2.3.) and the package 'segmented' (Version 0.5 – 1.4).

Optimal selection of sites based on species representation

The focus of the scoring method is to assign conservation value to the landscape and not guarantee high species representation per se. Linear Programming is a mathematical optimisation method from operations research (Williams et al., 2004) that has been used to first select a minimum number of sites in which full species representation is guaranteed. Here this method is used to select sets of cells that act as a baseline to compare the efficiency of the scoring method in achieving species representation. The method was then used to select the set of cells with the highest sum of conservation values that still met the species representation criteria (for more details see the appendices). The linear programming approach requires a catalogue of species (or at least a decent approximation of one) across all areas. While the recording effort was consistent across Fermanagh and Waterford, the same cannot be said for the hectad-scale records. The linear programming approach was therefore limited to the tetrad-scale for Fermanagh and Waterford. The linear programs were solved using R statistical software (Version 3.2.3.) and the package 'lpSolve' (Version 5.6.13).

Coincidence of protected area cover and important areas of plant diversity

The resolution of the areas of important plant diversity is at the same scale as the species distribution data used in the scoring method. For this reason, it is difficult to determine whether areas of important plant diversity at the hectad or tetrad scale coincide precisely with protected areas. To address this problem, we calculated the percentage of protected area cover for each cell in the set of cells that exceeded the threshold number of cells. We generated a shapefile of protected areas by merging individual shapefiles for Natural Heritage Areas in the Republic of Ireland, Areas of Special Scientific Interest in Northern Ireland, as well as both Special Areas of Conservation and Special Protection Areas across both areas (Figure A2). For each study area, we generated a histogram that plotted the number of cells that exceeded the thresholds against percentage cover by protected areas. The histograms profile the distribution of the percentage of protected area cover in the cells of each study area.

Results

Cell conservation values

A total of 997 of 1014 cells contained plant species at the hectad scale. Cell conservation values were calculated using 1019 species including 118 species of conservation concern. In Fermanagh, 526 of 541 cells contained 646 plant species at the tetrad scale including 44 species of conservation concern. In Waterford, 544 of 551 cells contained 707 plant species at the tetrad scale including 17 species of conservation concern. Cell conservation values varied across both counties but there were distinct areas of higher values across each of the study areas (Figures 1 - 3). The spatial distribution of cell conservation values broadly matched the spatial distribution of species-rich cells (Figures A3 – A5); although not all species-rich cells corresponded to cells with high conservation value.

The availability of comprehensive data coverage at the tetrad scale for counties Fermanagh and Waterford allowed a comparison of conservation values between the hectad and tetrad scales (Figures 2 & 3). These maps contrast the values at a given location and, as expected, show how information can be masked by coarse-scale data. High-value hectads tended to reflect areas with high-value tetrads, however this was not always the case and in some instances low to medium value hectads contained isolated high value tetrads that were only visible at the tetrad scale.

Selection of sets of important areas of plant diversity, and assessment of representation

The number of species present in the highest scoring cells was plotted against the number of high value cells until all Species of Conservation Concern were represented (Figure 4). These plots showed an initial large increase in the numbers of species present followed by a moderate uptake before levelling out with only slight increase in species presence with the inclusion of additional cells. At the hectad scale for Ireland, 95% of all species and 86% of SCC were represented by the second breakpoint in the segmented regression, corresponding to 6.17% of cells (n = 62) (Figure 4). At the tetrad scale in Fermanagh and Waterford (Figure 4) 88% (7.88% of cells, n = 42) and 87% (7.64% of cells, n = 42) of species were represented at the second breakpoint, respectively (Figure 4). Across the three study areas, the levels of representation of Species of Conservation Concern and all species were >=86% in the sets of cells selected using the 17% Aichi biodiversity target; representation of all species was >93%, and representation of Species of Conservation Concern ranged from 86-96% (Table 4).

Linear programming results

A linear programming approach to the selection of sets of cells was used to provide a comparison of the efficiency of the scoring method in including species within high conservation value areas. Cell conservation value was not considered at first within the programming approach. Instead the goal was to identify the minimum number of cells in which all species were present. These were 71 (13.5%) and 66 (12.13%) of cells for Fermanagh and Waterford respectively. There can be more than one solution to the linear programming problem and second set of linear programs was then run to identify which solution had the highest sum of cell conservation values.

Important areas of plant diversity

Important areas of plant diversity can now be defined as sets of cells from either 17% (from Aichi targets) or the second breakpoint value. This provides an objective basis for defining a threshold, above which the sets of highest-ranking cells comprise important areas of plant diversity.

Protected area cover of important areas of plant diversity

Overall, the protected area cover in the sets of important areas of plant diversity was low (Figure 5), and was similar to the protected area cover for all hectads in Ireland and tetrads in Fermanagh and Waterford (Figures A6 – A8) In all six comparisons, the highest incidence of tetrads was in the lowest category (0-10% protected area cover). Hectads tended to have a lower level of protected area cover due to their relatively large size. At the tetrad scale, the set of cells with the highest 17% of cell conservation values had low protected area cover. In Fermanagh, 42% of those cells had less than 20% cover, and 76% had less than 50% cover, leaving 24% of cells with greater than 50% cover by protected areas. In Waterford, 68% of cells had less that 20% cover, 90% had less than 50% cover, and 10% of cells had greater than 50% cover by protected areas. The level of protected area cover for sets of cells defined by the segmented regression breakpoints was greater, especially for Fermanagh, but the values were relatively low (Figure 5).

Discussion

We assigned cell conservation values to cells at two different scales in Ireland to develop a method of classification of areas in terms of importance for plant diversity. Hectad-scale cells with high conservation value tended to reflect areas containing tetrad cells with high values, although this was not always the case and at times the hectad values masked tetrads with high values. A high proportion of species were represented within these areas. The important areas of plant diversity showed some agreement with proposed local important plant areas and had low cover by protected areas.

Limitations of the scoring method

The quality of the method's output is dependent on the quality of the species distribution data. The collection of distribution data can be biased towards easily accessible areas and towards protected areas (Reddy & Davalos 2003) and can vary in the method used for sampling and in sampling effort (Anderson 2003). Collection of data can be overly focused on charismatic species (Possingham et al., 2000) to the detriment of species of less charismatic species of conservation concern (Boakes et al., 2010). The important areas of diversity identified in this research were based on vascular plant species only and therefore areas that are important to other taxa may not have been identified (Burgess et al., 2006). Other factors could be considered when identifying important areas of diversity, such as endemism, rarity, and habitat conservation value (Bou Dagher-Kharrat et al., 2018; Teillard et al., 2016), threats to species (Visconti et al., 2010), population dynamics and persistence of biodiversity (Cabeza & Moilanen 2001). The values assigned to species within scoring methods of identifying important areas of biodiversity can vary, for example Blasi et al. consulted a panel of national experts to grade species from low to high conservation value (Blasi et al., 2011) while Burgess et al. chose to assign higher weight to measures of species endemism than to species richness or non-species values (for example ecological or evolutionary phenomena, and important ecological processes) (Burgess et al., 2006). Species richness alone does not necessarily reflect importance or conservation value of an area and in our scoring method we included additional factors, such as the current conservation status of species. The plant distribution data were collected over a variety of time periods stretching back to 1987, a date coinciding with a major collection of plant data. This time period of data collection was selected to provide good data coverage across Ireland, however not all of these records could be considered to be recent data and are likely to contain both omission errors (where species are mistakenly thought to be absent) and especially commission errors (where species are mistakenly thought to be present) (Rondinini et al., 2006).

Including species information in addition to richness in conservation value

Biodiversity is not evenly distributed and there have been efforts to select priority areas (Mittermeier et al., 2011; Eken et al., 2004) by use of species-richness data alone. Relying on species-richness alone ignores the identity and relative conservation status of species, and does not necessarily identify the most important areas for plant conservation. The scoring method that we developed improves on this by focusing on sites with high species richness, thereby reflecting the diversity in each area, *and* the distribution of species that are important both in terms of their conservation status and level of distribution (Figures 1 – 3). This provided conservation value for grid cells in Fermanagh, Waterford, and Ireland (Figures 1 - 3) and in doing so differentiated the landscape across a spectrum from low to high conservation value. This was similar to maps of conservation value produced for other areas (e.g. Blasi et al., 2011; Burgess et al., 2006; Türe & Böcuk 2010) and offers a better input for conservation planning as it avoids classifying the landscape into important and non-important sites (Lindenmayer et al., 2008). Instead, the scoring method's output provides information on the entire landscape allowing greater flexibility in addressing conservation problems (Rodrigues et al., 2000). The benefit of having conservation information for every cell is that in addition to the identification of high-value areas, low and medium value areas are also identified and could be potential targets for improvement. It should be noted that detailed knowledge of an area is still very important to consider in conjunction with these types of maps. In Fermanagh it is clear that the central part of the county and part of the north west of the county are important areas for plant diversity. These correspond with lake and river-side areas that likely have high semi-natural habitat cover (Forbes and Northridge 2012). In Waterford it appears that the most important areas for plants are the coastal areas and an estuarine area at the west of the county. The northern border with Tipperary contains the Comeragh Mountains which contain important semi-natural habitats but as they are predominantly peatlands the plant conservation values appear lower than one might expect primarily due to the naturally low species-richness of these areas (Forbes and Northridge 2012).

The species richness of a cell has a direct effect on its conservation value as cells with a high number of species will have a higher number of values to contribute to the final cell value. This is an advantage of the method as it favours cells with high species richness. However, a possible drawback of this approach is that cells with relatively few species have a low cell conservation value, despite these species being of high conservation concern. A simple procedure could be undertaken to detect cells such as these after employing the scoring method. By dividing the conservation value of each cell by the number of species in the cell, any instances of low diversity of high value species can be identified. An example for Waterford is provided in Figure A9. In this case, the newly identified high value cells are located in the Comeragh mountain upland areas with low numbers of important species. This example shows that using the scoring method alone might omit such areas and that the secondary step could be conducted as a follow-on exercise depending on the goal of the analyses.

The importance of scale in conservation planning

In Ireland the hectad-scale data provided coverage for almost the entire island while comprehensive tetrad-scale data were limited to just two counties. The detail of conservation value was greatly improved when data of higher spatial resolution were used for Counties Fermanagh and Waterford. While the tetrad-scale data were collected on a county basis, the hectads overlapping the county borders also contain records from outside of Fermanagh and Waterford. This in turn will have influenced the conservation value of these hectads making it difficult to compare conservation values at border locations. The mapped patterns of high-value hectads broadly corresponded with areas with high-value tetrads in the two counties (Figures 2, 3). The relatively large area of a hectad will be of less use to practical conservation efforts but plant diversity in these areas still drives the conservation values and high value hectads could function as targets for further investigation or recording at finer scales. The lower value hectads should not be ignored however, as these could be masking smaller isolated high value areas. In some cases there are areas with medium to low conservation value at the hectad scale that are shown to contain some high value areas at the tetrad scale within the same hectad (Figures 2, 3). Important areas could be overlooked where a hectad contains few high value tetrads and is dominated by low value tetrads.

Data collected at, or converted to the hectad scale can result in better data coverage for a region, although this will simply mask underlying gaps in data coverage and in Ireland the distribution of tetrad-scale data for plant species is patchy and incomplete (Walsh et al., 2015) and so hectad-scale results such as those shown in Figure 1 should not be used in conservation planning. While it is clear that improved data resolution brings a higher level of detail and confidence in conservation value, the level of effort required for collecting comprehensive data coverage at finer scales also increases and can be prohibitive (Palmer et al., 2002), especially as it often depends on the work of volunteer recorders. A more complete tetrad-scale coverage might be achieved by improved co-ordination of volunteer recorder effort, or by paying for systematic monitoring programmes. An alternative approach would be to employ species distribution modelling to fill the gaps in the current tetrad data (Elith & Leathwick, 2009) and repeat the identification of important areas of plant diversity. Another issue with coarse grid-scale distribution data is the difficulty in comparing it to other spatial data. In this study, for example, a direct comparison of the coincidence of high value areas with protected areas was not possible as the irregularly shaped protected areas did not align to grid-scale plant distribution data. Thus, in the case of a tetrad that has 50% cover by a protected area, it remains unknown whether the species of highest conservation interest occur within the protected area or not.

Species representation in important areas of plant diversity

Our scoring method does not provide a definite line between high and low value sites but instead provides a conservation value for each grid square. At times it is useful to identify the highest value cells, for example when examining the effectiveness of protection mechanisms in meeting conservation targets or examining if the areas achieve conservation goals. By examining the level of species representation within the high value areas it was possible to objectively identify a set number of cells, i.e. those that ensured a high number of species were represented in the selected sets of high value cells (>80% of species). These areas achieved species representation levels (77% - 86% of species of conservation concern, 87% - 95%% of all species) comparable to those in other studies (Abellán et al., 2005; Blasi et al., 2011; Simaika & Samways 2009).

The full representation of species of conservation concern or other species was not attained within any grids examined (Figure 4). All scoring methods of spatial prioritisation lack the ability to consider how sites best complement each other in terms of feature representation (Arponen et al, 2005). However, the use of the segmented regression threshold can be used to select sets of areas in which a high number of species are represented, albeit not in the most efficient way. The segmented regression approach is a much more conservative approach that usually gave rise to a lower number of cells compared to 17% Aichi target or the number of cells selected by the linear programming approach. The linear programming approach demonstrated the most efficient way to achieve full species representation via the selection of the lowest number of sites in which the number of species was maximised. Used alone, the linear programming approach would only identify these sites and would not provide information on the remaining areas. When used as a follow-up to the scoring method information is provided for both conservation value in the wider area and for important areas of biodiversity.

Important areas of plant diversity do not necessarily coincide with protected areas

Protected areas in Ireland have been designated to conserve a variety of habitats and species. This includes designation on the basis of vegetation type thereby implicitly reflecting plant diversity and composition of more valued species. Additionally, sites have been selected for a limited number of plant species (NPWS 2013); however none are specifically designated for important areas of plant diversity yet the protection offered by areas designated for individual species or habitats can often benefit many other species (Le Saout et al. 2013).

The tetrad-scale spatial resolution of the plant data did not allow for a direct examination of the cover provided by the protected area network. Instead, we examined the proportion of protected area cover in the highest value cells, which was found to be low. These findings have implications for biodiversity conservation in Ireland. Protected areas can offer at least some protection to species that are not the explicit target of conservation goals at a site, (notwithstanding that many habitats within protected areas in Ireland have been found to be in unfavourable condition (NPWS 2013)). Important areas of plant diversity outside of the protected area network might not be protected at all, except where individual species are subject to legal protection (such as the Flora Protection Order). Populations of plant species of conservation concern can also occur outside of designated areas in Ireland (Walsh et al., 2015). In any event, the level of formal protection of the important areas of plant diversity identified here falls well short of the CBD Aichi biodiversity target of protection of at least 17% of important areas of biodiversity (CBD 2017). The locations of the important areas outside of protected areas could provide targets for appropriate conservation measures.

Conclusion

Both the Republic of Ireland and Northern Ireland have made commitments under national and international agreements to halt biodiversity loss and to protect the most important areas of biodiversity. If these conservation commitments are to be met then comprehensive knowledge of the geographic distribution of important areas of diversity for plants and other taxa will be needed. As with the case of Important Plant Areas, the important areas of plant diversity add to knowledge of the spatial distribution of plant diversity. Access to better plant distribution data, both in terms of resolution and coverage, will be needed for a more definitive identification and mapping of important areas of plant diversity in Ireland. When identified at reliable scale the scoring method could be used in spatial planning, and also combined with the linear programming approach to identify groups of high conservation value areas that also efficiently achieve coverage of many species. These could complement protected areas, Important Plant Areas and important areas for other taxa and be included in an overall national conservation strategy.

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Figure legends

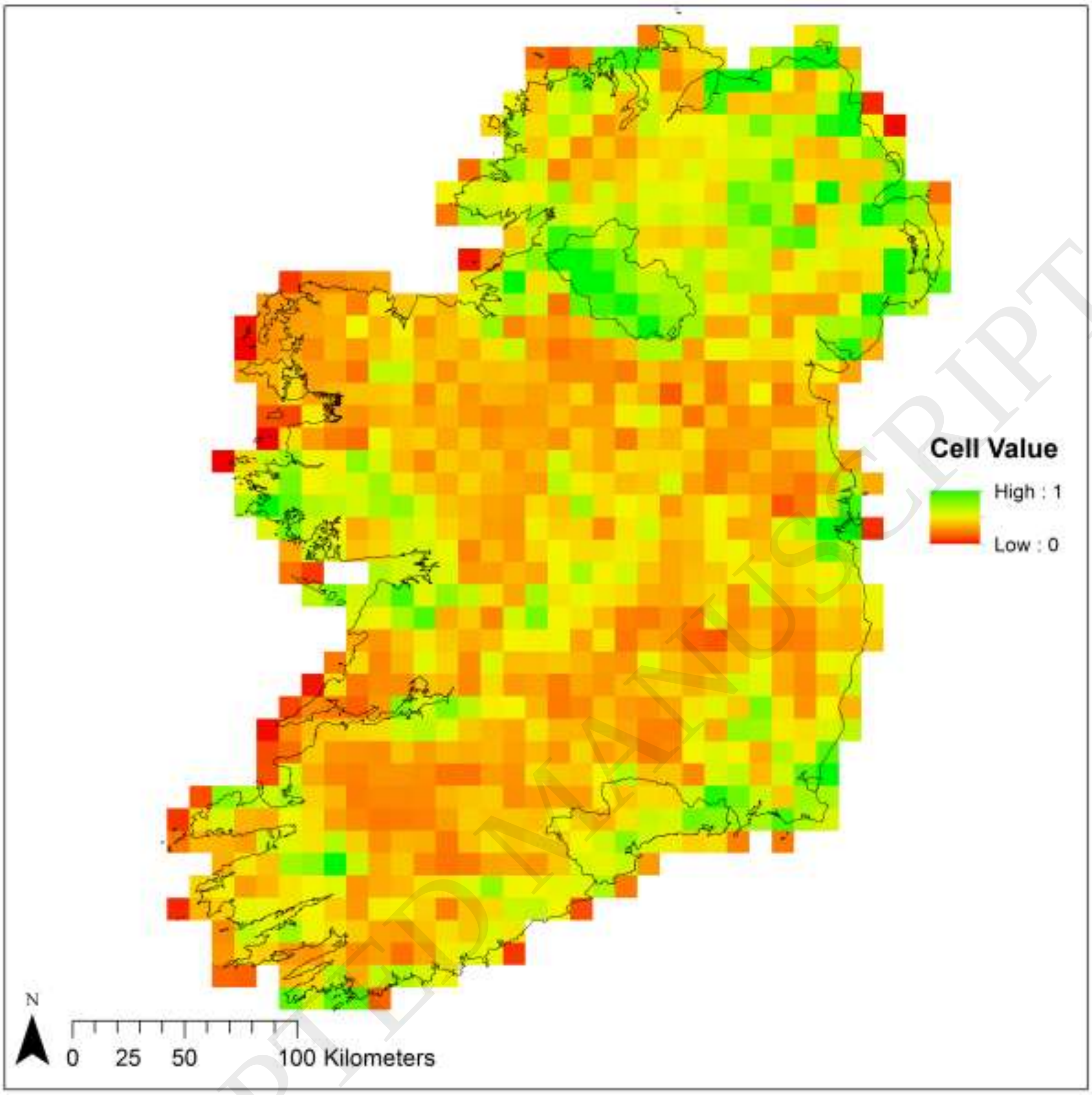
Figure 1: Spatial distribution of the cell conservation values at the hectad scale (10km x 10km) in Ireland. County Fermanagh is outlined in the north of the island and County Waterford in the south.

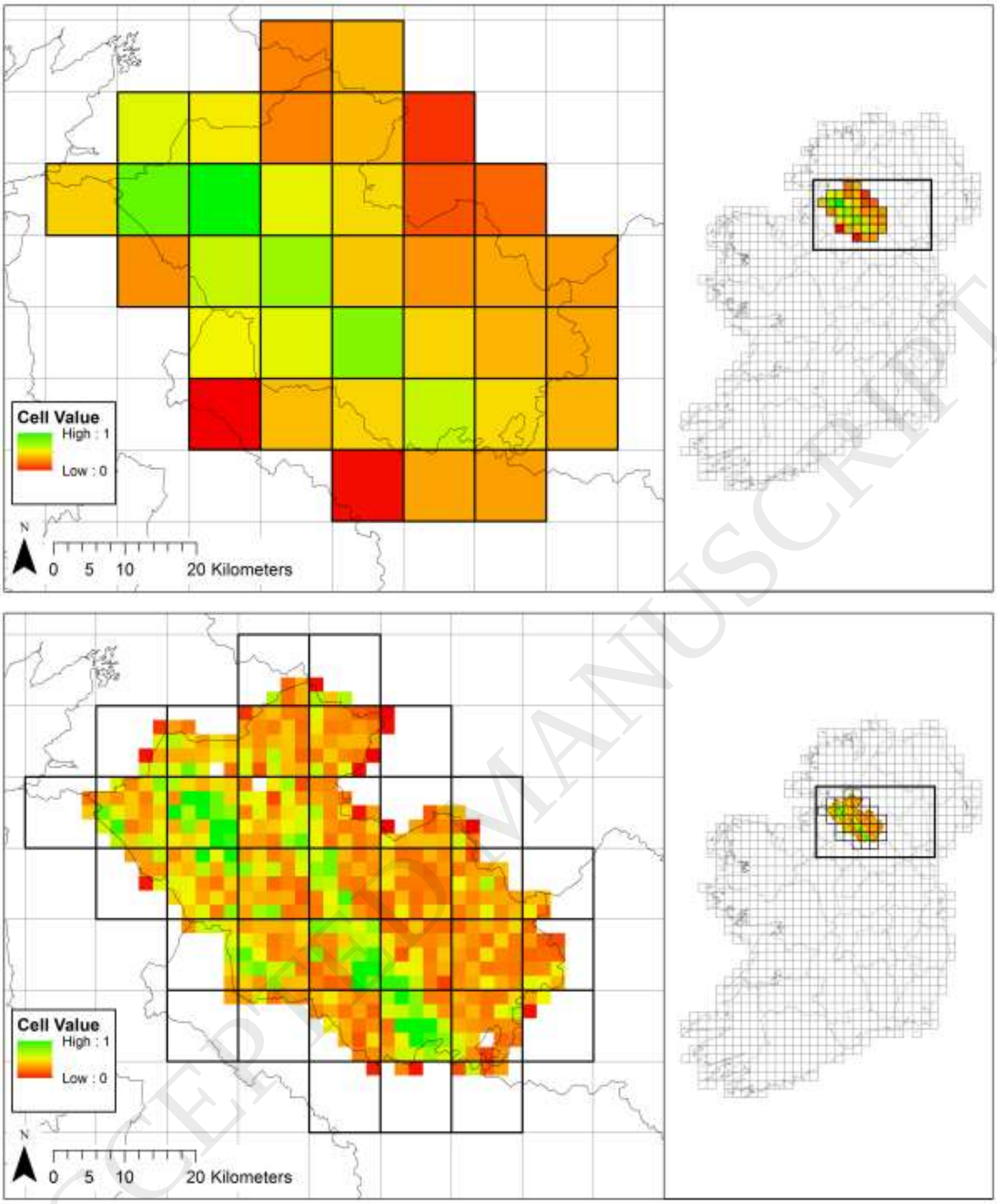
Figure 2: Spatial distribution of the cell conservation values at the hectad (10km x 10km) and tetrad (2km x 2km) scales in County Fermanagh.

Figure 3: Spatial distribution of the cell conservation values at the hectad (10km x 10km) and tetrad (2km x 2km) scales in County Waterford.

Figure 4: Species representation in relation to the number of cells across Ireland, Co. Fermanagh, and County Waterford. Cells (hectads or tetrads) were ranked in order of decreasing cell conservation value, and plotted against the cumulative percentage of species. Grey dashed vertical line indicates the segmented regression breakpoint and a threshold at 17%. (SCC: Species of conservation concern; Seg_regression: the segmented regression line).

Figure 5: Percentage cover of protected areas across the sets of cells with highest-ranking cell conservation values in Ireland, County Fermanagh, and County Waterford. The two histograms reflect the highest-ranking 17% of cells (left) and b) the set of cells defined by the segmented regression breakpoint (right).


Cell Value
High : 1
Low : 0
N
0 25 50 100 Kilometers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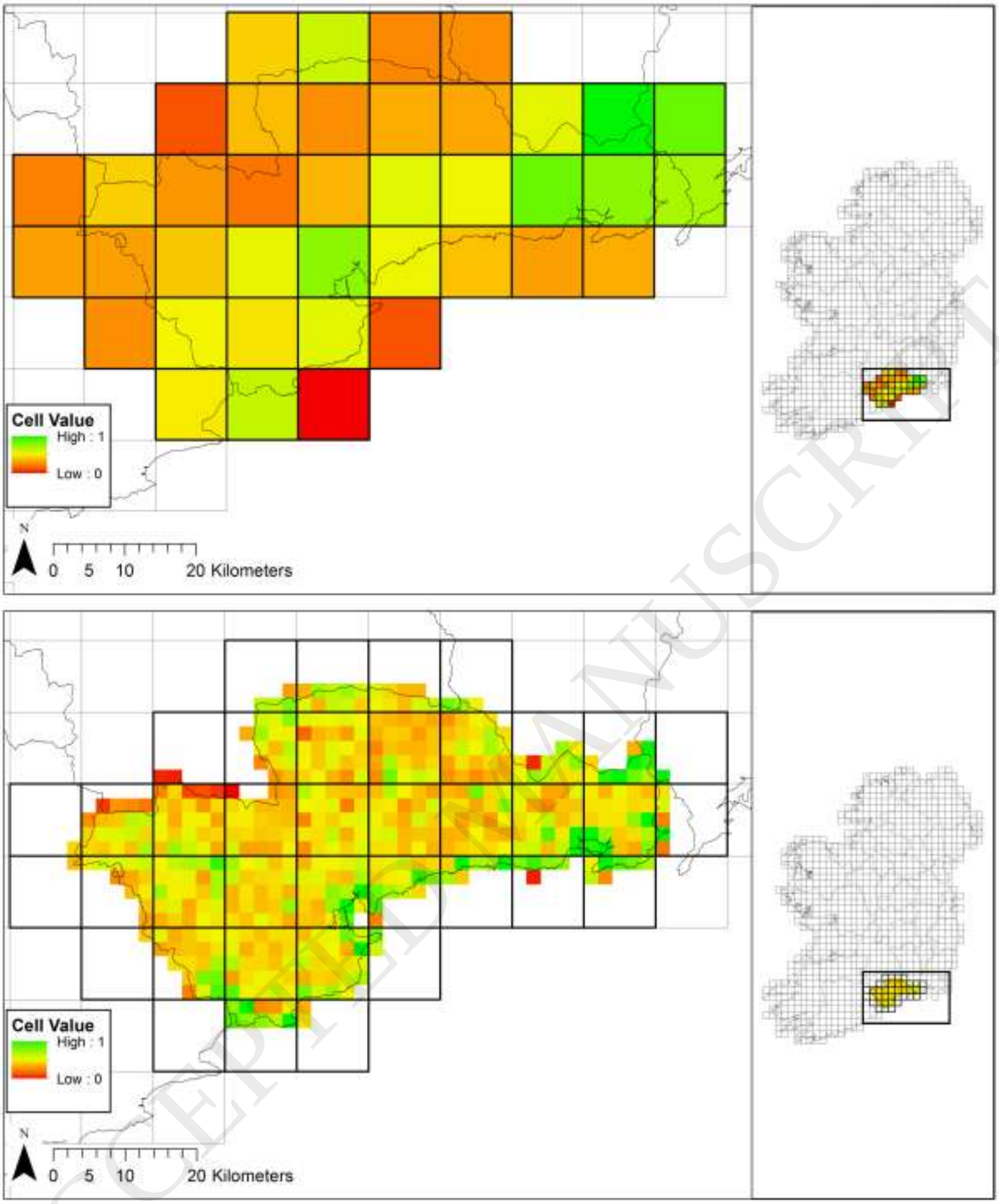
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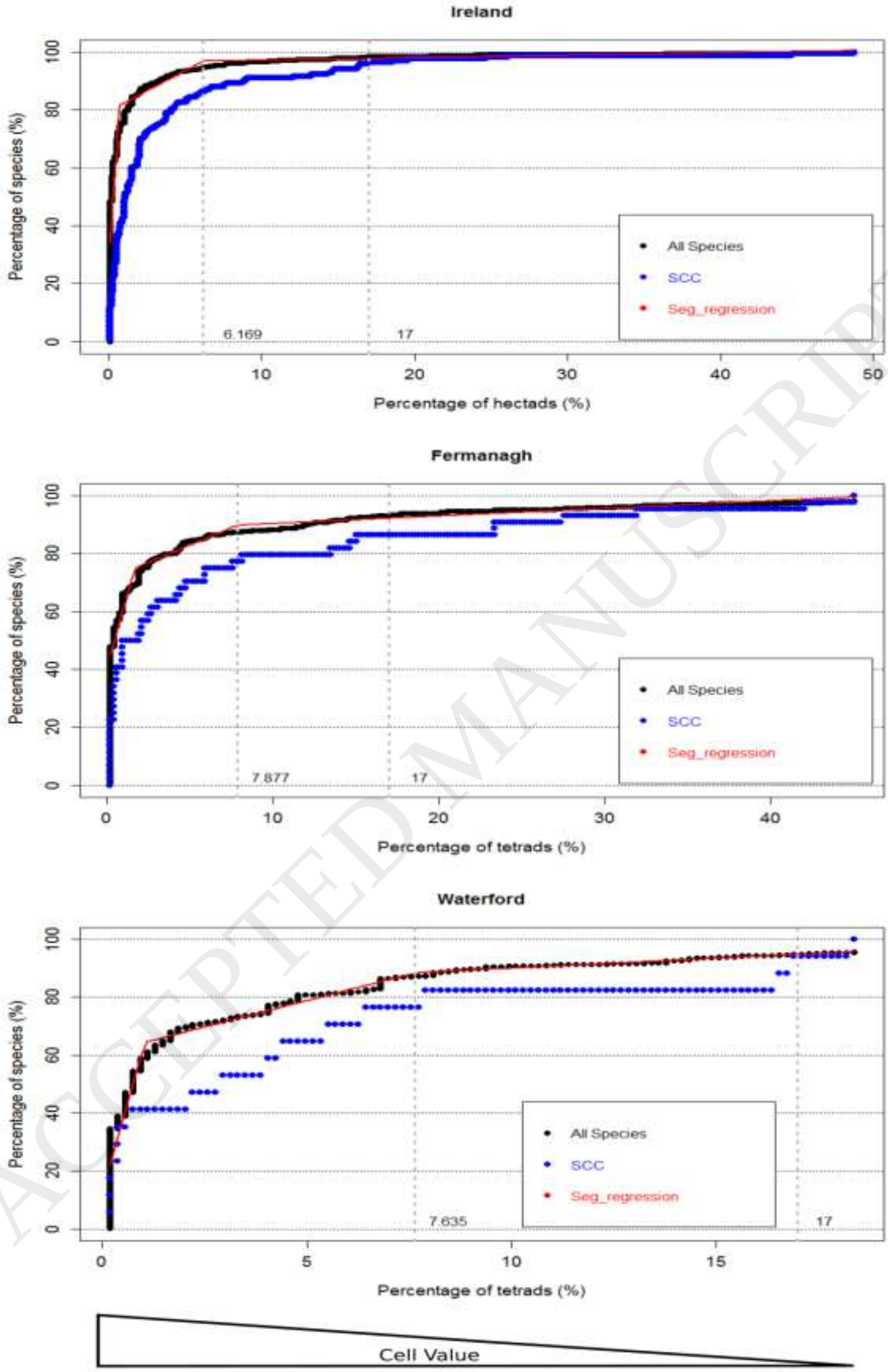
Ireland
Percentage of species (%)
Percentage of hectads (%)
6.169
17
All Species
SCC
Seg_regression
Fermanagh
Percentage of species (%)
Percentage of tetrads (%)
7.877
17
All Species
SCC
Seg_regression
Waterford
Percentage of species (%)
Percentage of tetrads (%)
7.635
17
All Species
SCC
Seg_regression
Cell Value

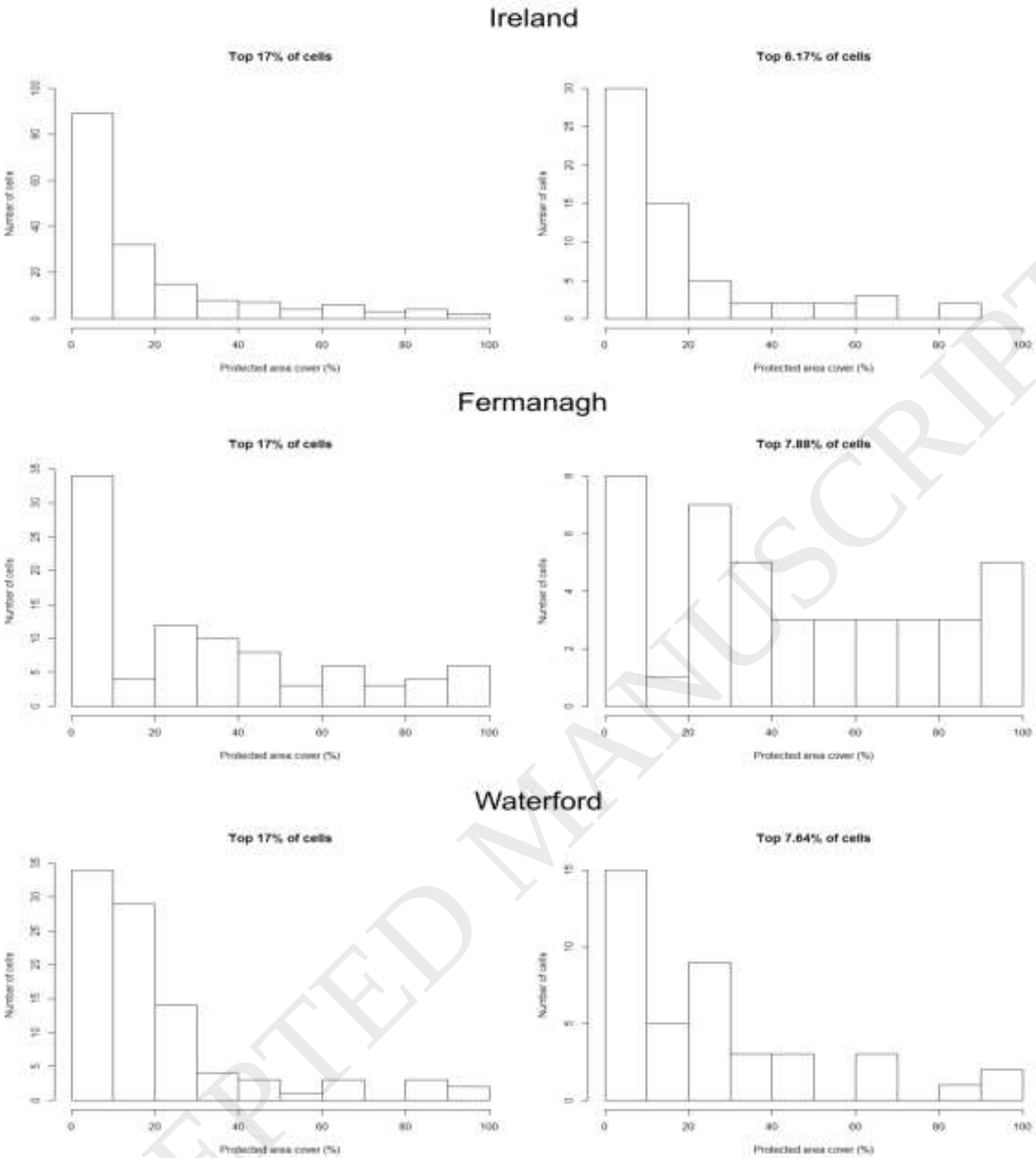
Ireland
Top 17% of cells
Top 6.17% of cells
Number of cells
Protected area cover (%)
Fermanagh
Top 17% of cells
Top 7.88% of cells
Number of cells
Protected area cover (%)
Waterford
Top 17% of cells
Top 7.64% of cells
Number of cells
Protected area cover (%)

Figure A1: An overview of the criteria and steps taken in the scoring method and identification of important areas of plant diversity.

Figure A2: The locations of protected areas in Ireland. These consist of Natural Heritage Areas in the Republic of Ireland, Areas of Special Scientific Interest in Northern Ireland, and both Special Areas of Conservation and Special Protection Areas across both areas.

Figure A3: The number of plant species per hectad in Ireland.

Figure A4: The number of plant species per tetrad in County Fermanagh.

Figure A5: The number of plant species per tetrad in County Waterford.

Figure A6: The distribution of values for protected area cover in hectads in Ireland.

Figure A7: The distribution of values for protected area cover in tetrads in County Fermanagh.

Figure A8: The distribution of values for protected area cover in tetrads in County Waterford.

Figure A9: The cell conservation values divided by the number of species in each cell at the tetrad scale (2km x 2km) in County Waterford.

Table 1: The number of species in each exclusive plant species category of the scoring method. (SCC: Species of conservation concern; Annex I: Annex I habitat indicators; SN: Semi-natural habitat indicators).

	SCC	Annex I	SN	Native	Total
Northern Ireland	150	431	106	330	1017
Republic of Ireland	112	459	106	339	1016

Table 2: Species Distribution Values based on categories of percentage distribution at the hectad scale in Ireland.

Percentage distribution across hectads	Species Distribution Values
≤10%	6
10% to 20%	5
20% to 40%	4
40% to 60%	3
60% to 80%	2
80% to 100%	1

Table 3: The number of cells in each study area and the maximum, minimum, median, and mean cell conservation values.

		Cell Conservation Value			
Area	**Number of cells**	**Maximum**	**Minimum**	**Median**	**Mean**
Ireland	997	173307	400	46323	51296
Fermanagh	526	84766	2	18544	22281
Waterford	544	46699	2462	16950	18250

Table 4: Species representation in the selected important areas of plant diversity, for the three study areas. We compared representation based on the Aichi biodiversity target, breakpoints identified by a segmented regression analysis, and a linear programming method. (SCC = Species of Conservation Concern).

Area	Method	Cells (%)	Representation of SCC (%)	Representation of all species (%)
Ireland	Aichi Target	17.00	96	98
	Breakpoint	6.17	86	95
Fermanagh	Aichi Target	17.00	86	93
	Breakpoint	7.88	77	88
	Linear Program	13.50	100	100
Waterford	Aichi Target	17.00	94	95
	Breakpoint	7.64	77	87
	Linear Program	12.13	100	100

Table A1: A glossary of terms used within the text.

Cell Conservation Value: A numerical value assigned to a grid cell by the scoring method. The value is equal to the sum of the Species Conservation Values in the cell and reflects the conservation value of the cell in terms of plant diversity.

Important Areas of Plant Diversity: Defined sets of cells with high cell conservation values important because of the richness and composition of plant species that occur there. In this study these areas were identified using threshold cell conservation value to select sets of areas from the highest cell conservation values.

Species Conservation Value: A numerical value assigned to each plant species in the scoring method. The value is equal to the product of the Species Conservation Weight and the Species Distribution Value.

Species Conservation Weight: A numerical value assigned to each plant species that reflects the conservation importance of the species based on national lists of species conservation status.

Species Distribution Value: An ordinal value assigned to each plant species based on a measure of the distribution of the species across Ireland. Species with low distribution levels were assigned a high ordinal value.

Species of Conservation Concern: Plant species of greatest conservation concern that are listed in the Red Data Book for Ireland, in the Northern Ireland Priority Species list or are a protected species in Ireland (see Supplement for further details).

Table A2: Species Conservation Values, calculated from the product of Species Conservation Weights assigned to reflect species conservation value. For example, a species with a Conservation Weight of 1000 and Distribution Value of 6 has a Conservation Value of 6000 (1000 x 6).

		Species Conservation Weight			
		SCC	A1	SN	Native
		1000	100	10	1
≤10%	6	6000	600	60	6
10.1% - 20%	5	5000	500	50	5
20.1% - 40%	4	4000	400	40	4
40.1% - 60%	3	3000	300	30	3
60.1% - 80%	2	2000	200	20	2
80.1% - 100%	1	1000	100	10	1