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Methods for the Identification of Important Areas of Plant Diversity in Ireland

Ph.D. Thesis

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June 2016



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Abstract

The loss of biodiversity is an on-going global issue that not only results in the extinction of species but also threatens the ecosystem services and goods on which humanity depends. The global community has responded with ambitious targets to halt and reverse the loss of biodiversity. The causes of biodiversity loss are well understood and conservation measures can be deployed to protect biodiversity. However, conservation resources are limited and to be effective must be targeted to the most important areas of biodiversity. Using vascular plant distribution records for Ireland this research examined the distribution of plant species of conservation concern to determine if additional conservation measures should be targeted to these species. In an attempt to aid the targeting of conservation measures to the most important areas of biodiversity this research also investigated methods for the identification of priority areas for plant conservation.

In an initial study vascular plant distribution records were collated and mapped for the island of Ireland. The tetrad scale (2km x 2km) data provided incomplete coverage for Ireland. Records for plant species of conservation concern were extracted and mapped at the tetrad scale for Ireland. The coincidence of the locations of the species of conservation concern and the distribution of areas designated for the protection of biodiversity in Ireland was examined. Between 22 – 40% of the locations of these species were found to occur outside of designated areas and for some individual species all of the locations occurred outside designated areas. The results indicated the importance of both designated areas and the wider countryside for biodiversity conservation. In particular the presence of species of conservation concern in non-designated areas highlights the need for conservation measures outside of designated areas.

Subsequent research investigated a method for the identification of the most important areas of plant diversity at the tetrad and hectad (10km x 10km) scales in Ireland. A criteria-based scoring method was developed to characterise the landscape in terms of conservation value and identify the important areas of plant diversity. The effect of each of the criteria on priority area identification

and on the representation of species (that is the extent to which species occur within a set of sites) within the priority areas was examined. The outcomes of this research identified a combination of criteria that allowed the identification of priority areas of high conservation value that contained a high species representation level.

A subsequent investigation examined an alternative method for the identification of priority areas for conservation. A complementarity-based method using linear programming was used to identify the minimum number of priority areas in which species representation was guaranteed. Additional linear programs were formulated to identify restricted numbers of priority areas in which species representation was maximised. This research also developed a means of incorporating the outputs of the scoring method into the linear programming method.

A combination of the plant distribution data, spatial environmental data, and a logistic regression method was used to build models to predict the distribution of the plant species of conservation concern group (SCC). The associations between the environmental data and SCC occurrence were examined and the predictive performance of both models was investigated using plant records in County Waterford.

To conclude, this research showed that the tetrad-scale plant distribution coverage is patchy for most of Ireland. However, even with incomplete data the research indicated that conservation measures could be targeted to sites outside of protected areas. The plant distribution data can be used to characterise the landscape in terms of conservation value and both the scoring method and linear programming method can be used to identify priority areas for conservation. The scoring method and linear programming method can be combined to efficiently identify priority areas of high conservation value and the research showed the potential use of species distribution modelling for conservation planning in Ireland.

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1. Introduction

Evidence suggests that humanity is causing a decline in global biodiversity (Cafaro 2015). The Convention on Biological Diversity has as its primary objective the conservation of biodiversity and as a signatory to the convention, Ireland is committed to halting biodiversity loss by 2020 (CBD 2010). Various measures such as legal protection, the use of protected areas, and agri-environment schemes have been used to safeguard species and habitats. However the effectiveness of conservation measures is dependent on knowledge of the locations of important reserves of biodiversity. Although information on the distribution of biodiversity exists, for example vascular plant diversity in Ireland, it is not known how complete the coverage of these data is for the island. Additionally it is not known how well the protected area network in Ireland captures the plant species of highest conservation concern.

These knowledge gaps have implications for conservation planning as conservation measures outside of protected areas may be necessary to complement any legal protection for plant species. The identification of areas that are important because of the number and conservation value of species they contain has been to the forefront of conservation research. Such areas can be identified (1) as targets for conservation action or (2) for further investigation into what may be driving the conservation value of each area. A method that can be used to identify priority areas has not been applied for flora in Ireland, though limited attempts have been made to identify Important Plant Areas at national and local scales (Green & Fitzpatrick, 2008; Plantlife, 2015). An approach that uses available plant records and the conservation status of plants could be used to identify priority areas based on the diversity and conservation value of species.

The identification of priority areas for conservation is an important step in conservation planning since limited conservation resources cannot always be applied to every important area (Margules & Pressey, 2000). Often a restricted

number of areas must be selected from a collection of candidate priority areas (Williams et al., 2004). While it is important to use the available plant records to identify areas of conservation value, unsurveyed regions could be important as areas of plant diversity and their identification could offer a more comprehensive contribution to conservation planning (Elith & Leathwick, 2007).

This research attempted to address these outstanding shortfalls in our knowledge of plant distribution in Ireland. The current known distribution of plants was mapped to show the degree to which record collection has been completed across the island. The locations of the more vulnerable plant species of conservation concern were examined in relation to areas designated for the protection of biodiversity. This examination was conducted to detail how many of these locations are within designated areas, and subject to whatever protection these areas might afford, and how many locations are occurring in the wider countryside where other forms of conservation measures might be more important for the survival of these species. A method for the identification of priority areas for conservation was constructed using the plant records and available information on the conservation and ecological status of plant species in Ireland. A mathematical optimisation method was then used to identify sets of the priority areas that most efficiently captured a maximum number of plant species within areas of high conservation value.

Finally, while these efforts provide valuable information based on the current plant records there remain areas of Ireland which have experienced low levels of plant recording. Any plant species occurring in these areas will not be represented in conservation planning. To address this issue the known distribution of plant species and independent environmental variables were used in a species distribution modelling approach to determine whether species occurrence could be predicted across all areas.

1.2 Biodiversity

The Convention on Biological Diversity defines biodiversity as the variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (CBD, 1992). This variety of organisms underpins the ecological processes that sustain the provision of ecosystem goods and services essential to the survival of humanity (Cardinale et al., 2012). In a recent major review of studies on the biodiversity of species it was estimated that there are over 290 000 land plant species and that this estimate is expected to reach 400 000 species when disputes over currently unnamed species are resolved (Pimm et al., (2014).

That said, globally biodiversity is in decline (Stokstad, 2010) and species losses have resulted in current rates of extinction that are approximately 1000 times the background rate of extinction (Pimm et al., 2014) reflecting a loss of biodiversity that is so rapid that it has been described as the sixth mass extinction (Ceballos et al., 2015). A third of all plant species are at risk of extinction and are going extinct at a greater rate than other groups of species (Pimm and Joppa, 2015).

1.3 Causes of biodiversity loss

The global loss in biodiversity largely results from the negative impacts of certain human activities (Baillie et al., 2004; Millennium Ecosystem Assessment, 2005). Pollution is a driver of biodiversity loss and run-off of nutrients from farmland can result in eutrophication of aquatic environments and damage of associated ecosystems (Smith et al., 1999). Anthropogenic greenhouse gases are accelerating climate change which in turn is predicted to increase species extinction rates (Bellard et al., 2012) especially in combination with land-cover change that will increase impacts on biodiversity (Mantyka-Pringle et al., 2015). The introduction of invasive species can have a negative

effect on the biodiversity of an area (Gaertner et al., 2009) as can the over-harvesting of natural resources (Novacek and Cleland, 2001).

Each of these factors can have significant negative impacts on biodiversity; however the single most important driver of biodiversity loss in terrestrial areas is the modification of habitats due to land-use change (Tasser and Tappeiner, 2002; Sala et al., 2000). Land-use change occurs during the conversion of natural landscapes for human use or when modifying existing human dominated landscapes (Foley et al., 2005). This can result in habitat fragmentation where a large amount of habitat is transformed into smaller patches (Wilcove et al., 1986). Apart from the immediate loss of habitat, habitat fragmentation can also impact negatively on biodiversity by reducing the size of habitat patches below the patch size requirements of certain species and by increasing the isolation of habitat patches (Fahrig, 2003). Smaller habitat patches also have a larger perimeter-to-area ratio and are more susceptible to harmful edge-effects (Woodroffe and Ginsberg, 1998). The intensification of land-use can disrupt ecosystems via an associated loss of biodiversity (Allan et al 2015), while land abandonment can also result in a reduction in biodiversity (Renwick et al., 2013).

1.4 Importance of biodiversity

A large variety of organisms underpins the ecological processes that sustain the provision of ecosystem goods and services of importance for humanity (Cardinale et al., 2012; Hooper et al., 2005) and high levels of local and regional diversity are crucial to maintaining ecosystem services over time (Duffy, 2008). Ecosystem goods and services are the benefits people obtain from ecosystem processes (Bullock et al., 2011). These are promoted by higher levels of biodiversity and include provisioning services such as in supporting food production, the production of raw materials and fuels, and regulating services such as pest control, carbon storage, and nutrient cycling (Gascon et al., 2015). Biodiversity can be a regulator of ecosystem processes, an ecosystem service or a good in and of itself (Mace et al., 2012).

Plants are primary producers and provide the majority of total biomass and physical structure for other organisms in terrestrial ecosystems (Santi et al., 2010). Plants also support services including carbon sequestration, maintenance of soil, and those that are of benefit to the production of goods (Cardinale et al., 2012) and are needed over time to maintain the many functions that underlie ecosystem services (Isbell et al., 2014). In the context of conservation planning plants can also function as surrogates for overall biodiversity and have been used as such in the selection of sites of conservation value (Saetersdal et al., 2004; Gioria et al 2010). This form of surrogacy is possible because the distribution of vascular plants has been found to correspond to other biodiversity features including butterflies (Maccherini et al., 2009), lichens (Saetersdal et al., 2004), and birds (Su et al., 2004). Furthermore expertise on vascular plants and information on their distribution are easier to find than for most other taxa (Chiarucci et al., 2005). There is evidence that the loss of biodiversity is changing important processes in ecosystems (Hooper et al., 2012) with serious consequences for the ecosystem services upon which humanity depends (Cardinale et al., 2012). Biodiversity loss can have an impact upon the provision of ecosystem goods and services which in turn can have detrimental impacts on important factors such as food and energy security, health, and the provision of clean drinking water (Millennium Ecosystem Assessment, 2005).

1.5 Response to biodiversity loss

In response to continuing biodiversity losses the Convention on Biological Diversity (CBD) provided a focus for concerted global actions to halt the decline of biodiversity (CBD, 2010). A strategic plan for biodiversity guides these actions and includes a goal of safeguarding ecosystems, species and genetic diversity. The CBD had aimed to halt biodiversity loss by 2010 but this was not achieved and the parties to the Convention have renewed action in the form of a new strategic plan for biodiversity. In the European Union a biodiversity strategy seeks to halt the loss of biodiversity and degradation of ecosystem services by 2020 (European Commission, 2011).

To date the designation of sites as protected areas has been a core mechanism for the safeguarding of biodiversity (Margules and Pressey, 2000). Areas designated for the protection of biodiversity have played a key role in conservation strategies (Le Saout et al., 2013) at the global, regional and local level (Gaston et al., 2008). Protected areas cover 13% of global land area (Le Saout et al., 2013), however it is now recognised that increasing protected area cover to 17%, a goal of the CBD Aichi Biodiversity targets for 2020, will not be enough to stem losses in biodiversity (Larsen et al 2015). While the use of protected areas has been successful in conserving some habitats and species (Geldmann et al., 2013) protected areas are not always ecologically representative and may not optimally protect biodiversity (Pimm et al., 2014). Networks of protected areas have been found to provide insufficient cover to biodiversity; for example protected areas do not adequately cover endangered vertebrates in Spain (Hernandez-Manrique et al., 2012), terrestrial ecosystems in Chile (Pliscoff & Fuentes-Castillo, 2011) and mammalian species in Canada (Wiersma & Nudds, 2009). In such cases the dependence of conservation strategies on the use of protected areas alone means that biodiversity is less likely to be adequately protected.

The on-going loss of biodiversity provides evidence that the use of protected areas alone is not enough to halt the decline (Mora and Sale 2011). There is now an increased recognition that the landscape outside of protected areas is important for the persistence of biodiversity (Willis et al., 2012). There have been various approaches to promote biodiversity other than the use of protected areas. These include integrating conservation and development through the use of biodiversity offsets designed to counter biodiversity losses (Bull et al., 2015), community conservation projects, and direct payments for ecosystem services.

Agriculture occupies 38% of the Earth's land cover representing the largest component of land-use, and the effects of agriculture on ecosystems therefore have an important impact on biodiversity (Foley et al., 2011). For example High Nature Value farmland (HNVf) which is often dominated by semi-natural

vegetation (EEA 2004) is mentioned in the Common Agricultural Policy (CAP) 2014-2020 under Article 5 in relation to restoring, preserving and enhancing ecosystems relating to agriculture. The intensity of farming practices will have an impact on the biodiversity present on a farm. Agri-environment payments are designed to promote agricultural management that reduces the negative effects of farming on biodiversity, while supporting management that preserves biodiversity (Batary et al., 2015). Within the European Union agri-environment payments include financial incentives that reward farmers for using practices that protect or enhance the environment (European Commission, 2005). From 2015 onwards approximately €12 billion per year has been earmarked for rewarding the use of farming practices that address biodiversity loss within the EU Rural Development Programme (European Commission, 2015). However if this expenditure is to be effective then the locations of important biodiversity must be known so that measures can be targeted to appropriate areas, e.g. the identification and mapping of different grassland types (Pe'er et al., 2014).

1.6 Conservation planning

Knowledge of the distribution of biodiversity is a requirement of conservation planning (Grantham et al., 2008) and for identifying sites for their biodiversity value (Kukkala and Moilanen, 2013). The limited availability of conservation resources means that measures cannot be applied to all areas and instead certain areas have to be prioritised for conservation action. Quantitative, scientifically sound methods are required to identify these areas and to provide justification for their prioritisation.

Priority areas should be the first locations to be targeted for conservation action (Margules et al., 2002). The research presented here includes the investigation of methods for the identification of priority areas for conservation but does not suggest sites to be considered for designation as new protected area networks. Appropriate management could be targeted to the identified areas regardless of whether the priority areas coincided with protected area. The conservation biology literature predominantly deals with the issue of prioritisation as 'reserve selection' however, as pointed out by Pressey and Cowling (2001), the

principles of reserve selection also apply to the identification of areas for the implementation of other conservation measures without assigning formal protected status.

As part of the processes of conservation planning, information on the biodiversity of an area must be compiled and conservation objectives identified. The contribution of protected areas to these objectives is then reviewed and conservation actions are implemented to maintain conservation areas (Margules and Pressey, 2000). The spatial distribution of biodiversity must be investigated to allow the implementation of conservation actions to appropriate areas. Spatial conservation prioritisation is a form of analysis that is used to identify the locations of important areas of biodiversity and to determine how conservation goals can be achieved efficiently (Kukkala and Moilanen, 2013). There is a wide range of core concepts that can be considered in spatial conservation prioritisation (Kukkala and Moilanen, 2013). This research does not incorporate every concept involved in spatial conservation prioritisation (e.g. examining how well priority areas conserve biodiversity) but instead focuses on interrelated elements such as (1) representation, which is the level of occurrence of a biodiversity feature (e.g. species) within a set of sites (Cabeza and Moilanen, 2001); (2) complementarity, which is a measure of the number of unrepresented species a new site adds to a collection of priority areas (Margules and Pressey, 2000); and (3) efficiency (also known as economy), where a conservation objectives are achieved at a minimum cost (Sarkar et al., 2006) (e.g. using the minimum number of priority areas).

1.7 The methods of prioritising areas featured in this research

There are two broad types of methods used in spatial conservation prioritisation: the scoring method of prioritisation and the complementarity-based prioritisation method (Abellan et al., 2005). The scoring method ranks sites in order of conservation value from the combined score of a number of criteria (Pressey and Nicholls, 1989) and the resulting highest scoring sites are identified as priority areas for conservation. A strength of scoring methods is that they are relatively easy to develop and describe, can incorporate many

different factors (Ferrier and Wintle, 2009) and can successfully prioritise areas for conservation (e.g. Burgess et al., 2006). However, the scoring method has a significant limitation in that it does not take account of the specific features (e.g. species) in each of the sites; so some features may be over-represented in the highest scoring sites while other features may be under-represented or absent (Pressey and Nicholls, 1989). This limitation means that the scoring method cannot guarantee that a feature will be represented in the highest scoring sites. The method can also be inefficient at maximising feature representation, in that it selects more sites than necessary to represent features.

Complementarity-based methods incorporate the principle of complementarity where the sites chosen as priority areas best complement each other in terms of achieving a conservation objective (Justus and Sarkar, 2002). One such objective is to maximise the representation of biodiversity features (such as species) in a minimum number of priority areas (e.g. Saetersdal et al., 1993). A solution to this planning objective is said to be optimal when the minimum number of sites in which all features have been represented is identified. Complementarity-based methods can use algorithms to search through all of the candidate sites to identify one or more combinations of sites in which the feature representation levels match those of the conservation objective (Cowling et al., 2003). Exact methods use algorithms to find a mathematically guaranteed optimal solution while heuristic methods use algorithms that find solutions that are close to but not guaranteed to be optimal (Haight and Snyder, 2009). Both the scoring and complementarity-based methods were investigated in this research for their usefulness in identifying priority areas for plant conservation in Ireland.

1.8 Species distribution modelling

Although the spatial targeting of conservation measures can be facilitated using the known distribution of biodiversity, there are often parts of the landscape that either exhibit low recorder effort or have not been surveyed at all. These areas have the potential to contain important species or habitats that would otherwise

be overlooked in conservation planning. One way to avoid omitting these areas is to statistically model the potential distribution of species based on known occurrences using environmental variables associated with the species (e.g. climate variables). This approach is generally known as species distribution modelling (SDM), but can also be referred to as habitat suitability modelling or environmental niche modelling (Ahmed et al., 2015).

The SDM approach combines information on the known distribution of species with the spatial distribution of environmental variables (e.g. climate and soils) across the entire landscape. SDMs are often used to predict species distributions (Elith & Leathwick, 2009) to improve land-use and conservation planning, for example in identifying priority areas for farmland biodiversity (Klimek et al., 2012), the distribution of plant species (Perez & Font, 2012; Zhang et al., 2012), or to combine species distribution with habitat uses (Brambilla & Saporetti, 2014). The SDM approach has been used successfully in a wide range of applications to explore the distribution of biodiversity and to support conservation planning (Guisan & Thuiller, 2005). In Ireland, statistical modelling techniques have been used to examine the relationship between biodiversity and various spatial data, for example modelling environmental and landscape variables to examine their relationship with semi-natural habitats in the west of Ireland (Sullivan et al., 2011). Species distribution models have also been used to improve knowledge of the distribution of badger populations and have added to a knowledge base for the management of bovine tuberculosis throughout the Republic of Ireland (Byrne et al., 2014). The environmental conditions associated with the distribution of the freshwater pearl mussel in Northern Ireland have also been examined to aid in the development of a conservation strategy for the species (Wilson et al., 2011). Distribution modelling has also been conducted for bats in Ireland to provide habitat suitability maps (Lundy et al., 2011).

1.9 Biodiversity conservation from an Irish perspective

The flora of Ireland is characteristic of Northwest Europe but contains fewer species than are found elsewhere in the region due to ecological factors (e.g.

climate, soil) and Ireland's earlier isolation in post-glacial times (Webb, 1983). Despite having fewer species Ireland still supports important botanical sites, for example in the Burren, Co. Clare where conditions allow a combination of alpine and Mediterranean species (NBG, 2015).

There is statutory protection for wildlife in Northern Ireland and the Republic of Ireland, as well as a Red Data Book (Curtis and McGough, 1988) list of species for the island of Ireland. Both areas have established Special Areas of Conservation for the protection of habitats and species. Other designated areas for the protection of biodiversity have also been established; for example, Natural Heritage Areas in the Republic of Ireland and Areas of Special Scientific Interest in Northern Ireland. A high proportion of the land-use in Ireland is dedicated to agriculture (DARD 2012) and presents a large target area for the protection and maintenance of important areas of plant diversity by way of agri-environment schemes. In Ireland, agri-environment schemes are operated under Rural Development Programmes in the Republic of Ireland and Northern Ireland. These schemes include instruments for increasing diversity and providing habitat for Irish plants; for example the GLAS scheme includes measures promoting hedgerows, low-input pastures, native tree planting, and the maintenance of traditional hay meadows (DAFM, 2015). While these measures can be of benefit to plant species, a report from the EU Court of Auditors highlighted shortcomings in the application of agri-environment schemes, including a limited use of targeting (EU Court of Auditors, 2011). Better knowledge of the distribution of important areas of plant diversity could assist in the development of assessments of the appropriate levels of geographic targeting of agri-environment funds, which are lacking according to the auditors' report. This knowledge would also allow the more precise targeting of funds to specific environmental needs.

Despite the use of protected areas (and other measures) the most recent assessment of habitats in Ireland reported that many habitats are in unfavourable status and the condition of many habitats is still in decline (National Parks and Wildlife, 2013). National biodiversity plans for Ireland

contain strategic objectives, including a need to strengthen the knowledge base for conservation, management and sustainable use of biodiversity and to conserve biodiversity in the wider countryside (DAHG, 2011; DOENI, 2015). If Ireland is to achieve these objectives then improved methods to identify where the most important areas of biodiversity occur will be needed. While there is information on the distribution of vascular plant species these data have not been used to examine overall patterns of plant diversity and distribution in Ireland and there is little in the way of research into the identification of important areas of diversity (but see the Important Plant Area programme in Northern Ireland; Plantlife, 2015).

1.10 Significance of this research

Biodiversity loss is an important global phenomenon. In Ireland policies have been developed to protect and sustain biodiversity and various conservation measures have been deployed, for example areas designated for the protection of biodiversity and legal protection of species. Knowledge of both the geographic location and coincidence of important areas of biodiversity with protected areas is required for the successful implementation of conservation strategies. Many actions aim to preserve species and habitats where they occur, therefore the ability to deploy such measures is directly dependent on knowing their spatial distribution. Plant species of conservation concern represents an important component of the flora of Ireland whose distribution, particularly in relation to protected areas, is not fully understood. These species represent the most vulnerable members of the Irish flora and as such are most in need of conservation. However not all areas can be afforded conservation action and limited conservation resources necessitate the prioritising of areas for conservation action. Few attempts have been made to identify priority areas for plant conservation in Ireland, and where these have been undertaken, area selection criteria have either been too strict resulting in the selection of a low number of sites (e.g. Important Plant Areas in Northern Ireland (Plantlife, 2015)), or rely on subjective user-defined criteria such as in the identification of local Important Plant Areas in Co. Waterford (Green & Fitzpatrick, 2008). The

application of methods to identify these priority areas using criteria appropriate for Ireland would allow the application of conservation measures or further study within them. The identification of locations that contain important collections of biodiversity is commonly undertaken throughout the world to highlight sites that should be targeted for conservation (Eken et al., 2004; Myers et al., 2000). While the identification of priority areas for conservation would be an important contribution to conservation planning, the efficient use of scarce conservation resources must also be taken into consideration. Priority areas should be selected based on their conservation value. Other considerations such as efficiently sampling the plant diversity of a region should also be considered. The available plant records offer a view of the current distribution of plant species; however the collection of records is usually conducted on a restricted basis given that the time, effort, and finances required to undertake systematic sampling at local scales is often prohibitive. It is therefore common that collections of records represent incomplete catalogues of species distribution and conservation efforts based on these records are likely to be less effective than with more complete datasets. Comprehensive knowledge of the potential distribution of important features of the Irish flora, such as species of conservation concern is unknown and represents an obstacle to effective conservation planning.

1.11 Aims of the research and thesis outline

Chapter 2 The distribution of vascular plant species of conservation concern in Ireland, and their coincidence with designated areas

There is a lack of knowledge of the patterns of species richness and diversity of vascular plant species in Ireland. To address this lack of knowledge the vascular plant distribution records for the island of Ireland were collated and mapped. This allowed the investigation of the first research question:

- What is the coverage provided by the distribution records for the combined plant species records at the tetrad-scale (2km x 2km) in Ireland?

Ireland has a network of protected areas for the protection of biodiversity; however it is not known how many of the locations of plant species of conservation concern occur outside of these protected areas. The collated plant distribution data were used to examine the coincidence of the locations of species of conservation concern and areas designated for the protection of biodiversity. This allowed the investigation of the following research objectives:

- To determine the extent to which the distribution of vascular plant species of conservation concern overlap with the Irish network of designated areas.
- To examine if the distribution shows a need for conservation measures outside of designated areas.

Chapter 3 A scoring method of spatial conservation for the identification of priority areas for plant conservation in Ireland

I also investigated whether a scoring method of spatial prioritisation of areas could be developed to identify priority areas for conservation. An appropriate number of priority areas could be identified so that limited conservation measures could be targeted to sites of high conservation value. This could be determined by the number and types of species in a site, and where the majority of species are represented.

Accordingly, the following research objectives were investigated:

- To develop a scoring method that differentiates between areas of high and low conservation value
- To determine the number of species that are contained within cells of high conservation value
- To select priority areas from candidate high value cells based on the number of species represented within the cells

- To compare the performance of the scoring method in terms of species representation to a random selection of areas and a selection based on species richness
- To compare the locations of priority areas identified using the scoring method to the locations of locally identified Important Plant Areas

Chapter 4 A complementarity-based method for the selection of sets of priority areas in Ireland

Conservation resources are scarce and must be applied in an efficient manner to the most important areas of biodiversity. A limitation of the scoring method is that it cannot identify efficient sets of priority areas (e.g. a minimum number of areas where species representation is maximised). A complementarity-based method of spatial prioritisation was investigated for the identification of sets of priority areas that efficiently maximise species representation. The goals of the complementarity-based research were as follows:

- To identify the minimum number of priority areas that are required to represent (1) all species and (2) all species of high conservation concern at least once.
- To find the sets of priority areas in which the maximum number of species can be represented when the number of cells in the priority area network is limited.

Chapter 5 Modelling the predicted distribution of plant species of conservation concern in Ireland

The current knowledge of the distribution of important features of the flora of Ireland is limited and represents an important obstacle in the development of effective plant conservation strategies. Gaps in species distribution records have often been addressed using species distribution modelling. A logistic regression modelling approach was undertaken in an effort to improve the

current knowledge of the distribution of plant species of conservation concern in Ireland. The following research goals were addressed:

- To build logistic regression models based on records of plant species of conservation concern and a selection of independent environmental variables.
- To examine which environmental variables are associated with the distribution of the plant species of conservation concern group.
- To compare the predictive ability of the logistic regression model built using largely incomplete national data to that of a model built using plant records from a well surveyed area (County Waterford).
- To map the predicted probability of the occurrence of plant species of conservation concern so as to add to the conservation planning knowledge-base.

The thesis ends with a synthesis and discussion of the research in Chapter 6.

The distribution of vascular plant species of conservation concern in Ireland,
and their coincidence with designated areas

Walsh, A., Finn, J., Jebb, M., Waldren, S., Sullivan, C., 2015. The distribution of
vascular plant species of conservation concern in Ireland, and their coincidence
with designated areas. *Journal for Nature Conservation* 24, 56–62.

The following thesis chapter features a research paper that was published in
the *Journal for Nature Conservation* in 2015. It is the work of Aidan Walsh,
John Finn, Matthew Jebb, Steve Waldren, and Caroline Sullivan.

2. The distribution of vascular plant species of conservation concern in Ireland, and their coincidence with designated areas

2.1 Introduction

Global biodiversity continues to decline (Stokstad, 2010), and of the estimated 350,000 plant species in the world (Paton et al., 2008), 20% are estimated to be threatened with extinction (Brummitt et al., 2008) due to habitat loss, overexploitation, biological invasions, climate change, and pollution (Miller et al., 2012). In response to declining biodiversity the Global Strategy for Plant Conservation (a programme under the Convention on Biological Diversity), has an overall objective of halting the loss of plant diversity (Wyse Jackson and Kennedy, 2009). The principal strategy for the conservation of biodiversity to date has been to designate areas to shield biodiversity features from threatening processes (Margules and Pressey, 2000). In developed regions, about 11.6% of terrestrial land area has been designated for the purposes of biodiversity conservation, while the global figure stands at about 12.7% (WDPA, 2011). In Europe, the Natura 2000 network consists of Special Areas of Conservation from the EU Habitats Directive and Special Protection Areas from the EU Birds Directive and is the world's largest network of protected areas. This network was proposed in 1992 to ensure the long-term survival of Europe's most valuable and threatened species and habitats (European Commission, 2002).

Although important, protected areas alone are not sufficient to guarantee the persistence of biodiversity (Mora and Sale, 2011), and sites outside of designated areas also contain important components of biodiversity. Such sites can facilitate ecological processes that contribute to the persistence of biodiversity across the landscape (Willis et al., 2012). Habitats of conservation interest outside of designated areas also provide connectivity among sites by creating a more permeable landscape matrix. This in turn helps to buffer habitats and species (both inside and outside of designated areas) from the

effects of fragmentation such as reduced dispersal and gene flow (Baranyi et al., 2011). The designation of new areas for the protection of biodiversity is not always feasible and habitats associated with vulnerable species could instead be targeted by other conservation measures such as payments for ecosystem services, biodiversity offset schemes and agri-environment schemes. Traditional farming practices in Europe frequently underpin the ecology of many important habitats and species (Polakova et al., 2011), and European landscapes consist of a complex mosaic of important wildlife habitats which occur inside and outside of designated areas. Agri-environment schemes aim to remunerate farmers for environmental protection including biodiversity conservation, and there is a strong policy pressure and opportunity to design more effective and efficient approaches to biodiversity conservation in farmed landscapes (European Court of Auditors, 2011). Thus, there is a strong role for conservation outside of designated areas.

To underpin such actions, knowledge of the spatial distribution of habitats and species inside and outside of designated areas is essential to guide cost-effective conservation strategies. The degree to which designated areas provide cover to the distribution of threatened species has been a focus for research. For example, 88% of Red-Listed plant species in Britain were represented in designated areas; however, 73% of the plant records did not coincide with these designated areas (Jackson et al., 2009). In three regions of Spain, 80–100% of threatened plant species occurred within protected areas (Gomez-Campo, 1997), while 76% of endemic species occurred within protected areas in the Baja California peninsula of Mexico (Riemann and Ezcurra, 2005). In western Norway, 78% of native and 60% of rare species were found within protected areas (Sætersdal et al., 1993). In Madagascar, 78% of the range of Boraginales (an order of flowering plants with many threatened species) was designated (Miller and Morgan, 2011). In Italy, 83% of Important Plant Areas have some legal protection (Blasi et al., 2011) and 8–31% of plant diversity hotspots on the Greek island of Crete coincided with designated areas (Dimitrakopoulos et al., 2004). For the most part these studies report similar levels of cover for threatened species provided by

protected areas despite variations in the types and combinations of protected areas involved. In all cases the studies reported that proportions of important plant populations occurred outside of designated areas.

Designated areas can be effective in supporting populations of species; however, where species are poorly represented other methods of conservation outside of designated areas will be required. Our research investigated the distribution of records of plant species of conservation concern, using the island of Ireland as a case study area. For the first time in Ireland, we collated a number of national-scale datasets of records of vascular plant distribution and used them to investigate the following questions: (1) what is the coverage provided by distribution records for all recorded vascular plant species on the island of Ireland?; (2) to what extent does the distribution of vascular plant species of conservation concern overlap with the Irish network of designated areas? (3) Does this distribution reveal a need for conservation measures outside of designated areas? While the study investigates the distribution of vascular plant species in Ireland an assessment of the effectiveness of protection provided to these species within designated areas was beyond the scope of this research.

2.2 Materials and methods

2.2.1 Study area

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. This study examines the distribution of vascular plant species of conservation concern (including protected species) that are relevant to the island of Ireland as well as specific categories for plants of high conservation value in the Republic of Ireland and Northern Ireland respectively (see Species of conservation concern subsection).

2.2.2 Species of conservation concern

Plant species on the Flora Protection Order of Ireland (Flora Protection Order, 1999) are afforded legal protection in the Republic of Ireland under the Irish Wildlife Act (Wildlife Act, 1976). Similar protection is afforded to plant species in Northern Ireland as listed on the Northern Ireland Wildlife Order (Wildlife Order, 1985). The Northern Ireland priority species list identifies plant and animal species that are considered to be under threat and in need of conservation action (NMNI, 2013). The Irish Red Data Book of Vascular Plants provides a list of threatened plant species on the island of Ireland (Curtis and McGough, 1988). Species listed in the Red Data book that were classified as not threatened were omitted from analysis. The Red Data Book list applies to the island of Ireland as a whole while the Priority Species list applies to Northern Ireland only. The Flora Protection Order and Northern Ireland Wildlife Order species apply to the Republic of Ireland and Northern Ireland respectively. Where applicable the mapping and analysis of each of these categories of plants was restricted to the different regions of the island. For this study, we have grouped species that have legislative protection together with those species listed on threatened species lists. Collectively we refer to these as 'species of conservation concern' except where it is necessary to refer to the individual categories.

2.2.3 Plant distribution database

Records of species of conservation concern were extracted from tetrad-scale data supplied by the Botanical Society of Britain and Ireland (BSBI) (see Table 2.1 for details). This represents the most comprehensive vascular plant data at the tetrad scale for Ireland. This dataset was supplemented with records of species of conservation concern extracted from rare plant inventories for the Republic of Ireland from the National Parks and Wildlife Service of Ireland (NPWS) (NPWS, 2012a) and for Northern Ireland from the Northern Ireland Environment Agency (NIEA) (Hunter and Wright, 2011). The spatial resolution of these records varied and only records of tetrad resolution (2 km × 2 km grid cells) or finer were extracted for analyses. All of these data were collated into a

plant distribution database together with information on the conservation status for each species.

Table 2.1 Sources of distribution records for plant species of conservation concern in Ireland

Source	Number of records	Number of species
National Parks and Wildlife Service of Ireland	2563	121
Northern Ireland Environment Agency	933	55
Botanical Society of Britain and Ireland	2582	169
Total	6078	176 (distinct species)

The data were collected in a non-random manner and with variable recording effort. It is therefore likely that the collection of the data was subject to biases typically associated with the collection of distribution data e.g. preference for sites closer to roads, species-rich sites, or sites of known past species occurrence. The recording effort was not consistent across the island and while many of the tetrads had low numbers of plant species records, there are some localised areas and counties where tetrads had high numbers (>200) of plant species records (e.g. County Waterford).

When considering records for all plant species, the number of species recorded per tetrad ranged from 1 to 468 and many tetrads had low numbers of species, reflecting low recording effort; for example, more than 2000 of the 6773 tetrads

had species counts ranging from 1 to 5 species. Figure 2.1 and Table 2.2 illustrate the percentage cover of tetrads provided by the plant distribution database for each of the counties of Ireland for all plant species records and for records of species of conservation concern. At the county level, the tetrad coverage for all plant species was generally low, with 14 of the 32 counties having less than 20% coverage. A further 10 counties have between 20% and 50% coverage, leaving 8 counties with greater than 50% coverage. Only two counties, Waterford and Tyrone, have tetrad coverage greater than 80% (Table 2.2). Note however, that the percentage coverage of species of conservation concern, though variable, is similar for the majority of counties. Despite the obvious ‘recorder effort problem’ (Hill, 2012) species of conservation concern are well represented even in those counties with a low percentage cover of all species records (Fig. 2.1, Table 2.2). This would be expected as recorders are more likely to record and report the presence of a rare plant than a very common plant.

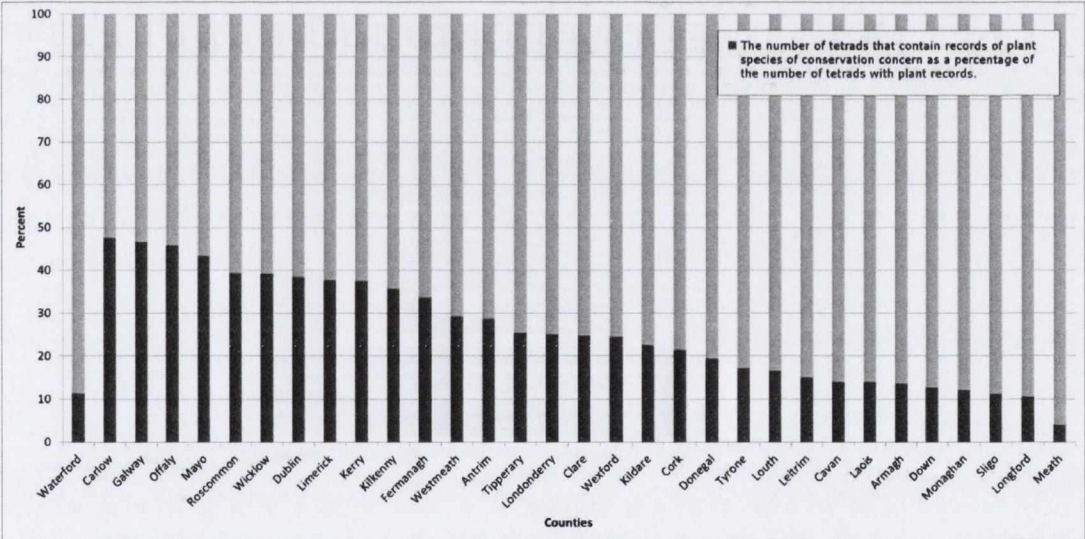


Figure 2.1 County-level distribution of all plant records and records of species of conservation concern in the database. The data are based on the number of tetrads in a county for which there are plant records, and tetrads that contain records of species of conservation concern (dark shading). Waterford is the only county that has had a complete census of plant distribution (100% coverage of tetrads) and is listed first to allow comparison with the other counties.

Table 2.2 A count of the total number of tetrads in each county of Ireland. Also shown are the number of tetrads that contain plant distribution data and the number of tetrads that contain distribution data for species of conservation concern.

County	No. of tetrads in the county	No. of tetrads in the county with plant records (Percentage shown in brackets)	No. of tetrads in the county with species of conservation concern (Percentage shown in brackets)
Cork	2067	415 (20.1)	89 (4.3)
Galway	1694	347 (20.5)	162 (9.6)
Mayo	1569	173 (11.0)	75 (4.8)
Donegal	1434	417 (29.1)	81 (5.6)
Kerry	1370	237 (17.3)	89 (6.5)
Tipperary	1068	106 (9.9)	27 (2.5)
Clare	942	218 (23.1)	54 (5.7)
Antrim	840	384 (45.7)	110 (13.1)
Tyrone	813	696 (85.6)	120 (14.8)
Down	702	487 (69.4)	62 (8.8)
Limerick	677	85 (12.6)	32 (4.7)
Wexford	646	441 (68.3)	108 (16.7)
Roscommon	619	61 (9.9)	24 (3.9)
Meath	585	50 (8.5)	2 (0.3)
Londonderry	535	307 (57.4)	77 (14.4)
Wicklow	521	102 (19.6)	40 (7.7)
Kilkenny	517	112 (21.7)	40 (7.7)
Sligo	516	302 (58.5)	34 (6.6)
Offaly	505	72 (14.3)	33 (6.5)
Waterford	501	501 (100.0)	57 (11.4)
Cavan	483	57 (11.8)	8 (1.7)
Westmeath	465	82 (17.6)	24 (5.2)
Fermanagh	464	294 (63.4)	99 (21.3)
Laois	433	50 (11.5)	7 (1.6)
Kildare	422	93 (22.0)	21 (5)
Leitrim	404	226 (55.9)	34 (8.4)
Armagh	331	147 (44.4)	20 (6)
Monaghan	320	83 (25.9)	10 (3.1)
Dublin	270	117 (43.3)	45 (16.7)
Longford	270	38 (14.1)	4 (1.5)
Carlow	230	42 (18.3)	20 (8.7)
Louth	226	24 (10.6)	4 (1.8)

We created a geospatial data layer (using the plant distribution database) to map the vascular plant species of conservation concern at the tetrad level. A tetrad vector grid (labelled with national tetrad codes) with a point of origin and spatial coverage matching that of the Irish National Grid was constructed using Hawth's Tools (Beyer, 2004). Analyses were restricted to terrestrial areas only. Only records of species of conservation concern from 1987 onwards were included for analyses. This date coincides with a Botanical Society of Britain and Ireland data collection event. Tetrads containing these species were identified as 'target tetrads' and their location with respect to designated areas was examined.

2.2.4 Designated areas

European Union member states are required to designate Special Protection Areas and Special Areas of Conservation under the Bird and Habitats Directives respectively for the protection of species and habitats. These directives have been transposed into law by the European Communities (Birds and Natural Habitats) Regulations 2011 in the Republic of Ireland and by the Conservation (Natural Habitats, etc.) Regulations (Northern Ireland) 1995 in Northern Ireland.

In addition to Natura 2000 sites, other areas of high conservation value in Ireland (because of their habitats, flora, or fauna) have been designated as Natural Heritage Areas in the Republic of Ireland and as Areas of Special Scientific Interest in Northern Ireland (Environment Order, 2002; Wildlife (Amendment) Act, 2000). These sites often occur on private lands and protection for species and habitats is provided by restrictions placed on harmful activities.

These designated areas represent the majority of sites designated for the conservation of biodiversity on the island of Ireland and so were used in this study. Areas that are solely designated as nature reserves or national parks are also present in Ireland, but were not included in the analysis. The Natura 2000 and Natural Heritage Areas boundaries for the Republic of Ireland were

downloaded from the National Parks and Wildlife Services online map viewer (NPWS, 2012b) and Natura 2000 and Areas of Special Scientific Interest boundaries for Northern Ireland from the Northern Ireland Environment Agency website (NIEA, 2012). All designated area boundary files were merged together in ArcMap 10.0 (ESRI, 2011) to create a single shapefile of designated areas on the island of Ireland. The area covered by the designated area networks in Ireland is provided in Table 2.3. The proportion of each tetrad area that overlapped with a designated area was calculated using ArcMap 10.0.

Table 2.3 The area (km²) of designated area networks in Ireland.

Designated Area	Area km2	Area (%)
Areas of Special Scientific Interest	1028	1.2%
Natural Heritage Areas	600	0.7%
Natura 2000	10417	12.3%
Total	11009	13%

The designated areas were not solely established for the protection of species of conservation concern. In particular, Special Protection Areas are designated for bird species and may not be providing protection to plant species of conservation concern. For this reason the analyses were also conducted without the inclusion of Special Protection Areas.

2.3 Analysis

2.3.1 Coincidence of target tetrads with designated areas

We analysed two scenarios to determine the extent to which target tetrads overlapped with designated areas.

Scenario 1: We only considered target tetrads that were conclusively outside of designated areas. Tetrads that had a proportion of their area designated were

identified and classified as being within the network. Tetrads that did not have any intersection with designated area were classified as being outside of the network. A count of species of conservation concern per tetrad for each of the target tetrads was calculated. This also facilitated an assessment of the spatial distribution of records inside and outside of designated areas for individual species. This analysis is a very conservative approach, and will tend to overestimate the degree of overlap between target tetrads and designated areas. Where tetrads contain, for example, less than 10% designated area, there is a possibility that species of conservation concern occur in the tetrad but outside of a designated area within that tetrad. For example, 3863 Red Data Book records were provided with 1 km × 1 km grid references in addition to tetrad references. This allowed a comparison of the coincidence of the records with designated areas at both scales. The results showed that approximately 10% of records that coincided with designated areas at the tetrad scale did not coincide at the 1 km × 1 km scale.

Scenario 2: We used a less conservative rule that classified tetrads with less than 10% coverage of designated area as being outside of the designated area network. The 10% coverage was an arbitrarily chosen value. The target tetrads were again mapped and their location in relation to the designated area network examined.

2.4 Results

2.4.1 Coverage provided by the distribution data for vascular plants

The plant distribution database contained 518,388 records distributed across 6773 (30%) of the 22,449 tetrads that encompass the terrestrial area of the island of Ireland (Fig. 2.2). Records of species of conservation concern were found to occur in 2117 (9.4%) of the tetrads covering Ireland.

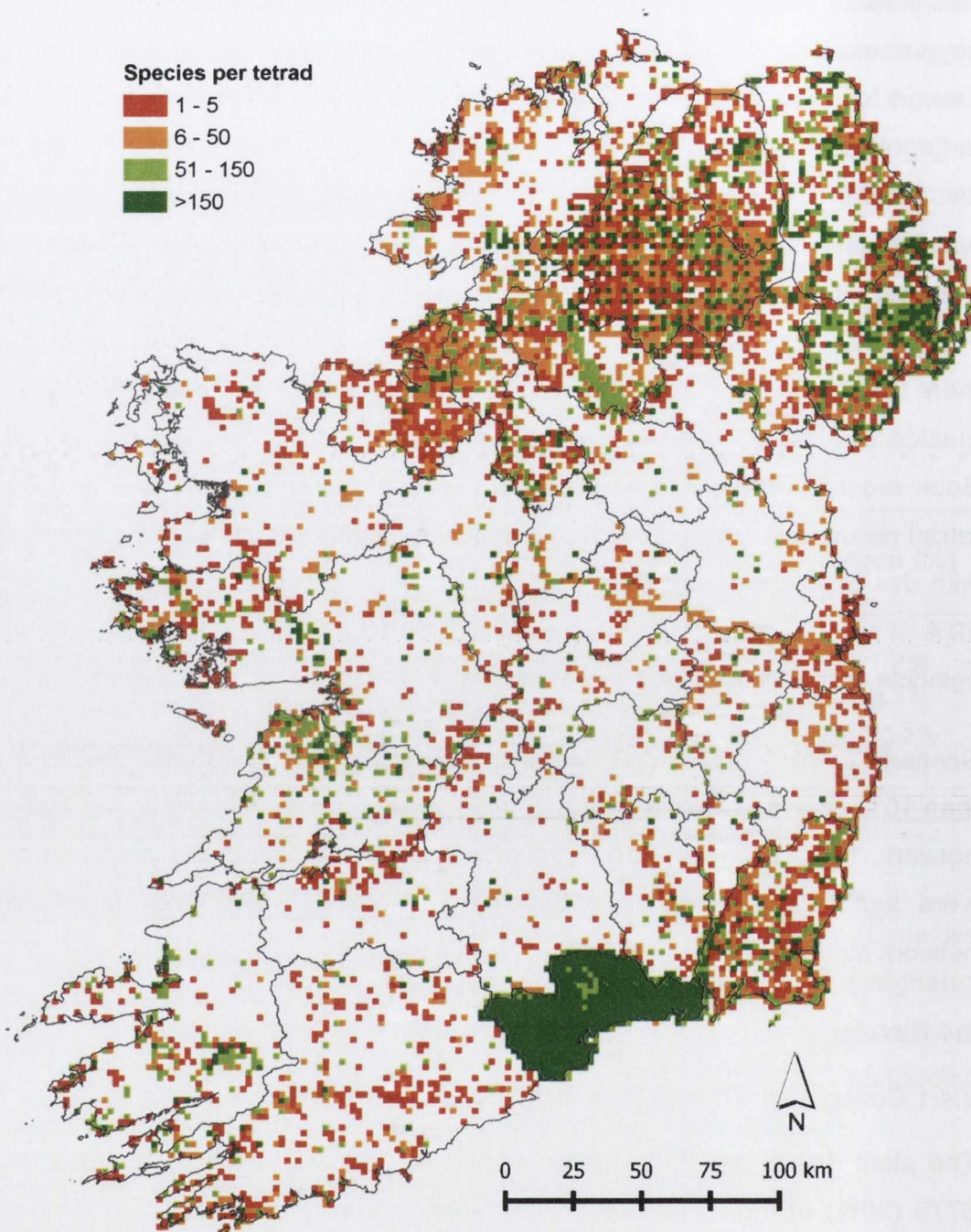


Figure 2.2: The distribution of all plant records at the tetrad scale for the island of Ireland.

2.4.2 Overlap of target tetrads with designated areas

The study area encompasses two political entities with different lists of species that are of conservation concern. For this reason, the Red Data Book category of species of conservation concern alone is applicable to the entire island while the remaining categories apply to either the Republic of Ireland or to Northern Ireland. Each category is therefore presented separately.

On the island of Ireland, 20.6% (1394) of the tetrads with plant data contained records of Red Data Book plant species. Of those, 32.4% (452) were completely outside of the Natura 2000 designated network (Fig. 2.3). When national designations (Areas of Special Scientific Interest and Natural Heritage Areas) were included with the EU designations, the percentage of tetrads with Red Data Book plant species that were outside designated areas was 28.0%. In the Republic of Ireland, 26.5% (300) of tetrads containing Red Data Book species were found completely outside of Natura 2000 designated areas. In Northern Ireland, tetrads containing Red Data Book plant species accounted for 11.8% (281) of tetrads with 57.7% (162) of these tetrads occurring completely outside of the Natura 2000 designated sites. The percentage of the target tetrads outside the designated areas was reduced with the inclusion of Areas of Special Scientific Interest and Natural Heritage Areas in the analysis (Table 2.4).

In the Republic of Ireland, 14.5% (657) of tetrads had records of Flora Protection Order plant species and 23.0% (151) of these tetrads were completely outside of Natura 2000. Tetrads containing Wildlife Protection Order and/or Priority List species in Northern Ireland accounted for 16.7% (398) of the tetrads with plant records in that region. Of these 49.5% (197) were located completely outside of the Natura 2000 network. The percentage of target tetrads outside the designated areas was reduced with the inclusion of Areas of Special Scientific Interest and Natural Heritage Areas in the analysis (Table 2.4). In the second scenario, there was an expected increase in the percentage of target tetrads outside of the designated area network (Table 2.4) e.g. the

percentage of tetrads with Red Data Book species outside of all the designated areas on the island of Ireland increased from 28% to 44%.

Table 2.4. The percentage of tetrads outside of designated areas for each category of species of conservation concern for scenarios 1 and 2. (SAC – Special Areas of Conservation, N2K – Natura 2000, NHA – Natural Heritage Areas, ASSI – Areas of Special Scientific Interest, RDB – Red Data Book, FPO – Flora Protection Order, WO – Northern Ireland Wildlife Order, PS – Northern Ireland Priority Species).

% tetrads outside designated areas				
	SAC	Species per tetrad	Combined SAC/NHA/ASSI	Species per tetrad
Scenario 1				
Island of Ireland RDB	38.0	up to 4	30.3	up to 4
Northern Ireland RDB	73.3	up to 4	41.3	up to 3
Northern Ireland WO/PS	64.6	up to 5	33.7	up to 3
Republic of Ireland RDB	29.5	up to 4	27.8	up to 4
Republic of Ireland FPO	25.0	up to 3	23.9	up to 3
Scenario 2				
Island of Ireland RDB	51.8	up to 4	47.1	up to 4
Northern Ireland RDB	82.9	up to 4	64.8	up to 3
Northern Ireland WO/PS	76.1	up to 5	60.1	up to 3
Republic of Ireland RDB	44.3	up to 4	43.0	up to 4
Republic of Ireland FPO	40.9	up to 3	40.2	up to 3
	N2K	Species per tetrad	Combined N2K/NHA/ASSI	Species per tetrad
Scenario 1				
Island of Ireland RDB	32.4	up to 4	28.0	up to 4
Northern Ireland RDB	57.7	up to 2	40.2	up to 2
Northern Ireland WO/PS	49.5	up to 3	31.7	up to 3
Republic of Ireland RDB	26.5	up to 4	25.4	up to 4
Republic of Ireland FPO	23.0	up to 3	22.1	up to 3
Scenario 2				
Island of Ireland RDB	46.3	up to 4	44.0	up to 4
Northern Ireland RDB	69.4	up to 3	61.6	up to 3
Northern Ireland WO/PS	63.6	up to 3	56.0	up to 3
Republic of Ireland RDB	40.9	up to 4	39.8	up to 4
Republic of Ireland FPO	38.2	up to 3	37.1	up to 3

- Area with nature conservation designation
- RDB plant record within area with nature conservation designation
- RDB plant record outside area with nature conservation designation

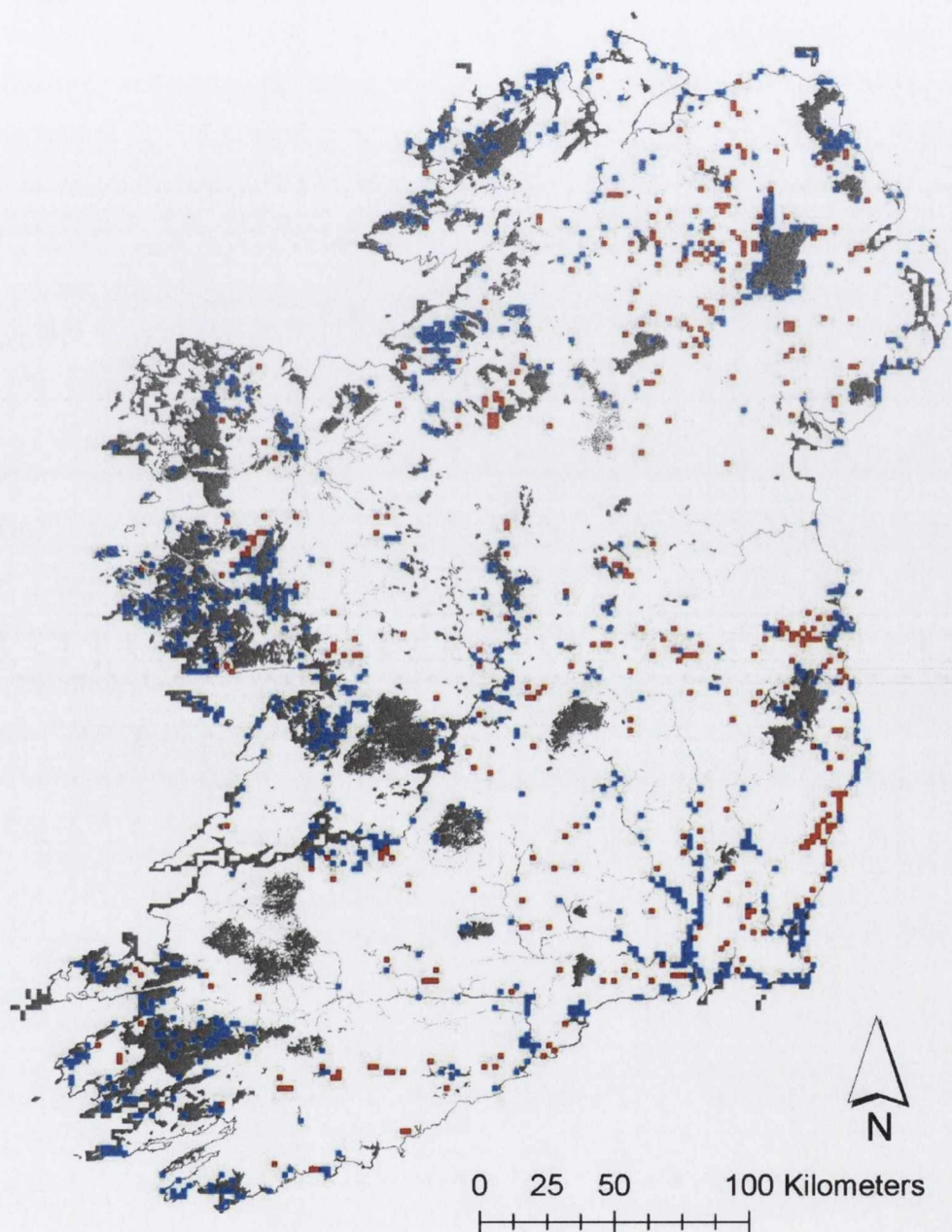


Figure 2.3: The distribution of tetrads that contain Red Data Book (RDB) species in Ireland. The red tetrads illustrate locations that are conclusively outside of designated areas while the blue tetrads represent locations that coincide with designated areas.

There was considerable variation across species both in the number of tetrads with records, and in their coincidence with designated areas (see Appendix 1, Tables 1a, 1b, 1c). Some species were found only within designated areas e.g. the 18 locations of the species *Pilularia globulifera* were all within designated areas. This was not the case for many species, e.g. *Gnaphalium sylvaticum*, where 53% (10 out of 19) of locations were within designated areas. Similarly, *Cirsium heterophyllum*, occurred in two known locations, one of which was within a designated area. Other species such as *Equisetum pratense* were found more frequently outside of designated areas than inside e.g. 64% (18 of 28) of its known locations were outside of designated areas. All of the locations of four Red Data Book species (*Adoxa moschatellina*, *Erica vagans*, *Papaver hybridum*, *Rubus chamaemorus*) occurred outside of designated areas.

Analysis across each of the species' categories showed that, for most of the species, more than 50% of their tetrads occurred in designated areas (Table 2.5). Many species had almost complete coincidence with designated areas; for instance, 42% (59/139) of Red Data Book species each had >95% of their tetrads coinciding with designated areas. However, many Red Data Book species had incomplete coincidence e.g. 36% (50/139) of species each had 26–75% coincidence with designated areas (see Table 2.5).

Table 2.5. A summary of the percentage of tetrads that coincide with designated areas for individual species for the Red Data Book (RDB), Flora Protection Order (FPO), and Wildlife Order/Priority Species (WO/PS) categories of species of conservation concern.

Percentage of tetrads that coincide with designated areas	Number of RDB species	Number of FPO species	Number of WO/PS species
No Cover	4	1	4
0.1% - 25%	0	0	1
26% - 50%	18	4	13
51% - 75%	32	15	12
76% - 95%	26	12	10
>95%	59	34	35
Total	139	66	75

2.5 Discussion

This is the first time that this type of spatial analysis has been applied to a national-scale collection of records of Irish vascular plant species of conservation concern. Although designated areas in Ireland do not encompass all species of conservation concern, they do coincide with the majority of these plant species. The number of target tetrads found inside of designated areas represents a large percentage of populations that could benefit from the forms of protection specifically afforded by the designated area network, e.g. the requirement of EU member states to avoid the deterioration of natural habitats within Special Areas of Conservation under article 6 of the Habitats Directive.

The designated areas do not necessarily cover species of conservation concern; however our results indicate that tetrads that contain these species occur more frequently in these areas than in the non-designated countryside. This may be in part due to bias in the distribution data as recorders may be

more likely to survey in designated areas while overlooking areas of unknown conservation value. Significant effort is required to collect comprehensive vascular plant data at the tetrad scale and this is often carried out on a voluntary basis. Our results have shown that the cover provided by the vascular plant data is incomplete and locations of species of conservation concern may have gone unrecorded at the tetrad scale. The mapped distribution records for all vascular plants offers guidance to where additional recording could take place to provide a stronger knowledge base for supporting conservation actions.

Approximately 60–80% of the locations of species of conservation concern in Ireland occur within designated areas and it could be argued that the higher occurrence of these species in designated areas is a sign of effective targeting. While this represents a large proportion of the locations of these species it cannot be guaranteed that the designated areas are providing good protection, particularly since the status of many of the protected habitats in Ireland has been found to be in unfavourable condition (NPWS, 2008). However the designated areas may still offer some form of protection and it is possible that this effect could be due to greater losses among populations in the unprotected landscape. If true, then this increases the need to identify where these species are occurring and to take steps to ensure their persistence.

The remainder of populations of plant species of conservation concern in the undesignated wider countryside (87% of the island) will continue to be even more susceptible to threatening processes such as land-use change, e.g. the intensification of farming practices and land abandonment (Tasser and Tappeiner, 2002). Furthermore, at the level of individual species, there is wide variation in the coincidence of designated areas with tetrads in which the species occur. Even if designated areas provide effective protection to species of conservation concern a more comprehensive conservation strategy could be achieved by implementing targeted conservation in the wider countryside. This would complement designated areas and other measures such as legislation for the protection of flora.

Overall, this work supports the growing recognition of the importance of conservation in the wider countryside. Two thirds of the land cover of Ireland can be categorised as agricultural (DARD, 2012). Similarly, land in tetrads containing plant species of conservation concern outside of designated areas is predominantly used for agriculture (Table 2.6), so populations of these species outside of designated areas could potentially be targeted by agri-environment schemes. A poor evidence base exists for supporting the design and targeting of biodiversity objectives in EU agri-environment schemes (Primdahl et al., 2010); while such schemes can be effective in the conservation of generalist farmland wildlife (Kleijn and Sutherland, 2003), their protection of rarer and threatened habitats and species is less clear (Kleijn et al., 2006). Nevertheless, well-designed and targeted schemes can be very successful (e.g., Kampmann et al., 2012). The targeting of agri-environment schemes to areas of high biodiversity value (such as areas containing species of conservation concern) has been identified as a means of improving conservation management effectiveness (Arponen et al., 2013).

Table 2.6. Land-cover in tetrads outside of designated areas that contained species of conservation concern in the Republic of Ireland.

Corine Land Cover 2006	Area (Km ²)	Percent (%)
Pastures	539.7	49.3
Peat bogs	120.4	11.0
Non-irrigated arable land	112.6	10.3
Discontinuous urban fabric	76.2	7.0
Land principally occupied by agriculture with areas of natural vegetation	61.5	5.6
Other Categories	184.6	16.9
Total	1095.1	100.0

2.6 Conclusions

The ability to prioritise areas for conservation in an objective manner would help address policy goals for increased effectiveness and efficiency for the delivery of biodiversity conservation. This prioritisation is of course dependent on the quality of the species distribution data. The limitations associated with the distribution data for all vascular plant species e.g. low overall cover, means that our current knowledge is incomplete and prioritisation will not be as effective as it could be. The distribution maps of the vascular plant records provides guidance to where additional recording would allow a more comprehensive view of the distribution of species of conservation concern.

The network of designated areas in Ireland includes a moderate part of the distribution of vascular plant species of conservation concern. However many of the locations of these species occur outside of the network and as some species occur mostly or totally outside of the designated areas, there is a clear need for additional conservation measures outside of designated areas. The locations of these species in the non-designated landscape offer an opportunity to better inform species-specific spatial targeting of conservation measures. To further aid the targeting of measures, steps could be taken to use the vascular plant distribution data in Ireland to identify the most important areas of plant diversity in the landscape.

3. A scoring method of spatial conservation for the identification of priority areas for plant conservation in Ireland

3.1 Introduction

The on-going depletion of global biodiversity (Ceballos et al., 2015) has provoked action in the form of global agreements and regional action plans to stem the losses of biodiversity, including goals to safeguard species and habitats (CBD 2010; European Commission 2011). The success of these goals will require knowledge of the locations of important areas of biodiversity so that limited conservation resources can be targeted effectively (Margules & Pressey, 2000; Rodrigues et al., 2000). There is therefore a need to devise methods for the identification of areas of high biodiversity value areas to inform conservation planning.

The identification of priority areas must be based on the value of the biodiversity within them (Abellan et al., 2005) and therefore prioritisation methods often rely on the spatial distribution of relevant components of biodiversity such as species distribution, habitat condition, or threats (Moilanen et al., 2009). Expert-driven methods use the experience of relevant experts to identify priority areas for conservation but are subject to the biases associated with experts' uneven knowledge and personal experience (Cowling et al., 2003). Criteria-based methods apply species threshold requirements for the prioritisation of areas and have been applied for globally important sites such as Important Bird Areas (IBA) (Brown et al., 1995), Important Plant Areas (IPA) (Anderson 2002), Key Biodiversity Areas (KBA) (Eken et al., 2004), and biodiversity hotspots (Myers et al., 2000). Algorithmic prioritisation methods incorporate the concept of complementarity where priority areas best complement each other in terms of the biodiversity they contain. These methods can identify priority areas that meet strict requirements (Williams et al., 2004) or attain near-optimal solutions to conservation targets (Watts et al., 2009). Scoring methods prioritise areas by assigning a value of biodiversity to

each spatial unit (i.e. grid-cell, site) based on a set of user-assigned criteria. The sites can then either be separated into classes of conservation importance (Burgess et al., 2006; Ture & Bocuk 2010) or ranked in order of conservation value and the highest value sites selected as priority areas (Abellan et al., 2005; Blasi et al., 2011).

A key function of priority areas of biodiversity is that they should represent the biodiversity of the region in which they are located (Margules et al., 2002). This role is known as representation and is defined as the extent to which natural features, such as species, occur within a set of sites (Cabeza & Moilanen 2001). The importance of representation within priority areas is reflected in the conservation literature where the level of the representation of features such as species and ecosystems is used as a measure of the effectiveness of priority areas (Albuquerque et al., 2013; Armenteras et al., 2003; Pliscoff & FuentesCastillo 2011; Rodrigues et al., 2004).

The objectives of this research were to provide conservation values for plants at two spatial scales (tetrad and hectad) in Ireland. This was achieved by developing a scoring method of prioritisation that used available species information and distribution records of vascular plants. The scoring method assigned a plant conservation value to each grid cell at the hectad scale (10km x 10km) for Ireland and at the tetrad scale (2km x 2km) for two counties in Ireland that had high resolution and cover of plant distribution data. The spatial scales used in the research were determined by the scale of the plant distribution data available. These scales do not allow the identification of specific sites but rather identify broader high value areas to inform conservation planning and to highlight areas for further research.

The relationship between species representation and the number of high value cells (potential priority areas) was investigated to determine if an objective cut-off value for the number of cells to be prioritised could be identified. The efficiency of the scoring method in terms of representation was examined by comparing the species representation of the method with areas selected at random and with areas selected using a species richness approach, where the

cells with the highest species counts were selected as priority areas. Finally, the locations of priority areas identified using the scoring method were compared to the locations of areas designated for conservation.

The scoring method outlined in this research assigns conservation value to the cells in each of the study areas. This provided useful information on the distribution of high value areas, but conservation planning often requires the identification of a limited number of priority areas for conservation action (Kukkala & Moilanen 2013). The concept of representation, the number of species captured by priority areas, is an important consideration in priority area selection (Margules et al., 2002). The relationship between the number of species and the number of priority areas identified by the scoring method was used to determine how many high value cells should be selected as priority areas.

3.2 Methods

The island of Ireland is located to the west of the European mainland and has a temperate, maritime climate (Kiely, 1999). 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 3.1). Both counties cover an area of approximately 1800km².

Hectad-scale distribution records of vascular plant species were provided by the Botanical Society of Britain and Ireland (BSBI) and 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 998 of the 1014 (99%) hectads in the island of Ireland. Two counties in Ireland, Fermanagh and Waterford, have detailed plant records at the tetrad scale (2km x 2km). Records from 1987 onwards were considered for both the hectad and tetrad scale analysis as this date coincides with a Botanical Society of Britain & Ireland data collection event. The distribution data

covered 512 of the 541 tetrads (95%) in County Fermanagh, and 544 of the 551 tetrads (99%) in County Waterford.

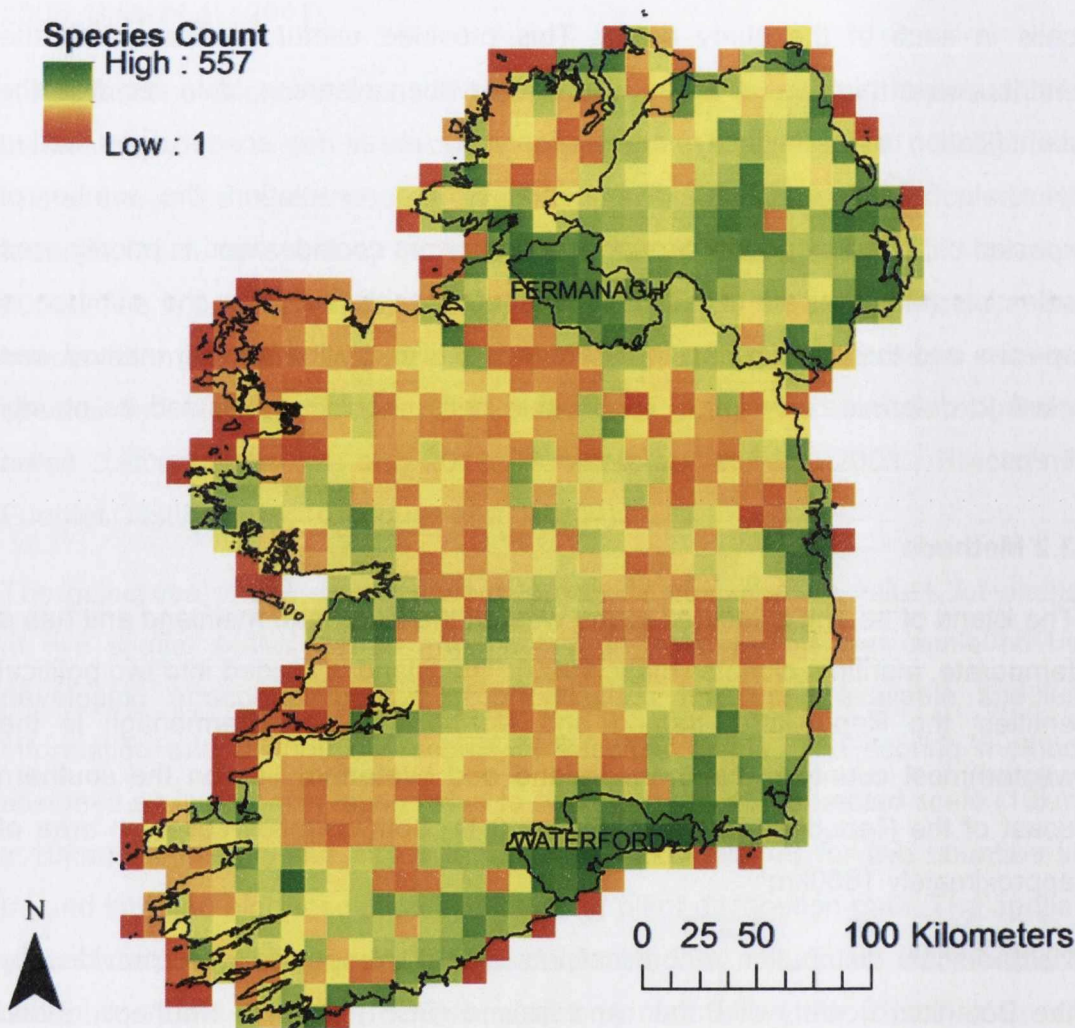


Figure 3.1: The species count per hectad for Ireland.

3.2.1 A scoring method for the identification of priority areas

The purpose of the scoring method was to assign a value to each cell corresponding to its importance as an area of plant diversity, based on established species information and the distribution of vascular plants. This value is hereafter referred to as the Cell Conservation Value. Using a combination of plant status and plant distribution data, a plant conservation value, represented in the scoring method as a Species Value, was devised for each species.

3.2.2 Plant species categories

Species were assigned to one of four categories in increasing order of priority; (1) native species, (2) Semi-natural habitat indicator species, (3) Annex I habitat indicator species and (4) Species of high conservation concern. The numbers of species in each exclusive category are shown in Table 3.1. Once assigned to a category the species is awarded a numerical value for use in the scoring method, defined as the Species Weight that reflects the importance of the species in terms of conservation value (Table 3.2). An initial construction of the scoring method used species weights of native = 1, Semi-natural = 2, Annex I = 3 and SCC = 4. On examination the representation of the SCC group within the highest scoring cells was found to be low. For this reason the species weights were changed to SCC = 1000, Annex I = 100, Semi-natural = 10, native = 1 (Table 3.3) to increase the influence of the SCC group on the values assigned to cells and thereby increasing the representation of the group in the highest value cells. Each species was assigned to one exclusive category.

Table 3.1: 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)

Study Area	SCC	Annex I	SN	Native	Total
Ireland	181	428	107	643	1359
Fermanagh	47	326	82	239	694
Waterford	25	364	93	351	833

Table 3.2: Species categories and associated criteria used to assign species weights in the scoring method.

Species Attribute	Criteria	Species Value
Species of conservation concern	Rare & threatened species	High
Annex I habitat indicator	Species indicative of habitats of European importance	
Semi-natural habitat indicator	Species indicative of habitat in a semi-natural state	
Native species	Species native to the island of Ireland	Low
Other species	Non-native species	No Value

3.2.3 Native species

Native status was assigned to species using the Irish Vascular Plant Synonym Workbook (Jebb, 2012). Non-native species that did not already feature in the other species categories were omitted from the analysis; however, there were some species that did not have native status according to the Irish Vascular Plant Synonym Workbook that were listed in other categories, for example as indicators of Annex I habitats. Although these species did not have native

status they were included in the scoring method due to their presence on the other species lists (i.e. Annex I habitat indicators etc.)

3.2.4 Semi-natural habitat indicator species

Semi-natural habitat indicator status was assigned using the Guide to Habitats in Ireland (Fossitt, 2000) which contains a list of species found in semi-natural habitats. Semi-natural habitats are any habitat where human induced change or management occurs, but which still appears as natural habitat (SDI4SEB, 2015). Indicator species can occur in several habitats and the presence of the species is not equivalent to the presence of the habitat. However the presence of a greater number of these indicator species is indicative of an area that is likely to contain these habitats. Habitat indicator lists will often refer to general species groups and in these instances the New Flora of the British Isles (Stace, 2010) was used to identify the correct species according to the species habitat description. Species in this category have been awarded the third highest species weight.

3.2.5 Annex I habitat indicator species

The Annex I habitat indicator category contains species indicative of habitats listed in Annex I of the Habitats Directive (Council Directive 92/43/EEC). A list of Annex I habitat indicators was collated for each of the Annex I habitats known to occur in Ireland (NPWS, 2008). Species lists for each habitat were created using a combination of the Interpretation Manual of European Union Habitats (Interpretation Manual - EUR27) and a series of reports produced for the National Parks and Wildlife Service of Ireland (Perrin et al., 2010; Barron et al., 2011; Fernandez et al., 2012; Cross and Lynn, 2013; Delaney et al., 2013; O'Neill et al., 2013, O'Neill and Barron, 2013; Wilson and Fernandez, 2013). The species in this category have been awarded the next highest species weight as they are indicative of habitats that are important in terms of the conservation of biodiversity at the EU and national level.

Table 3.3: Species values that are derived from a combination of species weights assigned to reflect species conservation value and species distribution values that were assigned to species based on their percentage distribution at the hectad scale in Ireland. For example, a species with a weight of 1000 and in distribution category 6 has a species value of 6000 (1000 x 6). (SCC = Species of Conservation Concern, A1 = Annex I habitat indicator species, SN = Semi-natural habitat indicator species, Native = native species).

Distribution	Species				
	Distribution Value Categories	Species 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

3.2.6 Species of conservation concern

The species of conservation concern category consists of species listed as threatened in the Irish Red Data Book (Curtis and McGough, 1988). This list is supplemented by species scheduled for protection on the Flora Protection Order of Ireland (Flora Protection Order, 1999) and the Northern Ireland Wildlife Order (Wildlife Order, 1985), and also by species listed as requiring conservation action in the Northern Ireland Priority Species list (NMNI, 2013). The Red Data Book provides a list of rare and threatened species while the Flora Protection Order and Northern Ireland Wildlife Order each contain a list of

species that are afforded legal protection. Species on the Northern Ireland Priority Species list are in need of conservation action because of their decline, rarity and importance. It is assumed here that these lists collectively represent those species that are of greatest conservation concern. It is also assumed that species of high conservation concern require more urgent conservation action than species in the other categories and consequently species in this category have been assigned the highest species weight (Table 3.2).

3.2.7 Plant species distribution value

Species distribution values were calculated by examining species distribution records at the hectad (10km x 10km) scale for the island of Ireland (from 1987 on). A percentage value for each species was calculated by dividing the number of hectads that a species occurred in by the total number of hectads with plant distribution data in Ireland. Species with a more limited distribution are more vulnerable than those with a widespread distribution (Mouillot et al., 2013) and these have accordingly been assigned a higher ordinal value (Table 3.3). Although the hectad-scale data appears 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). And it is for this reason that indicative broad bands of species distribution are used within the scoring method rather than relying on direct percentage values derived from the somewhat inaccurate hectad-scale distribution data.

A final Plant Species Conservation Value was calculated as follows:

$$\text{Plant Species Conservation Value} = \text{Species Weight} \times \text{Species Distribution Value}$$

3.2.8 Identification of priority areas for conservation

Cell Conservation Values were assigned to each grid cell both nationally for hectad scale data and for tetrad scale data in counties Waterford and Fermanagh. A Cell Conservation Value is equal to the sum of the Species Values associated with the plant species in the cell. Each species contributed a single Species Value to the Cell Conservation Value regardless of the number of times that species occurred in the cell, or any measure of its abundance.

Scoring Method:

$$\text{Cell Conservation Value} = \sum \text{Species Values in each cell}$$

The SCC 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 cells with high values represent the areas most important for plant diversity as determined by the scoring method. However, this does not identify which cells that should be prioritised. Cut-off points to identify the top priority cells were selected using piece-wise regression for Waterford, Fermanagh and the island of Ireland. Firstly, species representation within the cells was examined in order to determine a value that could be used as a prioritisation cut-off point. The cells were ranked in order of value and the number of species present was plotted against a number of the highest value cells until all of the Species of Conservation Concern (SCC) were represented. The plots of species representation within sites (also known as species accumulation curves) (Condit et al., 1996), showed a relationship that is typical of that found in biodiversity studies and follows an asymptotic pattern until a maximum number of species is recorded (Soberon & Llorente 1993). This type of accumulation curve has been observed in other studies, including priority area identification in

Spain (e.g. Abellan et al., 2005) and research examining species representation within protected areas in Canada (Wiersma & Nudds 2009).

Secondly, piece-wise regression (also known as broken-stick or segmented regression) can be used to locate critical thresholds in the relationship between two variables (Toms & Esperance 2003). Piecewise-regression was used to identify the point at which an abrupt change in species representation occurred in the species accumulation curves. This allowed the selection of a fixed number of high value cells in which species representation is kept at a high level without including additional cells that only marginally improved representation. This provided an objective approach to deciding how many of the highest scoring cells should be selected as priority areas in each study area. Each cut-off point corresponded to the estimated break point (as the nearest percentage of cells) identified by the piece-wise regression when applied to plots of species representation against the number of high value cells for each study area.

All cells with values above the suggested cut-off point can be considered the top priority cells. Representation of the species of conservation concern category and for total species numbers in priority areas identified by the scoring method and piece-wise regression were compared to those in a number of cells identified using species richness and randomly selected cells. The areas selected using richness correspond to the cells with the highest species counts while the random selection was obtained by selecting a set number of cells at random 1000 times and using the mean species representation value of the top 5% of the random distribution (Aruajo et al., 2004). In each case a number of cells corresponding to the value identified by the scoring method and piece-wise regression were identified using the richness and random selection approaches. The random sampling and broken-stick regression analysis was conducted using the R statistical software package.

The degree to which the identified priority areas tended to cluster was examined by calculating Global Moran's I values using ArcGIS 10 .0 based on the distribution of the identified priority areas. The Global Moran's I statistic

provides a measure of the degree to which a spatial pattern is clustered, dispersed, or random (ESRI, 2015).

3.2.9 Coincidence of priority areas with conservation designated areas and local Important Plant areas

The priority areas identified by the scoring method were compared to the locations of known priority areas for habitats using designated protected areas boundaries across the jurisdictions. These were Natural Heritage Areas in the Republic of Ireland, Areas of Special Scientific Interest in Northern Ireland and Special Areas of Conservation, Special Protection Areas across both areas. The priority areas identified were also compared to the locations of previously identified local Important Plant Areas in County Waterford (Green and Fitzpatrick, 2008).

3.3 Results

3.3.1 Plant Species Conservation Values

The scoring method assigned a single conservation value to the cells in each of the study areas to differentiate between areas of high and low cell conservation value (Figure 3.2; Table 3.4). The spatial distribution of the Cell Conservation Values show strong positive clustering values (Global Moran's I: Fermanagh: 0.45, Waterford: 0.32, Ireland: 0.46).

The number of species present in the highest scoring cells was plotted (Figure 3.3) against the number of high value cells. These plots showed a relationship between the number of cells and the number of species represented that was similar at both the hectad and tetrad scale. Relatively low numbers (approximately 50% - 80%) of species were present in the top 5% of cells and the numbers of species quickly increased with the addition of cells up to approximately 8% - 10% of top scoring cells. At this point the number of additional species present in the collection of cells increased at much slower rate and 20%, 44%, and 52% of the highest scoring cells were required to

guarantee that all SCC were represented in Waterford, Fermanagh, and Ireland respectively.

Table 3.4: The number of cells in each study area and the maximum, minimum and average cell conservation values.

Study Area	Number of cells	Cell Conservation Value		
		Maximum	Minimum	Average
Ireland	998	190699	36	54954
Fermanagh	512	88257	6	21606
Waterford	544	55576	2562	19185

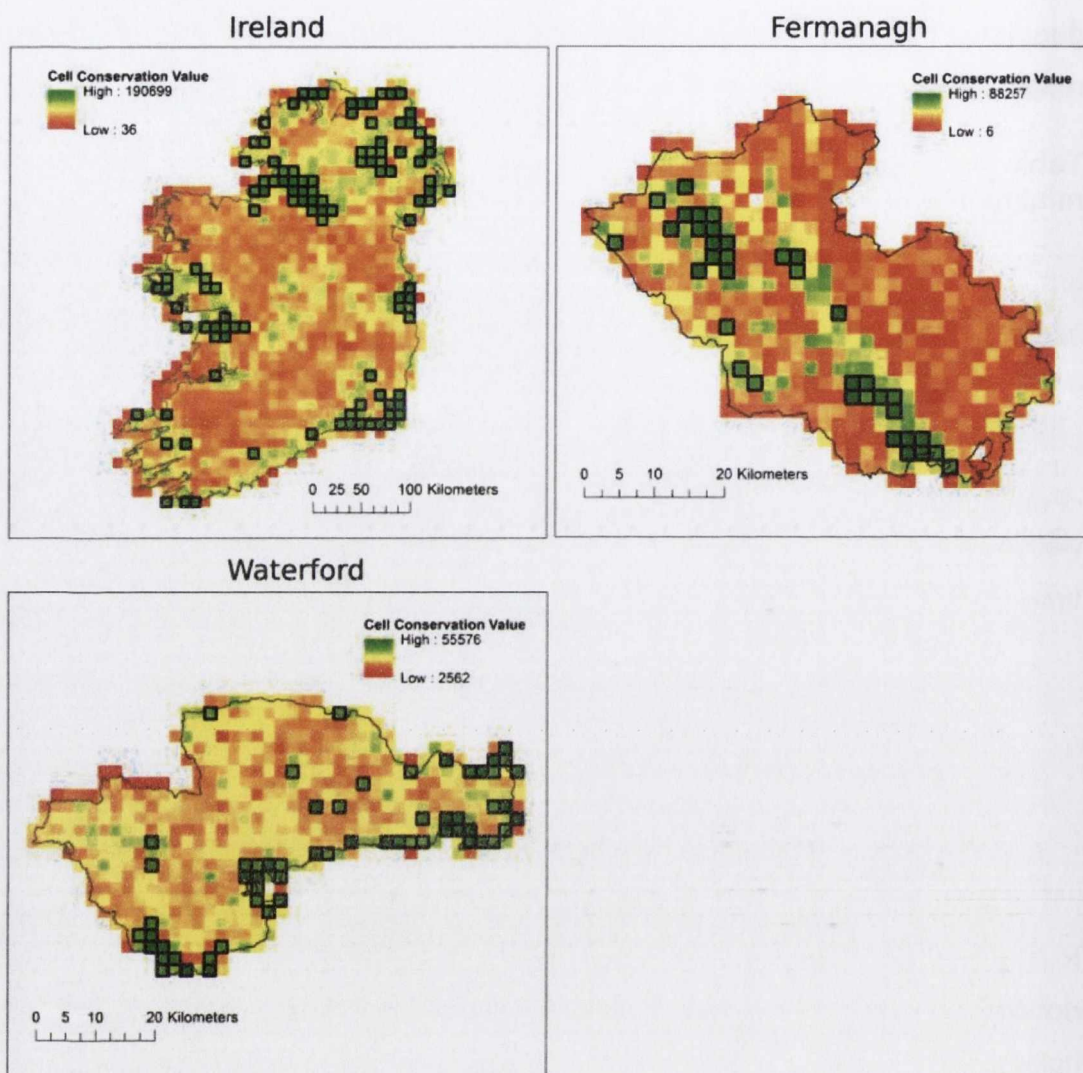


Figure 3.2: The Cell Conservation Values for Ireland, Co. Fermanagh, and Co. Waterford with the cells identified as priority areas outlined in bold.

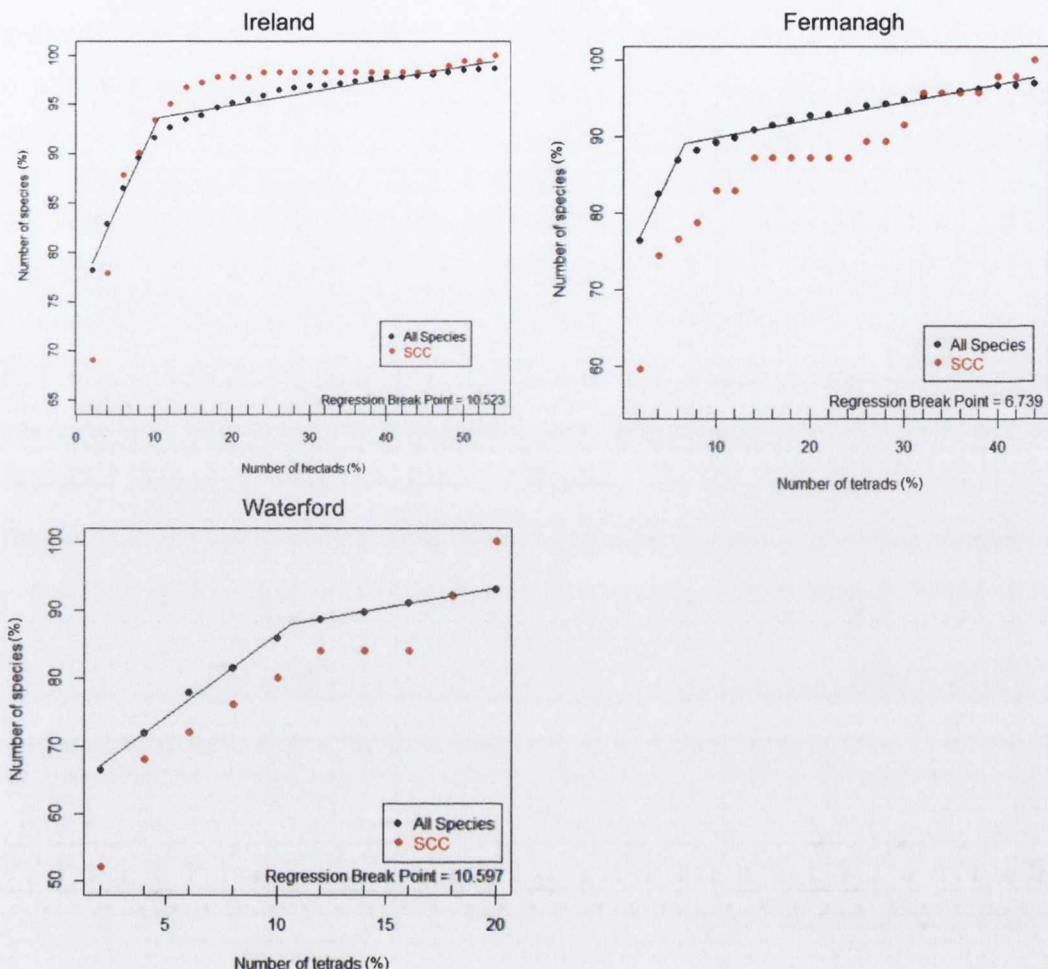


Figure 3.3: The number of species in cells with the highest cell conservation values in Ireland, Co. Fermanagh, and Co. Waterford. The black lines show the piece-wise regression lines identified for each study area.

3.3.2 Identification of Priority Areas

The plots of species presence in the top scoring cells showed that the relationship between the representation of all species and the number of prioritised cells changes as the number of cells increased. Piece-wise regression was used to calculate a break point in the plots that identified where that change in the relationship was occurring (Figure 3.3). The cells were ranked in order of cell conservation value and a number of highest value cells that corresponded with the regression break point were selected as priority

areas. These priority areas were not evenly spread out across each study area and instead exhibited a positive clustering in each case (Global Moran's I: Fermanagh: 0.31, Waterford: 0.23, Ireland: 0.30).

In addition to the use of a scoring method for the identification of priority areas a random selection of cells and a selection using the cells with highest species counts were used to allow a comparison of species representation. The random selection approach provided the lowest representation of all species and of species of conservation concern (Table 3.5). The scoring method and richness approach achieved very similar representation levels for all species; however the scoring method achieved a higher level of representation for species of conservation concern.

Table 3.5: The number of species in the priority areas identified using three methods: a scoring method, a species richness method, and a random selection of cells. The break-point was identified using a piece-wise regression analysis of species representation in the highest scoring cells as identified by the scoring method. (SCC = Species of Conservation Concern)

Study Area	Method	Break-point	Cells (%)	SCC (%)	Species (%)
Fermanagh	Scoring	6.7	7	78	88
	Richness		7	70	87
	Random		7	38	61
Waterford	Scoring	10.6	11	84	88
	Richness		11	60	87
	Random		11	48	80
Ireland	Scoring	10.5	11	92	92
	Richness		11	86	91
	Random		11	75	84

3.3.3 Coincidence of priority areas with conservation designated areas and local Important Plant areas

Sites have been designated for the protection of habitats across Ireland and 99% of the priority areas identified at the hectad scale contained designated areas. At the tetrad scale, 94% of the priority areas in Fermanagh and 82% of areas in Waterford contained at least some designated area (Figure 3.4). In addition to partial coincidence with designated areas a large percentage of priority areas identified in both Waterford and Ireland occurred at the locations that intercepted the coast line, where 58% of priority areas in Waterford and 56% of priority areas in Ireland intersected the coast (Fermanagh is a landlocked county).

IPAs have been identified at the local level for Co. Waterford (Green & Fitzpatrick 2008). Figure 3.5 shows the distribution of both the local IPA and of scoring method priority areas. The priority areas overlapped with 47% of the local IPA cells; some cells for which IPAs were designated had only moderate conservation value (Figure 3.5).

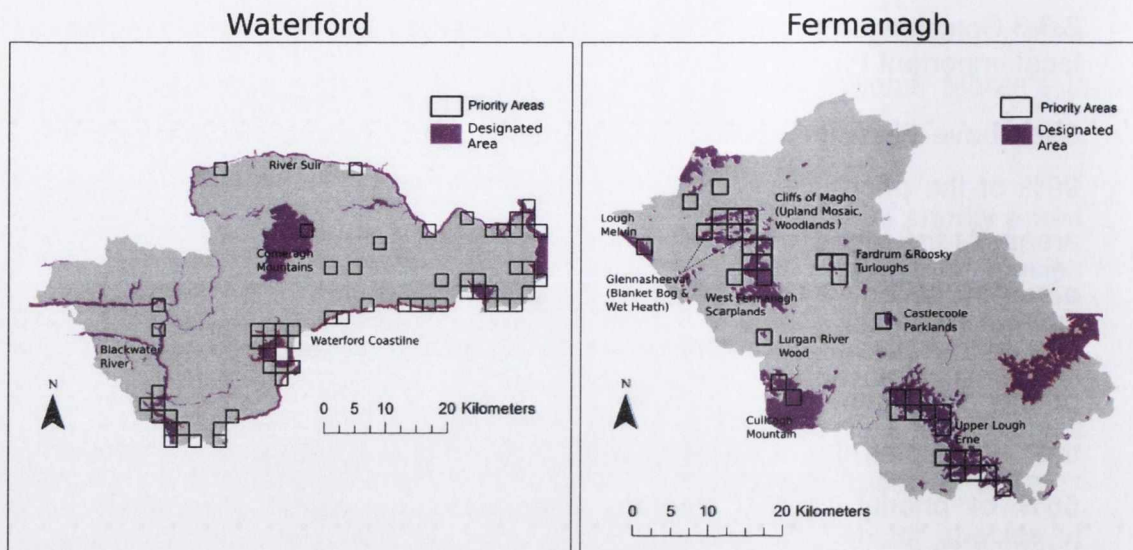


Figure 3.4: The distribution of the priority areas identified using the scoring method (in bold) and designated areas in Co. Waterford and Co. Fermanagh.

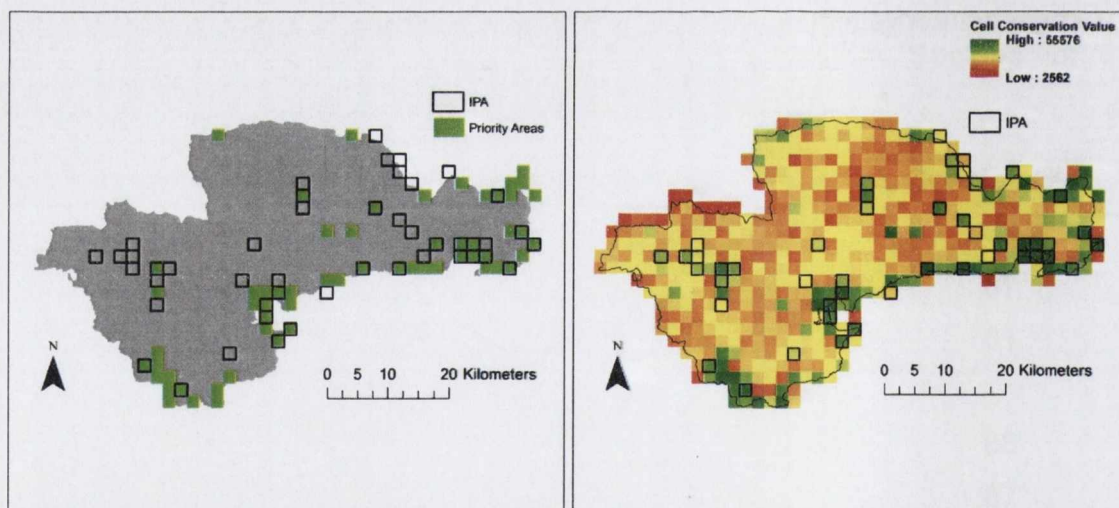


Figure 3.5: The distribution of the priority areas (and cell conservation values identified using the scoring method and Important Plant Areas (in bold identified for Co. Waterford).

3.4 Discussion

3.4.1 Calculating plant species conservation values

The plant species conservation values per cell were derived from values assigned to species within the scoring method and the known plant distribution data. This allowed for the identification of areas with a range of conservation values from high to medium and low conservation value for Waterford, Fermanagh and the island of Ireland (Figure 3.2). This also provides an index of conservation value similar to those produced for other areas (e.g. Blasi et al., 2011; Burgess et al., 2006; Ture & Bocuk 2010). The output of the scoring method 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 lesser conservation value (Boakes et al., 2010). The use of biased data can impact the representation of species and can result in less effective priority areas for conservation (Grand et al., 2007). The issue of potential bias should be considered in the interpretation of the cell conservation values and identified priority areas and also in any future implementation of the scoring method of priority area identification. The scoring method presented in this research is based on higher plant species only and therefore areas that are important to other taxa may have been omitted (Burgess et al., 2006). The selection of priority sites for conservation would benefit from the development of similar indices for bryophytes, invertebrates and vertebrates. The scoring method does however avoid the use of subjective lists of species as criteria, for example axiophytes defined as 'worthy plants' (Green & Fitzpatrick, 2008).

The Species of Conservation Concern (SCC) received the highest species weight in an effort to increase the influence of this species category on the cell conservation values. The SCC category as defined in this research consist of Flora Protection Order and Red Data Book species numbering a total of 134 in

the Republic of Ireland and of Red Data Book, Northern Ireland Wildlife Order species and Priority species numbering 124 in total in Northern Ireland.

The set number of priority areas identified using the piece-wise regression was used to compare the performance of the scoring method in terms of species representation to a random and richness approach to priority area selection. The ability of species richness approach to capture rare species is scale dependent, as larger spatial units are more likely to capture those species (Reid et al., 1998). It is likely that the same effect is responsible for the results seen for all species and with the random selection of sites. Studies using relatively large spatial units reported high levels of species representation in identified sets of reserves. For example, a random set of reserves selected at 50km grid cell size achieved almost the same level of representation of plant species in Europe as sites selected by algorithmic methods (Araujo et al., 2004). At the hectad-scale in Britain, 89% of bird species were represented in areas selected using a species richness approach (Williams et al., 1996). This is evident in the species representation achieved by the prioritisation methods used in this research where the hectad-scale representation of SCC and all species was higher for each method when compared to the tetrad-scale (Table 3.5). The species richness approach outperformed the random selection of priority areas in each of the study areas. This agrees with the outcome of reserve selection in Greece where a richness approach was more efficient at representing species than a random selection of areas (Kati et al., 2004).

The scoring method performed the best out of the three prioritisation methods (Table 3.5) and achieved species representation levels (78% - 92% SCC, 89% - 92% all species) comparable to those found in other studies while using only 7% - 11% of cells. While the species representation levels for all species were similar for the richness and scoring method approaches, the scoring method had higher representation of species of conservation concern and therefore selected priority areas containing more vulnerable plant species. However, the scoring method did not attain full representation of either all species or species of conservation concern and priority areas selected by this method would not

fully sample the plant diversity in Ireland. The use of three different scoring methods for priority area identification based on the distribution of water beetles in Spain resulted in 89% - 94% of all species represented and the representation of 61% - 94% of rare, vulnerable, or endemic species within 20% of hectads (Abellan et al., 2005). A combined scoring and expert-driven method in Italy identified IPAs where 78% - 90% of threatened and 86% of all plant species were represented in the 41% of cells that intersected IPAs (Blasi et al., 2011). A representation level of 81% of red listed dragonflies was achieved in priority areas identified using a scoring method in South Africa (Simaika & Samways 2009).

Additionally, the scoring method only focused on species distribution and conservation value when calculating cell conservation values. Other factors can be of importance in selecting priority areas for conservation, such as threats to species (Visconti et al., 2010), population dynamics and persistence of biodiversity (Cabeza & Moilanen 2001). The spatial design of priority area networks may also need to be considered by incorporating elements such as priority area size, number, proximity, connectivity, and shape (Williams et al., 2004).

3.4.2 Identification of priority areas

There is a tendency of cells with similar cell conservation values and of the priority areas to cluster together indicating that the same types of habitats are being selected on multiple occasions though this would require further investigation to determine if this is true. This does not conflict with the goal of the scoring method to identify all areas of high value but it does indicate a level of redundancy, where replicated instances of the same feature occurs within a collection of areas (Hooker et al., 2011). This is a direct result of the lack of consideration for complementarity within all scoring methods of spatial prioritisation (Arponen et al., 2005), and highlights the importance of all of the high value cells in an area. The clustering or association of priority areas with particular habitats may also indicate that some habitats (e.g. coastal areas or a lake) may have had influence over the priority area selection. Alternatively the

scoring method could be selecting from the highest value areas from amongst the limited types of habitat within each study area. Further research would be needed to understand the representation of habitat and landscapes within the priority areas. Where priority areas coincide with designated sites at the tetrad scale there may be a mix of habitats despite some habitats featuring more than others, for example habitats associated with the designated areas in Fermanagh and Waterford: freshwater, woodland, blanket bog, wet heath, and upland areas in Fermanagh and river, estuary, coastal, and upland areas in Waterford (Figure 3.4). Each cell is likely to contain a mosaic of habitats given the 2km x2km scale and it is not possible to identify if it is the collective habitats or individual sites that are driving high conservation values. The coincidence of the priority areas with designated sites could mean that the designated area network is an important factor in the conservation of plant species. This would be at odds with reports in the conservation literature that found that while globally protected areas are safeguarding species from threatening processes (Gaston et al., 2006), studies at finer scales have highlighted instances where protected areas are not effective (Barber et al., 2012; Devictor et al., 2007; Liu et al., 2001).

An effort has been made to apply the IPA selection procedure at the local scale for tetrads in Co. Waterford (Green & Fitzpatrick 2008). This criteria-based method used thresholds such as the presence of Flora Protection Order species, species indicating important habitats, and species of interest as determined by expert opinion. Of the IPA cells, 75% occur within the top 20% of cell conservation values and the remainder occur within the top 60% of values (Figure 3.5). The priority areas identified using the cell conservation values and piecewise-regression agree at least in part with the identified local IPA and coincide with 47% of the IPA cells (Figure 3.5).

Spatial prioritisation methods seek to identify sets of sites that best meet conservation goals and to allow the targeting of conservation measures to appropriate areas (Kukkala & Moilanen 2013). A methodology already exists for the identification of areas of the highest botanical importance in the form of the

Important Plant Area (IPA) programme. However, the selection criteria in the UK IPA identification process uses globally threatened, EU threatened, endemic and near endemic species (Plantlife 2015a) that place focus on global and regional scale priority areas rather than on local or national sites. Only four sites met the criteria for IPAs in Northern Ireland (Plantlife 2015b) and this may indicate that, in the context of Ireland, the criteria for IPA selection may be too strict. The focus of IPA selection criteria on species of global or European importance rather than species of national conservation concern is likely to limit the range of sites suitable for IPAs, especially when Ireland has few true endemic (Rich et al., 2008) or globally threatened vascular plant species.

Grid-based distribution maps such as the hectad and tetrad scale maps generated in this research are not likely to correspond to relevant sites on the ground (Eken et al., 2004) and the priority areas identified using the scoring method could instead highlight broader areas of high conservation value. As with the case of IPAs, the priority areas add to knowledge of the spatial distribution of plant diversity. These priority areas could be used to complement protected areas, IPAs and priority areas for other taxa and included in an overall national conservation strategy.

While some priority areas overlap with protected areas these do not necessarily target protection to plant species, and populations of plant species of conservation concern occur outside of designated areas in Ireland (Walsh et al., 2015). The locations of priority areas could be used to guide conservation measures allowing the targeting of specific features without the need for expanding or designating additional protected areas. This is of particular relevance for Ireland where future agri-environment schemes are expected to provide targeted protection of biodiversity in both the protected and unprotected countryside (DAHG 2011). The identification of priority areas for plant conservation could be further explored by using complementarity based methods to maximise species representation. These methods could incorporate the cell conservation values to identify efficient networks of these areas. Such networks would consist of the minimum number of sites of high conservation

value that guarantees or maximises species representation. This forms the topic of the next thesis chapter.

3.4.3 Conclusion

The scoring method identified areas of high conservation value based on the distribution of plant species in Ireland. A fixed number of priority areas for conservation can be identified using the level of species representation and the cell conservation values. The scoring method outperforms the richness and random selection methods of prioritisation when species representation is examined. The method can also achieve species representation levels comparable to other scoring methods using fewer areas than in those studies.

4. A complementarity-based method for the identification of priority areas for plants in Ireland

4.1 Introduction

Methods for the identification of priority areas for conservation can be classified into two broad types, the scoring-based and complementarity-based methods (Abellán et al., 2005). A scoring method ranks sites in order of a value derived from a variety of criteria (Pressey and Nicholls, 1989; Chapter 3). A major limitation of scoring methods is that high value sites may share many of the same features while other features may occur in lower value sites; therefore scoring methods often perform poorly in maximising or guaranteeing species representation (Ferrier and Wintle, 2009), the extent to which species occur within a set of sites (Cabeza and Moilanen, 2001). This limitation led to the development of methods that incorporate the principle of complementarity which ensures that areas selected for inclusion in a set of priority areas complement those that have already been selected (Justus and Sarkar, 2002), avoiding unnecessary duplication.

The resources available for the protection of biodiversity are limited and it is necessary to prioritise areas for conservation (Margules and Pressey, 2000). Therefore a goal of conservation planning is to identify priority areas that are efficient in representing species relative to cost (Cabeza and Moilanen, 2001). The greater the number of sites to be targeted, the greater the cost of implementing conservation measures, so efficient reserve networks should consist of the minimum number of sites required to meet a particular conservation objective (Williams et al., 2005). Both complementarity and efficiency can be incorporated in conservation planning by using algorithmic methods.

One algorithmic method known as linear programming is an exact mathematical optimisation technique that can be used to prioritise areas for the conservation of biodiversity (Billionnet, 2013). Prioritisation problems such as

guaranteeing species representation within a minimum set of priority areas can be formulated as optimisation problems (Moilanen et al., 2009). These problems consist of an objective function, e.g. to select a minimum number of priority areas and a set of constraints, e.g. that each species must be represented once in the final selection of priority areas. The method contains a series of constraints that forces the selection of priority areas to a group of cells that collectively represent as many species as possible, thereby following the principle of complementarity.

Prioritisation problems can be formulated as linear programs and solved using algorithms. To solve the Set Covering Problem (SCP) a linear program selects the minimum number of sites in which all species under consideration in the prioritisation problem is represented at least once (e.g. Underhill, 1994, Camm et al., 1996). Instead of requiring full species representation, the Maximal Covering Problem (MCP) relates to the maximisation of species representation in a minimum number of sites (e.g. Camm et al., 1996; Church et al., 1996; Csuti et al., 1997; Gaston and Rodrigues, 2003). Solutions to the MCP will maximise species representation in the selected sites; however if the number of sites is limited to a value less than that required to represent all of the species, the linear program will drop the species that require extra sites. Williams et al., (2004) provide a review of the use of mathematical optimisation techniques in reserve design. Studies have also compared the performance of criteria-based scoring methods and complementarity methods (e.g. Abellán et al., 2005, Marignani and Blasi, 2012).

Conservation planning should include explicit goals (Margules and Pressey, 2000); for example maximising the representation of biodiversity within a network of priority areas for conservation (Margules et al., 2002). The availability of distribution records for vascular plants in Ireland offers an opportunity to apply complementarity based methods for the identification of priority areas for the conservation (Walsh et al., 2015; Chapter 3). In this research sets of priority areas that guarantee representation of species of high

conservation concern while maximising the representation of other species were identified.

A series of conservation planning problems were solved using linear programs based on the distribution of vascular plant species at the tetrad (2km x 2km grid cell) and hectad (10km x 10km grid cell) scales. Here the goals were to:

- (1) identify the minimum number of cells that are required to represent (a) all species (See Species Categories in the Methods section) and (b) all species of conservation concern at least once;
- (2) find the sets of cells in which the maximum number of species can be represented when the number of cells in the priority area network is limited;
- (3) incorporate additional information in the form of cell conservation values derived from the scoring method of Chapter 3 into the linear programming models.

In each case the full representation of species of high conservation concern is guaranteed.

4.2 Methods

4.2.1 Study area

The island of Ireland is located to the west of the European mainland and has a temperate, maritime climate. The island is divided into two political entities; the Republic of Ireland and Northern Ireland. The plant distribution data used in this study were collected using recording systems based on the Irish national grid. The hectad recording system consists of individual cells covering 100km² (10km x 10km) while the tetrad grid consists of cells covering 4km² (2km x 2km). In both cases each species records were assigned by recorders to a specific grid cell. The identification of priority areas using linear programs was completed at the hectad scale for Ireland. The tetrad scale data were relatively low for most of the island of Ireland (30.9% cover); however, two counties, Fermanagh (Northern Ireland) and Waterford (Republic of Ireland), contain the

most complete tetrad scale coverage, and priority areas were identified at the tetrad scale for these counties. Both counties cover an area of approximately 1800 km².

4.2.2 Data

Hectad and tetrad scale distribution records of vascular plant species were obtained from the Botanical Society of Britain and Ireland (BSBI). These were supplemented with data from the Northern Ireland Environment Agency (NIEA) (Hunter and Wright, 2011) and the National Parks and Wildlife Service of Ireland (NPWS) (NPWS, 2012a). Only records from 1987 onwards were retained for both the hectad and tetrad scale analysis as this date marks a major BSBI data collection period and records prior to this may not currently be extant, unless confirmed by a post 1987 survey. The data were converted into a binary presence/absence distribution matrix for each of the study areas. This binary matrix formed the basis of the formulation of the linear programs.

4.2.3 Species categories

Each species in this study was assigned to one of two categories based on criteria used in the scoring method in Chapter 3 (See Scoring method of prioritisation);

- (1) Species of high conservation concern
- (2) Species of lower conservation concern

4.2.4 Scoring method of prioritisation

A scoring method was used in Chapter 3 to identify priority areas for conservation. Species were assigned to categories based on their presence on national species lists. The species of conservation concern category in the scoring method consisted of species listed as threatened in the Irish Red Data Book (Curtis and McGough, 1988). This list was supplemented by species scheduled for protection on the Flora Protection Order of Ireland (Flora

Protection Order, 1999) and the Northern Ireland Wildlife Order (Wildlife Order, 1985), and also by species listed as requiring conservation action in the Northern Ireland Priority Species list (NMNI, 2013).

Three other species categories were used in the scoring method and are grouped together into the species of lower conservation concern in this study:

(1) The Annex I habitat indicator category contained species that are indicative of habitats listed in Annex I of the Habitats Directive (Council Directive 92/43/EEC). A list of Annex I habitat indicators was collated for each of the Annex I habitats known to occur in Ireland (NPWS, 2008). Species lists for each habitat were created using a combination of the Interpretation Manual of European Union Habitats (Interpretation Manual - EUR27) and a series of reports produced for the National Parks and Wildlife Service of Ireland (Perrin et al., 2010; Barron et al., 2011; Fernandez et al., 2012; Cross and Lynn, 2013; Delaney et al., 2013; O'Neill et al., 2013, O'Neill and Barron, 2013; Wilson and Fernandez, 2013).

(2) Species that are indicative of semi-natural habitats were identified using the Guide to Habitats in Ireland (Fossitt, 2000) which contains a list of species found in semi-natural habitats. Habitat indicator lists will often refer to general species groups and in these instances the New Flora of the British Isles (Stace, 2010) was used to identify the correct species according to the species habitat description.

(3) Native status was assigned to species using the Irish Vascular Plant Synonym Workbook (Jebb, 2012). Species that occur in any of these three categories correspond to the species of lower conservation in this study. They are grouped together into one category in this study to allow comparison between the two prioritisation methods.

In the scoring method each species was assigned a species weight in relation to their importance in terms of conservation. This value was combined with a distribution value for each species and the values for all species in each cell were summed to produce a cell conservation value. The cells with the highest

cell conservation values were identified as priority areas. The results of the best scoring method solutions are included in this chapter for comparison with the results of the linear programming method.

4.3 Conservation planning problems and linear programming solutions

4.3.1 Set Covering Problem

Linear Programming (LP) is a mathematical optimisation technique from operations research (Williams et al., 2004). Linear programs find decision variables that optimise an objective function subject to constraints. These programs are referred to as integer programs when some or all of the variables take integer values (Haight and Snyder, 2009). Furthermore the technique is known as a binary integer program when the variables are restricted to the values of 0 or 1. This is typically the case in conservation planning problems as site selection decisions are binary, as is the case in this study where only complete cells (and not parts of cells) can be selected. Two binary integer programs deal with the efficient representation of species within a network of sites. The Set Covering Problem (SCP) seeks to minimise the number of sites selected while guaranteeing species representation (Camm et al., 1996). An optimal solution to the SCP can be found by solving the following objective function (Camm et al., 1996):

$$\text{Min } \sum_{j \in J} x_j \quad (\text{I})$$

$$\text{Subject to } \sum_{j \in N_i} x_j \geq 1 \text{ for all } i \in I \quad (\text{II})$$

$$x_j = (0, 1) \text{ for all } j \in J \quad (\text{III})$$

The objective function (I) seeks to minimise the number of sites selected, subject to constraints (II) and (III). J denotes the set of candidate sites from which to select and I denotes the set of species to be covered. Note that the linear programs do not include the species categories outlined in the Methods section; instead a set of constraints is included in the program for each species, e.g. if an objective of a linear program is to guarantee the representation of species of high conservation value then a set of constraints is included in the program for each species that features in the species of high conservation category. N_i is a subset of J and is the set of sites that contain species i of the set of species. The variable $x_j = 1$ if site j is selected, 0 if site j is not selected. Constraint (2) requires that each species must feature in at least one of the sites selected. Constraint (3) states that the variables are binary.

4.3.2 Maximal Coverage Problem

The second program solves the Maximal Coverage Problem (MCP) and can be used to maximise species representation in a set of sites when the number of sites allowed in the solution is limited (Camm et al., 1996):

$$\text{Max } \sum_{i \in I} y_i \quad (\text{IV})$$

$$\text{Subject to } \sum_{j \in N_i} x_j \geq y_i \text{ for all } i \in I \quad (\text{V})$$

$$\sum_{i \in J} x_j = k \quad (\text{VI})$$

$$y_i = (0, 1) \text{ for all } i \in I \quad (\text{VII})$$

$$x_j = (0, 1) \text{ for all } j \in J \quad (\text{VIII})$$

I , J , N_i and x_j are defined as in the SCP (Camm et al., 1996). Here the objective function (IV) seeks to maximise the number of species represented in

the chosen set of sites using the variable y_i . This variable is defined (V) as $y_i = 1$ if species i is in at least one site, 0 if it is not. Constraint (VI) restricts the number of sites that can be selected to a value k .

4.3.3 Modified Maximal Coverage Problem

The SCP identifies the minimum number of sites required to represent each species. Let z equal this number of sites. The variable k can then be assigned the value of $z - n$, where n is an integer value ≥ 1 , to examine how many species can be represented when the number of cells available is not sufficient to guarantee that all species are represented.

The MCP will identify a set number of sites which contain the highest representation of species, however the program will not distinguish among species categories and species of higher conservation concern are as likely to be dropped from the selected sites as any other species. This can be overcome by the addition of further constraints to the MCP program:

$$\sum_{j \in N_i} x_j \geq 1 \text{ for all } i \in L$$

Here L is a subset of I and is the set of species which must be represented at least once in the chosen set of sites (e.g. species of high conservation concern). This constraint forces the inclusion of sites so that each of the species in the set L is represented at least once. The remaining set of species, M , consists of the species in I after the species of L have been removed. The objective function aims to maximise the number of the species in M in the selected set of sites:

$$\sum_{j \in N_i} x_j \geq y_i \text{ for all } i \in M$$

In each of these linear programs, alternative solutions (if they exist) can be identified. Arthur et al., (1997) introduced an additional constraint that prevents already identified solutions to the program from being generated again.

The existing solution to the program is a set of selected cells represented by x_j^* ($j = 1, \dots, N$) where $x_j^* = 1$ if the cell j is in the selected set, 0 otherwise. A new set of constants is defined as $b_j = x_j^*$ and is included in a new constraint in the linear program, where n is equal to the number of cells in the existing solution:

$$\sum_{j=1}^N b_j \cdot x_j = n - 1$$

4.3.4 Maximum Cell Value

The linear programs aimed to guarantee or maximise species representation as efficiently as possible. However it is possible to include other values in a linear program. In Chapter 3 a scoring method was used to calculate a cell conservation value that reflects the conservation value of that cell. A linear program can be constructed to select the minimum number of sites that maximises species representation while maximising the total value of the cells. The program maximises the sum of the products of the cell conservation value and the cell, where the cell is assigned a value of 1 if selected, 0 otherwise. A prerequisite of this approach is knowledge of the minimum number of sites required so that all species are represented at least once. This value is provided by the SCP program and is represented here by the variable k . Constraint (XI) restricts the number of sites in the solution to the value of k .

$$\text{Max} \sum_{j \in J} (x_j \cdot v) \quad (\text{IX})$$

$$\text{Subject to } \sum_{j \in N_i} x_j \geq 1 \text{ for all } i \in I \quad (\text{X})$$

$$\sum_{j \in J} x_j = k \quad (\text{XI})$$

$$x_j = (0, 1) \text{ for all } j \in J$$

The modified MCP program can identify the set of sites that guarantees the representation of some species while maximising the representation of the remaining species. The solution can show which specific species, defined as P , can be represented within the site limit of the program (k). An additional linear program, here named the Maximum Cell Value (MCV) program can then identify the set of sites that matches this representation level and maximise the total cell conservation value by using the set P in the program constraints.

4.3.5 Solving linear programs

The branch and bound algorithm is the most effective optimal algorithm for solving integer programs (Haight and Snyder, 2009). The algorithm first relaxes the binary restrictions and solves the problem. If this relaxation is an integer then the optimal solution has been found. If the variables are not integers then branching takes place and new sub-problems are formed and solved. This process is repeated until the overall problem is solved or does not converge (Csuti et al., 1997).

LPSolve and Coin-OR CBC are publicly available free linear programming solvers. The LPSolve software uses the branch-and-bound algorithm for solving linear integer programs (LPSolve, 2014) and LPSolve IDE (LPSolve IDE, 2014) provides a convenient user interface. Coin_OR or the Computational Infrastructure for Operations Research project provides the Coin_OR CBC

solver as open-source software for operations research (Coin_OR, 2015). The CBC solver also uses a branch-and-bound algorithm, although the method is referred to as 'branch-and-cut' as the solver uses a cut method to relax integer restrictions. LPSolve was used to solve all but one of the linear programs in this study. The modified MCP at the SCP lower cell limit for Ireland was not solved using LPSolve, and it is likely that this program exceeded the capabilities of the solver. Instead this program was solved using the Coin_OR CBC solver.

4.3.6 Linear programs applied in this study

Linear programs were formulated to solve a series of conservation objectives. The programs and objectives are listed as follows:

(1) SCP for all species:

- Identify the minimum number of cells required to guarantee that all species feature at least once

(2) SCP for species of high conservation concern:

- Solution only guarantees the representation of species of high conservation concern
- Identifies the minimum number of cells required to guarantee that all species of high conservation concern feature at least once

(3) Modified MCP for all species:

- Guarantees that species of high conservation concern feature at least once in the solution
- Maximises the number of other species of lower conservation concern that feature in the solution
- Achieves these objectives when the number of cells in the solution is limited to a value equal to or less than that identified by (1)

(4) MCV for all species:

- Guarantees that species of high conservation concern feature at least once in the solution
- Maximises the number of species of lower conservation concern that feature in the solution
- Maximises the combined cell conservation value of the cells that feature in the solution
- Achieves these objectives when the number of cells in the solution is limited to a value equal to or less than that identified by (1)

Programs 1 and 2 examined all of the cells in the study area to identify the minimum number of cells in which the objectives are satisfied. Programs 3 and 4 also examined all of the cells in the study area but the number of cells that may be included in each solution was limited to a user-specified number. A conservation objective of each of the programs is that all species of high conservation concern are represented at least once in the identified set of cells. The minimum number of cells required to represent all species identified in (1)

and the minimum number of cells required to represent all species of high conservation concern identified in (2) mark the upper and lower cell limits of MCP and MCV programs. MCP and MCV models with a cell limit less than the lower limit will not be solvable as there will not be enough cells in any solution to guarantee that all species of high conservation concern are represented. The use of cell limits greater than the upper bound will result in less efficient solutions where more cells are selected than are needed to guarantee that all species are represented.

The species present in each solution were catalogued to ensure that all species of high conservation concern were represented in each case and to measure the level of representation for the species of lower conservation concern. All of the linear programs accomplished this objective. The sum of the cell conservation values for each solution was calculated to allow comparisons between each of the program solutions and with the scoring method.

The series of linear programs used in this study are shown in Table 4.1 and the number of cells and species used in the linear programs for each of the study areas is shown in Table 4.2.

Table 4.1: The linear programs and corresponding conservation objectives used in this study. (SCP: Set Covering Problem; MCV: Maximum Cell Value; SCC: Species of higher Conservation Concern)

Linear Programs	Conservation Objective
SCP All Species	Identify the minimum number of cells required to guarantee that all species feature at least once
MCV All Species	Identify the set of cells with the maximum sum of the cell importance values in which all species feature at least once
SCP SCC	Identify the minimum number of cells required to guarantee that all species of high conservation value feature at least once
MCV SCC	Identify the set of cells with the maximum sum of the cell importance values in which all species of high conservation value feature at least once
Modified MCP programs for a range of 50% to 90% of the SCP Upper Limit and at the SCP Lower Limit	Identify the set of cells in which the species of high conservation concern are represented at least once and that maximises the representation of the species of lower conservation value. These objectives must be achieved while the number of cells permitted in the program solution is limited to a proportion of the cells required to represent all species i.e. the SCP Upper Limit
MCV programs for a range of 50% to 90% SCP Upper Limit and at the SCP Lower Limit	Identify the set of cells with the highest sum of cell importance values that satisfy the objectives of the corresponding Modified MCP programs.

Table 4.2: The number of cells and species used in the linear programs for each of the study areas. The number of species in the species of high conservation concern category is shown as a percentage of the total number of species in each study area.

Study area	Number of cells	Number of species	Species of high conservation concern as a percent of total species
Fermanagh	512	694	6.8
Waterford	544	833	3
Ireland	998	1359	13.3

The MCV program identified the set of cells that has the highest total of cell conservation values for each scenario examined by the MCP and SCP programs. Therefore the MCV solutions contain exactly the same number of cells and the same level of species representation as the MCP and SCP scenarios (Tables 4.3 – 4.5). However the MCV does not select the same set of cells unless the cells of the MCP or SCP solution happen to be the set with the highest sum of cell conservation values. The MCV programs were subject to the same range of cell limits that were used in the MCP programs. A cell limit equal to the SCP Upper Limit was also used for MCV programs to identify the set of cells that provides the highest sum of cell conservation values, while still ensuring representation of all species.

The cells identified by each of the linear programs were mapped for comparison to maps of priority areas identified by the scoring method of Chapter 3. Figures 4.1 – 4.3 include maps of the species count per cell for the species in the categories outlined in the methods section. The figures also

contain maps of the cells selected by the MCV program while using the SCP Upper and Lower Limits (Figures 4.1 – 4.3).

4.4 Results

4.4.1 General results

Tables 4.3 – 4.5 detail the results of the linear programs for each of the study areas. The name of the linear program is shown with the corresponding number of cells in the solution. As all the linear programs guarantee 100% representation of the species of higher conservation value only the levels of representation of species of lower conservation value are shown. The sum of cell conservation values for the cells that feature in the solution were calculated from values generated by the scoring method of Chapter 3. The first four linear programs find solutions that guarantee species representation with and without the objective of maximising the sum of cell conservation values. The SCP All Species program identifies the minimum number of cells required to guarantee that all species that feature in the categories outlined in 'Species categories' in the methods section. This number of cells was defined as the SCP Upper Limit. The MCV All Species program identified the equivalent number of cells in which species representation is guaranteed and the sum of cell conservation values is maximised. The SCP SCC program has the same objective as the SCP all Species program except that only the representation of species of high conservation concern was guaranteed. The MCV SCC program identified the equivalent number of cells in which the species of high conservation concern representation was guaranteed and the sum of cell conservation values was maximised.

The series of Modified MCP programs guarantee the representation of the species of high conservation concern and maximise the representation of the species of lower conservation concern. However the number of cells that can be included in the solution was restricted. For example, the first Modified MCP program in each table was restricted to selecting a number of cells that equals 90% of the SCP Upper Limit value. A Modified MCP program was used to

produce solutions for cell limits of 90% of the SCP Upper Limit to 50% of the SCP Upper Limit. A Modified MCP program was also used to produce solutions at the SCP Lower Limit (i.e. the minimum number of cells required to guarantee the representation of all species of higher conservation value). The MCV program was then used to identify the equivalent number of cells for each Modified MCP and matched the species representation levels of the Modified MCP program but selected the cells in which the sum of cell conservation values was maximised.

4.4.2 SCP All species

All species were represented in the sets of cells identified in the solutions for this program. The minimum number of cells required to achieve this was identified for each study area (Tables 4.3 – 4.5). This value was defined as the SCP Upper Limit and was used to limit the number of cells that could be included in the solutions of the MCP and MCV programs. The value was similar for each study area (approximately 12% to 17% of cells).

4.4.3 SCP for Species of high conservation concern

This SCP program focused only on the representation of species of high conservation concern. The level of representation for the associated species of lower conservation concern ranged from 72.5% to 91% of species. The minimum number of cells required to achieve representation of species of high conservation concern was identified for each study area (Tables 4.3 – 4.5). This value was defined as the SCP Lower Limit and marks the lowest value that should be used as a cell limit in the MCP and MCV programs. The use of a cell limit value lower than the SCP Lower Limit would result in the omission of species of high conservation concern from the program solution. The percentage of species that belong to the species of high conservation concern category is low (Table 4.2) which is likely the reason why only 3% - 4% of cells are required to represent these species in each study area.

4.4.4 Modified MCP

The modified MCP ensured that all species of high conservation concern were represented and that the maximum number of species of lower conservation concern was present in each solution. This is achieved while the number of cells that can be included in the solution is limited. The cell limits in the MCP programs were in the range of 50% - 90% of the SCP Upper Limit and also included the SCP Lower Limit value. These values present examples of what can be achieved in terms of species representation when the number of cells included in the priority area network is limited to a value less than that required to represent all species. The representation of species of lower conservation concern was in the range of 76.6% to 99.2% of species across all of the MCP program solutions. Of note is the >90% representation of these species achieved by the modified MCP in each of the study areas when a cell limit equal to 50% of the SCP Upper Limit is used (i.e. 100% of species of high conservation concern and >90% of species of lower conservation concern can be represented in half the number of cells required to represent all species).

Table 4.3 The results of the linear programs for County Fermanagh. The number of cells, the sum of the cell conservation values, and the percentage of species of lower conservation concern represented in each solution are shown. (SCC = Species of highest conservation value; SCP = Set Covering Problem; MMCP = Modified Maximal Covering Problem; MCV = Maximum Cell Value).

Linear Program	Cells in solution (% of total)	Representation %	Sum of Cell Values (x 10 ⁶)
SCP All Species	14.8	100.0	2.57
MCV All Species	14.8	100.0	2.75
SCP SCC	3.9	78.1	0.93
MCV SCC	3.9	81.9	1.01
MMCP 90% SCP Upper Limit	13.3	98.8	2.29
MMCP 80% SCP Upper Limit	11.9	97.7	2.09
MMCP 70% SCP Upper Limit	10.4	96.4	1.97
MMCP 60% SCP Upper Limit	9.0	95.4	1.87
MMCP 50% SCP Upper Limit	7.4	93.5	1.50
MCV 90% SCP Upper Limit	13.3	98.8	2.49
MCV 80% SCP Upper Limit	11.9	97.7	2.24
MCV 70% SCP Upper Limit	10.4	96.4	2.08
MCV 60% SCP Upper Limit	9.0	95.4	1.95
MCV 50% SCP Upper Limit	7.4	93.5	1.50
MCV SCP Lower Limit	3.9	82.2	0.94

Table 4.4 The results of the linear programs for County Waterford. The number of cells, the sum of the cell conservation values, and the percentage of species of lower conservation concern represented in each solution are shown. (SCC = Species of highest conservation value; SCP = Set Covering Problem; MMCP = Modified Maximal Covering Problem; MCV = Maximum Cell Value).

Linear Program	Cells in solution (% of total)	Representation %	Sum of Cell Values (x 10 ⁶)
SCP All Species	16.70	100.0	2.30
MCV All Species	16.70	100.0	2.34
SCP SCC	3.30	72.5	0.64
MCV SCC	3.30	75.1	0.66
MMCP 90% SCP Upper Limit	15.10	98.9	2.15
MMCP 80% SCP Upper Limit	13.40	97.8	1.93
MMCP 70% SCP Upper Limit	11.80	96.7	1.72
MMCP 60% SCP Upper Limit	10.10	95.5	1.52
MMCP 50% SCP Upper Limit	8.50	93.8	1.30
MCV 90% SCP Upper Limit	15.10	98.9	2.15
MCV 80% SCP Upper Limit	13.40	97.8	1.95
MCV 70% SCP Upper Limit	11.80	96.7	1.74
MCV 60% SCP Upper Limit	10.10	95.5	1.52
MCV 50% SCP Upper Limit	8.50	93.8	1.30
MCV SCP Lower Limit	3.30	72.1	0.78

Table 4.5 results of the linear programs for Ireland. The number of cells, the sum of the cell conservation values, and the percentage of species of lower conservation concern represented in each solution are shown. (SCC = Species of highest conservation value; SCP = Set Covering Problem; MMCP = Modified Maximal Covering Problem; MCV = Maximum Cell Value).

Linear Program	Cells in solution (% of total)	Representation %	Sum of Cell Values (x 10 ⁶)
SCP All Species	12.60	100.0	10.22
MCV All Species	12.60	100.0	10.52
SCP SCC	4.10	78.3	3.88
MCV SCC	4.10	80.5	4.23
MMCP 90% SCP Upper Limit	11.30	98.9	9.03
MMCP 80% SCP Upper Limit	10.10	97.9	8.23
MMCP 70% SCP Upper Limit	8.80	96.8	7.61
MMCP 60% SCP Upper Limit	7.60	95.7	6.82
MMCP 50% SCP Upper Limit	6.30	93.5	5.93
MCV 90% SCP Upper Limit	11.30	98.9	9.42
MCV 80% SCP Upper Limit	10.10	97.9	8.49
MCV 70% SCP Upper Limit	8.80	96.8	7.66
MCV 60% SCP Upper Limit	7.60	95.7	6.85
MCV 50% SCP Upper Limit	6.30	93.5	5.95
MCV SCP Lower Limit	4.10	83.6	5.57

4.4.5 MCV

The sum of the cell conservation values for each of the MCV program solutions were greater than or equal to the sum of values from the other program solutions. The MCV program identified sets of cells with a greater sum of cell conservation values than the sets of cells identified by the SCP programs for all species and for species of high conservation concern in all of the study areas, for example, the sum of cell conservation values in Fermanagh for the SCP All Species program was 2.57 x 10⁶ compared to a value of 2.75 x 10⁶ for the MCV

program for all species in that county. In many cases the MCV sum of cell conservation values was greater than the values of the MMCP program solutions, for example, with a cell limit of 50% - 90% of the SCP Upper Limit, the Ireland MCV sum of cell conservation values was greater than those for the MMCP program solution. In other cases the MCV program and MMCP program solutions had the same sum of cell conservation values though this occurred more often when the cell limit approached the SCP Lower Limit. Note that the MCV at SCP Lower Limit program had a sum of cell conservation value less than that of the MCV SCC program. Although both programs have the same number of cells in their solutions and both guarantee the representation of species of high conservation concern, the MCV at SCP Lower Limit program also has the objective of maximising the representation of species of lower conservation concern. The levels of species representation decreased slightly across the MCV programs however there was a more noticeable decrease in the sum of cell conservation values.

4.4.6 Comparison of locations of cells

Figures 4.1 – 4.3 show maps of each of the study areas where cells have been identified as priority areas by both the scoring method of Chapter 3 and a selection of the linear programs used in this study, and also includes maps of the species count per cell. The cells identified as priority areas for conservation in the scoring based method of Chapter 3 occur predominantly in species-rich areas and are particularly associated with coastal areas apart from landlocked County Fermanagh where most of the selected cells occur in areas of wetland habitat. In contrast, the cells identified by the linear programs are more widely distributed throughout the study areas. The scoring method solutions could only achieve a >80% level of species representation without guaranteeing that species of high conservation concern were represented. The MCV solutions achieved 100% representation of species of high conservation concern and also achieved representation levels of >87% for the species of lower conservation concern. The cells identified by the scoring method are more clustered and less well distributed than the cells identified by the linear

programs. The cells identified by the linear programs also occur in both species-rich and species-poor areas.

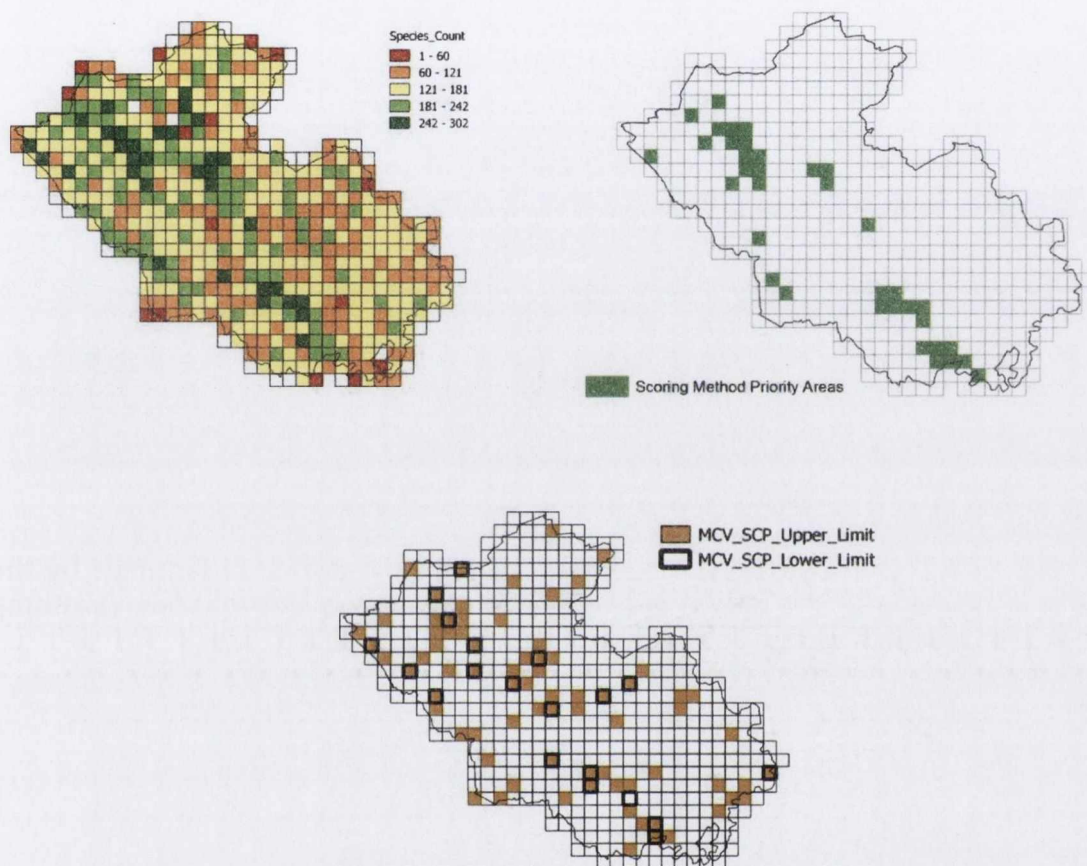


Figure 4.1 The distribution of cells in County Fermanagh identified by the scoring-based (top right) and linear programming approaches (bottom).
A. The species count per cell is shown at the top left.

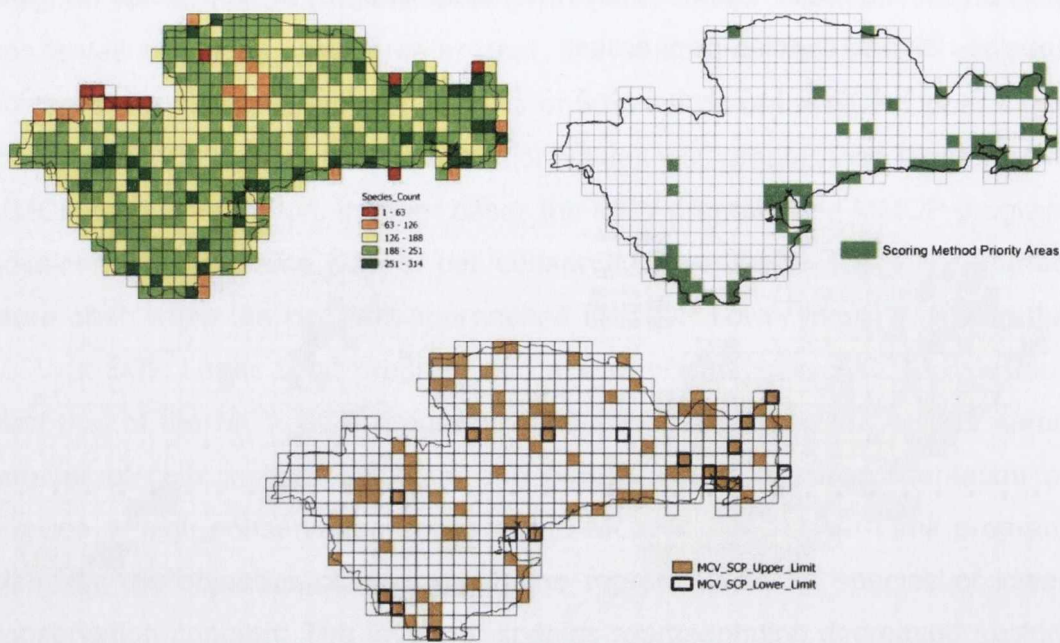


Figure 4.2 The distribution of cells in County Waterford identified by the scoring-based (top right) and linear programming approaches (bottom).
A. The species count per cell is shown at the top left.

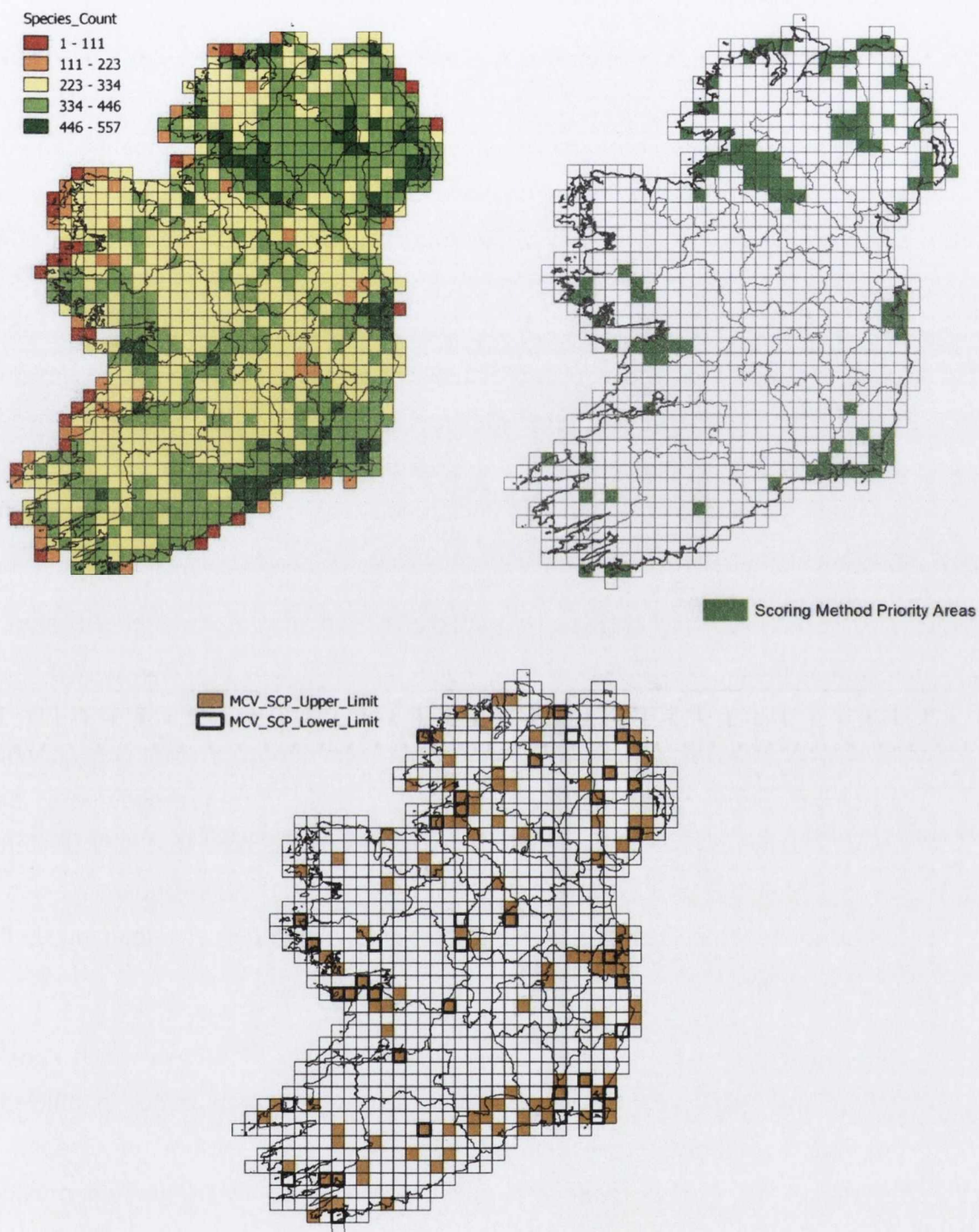


Figure 4.3 The distribution of cells in Ireland identified by the scoring-based (top right) and linear programming approaches (bottom). A. The species count per cell is shown at the top left.

4.5 Discussion

The spatial prioritisation of areas for conservation has typically been associated with reserve selection but is not limited to the designation of protected areas. The principles of reserve selection are equally valid for the identification of areas for the implementation of other conservation measures (Pressey and Cowling, 2001), such as habitat management and restoration (Moilanen et al., 2011), and the use of agri-environment schemes and other payments for ecosystem services (Primdahl et al., 2010; Wünscher et al., 2008). In keeping of the general theme of the thesis the goal of this study was not to design a new reserve network or to nominate sites for the expansion of existing reserve networks. Instead priority areas were identified so they could be targeted by appropriate management or for consideration in conservation planning, whether or not they occur inside a protected area.

The results of this study show that exact methods for optimal selection of priority areas that efficiently represent species (i.e. maximum number of species in a minimum of cells) can be conducted for vascular plants in Ireland. The SCP program was used to identify the minimum number of cells in which all of the species of high conservation concern would be represented at least once. The remaining species were not targeted for inclusion and their presence in the solution was coincidental. Nevertheless over 70% of these species of lower conservation concern were represented within the cells selected by this SCP program.

The linear programs identified the minimum number of cells in which species are guaranteed to be represented and these performed better in efficiently maximising species representation than the scoring method of Chapter 3. Huang et al., (2012) found that a complementarity-based method provided better species representation than a method based on diversity indices when identifying plant diversity hotspots in China. Similarly in Italy a criteria-based method of priority area identification selected 10% of the study area which represented 74% of habitats and species, compared to 7% of areas selected by a complementarity-based method in which all habitats and species occurred

(Marignani and Blasi, 2012). In each of the study areas 12 – 17% of cells were required to guarantee that all species (both species of high and lower conservation concern) were represented, dropping to 3 – 4% of cells when guaranteeing the representation of species of high conservation concern. This compares well to the results of other studies where the percentage of areas required to ensure species representation varied. For example, 75% of areas were required to represent all species of plants in deciduous woodlands in Norway (Saetersdal et al., 1993); 5% of areas were required for terrestrial vertebrate representation in Oregon, US (Csuti et al., 1997); 7% of areas were required to represent all plant habitat and plant species in Italy (Marignani and Blasi, 2012); and <1% of sites were required to guarantee bird species representation in Britain (Williams et al., 1996).

The standard Maximal Covering Problem does not target any particular species. A modified version of the MCP (MMCP) allowed a more focused approach by requiring the representation of some species while maximising the representation of others. This novel approach is a useful way of ensuring that prioritisation is targeted towards species of greatest conservation concern, while at the same time maximising the inclusion of other species and therefore increasing the species diversity within the priority areas. The modified MCP proved to be very efficient at maximising species representation in each of the study areas (Tables 4.3 – 4.5). This would be expected at the hectad scale where such a large cell size will contain many habitats and species. The results show that this trend is also seen at the tetrad scale and perhaps indicates a rich diversity of habitats within the tetrads in the studied counties.

The difference in species representation levels between the various MMCP scenarios is small, with 93% to 99% representation for species of lower conservation concern. Often there is more than one set of cells that will meet the requirements of the linear programs and additional information is required to decide which solutions are best. In this study extra information was introduced into the linear programs in the form of cell conservation values from a scoring

method of Chapter 3. The scoring method assigned a numerical value to each cell based on the conservation value of the cell. The MCV linear program was constructed to select a set of cells with collective cell conservation values that were the maximum possible for that number of cells and level of species representation (first identified using the modified MCP). The MCV programs successfully identified sets of cells with the highest sum of cell conservation values, though in some cases these were the same set of cells identified by the MMCP program. The sum of the values of the priority areas identified using the MCV programs are marginally higher than in other solutions (Tables 4.3 – 4.5). This size of the difference in the values is not the key point but rather that the MCV solutions have the *highest* sum of cell conservation value. It is the capacity to include information in addition to species representation that makes the MCV linear programming approach a superior prioritisation method to the other linear programming methods.

The scoring method of Chapter 3 takes no account of complementarity when identifying the highest value cells. It is probable that similar high value habitats are repeatedly represented in the identified cells with highest value such as coastal habitats in Co. Waterford and wetland habitats in Co. Fermanagh. In contrast the SCP linear programming approach identifies sets of cells that are more widely distributed (Figures 4.1 – 4.3) and is likely to contain a greater variation of habitat types; this is also a feature of the cells identified by complementarity-based methods in Spain (Abellán et al., 2005). This shows an added value of the complementarity-based approaches as they potentially target a wider variety of habitat types. A feature of the scoring method was that high species representation (>80% of species) was achieved within the top 6 – 12% of cells after which only very small improvements in species representation was observed when more cells were added. The SCP solutions showed that the representation of species of high conservation concern can be achieved within fewer cells than with the scoring method. All of the SCP solutions required more cells than the scoring method solutions but guaranteed that all species were represented.

However the MCV program offers the ability to identify high value, efficient sets of priority areas and is a step towards the integration of scoring and complementarity based methods.

Both the scoring and linear programming approaches identified sites that coincided the more species-rich areas; this is particularly noticeable at the hectad scale for the island of Ireland (Figure 4.3). This is to be expected for the scoring approach where species richness has a direct impact on the value of cells. The linear programming approach is likely selecting from species-rich cells that best complement each other in terms of species representation. If the low species counts in other areas are the result of reduced recording effort, then the unrecorded species there would have an effect on both prioritisation methods. The effectiveness of all prioritisation techniques, including exact and scoring-based methods, are dependent on the quality of the species distribution data (Pressey and Cowling, 2001).

There may be more than one solution to the conservation problems outlined in this research and a means to identify them using linear programming is available (Arthur et al., 1997). While this was not an objective of this research an iterative programming approach could identify many (or all) of the possible solutions. This would allow the analysis of the frequency with which individual cells feature in the linear programming solutions. This would help to show the importance of individual cells in achieving a selection of conservation planning objectives. This is particularly important to where compromises sometimes have to be made due to competing land-use. Conservation planning therefore requires some flexibility when selecting priority areas. The cells that appear more frequently in the programming solutions are not likely to be substituted by a different cell of comparable conservation value. Therefore, the removal of these cells from a priority area selection would likely result in less effective priority areas for conservation.

While species representation can be kept relatively high over the range of cell limits, the decrease in cell conservation value indicates the process is selecting the bare minimum of habitats for inclusion in priority areas for conservation.

The scoring method may be less efficient at ensuring species representation but it is likely to include multiple instances of the same habitat lending an element of redundancy to a network of priority areas (Simaika & Samways, 2009). Exact prioritisation methods such as linear programming will select the minimum amount of cells containing the species and therefore their habitats. Focusing limited conservation measures as efficiently as possible is a goal of conservation biology (Moilanen and Cabeza, 2001); however such action might not be of benefit to the long-term survival of species (Williams et al., 2005). Species or habitats that occur infrequently in the identified priority areas would be at greater risk of being lost due to impacts on the priority area e.g. damage to habitat or the arrival of invasive species. The risk of loss would be lessened where there are multiple instances of the species or habitats in the priority areas.

This is not the only concern surrounding the use of exact methods in spatial prioritisation. The linear form of objectives is limited to relatively simple conservation problems (Moilanen, 2008). The use of algorithms to solve spatial prioritisation problems might not be as transparent as using a scoring method; however, Vanderkam et al., (2007) argue that systematic approaches provide more justifiable reasons for identifying priority areas than approaches based on subjective decisions. While this research focused on species representation and the inclusion of cell conservation values, other factors need to be considered in the assignment of priority areas for conservation such as the size, shape and connectivity of the areas (Abellán et al., 2005). Techniques have been developed to address these issues (e.g. Clemens et al., 1999; Alagador and Cerdeira, 2007; Alagador et al., 2012) though they are more difficult to solve (Pressey et al., 1996). The increasing complexity of conservation planning problems has led to the development of heuristic and meta-heuristic methods that provide many good but sub-optimal solutions (e.g. Watts et al., 2009). These heuristic methods are capable of finding a large number of the solutions that are almost as good as those produced by exact methods such as linear programming. One example of a more complex conservation planning problem would be the requirement to identify all the

possible solutions to linear programming problem. For large optimisation problems the number of different solutions can be so high that the time taken to compute the solutions is prohibitive (Moilanen and Ball, 2009).

It is clear that the spatial prioritisation of areas for conservation is a difficult task with many factors to consider. What cannot be answered here is whether the identified solutions are appropriate to meet the requirements for the persistence of species. This would require the examination of more detailed information for example population sizes, species-specific connectivity, spatial population dynamics and influence of threats (Moilanen, 2008). The methods also help to integrate the scoring and exact approaches that could be used together in landscape planning to meet common conservation objectives (Marignani and Blasi, 2012). The advantages of both scoring and exact methods have been discussed in the conservation biology literature (e.g. Justus and Sarkar, 2002; Simaika and Samways, 2009) however there also have been calls to combine both methods so conservation planning might benefit from both (Cowling et al., 2003; Marignani and Blasi, 2012).

Despite some drawbacks, algorithmic prioritisation methods can provide valuable information and options to landscape planners and conservation scientists, particularly at a time when the resources at their disposal are scarce. The MCV programs in this study provide full representation of species of high conservation concern along with over 90% of remaining species. At the same time the programs select the set of cells with the highest collective cell conservation value. The methods outlined in this study cannot on their own identify the most appropriate set of priority areas but instead can provide valuable information to help guide the conservation planning processes.

5. Modelling the distribution of a group of plant species of conservation concern in the Republic of Ireland

5.1 Introduction

Plants are primary producers in terrestrial ecosystems, provide valuable ecosystem services and sustain the diversity of other taxa (Henrys et al., 2015). However, many plant species are threatened with extinction (Pimm and Joppa, 2015), which has prompted conservation plans such as the Global Strategy for Plant Conservation (GSPC, 2002). Information about the geographic distribution of biodiversity is one requirement of conservation planning (Grantham et al., 2008). Species distribution models (SDM) are used to predict where species could occur (Ahmed et al., 2015) in order to inform survey design, reserve selection, risk assessment and to identify restoration sites (Elith & Leathwick 2007). In practice SDMs have been used to supplement incomplete distribution data to guide decisions in conservation activities such as invasive species management, identifying critical habitat, and relocating species (Guisan et al 2013). SDMs can be used to examine the association of distribution records with relevant independent environmental variables. Models that predict species distribution based on their association with environmental factors can be useful for conservation planning (Henrys et al., 2015). Such models can be used to produce predictive maps to guide conservation action (Zhang et al., 2012). Species distribution modelling has been successfully conducted using plant species to better inform conservation strategies by predicting species rich areas, contributing strategies for restoring or protecting biodiversity, and identifying priority areas for conservation (Iturbide et al 2015; Guisan et al., 1999; Henrys et al 2015; Klimek et al., 2014; Perez & Font 2012; Rupprecht et al., 2011; Williams et al., 2009; Zhang et al., 2012).

SDMs rely on the availability of species distribution records and other ecologically relevant spatial information such as climate and soil data. While SDMs that use presence and absence data tend to perform better than presence-only models (Elith et al., 2006), reliable absence data are rarely available (Barbet-Massin et al., 2010). However distribution records often occur

in a presence-only format and SDMs have been developed to model these distributions (Tsoar et al., 2007). Presence-absence models can instead use background or pseudo-absence data in place of true absences (Zaniewski et al., 2002). Pseudo-absences can consist of a sample of records randomly selected from the background areas in which species do not occur (Pearce & Boyce, 2006).

One of the most common approaches that use presence-absence data to model species distributions is the use of logistic regression (McDonald et al., 2013) due to a strong predictive ability (Elith & Leathwick 2007). This form of regression is particularly useful in modelling binary events (Stoltzfus, 2011) such as the presence-absence of species (Austin 2007). Logistic regression requires both presence and absence data; however pseudo-absences can be included in place of true absence data in logistic regression models (Hijmans & Elith 2015). Logistic models have been used in a variety of applications, including estimating species abundances (Byrne et al., 2014), predicting species distributions (Manel et al., 1999), and modelling invasive species distributions (Evangelista et al., 2008).

The distribution modelling of plant species has been conducted in Ireland focusing on the potential effects of climate change (Hodd et al., 2014; Berry et al., 2002; Sharkey et al., 2013). Furthermore, the identification of priority areas for plant conservation is limited at the tetrad scale to counties with good data coverage (Chapters 3 & 4). It could be argued that knowledge of the distribution of rarer species may be better than for more widespread species, due to targeted surveying and monitoring. However, a plant distribution database has been collated using plant records at the tetrad scale for Ireland and the distribution of plant species is limited to 30% of the tetrads in Ireland (Chapter 2; Walsh et al., 2015). The use of species distribution modelling could improve on current knowledge to inform plant recording schemes and conservation policy in Ireland. The availability of the plant distribution database and other spatial datasets (e.g. land cover, soil types) presented an opportunity to model plant Species of Conservation Concern SCC occurrence. The national plant

records are incomplete but contain a subset of much more complete set of plant records from a thorough survey of County Waterford. This allowed the testing of the ability of an SDM to accurately predict SCC occurrence against this more complete dataset.

A more complete view of the distribution of these species would aid in conservation strategies as any potential unrecorded SCC occurrences cannot factor into planning. An effective SDM could show if the SCC are associated with particular landscape types. In the context of the current incomplete plant records an SDM could identify new survey areas where the species might occur or that are suitable for species to re-establish. There may be a potential gap in knowledge of the distribution of SCC in Ireland. This could be examined by the using a predicted distribution of SCC to highlight potential areas for further investigation. Therefore the following research objectives were investigated in relation to the potential application of the distribution modelling of a plant group to inform conservation planning in Ireland: (1). To use a logistic regression SDM approach to examine the association of environmental factors with the occurrence of plant species of conservation concern; (2). To build and compare a model based on national presence-only dataset and a model based on a more complete plant distribution dataset; (3). To examine the predictive performance of the models using a more complete plant dataset as a test case; (4). To produce maps of the predictive probability of SCC occurrence for the Republic of Ireland; (5). To examine where areas of high and low probability are occurring to improve the knowledge base for conservation planning. (6) To compare the locations of priority areas identified in Chapters 3 & 4 to the predicted probability of SCC occurrence in Co. Waterford.

5.2 Data & Methods

5.2.1 Plant distribution dataset

The plant dataset used in this research consisted of tetrad scale (2km x 2km grid of cells) plant records for Ireland. These data were collected by different recording groups with varying recorder effort, are likely biased towards

particular areas, and were collected as presence-only records. A subset of these records contains a thorough survey of County Waterford. The data covered 30% of the island meaning that there is a large area of the island that has not been surveyed at tetrad level (Chapter 2; Walsh et al., 2015). A group of plant Species of Conservation Concern (SCC) have been identified in the Republic of Ireland as those that are listed in the Flora Protection Order of Ireland (Flora Protection Order, 1999) in addition to species that are classified as threatened in the Irish Red Data Book of Vascular Plants (Curtis and McGough, 1988; Walsh et al., 2015). The SCC group consists of 122 species whose known distribution covers approximately 6% of the Republic of Ireland (Figure 5.1).

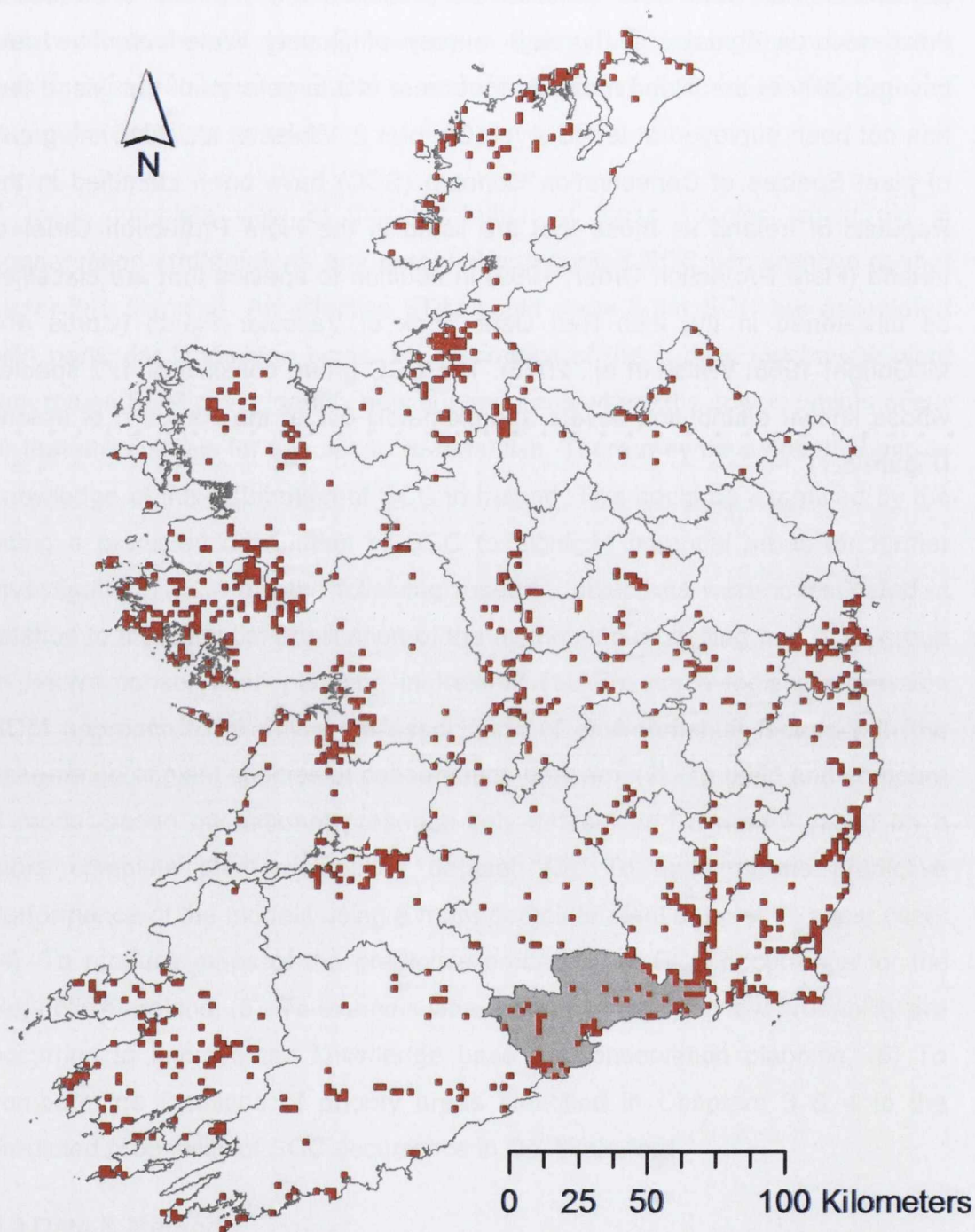


Figure 5.1: The distribution of tetrads that contain plant species of conservation concern (SCC) in the Republic of Ireland. County Waterford is highlighted in grey.

5.2.2 Logistic regression

Logistic regression is well suited for describing relationships between a categorical response variable and one or more categorical or continuous independent variables (Peng et al., 2002). When used to model the presence or absence of species where the response variable takes the dichotomous form of 0/1 the method is referred to as binary logistic regression. The logistic regression detects the independent variable contributions using the following equation:

$$\text{Probability of outcome (Y)} = \frac{e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots \beta_i X_i}}{1 + e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots \beta_i X_i}}$$

Here, Y represents the estimated probability of being in one binary category versus the other. The component $\beta_1 X_1 + \beta_2 X_2 + \dots \beta_i X_i$ is the value of each independent variable (X_i) weighted by its respective beta coefficient (β). The component $e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots \beta_i X_i}$ is the linear regression equation for the independent variables expressed in the logit scale. A binary outcome expressed as a probability must take a value between 0 and 1. The logit scale can yield the logit or log of the odds of being in one binary category versus the other (Stolzfus, 2011). Through the use of these equations the logistic regression identifies the strongest linear combination of independent variables that promotes the likelihood of detecting the observed response (Stolzfus, 2011).

5.2.3 Independent variables

The independent variables that typically feature in plant species distribution modelling include climate, soil, and elevation variables (Guisan et al., 1999; Iturbide et al., 2015; Williams et al 2009; Zhang et al., 2012). The independent variables selected for this research included these types of variables in addition to data on land cover and agricultural stocking density (Table 5.1). Each tetrad can contain a variety of soil, subsoil, and land cover classes. The dominant soil, subsoil, and land cover variables correspond to the variable class with the

greatest area in each tetrad. The soil, subsoil, and land cover diversity were calculated using Shannon's diversity index. The neighbourhood value of a tetrad corresponds to the number of the neighbouring tetrads that contain the presence of a species of conservation concern. All independent variables were aggregated to the resolution of 2 km x 2 km in ArcMap.

Table 5.1: Descriptions of the independent variables used to construct the species distribution models for plant species of conservation concern in the Republic of Ireland.

Independent variables	Description	Derived
X & Y geographic coordinates	Continuous	Irish Grid (Transverse Mercator)
Maximum elevation	Continuous	Digital Elevation Model (20m resolution)
Maximum temperature	Continuous	Teagasc
Minimum temperature	Continuous	Teagasc
Mean precipitation	Continuous	Teagasc
Dominant soil type	Categorical	Teagasc EPA soils and subsoils (Teagasc; S. Green)
Dominant subsoil type	Categorical	Teagasc EPA soils and subsoils (Teagasc; S. Green)
Dominant land cover type	Categorical	CORINE (level 3)
Soil diversity	Continuous	Teagasc EPA soils and subsoils (Teagasc; S. Green)
Subsoil diversity	Continuous	Teagasc EPA soils and subsoils (Teagasc; S. Green)
Land cover diversity	Continuous	CORINE (level 3)
Proportion designated area cover	Continuous	Designated area boundary data (NPWS)
Lake area	Continuous	National digital map of lakes
Distance to coast	Continuous	National vector shapefile
Sum of river length	Continuous	National digital map of rivers
Proportion of semi-natural land cover	Continuous	CORINE (level 3)
Stocking density	Continuous	Teagasc
Neighbourhood value	Continuous	Neighbourhood analysis of national tetrad grid

5.2.4 Multicollinearity

Multicollinearity among variables in species distribution modelling is a serious problem and can cause model over-fitting (Zhang et al., 2012), where models include more terms than are necessary (Hawkins, 2004). An assumption of logistic regression is the absence of multicollinearity among independent variables within a model. The Variance Inflation Factor (VIF) is a statistic used to measure possible multicollinearity among the predictor variables (Robinson & Schumacker, 2009). All of the independent variables were included in the initial model building and the VIF associated with each independent variable was calculated. A strict VIF value of 2 was chosen (Zuur et al., 2010), above which variables were considered to exhibit multicollinearity. A series of model iterations were conducted where the variable with the highest VIF was removed at each stage until all VIF values were ≤ 2 . The geographic coordinate variables were retained in the model regardless of their VIF values so as to include the influence of geographic distribution in the model.

5.2.5 Model datasets

The plant records in County Waterford were systematically collected and subject to consistent recorder effort and for the purposes of this research it was assumed that the County Waterford data could perform the role of a presence-absence dataset for model building. The County Waterford data were split into a training dataset, where 70% of the data were randomly selected, to build the model, hereafter referred to as the Waterford model. The remaining 30% of the data were retained as a test dataset to validate the logistic regression models. A subsequent attempt to predict national SCC distribution using the Waterford model was not successful. The model was built using environmental variables associated with a relatively small area of Ireland and could not characterise the full range of environmental variables to make predictions for the national dataset.

Instead a new logistic regression model was built using the incomplete national plant distribution data. First the County Waterford data was removed from the national plant dataset. The average number of tetrads per county in the Republic of Ireland that contained plant distribution data was calculated and a random sample of the County Waterford data matching the average number was extracted and re-introduced to the national dataset. A logistic regression modelling approach requires the use of presence and absence data. Here the presence data are the locations of tetrads that contain any number of species of conservation concern. The plant distribution data were collected as presence-only data however the modelling could be facilitated by including pseudo-absences in the place of known absences. Pseudo-absences can consist of a sample of records randomly selected from the background areas in which species records are missing (Pearce & Boyce, 2006). Pseudo-absences were selected from the locations in the national dataset that did not contain a presence of SCC. Three sets of pseudo-absences ($n = 1066$ matching the number of presence locations, $n = 5000$ and $n = 10000$) were randomly selected. These were combined with the SCC presence data to form the dataset to build the model. The performance of the models built using each of the sets was compared to determine how many pseudo-absences should be included in the final model. The logistic regression model built using the pseudo-absence approach contained the pseudo-absence data and the data for the locations that contain a presence of SCC. This model is hereafter referred to as the National model (Table 5.2).

Table 5.2: The logistic regression models, the data used to build the models and the dataset used to validate the models. (SCC: Species of Conservation Concern)

Model Name	Training Data Coverage	Testing Data
National	National presence of SCC and pseudo-absences	Waterford (30% sample)
Waterford	Waterford (70%)	Waterford (30% sample)

5.2.6 Model validation

Confusion matrices were used to examine the performance of the models in terms of ability to predict presence and absence of SCC for the test dataset. The model predictions can contain two types of prediction errors associated with the presence-absence of the response variable: false positives, incorrectly predicting a presence and false negatives, incorrectly predicting an absence. The performance of a presence-absence model can be summarized in a confusion matrix that tabulates the observed and predicted presences and absences (Fielding & Bell, 1997). The confusion matrices also detail the sensitivity and specificity of model predictions. The sensitivity is a measure of how often a model correctly predicts a presence and the specificity is a measure of how often the model correctly predicts an absence.

However the predicted probabilities must first be converted to presence-absence values in order to compare the model predictions to the presence and absence values of the test dataset. The probabilities can take any intermediate values from a range of 0 to 1. A break-point in the probability values must be selected above which values are said to predict a presence in the tetrad and below which predict an absence. A common, though arbitrary, means to do this is to assign probability values above 0.5 as presence and those below 0.5 as

absence (Pearce & Ferrier, 2000). A more objective way of selecting a break-point is to measure the sensitivity and specificity of the models. A plot of the sensitivity and specificity values over a range of probability break-points can then be used to identify a break-point that maximises sensitivity and specificity. The sensitivity and specificity values were calculated for model predictions for the test dataset and plotted to determine the probability value at which both of these values were maximised.

The area under the receiver operating characteristic curve (AUC) is used extensively to evaluate SDM predictive performance i.e. a model's ability to discriminate between sites where a species is present and sites where a species is absent (Elith & Leathwick 2007). The AUC is calculated using the full range of probability values rather than the predicted presence-absence values as determined by a probability break-point (Liu et al., 2005). An AUC score of 0.5 indicates that a model has no discriminatory ability and a score of 1 indicates perfect discriminatory ability (Elith & Leathwick 2007). AUC values were calculated for the national and training models' ability to discriminate between presence and absence of SCC in the test training dataset.

5.2.7 Spatial clustering of probability of SCC occurrence

The Local Indicator of Spatial Association (LISA) allows the decomposition of global indicators, such as Moran's I, into the contribution of each individual observation (Anselin, 1995). The LISA cluster map takes locations with significant ($p=0.05$) local Moran's statistics and codes them by the type of spatial autocorrelation, e.g. high probability cells neighbouring other high probability cells (high – high), to identify spatial clusters and possible spatial outliers e.g. high – low, low - high (Anselin, 1995). This allowed the mapping of the clustering to SCC probability values.

5.2.8 Bivariate local Moran's I

The bivariate local Moran's I statistic provides a measure of multivariate spatial correlation. The use of the statistic allows an examination of the spatial correlation of two variables (e.g. probability of SCC occurrence and stocking

density). The concept is based on the extent to which values for one variable observed at a given location show an association with another variable (Anselin et al., 2002). The LISA cluster map and the local Moran's I were produced using the GeoDa spatial analysis software package (Anselin et al., 2006). All other data manipulation and statistical analyses were conducted using the R statistical software.

5.2.9 Priority areas for conservation and predicted SCC distribution

Maps of the priority areas identified in Chapters 3 & 4 were combined with maps of the predicted SCC probability values for County Waterford. Histograms of the probability values within the priority areas were also created. This allowed a comparison of the distribution of the SCC probability values and priority areas.

5.3 Results

5.3.1 Factors associated with the distribution of the SCC group

A set of independent variables that typically feature in plant species distribution were included in the logistic regression model building (Table 5.1). The absence of multicollinearity among the independent variables is an assumption of logistic regression. The independent variables were screened for multicollinearity by examining the Variance Inflation Factors (VIF). This procedure reduced the number of the original 20 independent variables to 16 variables for the National model and 14 variables for the Waterford model (Tables 5.3 & 5.4). In both cases the climate variables were dropped in addition to the distance to coast and dominant soil variables in the training model.

An examination of the predictive performance of the models showed that the models performed better when the non-significant variables were retained. Tables 5.3 & 5.4 report the model summaries for the National and Waterford models. The value of the variable coefficient estimates (the estimates column in the tables) correspond to the change in the log of the odds (or log-odds) of

SCC presence for one unit increase in the independent variable. A more intuitive value can be derived by exponentiation of the log-odds value to produce an odds-ratio, where one unit change in the independent variable multiplies the odds of SCC presence by the odds-ratio value (Stoltzfus, 2011). The odds-ratios for the independent variables are listed within the coefficient estimates in tables 5.3 & 5.4. An odds-ratio value of 1 indicates no association, values greater than 1 indicate a positive association, and values less than 1 indicate a negative association.

The odds-ratios indicate that both the National and Waterford models showed a weak association of SCC presence with lower elevation and a stronger association with greater soil, subsoil and land cover diversity (Tables 5.3 & 5.4). Increased levels of designated area and semi-natural cover were also associated with a higher probability of presence and when neighbouring tetrads contained SCC. The association of designated area cover with SCC presence was much greater for the Waterford model while there were conflicting associations involving stocking density between the two models. The National model indicated a positive association of SCC presence with stocking density. In both models SCC presence was more likely when a tetrad cell had neighbouring cells that contained SCC.

Table 5.3: The independent variables included in the Waterford model with the resulting model coefficients and odds-ratios (SCC = Species of Conservation Concern; Dom. = Dominant).

Variable	Estimate	Std. Error	z value	Pr(> z)	Significant	Odds Ratio
(Intercept)	-3.9420	3.6458	-1.0813	0.2796		
X Coordinate	6.37x10 ⁻⁶	1.42x10 ⁻⁵	0.4495	0.6531		1.000
Y Coordinate	-2.23x10 ⁻⁵	2.89x10 ⁻⁵	-0.7718	0.4402		1.000
Max Elevation	-0.0101	0.0039	-2.5490	0.0108	*	0.990
Soil Diversity	0.0410	0.0277	1.4809	0.1386		1.042
Subsoil Diversity	0.0181	0.0494	0.3657	0.7146		1.018
Land Cover Diversity	0.4200	0.7788	0.5392	0.5897		1.522
Proportion Designated Area	2.7684	1.9750	1.4018	0.1610		15.934
Lake Area	7.52x10 ⁻⁷	1.18x10 ⁻⁵	0.0637	0.9492		1.000
River Length	7.63x10 ⁻⁵	0.0001	0.7399	0.4594		1.000
Proportion Semi-Natural	-0.6201	2.0948	-0.2960	0.7672		0.538
Stocking density (ln)	-1.7619	0.6564	-2.6841	0.0073	*	0.172
SCC Neighbour	0.4176	0.1779	2.3474	0.0189	*	1.518
Dom. subsoil	Wald test (chi ² , (DF: 6) = 0.87, P=0.99)					
Dom. land cover	Wald test (chi ² , (DF: 12) = 5.3, P=0.95)					

Table 5.4: The independent variables included in the National model with the resulting model coefficients and odds-ratios (SCC = Species of Conservation Concern; Dom. = Dominant, OR: Odds Ratio).

Variable	Estimate	Std. Error	z value	Pr(> z)	Significant	OR
(Intercept)	-2.553	0.637	-4.007	6.13x10 ⁻⁵		
X Coordinate	-3.22x10 ⁻⁶	7.22x10 ⁻⁷	4.461	8.14x10 ⁻⁶	*	0.999
Y Coordinate	-2.55x10 ⁻⁶	5.07x10 ⁻⁷	-5.024	5.05x10 ⁻⁷	*	0.999
Maximum Elevation	-2.57x10 ⁻³	3.79x10 ⁻⁴	-6.76	1.38x10 ⁻¹¹	*	0.997
Soil Diversity	2.75x10 ⁻⁴	5.84x10 ⁻³	0.047	0.962376		1.000
Subsoil Diversity	2.25x10 ⁻²	8.35x10 ⁻³	2.697	0.006988	*	1.022
Land Cover Diversity	8.51x10 ⁻¹	1.04x10 ⁻¹	8.172	3.03x10 ⁻¹⁶	*	2.342
Proportion Designated Area	9.79x10 ⁻¹	1.63x10 ⁻¹	6.01	1.86x10 ⁻⁹	*	2.660
Lake Area	2.93x10 ⁻⁷	9.02x10 ⁻⁸	3.246	0.001168	*	1.000
Distance to Coast	-4.95x10 ⁻⁶	2.15x10 ⁻⁶	-2.665	0.0077	*	0.999
River Length	2.09x10 ⁻⁵	1.51x10 ⁻⁵	1.385	0.16611		1.000
Proportion Semi-Natural	6.79x10 ⁻¹	2.06x10 ⁻¹	3.293	0.00099	*	1.971
Stocking Density (ln)	2.58x10 ⁻²	7.61x10 ⁻²	0.339	0.73441		1.026
SCC Neighbour	7.11x10 ⁻¹	3.10x10 ⁻²	22.925	< 2 x10 ⁻¹⁶	*	2.036
Dom. soil	Wald test (chi ² , (DF: 22) = 0.13.0, P=0.93)					
Dom. subsoil	Wald test (chi ² , (DF: 37) = 23.0, P=0.97)					
Dom. land cover	Wald test (chi ² , (DF: 27) = 45.8, P=0.013)					*

5.3.2 Predictive performance of the models

A cross-validation of the logistic regression models was conducted by examining how well predicted presences and absences of SCC compared to the true presence and absence of the test dataset. Both the National and Waterford models showed good discriminatory power with area under the receiver operating curve (AUC) values of 0.84 and 0.80 respectively. The predicted probability values were converted to binary presence/absence values to allow the comparison of predicted and true presence and absence values. The sensitivity and specificity of the model predictions were plotted over a range of probability values to identify the value at which the sum of sensitivity and specificity was maximised (Figures 5.2 & 5.3), this corresponded to a probability of 0.2. This value was used as the break-point in the predicted probability values, where values above 0.2 were assigned as a presence and values less than 0.2 were absences. The predicted binary presence-absence values were compared to the true presence/absence values using confusion matrices (Table 5.5). These matrices are classification tables that describe the agreement between observed presence and absence of a species and the predicted presence or absence (Figure 5.4) (Pearce & Ferrier, 2000).

Both models correctly predicted the same percentages of presences (74%) and also predicted presences where true absences occur, indicating that the models tend to overestimate the number of SCC presences. Predictions for the entirety of County Waterford were also calculated and here the Waterford model performed best at predicting the true presences and absences (72% to 67% and 88% to 82% respectively). Figures 5.5 – 5.8 show the distribution of the predicted probability values for both models and the distribution of true SCC presences.

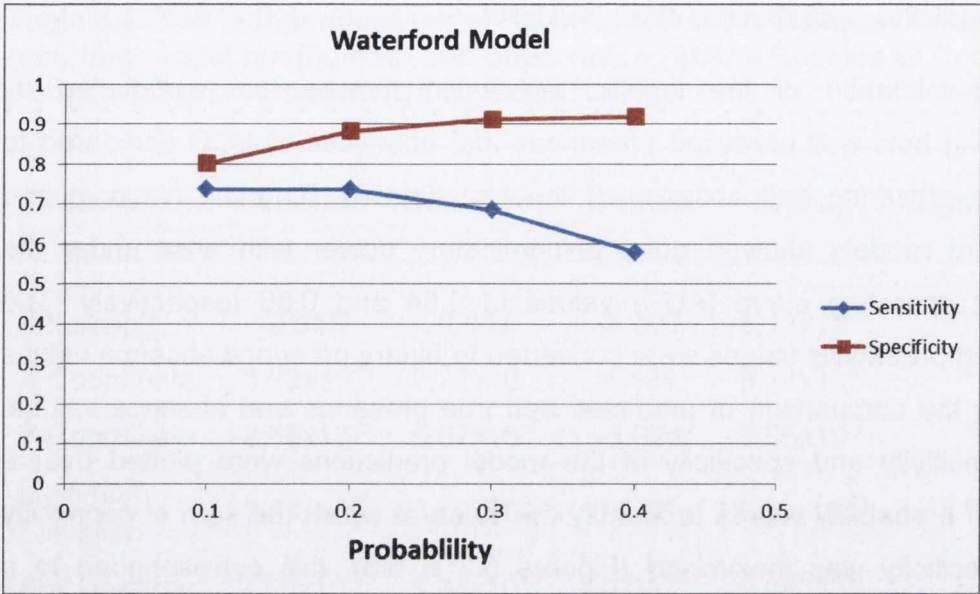


Figure 5.2: The sensitivity and specificity values resulting from the modelling of species of conservation concern (SCC) presence using the Waterford model for the test dataset over a range of probability values.

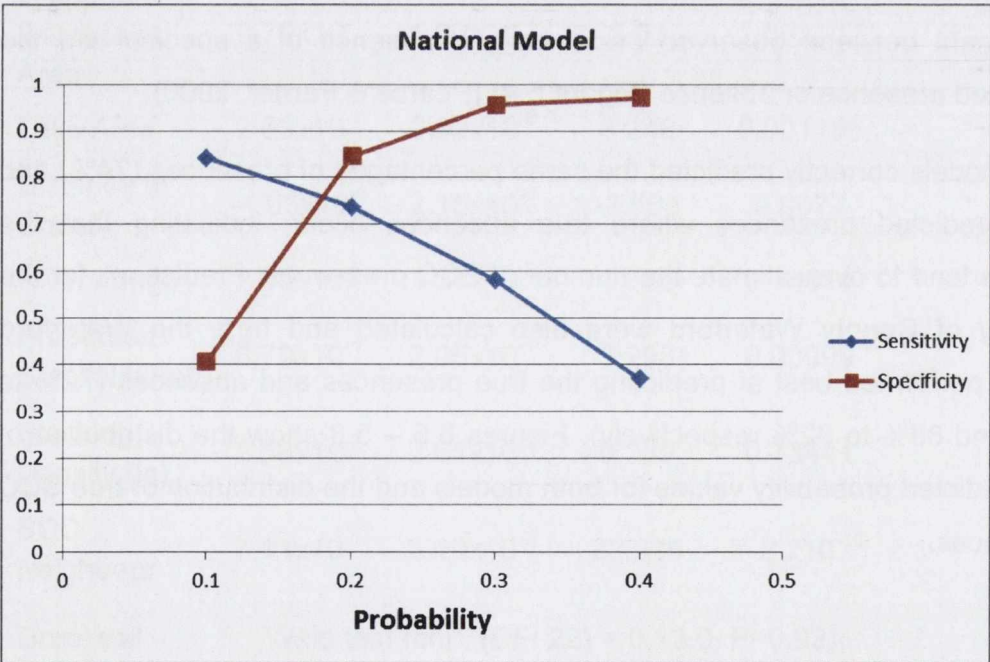


Figure 5.3: The sensitivity and specificity values resulting from the modelling of species of conservation concern (SCC) presence using the national model for the test dataset over a range of probability values.

	Recorded absent	Recorded present
Predicted absent	A	B
Predicted present	C	D

Figure 5.4: An overview of a confusion matrix. The matrix is presented as a classification table describing the agreement between the observed presence and absence of a species and the predicted presence or absence of a species. Each of the values A, B, C and D, represent numbers of observations (Pearce & Ferrier, 2000).

Table 5.5: Confusion matrices showing the performance of the national and training models in correctly predicting presence and absence of the species of conservation concern (SCC) group. The matrices compare the predicted values (0/1) at the leftmost column with the true values (0/1) in the top row, for example the national model correctly predicted 74% of presences and 85% of absences for the Waterford test data.

		Waterford Test Data True Values; Absence = 136, Presence = 19		Waterford All Data True Values; Absence = 463, Presence = 64	
		0	1	0	1
National Model	0	85	26	82	33
	1	15	74	18	67
Training Model	0	88	26	88	28
	1	12	74	12	72

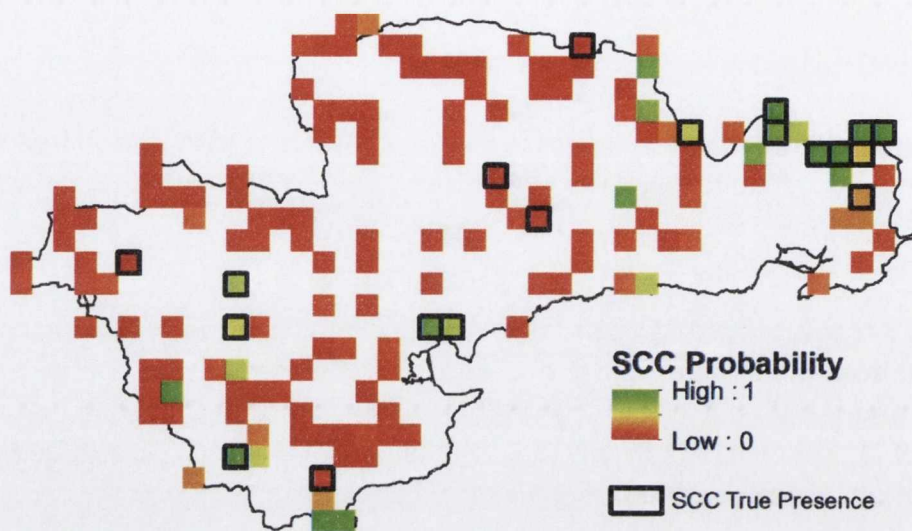


Figure 5.5: The distribution of the probability of species of conservation concern (SCC) presence in the test study area as predicted by the Waterford model.

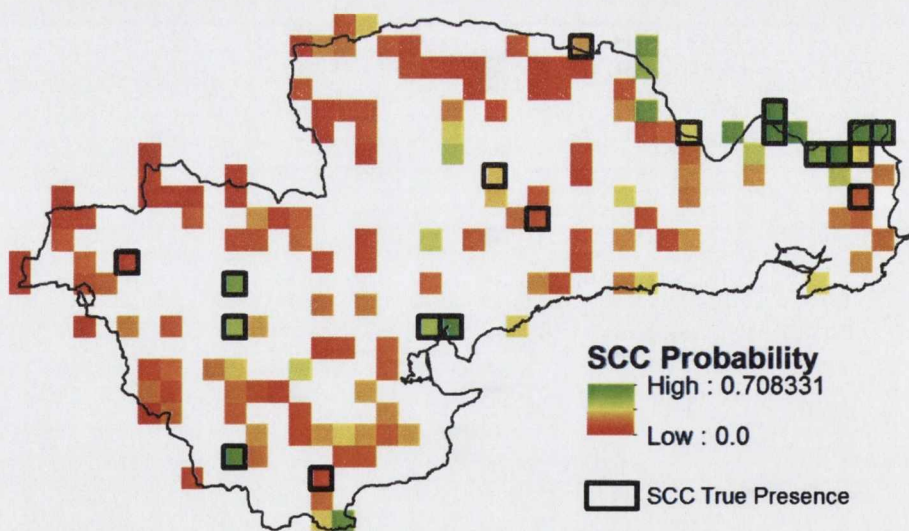


Figure 5.6: The distribution of the probability of species of conservation concern (SCC) presence in the test study area as predicted by the National model.

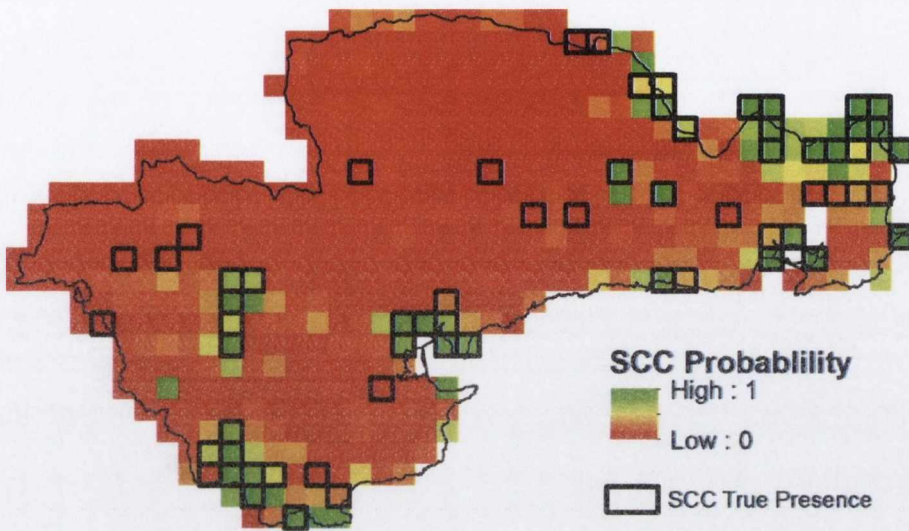


Figure 5.7: The distribution of the probability of species of conservation concern (SCC) presence in County Waterford as predicted by the Waterford model.

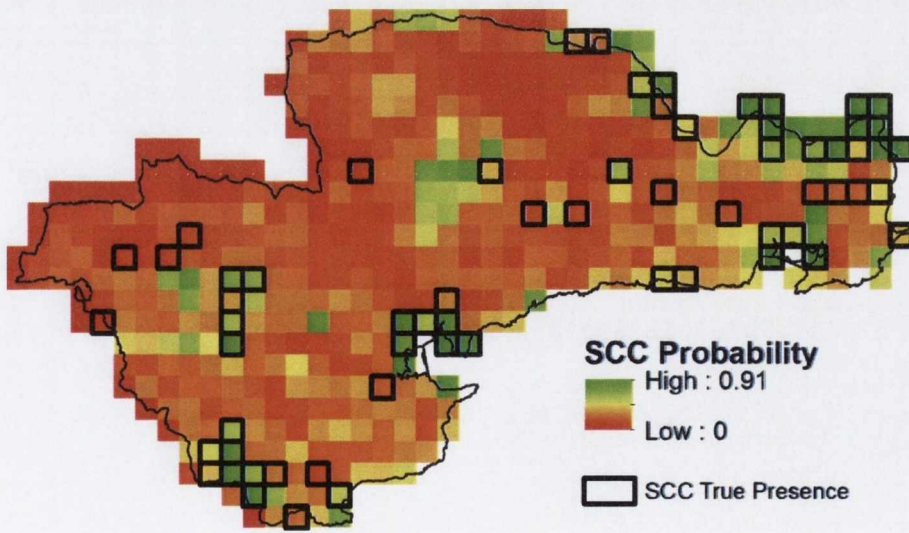


Figure 5.8: The distribution of the probability of species of conservation concern (SCC) presence in County Waterford as predicted by the National model.

5.3.3 Predictive maps of SCC distribution

The National model was used to predict probability values of SCC occurrence for Ireland. These values were mapped to show the distribution of high and low probability values in the model (Figure 5.9). A Local Indicator of Spatial Association (LISA) cluster map shows the clustering of the high and low probability values (Figure 5.10). The pattern of high probability values broadly follows the distribution of lower stocking density (Figure 5.11) and higher semi-natural cover (Figure 5.12). The bivariate Moran's I values for these variables are reported in table 5.6. The performance of the National model was not as good as for the Waterford test data and the model predicted 40% of the presence of SCC.

Table 5.6: The bivariate Moran's I values for the spatial correlation of SCC probability values with stocking density and semi-natural land cover. A value of 0 indicates no spatial correlation; 1 indicated positive correlation; -1 indicates negative correlation.

Bivariate Moran's I				
	County Waterford Data		National Data	
	Stocking density	Semi-natural cover	Stocking density	Semi-natural cover
National model	-0.2	-0.03	-0.33	0.2
Waterford model	-0.15	-0.16	-	-

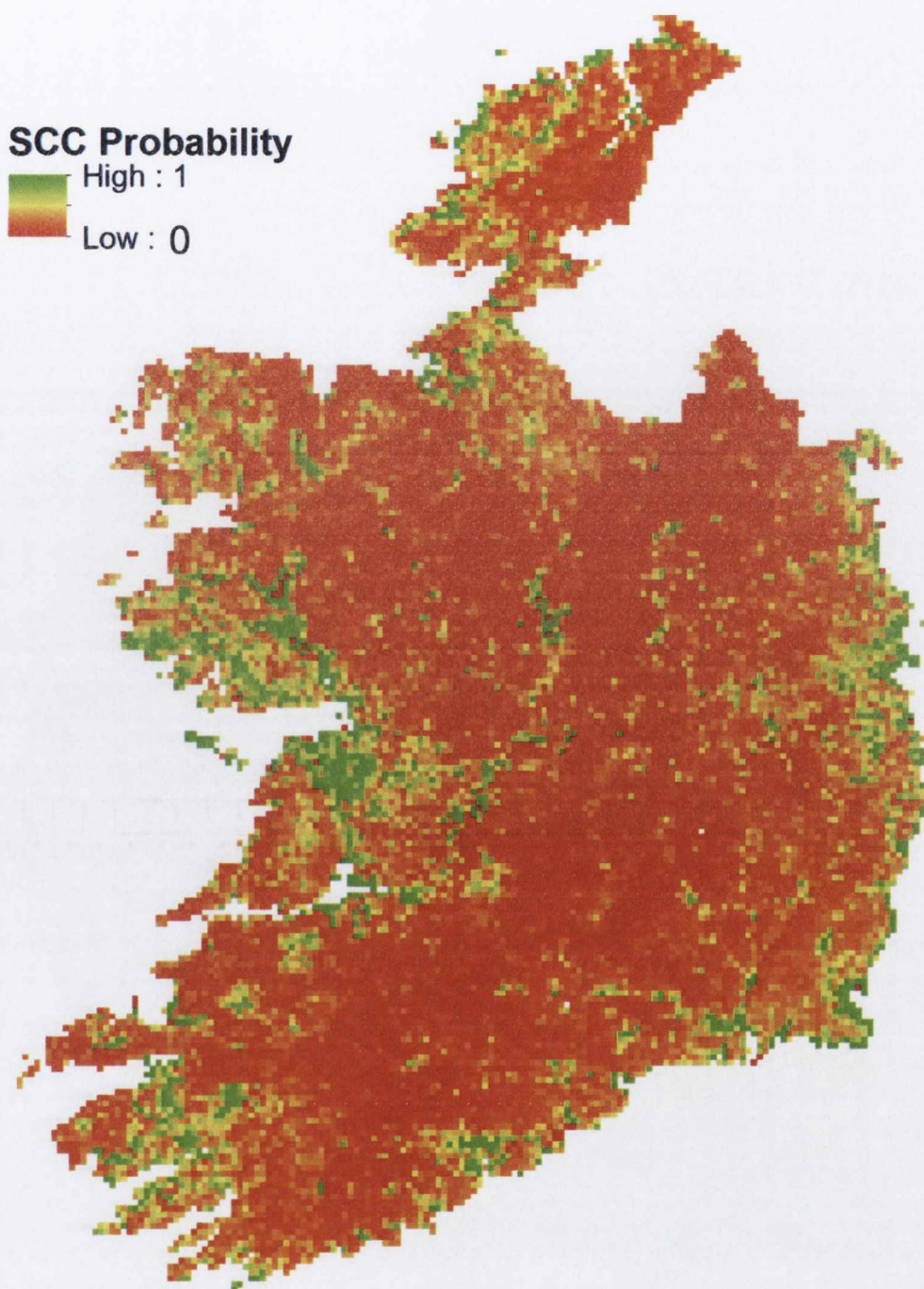


Figure 5.9: The distribution of the probability of species of conservation concern (SCC) presence in the Republic of Ireland as predicted by the National model

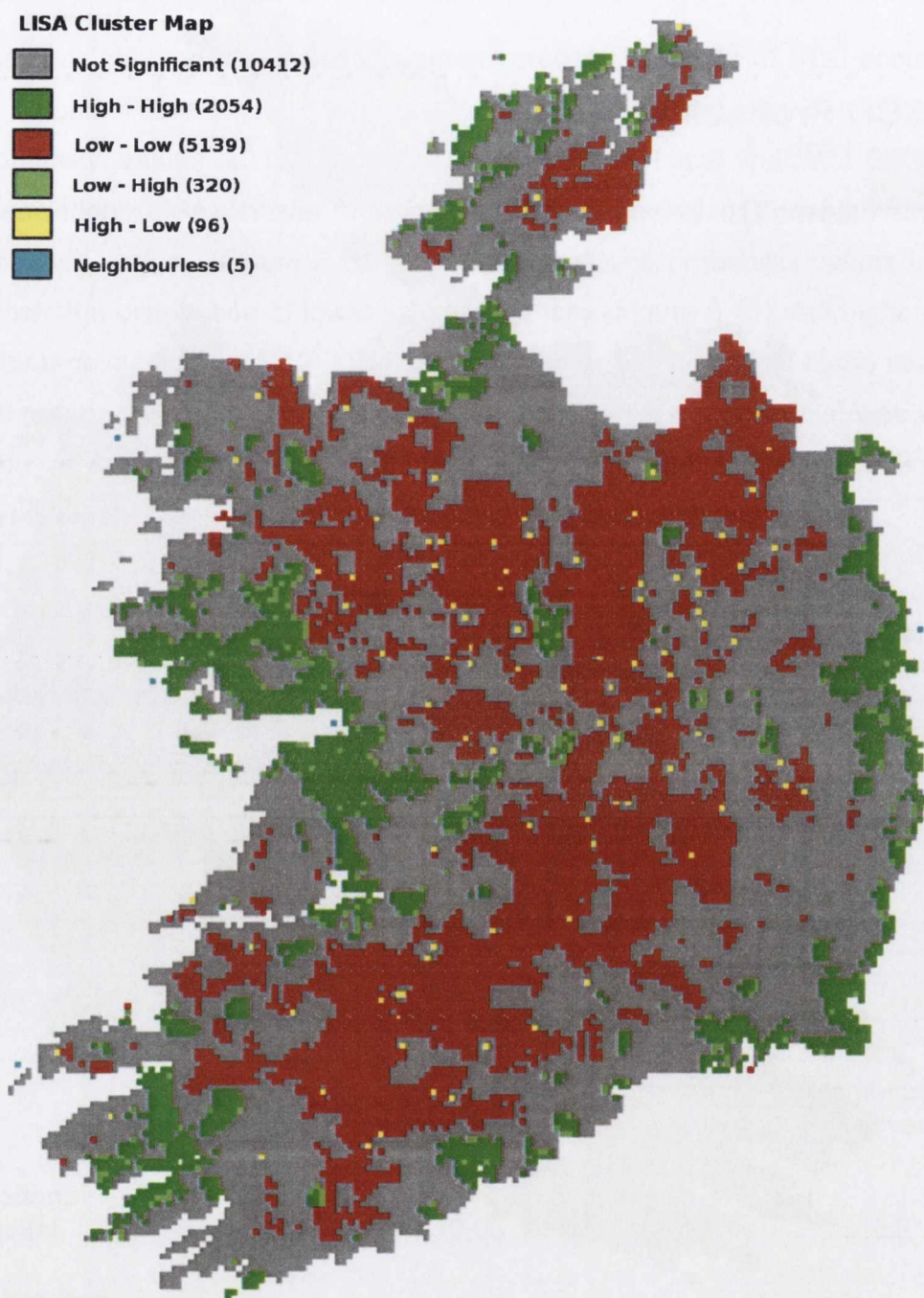


Figure 5.10: The Local Indicator of Spatial Association (LISA) showing clustering of high (dark green cells) and low probability (red cells) of species of conservation concern (SCC) presence in the Republic of Ireland as predicted by the national model (without including the county variable). The cluster map also shows spatial outliers such as lone tetrads with high probability values surrounded by low probability areas (yellow cells).

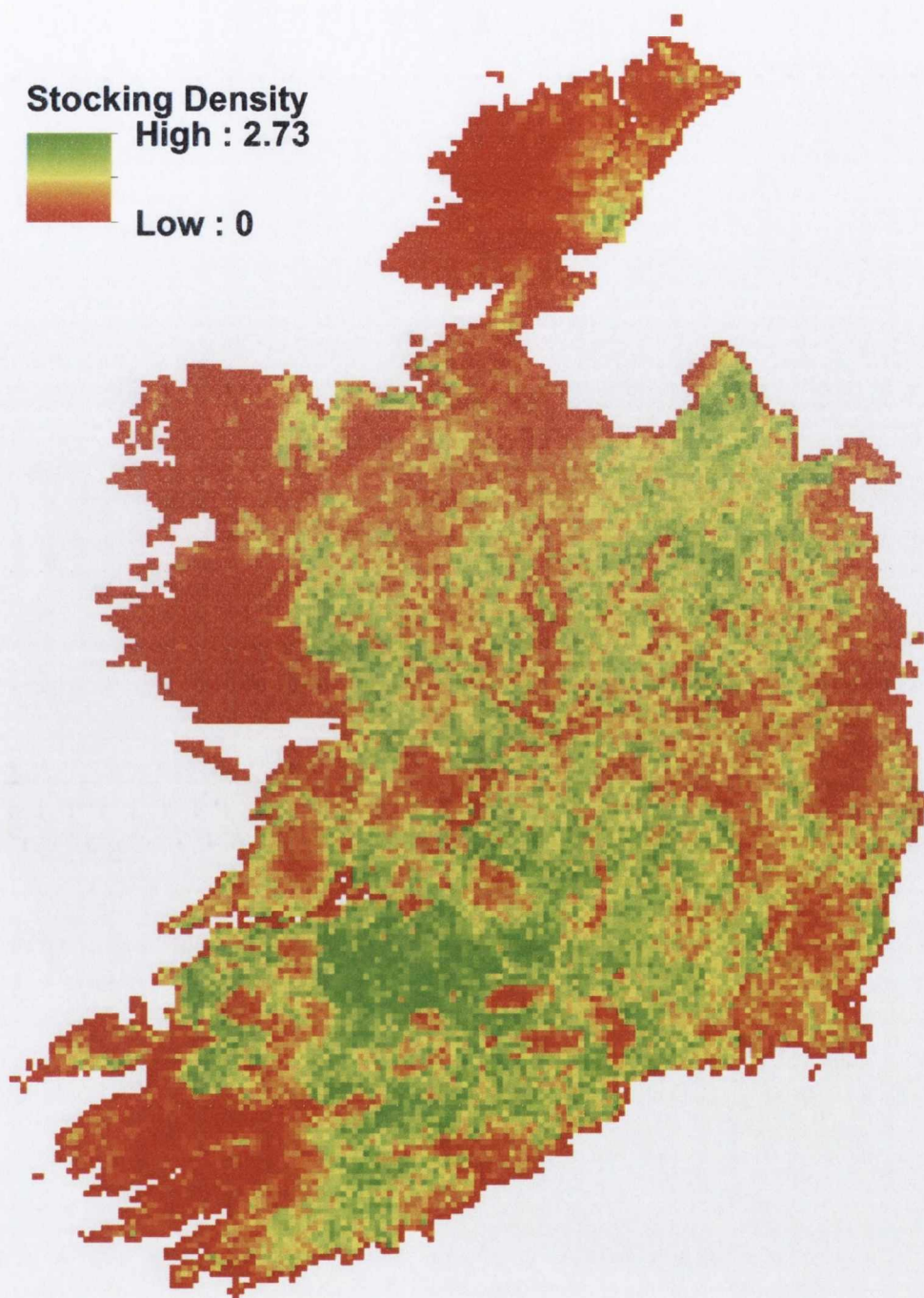
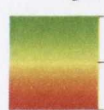


Figure 5.11: The distribution of stocking density values at the tetrad scale in the Republic of Ireland.

Proportion semi-natural cover



High : 1

Low : 0



Figure 5.12: The distribution of semi-natural cover at the tetrad scale in the Republic of Ireland.

5.3.4 Priority areas for conservation and predicted SCC distribution

Figures 5.13 – 5.18 show the priority areas identified in Chapters 3 & 4 for County Waterford together with the SCC probability values produced by the logistic regression models. The figures include histograms of the distribution of the probability values within the priority areas. Figures 5.13 & 5.14 show the priority areas identified using the scoring method of prioritisation of chapter 3. Here the priority areas are also coinciding with higher probability values. In figures 5.15 & 5.16 most of the priority areas coincide with higher probability values (using the 0.2 probability break-point as a guide). These priority areas were identified using a linear programming approach with objectives that included selecting a minimum number of areas in which each SCC species was represented at least once. In figures 5.17 & 5.18 the linear programming approach aimed to guarantee that all species were represented and these priority areas cover a wider range of probability values and notably more of the lower values.

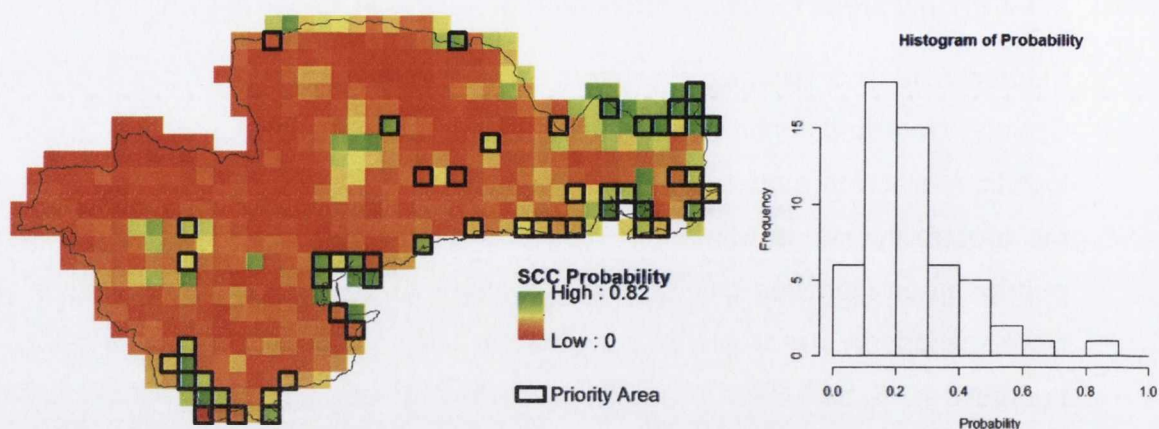


Figure 5.13: The priority areas identified using the scoring method of prioritisation (Chapter 3) and the probability of occurrence of the species of conservation concern as predicted by the National model. The distribution of the probability values occurring in the priority area tetrads is also included.

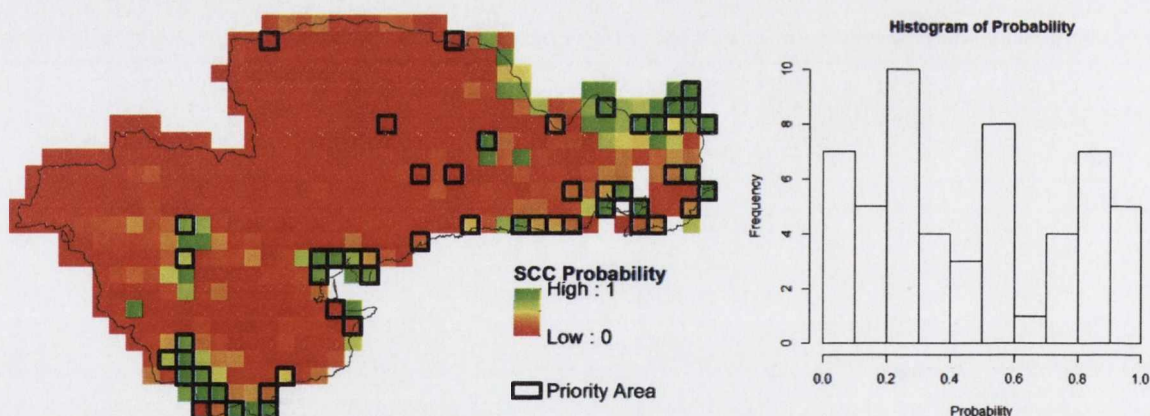


Figure 5.14: The priority areas identified using the scoring method of prioritisation (Chapter 3) and the probability of occurrence of the species of conservation concern as predicted by the Waterford model. The distribution of the probability values occurring in the priority area tetrads is also included.

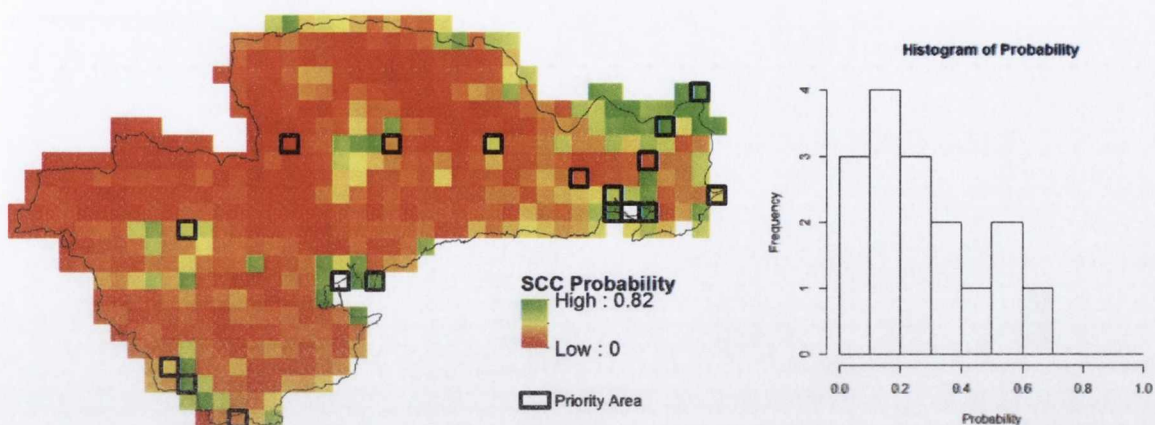


Figure 5.15: The priority areas identified using the complementarity-based method of prioritisation (Chapter 4) and the probability of occurrence of the species of conservation concern (SCC) as predicted by the National model. The priority areas correspond to the linear program that identified the minimum number of high conservation value tetrads in which all SCC were represented. The distribution of the probability values occurring in the priority area tetrads is also included.

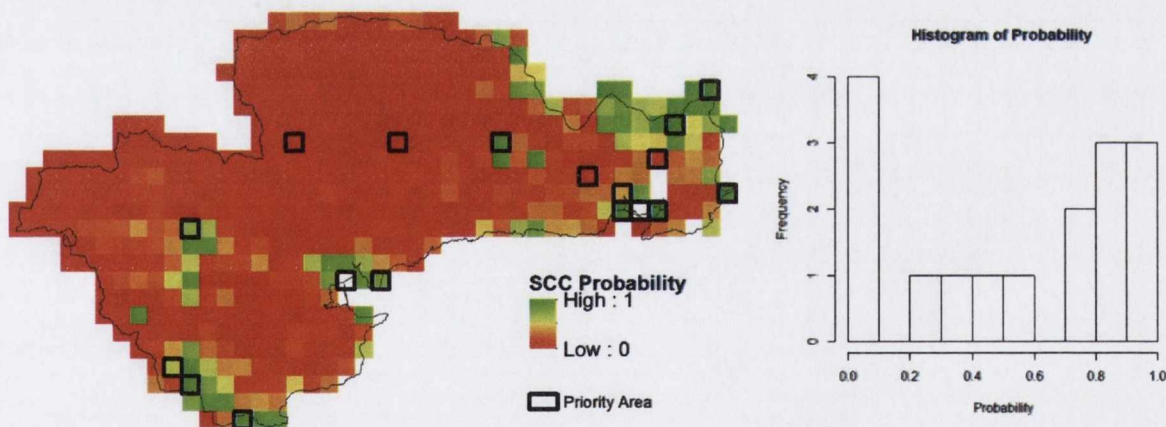


Figure 5.16: The priority areas identified using the complementarity-based method of prioritisation (Chapter 4) and the probability of occurrence of the species of conservation concern (SCC) as predicted by the Waterford model. The priority areas correspond to the linear program that identified the minimum number of high conservation value tetrads in which all SCC were represented. The distribution of the probability values occurring in the priority area tetrads is also included.

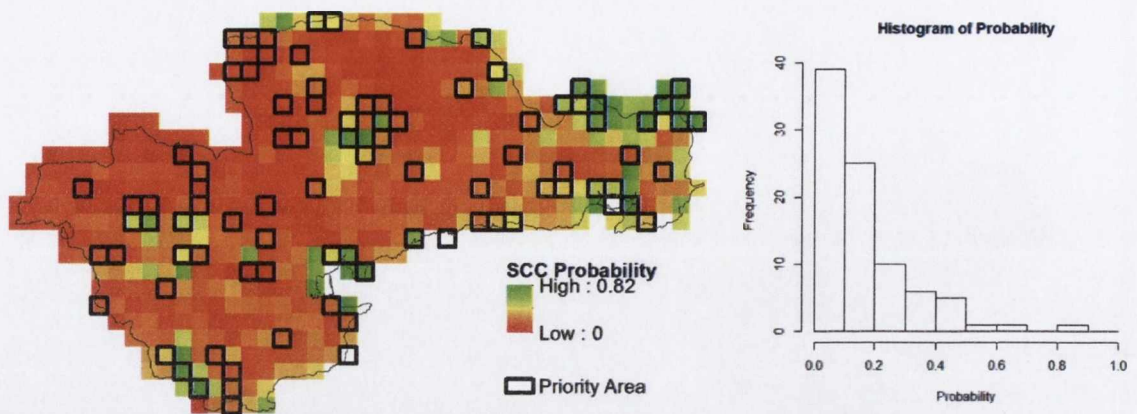


Figure 5.17: The priority areas identified using the complementarity-based method of prioritisation (Chapter 4) and the probability of occurrence of the species of conservation concern (SCC) as predicted by the National model. The priority areas correspond to the linear program that identified the minimum number of high conservation value tetrads in which all species were represented. The distribution of the probability values occurring in the priority area tetrads is also included.

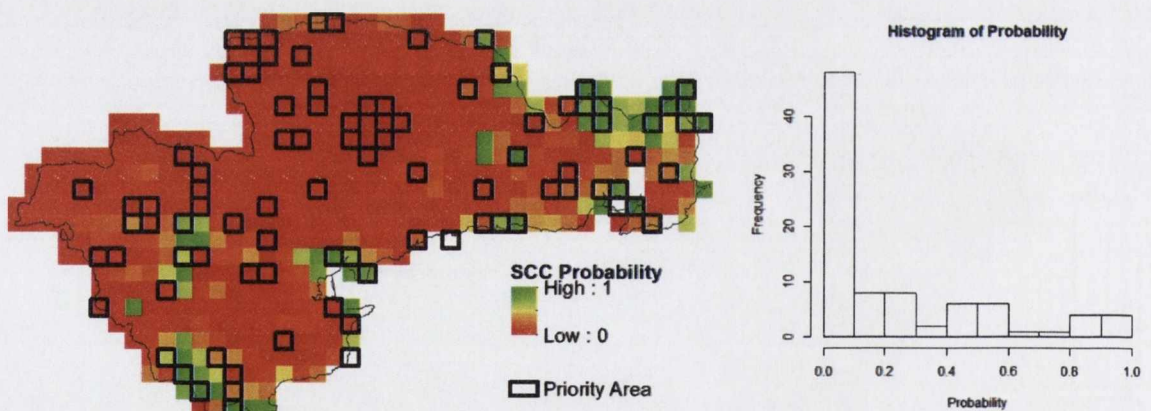


Figure 5.18: The priority areas identified using the complementarity-based method of prioritisation (Chapter 4) and the probability of occurrence of the species of conservation concern (SCC) as predicted by the Waterford model. The priority areas correspond to the linear program that identified the minimum number of high conservation value tetrads in which all species were represented. The distribution of the probability values occurring in the priority area tetrads is also included.

5.4 Discussion

5.4.1 Species distribution modelling and pseudo-absences

Species distribution modelling (SDM) has developed as an important tool for conservation planning by filling knowledge gaps, assisting in decision-making, and acting as an input when designing conservation networks (Barker et al., 2014). While no single modelling approach has been shown to be the best (Williams et al., 2009), the most effective models make use of presence and absence data or background data associated with pseudo-absence locations when reliable absence data are not available (Barbet-Massin et al., 2012). In this form the distribution models characterise both the locations of presence and a background sample of pseudo-absence data thereby characterising the environment of the study area (Ilturbide et al., 2015).

The ability to identify the full extent of species ranges is an important challenge for SDMs given that the areas those ranges cover are likely to be heterogeneous (Williams et al., 2009). The inclusion of background data and the closely related pseudo-absences allow the characterisation of the study area particularly in relation to presumed absence sites. An earlier SDM approach has shown that model predictive performance increases substantially in response to the inclusion of greater numbers of background areas (Phillips & Dudik 2008). The model building approach described in this research followed Barbet-Massin et al., (2012) in selecting 10000 pseudo-absences; the use of a lower number pseudo-absences resulted in insufficient information in the data to estimate the models. This finding supports recommendations to use a large number of pseudo-absences in SDM (Barbet-Massin et al., 2012). However, increasing the number of pseudo-absences also increases the chance of a pseudo-absence occurring on suitable habitat for plant species of conservation concern (SCC) that is either currently unoccupied or has not been surveyed; with the consequence that these pseudo-absences would affect the predicted probability of occurrence at that site (Williams et al., 2009).

5.4.2 Modelling the distribution of a group of species

The choice of the SCC group as a response variable departs from traditional SDM approach of modelling individual species distributions. The modelling of a group of species has the potential to generalise predictions because of the broadening of the relationship between species group occurrence and the environmental variables (Barker et al., 2014). This might explain the low levels of association of SCC occurrence with the environmental variables (Tables 5.2 & 5.3). The SCC group of plants contains over 120 species from a range of different habitats such as coastal habitats, woodlands, uplands, and bogs and the characterisation of the environmental variables associated with a diverse group of habitats presented a challenge in the SDM approach. However the models' predictive performance of the presence and absence of SCC in the test study area indicates that the environmental variables provided enough information to make successful predictions (Table 5.5).

The modelling strategy first assembled species into a group before building the models, known as the assemble first, predict later approach (Ferrier & Guisan, 2006). This approach has been used in species abundance modelling (Barker et al., 2014), a similar method to SDMs that predicts abundances rather than presence of species. The advantages of grouping species before modelling are that it is more time-efficient process avoiding the need to build and evaluate models for all individual species. The approach can also include species with insufficient data for modelling by using more abundant species as surrogates (Barker et al 2014). SDMs using grouped species can more rapidly analyse potential distributions and provide added value to rare species data (Ferrier & Guisan, 2006). The level of predictive performance in the Waterford test study area was unexpected given that threatened species tend to have geographically restricted distributions due to stricter ecological and habitat requirements (Parviainen et al., 2009), and that the species were modelled as a group. However, threatened species diversity can be contained in small areas of the landscape (Reid, 1998) and each tetrad is likely to contain a variety of habitats that could be harbouring a similarly varied number of species.

5.4.3 Factors associated with SCC occurrence

The model building approach involved the selection of environmental predictor variables based on their availability and the assumption that the variables were associated with the distribution of SCC. The climate variables were removed from the models as they were contributing to multicollinearity; the absence of which is an assumption of logistic regression. This has implications for the use of the models in any future analysis of the effect of climate change on predicted species distributions (e.g. Barbet-Massin et al., 2010; Matin et al., 2012; Moor et al., 2015). The remaining variables could be acting as surrogates for other as yet unknown variables that may be more strongly associated with SCC presence or for which data are currently deficient (Austin 2007). Factors such as forest cover, density of hedges, or population density could be considered in future modelling of plant species. After accounting for multicollinearity all of the remaining independent variables were retained in the final models as removal of the non-significant variables at this stage did not improve model performance. These results support the findings of Steyerberg et al., (2011) that the stepwise removal of non-significant variables from logistic regression models does not necessarily improve the predictive performance of the models.

Where associations between SCC occurrence and the environmental variables did occur they are relatively weak as shown by the resulting odds ratios (Tables 5.3 & 5.4). This weakening of the associations may have been due to the attempt to characterise the environmental variables associated with a diverse group of species from a variety of habitats. The variables with the strongest positive effect on the odds ratios included land cover diversity and semi-natural habitat cover, both of which indicate that a more heterogeneous landscape favours the occurrence of this group of species. The proportion of the tetrads covered by designated areas also had a positive association with SCC occurrence indicating that these areas could be affording some protection the plant species. This association might be due to potential bias in the collection of records from these areas; however the strong association of these areas with SCC arising in the Waterford model based on a relatively complete dataset

would not support this view (Table 5.3). The National and Waterford models showed differing associations between both stocking density and semi-natural land cover and SCC occurrence. This might indicate that in indicating that in at least some cases SCC are linked with agricultural land (Table 5.6).

5.4.4 Model performance

The predictive ability of SDMs should be examined using datasets that are independent of the data used to build the models (Fielding & Bell 1997). In this study a subset of the County Waterford dataset was reserved for this purpose. Two models were built to model SCC occurrence; the Waterford model using a subset of the County Waterford dataset and a National model based on the national presence-only and pseudo-absence data. While the Waterford model outperformed the National model the differences in model performance were small and the national model matched the Waterford model in correctly predicting SCC presence in Co. Waterford (Table 5.5).

The area under the curve (AUC) is a metric that is considered to be an effective indicator of model performance and is independent of the threshold probability at which a species is said to be present (such as the probability break-point used in this research). AUC values of 0.7 - 0.9 indicate useful models (Manel et al., 2001). In other studies the majority of distribution models for British plants and lichens had an AUC value of >0.8 (Henrys et al., 2015) and a value greater than 0.7 for models of British coastal plants (Jarvis et al., 2016). Studies which provide summaries of large multi-species modelling also report AUC values >0.7 (Elith & Leathwick, 2007) and predictive models for rare plant species achieved values of 0.83 – 0.95 (Williams et al., 2009). Using this metric the models of SCC occurrence are performing well (AUC = 0.80, 0.84) and compare favourably to the AUC values for modelling in other studies.

5.4.5 Local predictive mapping of SCC occurrence

The use of the AUC remains a popular means to evaluate and compare models however concerns have been raised in relation to the use of AUC in this manner (see Lobo et al., 2008). Additionally, models with similar evaluation

statistics can produce large differences in predictions, highlighting the importance of visually interpreting probability maps (Parviainen et al., 2009). The SCC probability maps for County Waterford provide an example to support this assertion. Here the National and Waterford models achieve similar AUC values however the national model provides a wider distribution of high probability values (Figures 5.5 – 5.8). This is likely due to the failure of the training model to fully characterize the environmental data associated with all of the habitats that occur nationally beyond the Waterford study area.

The predicted probability maps show a notable difference between the national and training model predictions for County Waterford (Figures 5.7 & 5.8). An area of upland habitat associated with the Comeragh mountains in the centre of County Waterford, while prominent in the predictive map produced by the national model are absent in the predictive map produced using the training model. The national model also shows a wider distribution of higher probability values than those predicted by the training model. The greater geographic range and number of data points in the national data characterises environmental variables associated with a wider range of SCC locations (and therefore habitats) and this is being reflected in the predictive maps.

5.4.6 Mapping of the national predicted occurrence of SCC

Species distribution models can be used to produce predictive models of species occurrence and to inform conservation planning, for example for plant species in Britain (Henrys et al., 2015; Jarvis et al., 2016) and for rare plants in California (Williams et al., 2009). The predictive distribution map produced in this study for Ireland shows areas of high and low probability of SCC occurrence and shows evidence of clustering of high and low probability values (Figure 5.10). The cluster map provides a clearer view of the main areas of clustering. These areas appear to follow trend of land-cover featuring lower levels of stocking density and higher semi-natural cover (Figures 5.11 – 5.12). This is confirmed by the measures of the spatial correlation between these variables and the probability of SCC occurrence (Table 5.6).

The prediction of the distribution of the SCC group was produced for Ireland using the national model. The national plant distribution records are potentially biased and recorder bias in the absence data can be partially addressed by the inclusion of pseudo-absences; however bias in the presence records remains.

The tetrad scale of this study does not allow the direct association of a probability value with underlying habitat as there will be a variety of habitats within each tetrad. However the locations of areas of high probability values can be broadly compared with localities throughout Ireland. Both the maps of SCC probability and the cluster map show some of the general regions of high SCC probability (Figures 5.10 & 5.11). Of note are the eastern and southern coastal habitats and western areas of Counties Kerry and Cork, including Killarney national park. The river Shannon, including the major lake areas of Lough Ree and Lough Derg and the Shannon estuary are also prominent. High probability areas also coincide with the Burren in County Clare. The Aran Islands, Lough Corrib, Lough Mask, and Connemara in County Galway show clustering of high SCC probability. Further north these areas coincide with Lough Conn and western County Mayo, in addition to other smaller clusters through Counties Sligo, Leitrim, and Donegal, including Glenveagh national park. The coincidence of the higher probability values with these areas reflects areas of lower stocking density and higher semi-natural cover apart from prominent urban areas such as Dublin and Cork where a greater recording effort might be factoring into probability scores.

The national model predicted large areas of low probability of SCC presence occurring as large interconnected clusters across the country (Figures 5.9 & 5.10). In general these coincide with low semi-natural cover and higher stocking densities; however the cluster map also shows spatial outliers including lone tetrads with high probability values surrounded by areas of low probability (Figure 5.10). Although suitable SCC habitat cannot be predicted using this study, these spatial outliers may be worthy of investigation to see if SCC at these locations are isolated and potentially surrounded by unsuitable habitat. When the predicted probabilities were converted to presence/absence values

the national model was not as successful at the national scale as it was at the local scale but is still effective (e.g. predicts 40% of true presences) considering the scale and breadth of the study area. However, the modelling of SCC should be improved before such a predictive map could form the basis for surveying for new locations containing SCC. That said, the predictive map as it stands still offers an improvement over the use of a potentially incomplete national recording of plant species of conservation concern.

A central theme of this thesis was to identify areas of plant diversity as priority areas for conservation or further study. The application of a species distribution modelling approach to predict the distribution of the plant species of conservation concern could itself provide a useful way to identify priority areas throughout Ireland. This would be especially useful given that the low data cover provided by the plant records prevent the application of the priority area identification methods from Chapters 3 & 4 from being applied nationally at the tetrad-scale. The locations of some of the sets of priority areas identified by those methods in County Waterford coincide with the areas with high predicted probability of SCC. Priority areas identified using a linear programming method showed contrasting levels of coincidence with the high probability values (Figures 5.15 - 5.18). One of these had a strict requirement to guarantee that only each member of the SCC group in Waterford was required to be represented in the identified set of priority areas and, as might be expected, coincided with more of the higher probability areas (Figures 15.15 – 15.16). The second linear program required that all species, not just SCC, be represented resulting in a more widely distributed selection that contain a wider range of SCC probability values (Figures 15.17 – 15.18). This requirement also means that the set of priority areas contains many more tetrads than the solutions provided by the other prioritisation methods. The priority areas identified by the scoring method of Chapter 3 also coincides with many of the higher probability areas (Figure 15.13 – 15.14). The SCC group was principal focus of all of the prioritisation methods and this is reflected in the coincidence of the priority areas with areas of high probability of SCC occurrence. However, many of the prioritisation methods also focus on other plant species in an effort

to select priority areas that are of higher plant diversity and therefore more representative of the flora of Ireland.

The use of the predictive modelling of the SCC group would not guarantee the identification of the more diverse important plant areas, as indicated by the comparison with the second linear programming approach focused on representing all species (Figures 15.17 - 15.18). It would therefore be more useful to use the prioritisation methods of Chapter 3 & 4 as these put more focus on species diversity within priority areas. A species distribution modelling approach could still factor in the identification of priority areas and the predicted distribution of plant species (or groups of species) could be used to extend the identification of sites beyond well surveyed areas.

5.4.7 Future improvements for the modelling of SCC

Many methods exist for species distribution modelling but logistic regression is suited to predicting the presence-absence of species as it takes a categorical response variable. Distribution modelling using this method requires presence and absence data, or background pseudo-absence data where the latter are missing or unreliable. In the case of the SCC modelling at least, a large number of background pseudo-absences were required to adequately characterise the environmental conditions of the study area. The pseudo-absences were selected at random from the national data (excluding sites of SCC presence) and this runs the risk of selecting areas of suitable SCC habitat as absences (Engler et al., 2004). The selection of pseudo-absences could be improved by selecting tetrads with the same bias as the presence data (Phillips et al., 2009) or restricting selection to known surveyed sites (Elith & Leathwick 2007) or to unsuitable habitats (Engler et al., 2004; Iturbide et al., 2015).

The application of the model built using the Waterford training data is limited in its applicability outside of County Waterford due to a lack of characterisation of environmental variables in the model (likely due to Waterford being a limited subset of the national study area). This issue can be overcome by the removal of these environmental variables from the model but this would result in a less

effective predictive model. However this presents an opportunity to address this knowledge gap by targeting plant recording to areas where the missing environmental variables occur (avoiding the need to for extended time-consuming surveys). The goal of this approach would be to provide an unbiased assessment of the full range of factors governing species distributions (Araujo & Guisan, 2006). This would allow the application of the better performing training model for predicting SCC or at least to test the extent to which the model is effective outside of County Waterford. Species distribution models could also be improved by dividing the large SCC group into community-level subgroups (Ferrier & Guisan 2006) which might reveal stronger associations with environmental variables.

5.4.8 Conclusion

The distribution of SCC probability values at the national and local scale follow other spatial trends and show increased probability of occurrence in areas of greater semi-natural habitat and decreased probability in areas of more intensive land use. The distribution of high probability values also occur in many of the locations identified as priority areas by the scoring and complementarity methods of prioritisation (Chapters 3 & 4). This gives insight into the underlying factors that drive both the distribution of SCC species (and priority areas) in Ireland in that areas of semi-natural habitat might be associated with areas of higher probability of SCC occurrence.

This research provides an example of the predictive modelling of a group of species and supports the view that that it is possible to predict the distributions of a species group using available environmental data. There is also the potential to use this modelling approach in areas with medium-poor data coverage as combining individual species distributions into a group can provide a better set of data for model building (Arponen et al., 2008). The species group modelling approach also provides data on a large number of species in a form that may be more interpretable by decision makers for conservation planning

(Ferrier & Guisan, 2006). The approach could also be applied for other species groups, or could include additional environmental and higher resolution data should it become available, to more accurately prediction of species distributions.

To date, knowledge of the distribution of the plant species of conservation concern may have been limited due to the level of recording effort across the Republic of Ireland. The predictive maps arising from this research provide improved knowledge of the distribution of important areas of plant diversity in Ireland. The modelling approach outlined in this research could contribute to spatial conservation planning by identifying potential locations of plant species of conservation concern for further surveying and research or as an input for priority area identification. This provides an improvement on the currently incomplete plant distribution data and provides a viable alternative basis for conservation planning (Parviainen et al., 2009).

6. Discussion

6.1 Introduction

The advent of large-scale losses in biodiversity has prompted a response from the global community that includes the use conservation planning to safeguard biodiversity. This form of planning involves decisions in respect of locations for positive actions for biodiversity such as protecting or restoring areas, and also for negative actions such as the destruction of habitat for development or the intensification of practices on agricultural land. Conservation resources are limited and having access to information generated by quantitative methods can enhance the credibility of the decision making process (Sarkar et al 2006). Conservation planning requires access to a variety of information including knowledge of the distribution of important features of biodiversity (Kukkala & Moilanen, 2013). The locations of these features can be identified by means of an assessment of the conservation value of the landscape using what Ferrier & Wintle (2009) refer to as spatial conservation prioritisation. I hereafter refer to this process as prioritisation and to the sites the process identifies as priority areas; those being important areas of vascular plant diversity that deserve high priority for either conservation or further examination.

This research was conducted on the theme of conservation prioritisation using techniques to provide spatial information to inform conservation planning. Chapter 2 examined the extent of the tetrad-scale plant data coverage and the coincidence of the locations of plant species of conservation concern with protected areas. In chapter 3 a scoring method of prioritisation was developed to identify priority areas of important plant diversity. This was extended in chapter 4 where first strict requirements were solved using a linear programming method and then combined with the scoring method outputs. Chapter 5 included the modelling of the distribution of the plant species of conservation concern group. Some of the challenges in conservation planning and their solutions are discussed with particular reference to the research findings regarding plant diversity in Ireland. The research presented in this thesis could inform conservation planning and further research or surveying in

relation to the distribution of plants in Ireland. This research did not attempt to provide a complete solution to the problem of plant conservation in Ireland. Instead first steps were taken to improve the conservation knowledge-base by using current information on the distribution of species to address a series of research objectives.

Research objectives:

- To determine the coverage provided by the distribution records for all recorded vascular plant species at the tetrad-scale (2km x 2km) in Ireland.
- To develop a scoring method of priority area identification that differentiates between areas of high and low vascular plant conservation value
- To examine determine the number of vascular plant species that are contained within cells of high conservation value
- To select priority areas from candidate high value cells based on the number of vascular plant species represented within the cells
- To compare the performance of the scoring method in terms of species representation to a random selection of areas and a selection based on species richness
- To compare the locations of priority areas identified using the scoring method to the locations of locally identified Important Plant Areas
- To identify the minimum number of priority areas that are required to represent (1) all species and (2) all species of high conservation concern at least once.
- To find the sets of priority areas in which the maximum number of species can be represented when the number of cells in the priority area network is limited.
- To build logistic regression species distribution models based on records of plant species of conservation concern and a selection of independent environmental variables.

- To examine which environmental variables are associated with the distribution of the plant group.
- To compare the predictive ability of the logistic regression model built using national data to that of a model built using an independent dataset.
- To map the predicted probability of the occurrence of plant species of conservation concern so as to add to the conservation planning knowledge-base.

Chapters 2 – 5 of this thesis report the research undertaken to address the research objectives. I will first provide a view of the organising of the plant records into a distribution database. This is followed by an overview of the thesis chapters before discussing the findings of the research. The chapter ends with a discussion of the limitations of the work and recommendations for future research.

6.2 Preparation of plant distribution database

The plant distribution data were obtained from a number of different sources and data preparation work was required to be carried out before the data could be analysed. I will first present some of the more challenging aspects of preparing the distribution data for analysis before discussing the research findings in later sections.

Over the course of this research a substantial effort was required to create the database that held the vascular plant distribution records. The data were sourced from a number of different organisations and individuals where the use of a standardised naming system for species was not used. As a result, the collated data contained many instances where a certain species appeared under a variety of different names. Each of the species names had to be checked and where necessary corrected to match a standard species list, which in this case was *The New Flora of the British Isles*, Third Edition (Stace, 2010). The data contained over 2,400 species after all the species names had been standardised. The bulk of the data were supplied at the hectad and tetrad scales however some data were recorded using different geographic coordinate

systems. These had to be converted to the relevant grid scale. Hectad and tetrad grid shapefiles had to be created to allow the mapping of the distribution data using a GIS. A method had to be devised to assign the correct grid cell reference to each cell in the shapefiles. The hectad shapefile contained more than 1000 cells while the tetrad shapefile contained over 22, 000 cells. Once all of the data preparation work was completed the data were collated in a database where further work led to the analysis presented in this study. The plant distribution database will be made publicly available via Teagasc. The following sections provide a review of the results of Chapters 2 – 5, which featured an examination of the coincidence of species of conservation concern with designated areas, methods for identifying priority areas, and species distribution modelling.

6.3 Summary of research

I investigated the level of coverage provided by the tetrad-scale data for plants in Ireland. The vascular plant distribution data were collated and mapped at the tetrad scale to illustrate the level of coverage provided by the data. I also investigated the coincidence of tetrads containing plant species of conservation concern with areas designated for the protection of biodiversity (Walsh et al. 2015; Chapter 2). Using the collated plant distribution data from Chapter 2, I developed a scoring approach to identify priority areas for conservation. I developed several criteria (species of high conservation concern, Annex I habitat indicator species, Semi-natural habitat indicator species, native species, species distribution) and assigned values to species based on these criteria. A single conservation value for each grid cell was calculated based on the species values in Co. Fermanagh, Co. Waterford, and Ireland. The cells were ranked in terms of cell conservation value and the identification of the highest valued cells facilitated the prioritisation of areas.

A class of methods of prioritisation have been developed to incorporate the principle of complementarity (Ferrier and Wintle, 2009); where sites selected for inclusion in a set of priority areas complement those that have already been selected (Justus and Sarkar, 2002). This allows the use of complementarity-

based methods to maximise the inclusion of species within a minimum number of priority areas. An inability to account for complementarity is a feature of scoring methods of prioritisation and means that priority areas identified using scoring methods can have poor representation for some species and an over-representation of others (Simaika & Samways, 2009). I used a linear programming approach to develop a complementarity-based method for selecting priority areas that maximised species representation using as few sites as possible. The collated plant distribution data were used with this method to select the minimum number of cells that achieved a number of conservation objectives. I then combined the outputs of the scoring method of priority area identification with the complementarity-based approach to make use of the benefits of both the methods. Those benefits being the identification of the areas of highest conservation value using the scoring method and ensuring the efficient representation of species using the complementarity-based method. A combination of the two methods allowed the identification of the minimum number of high conservation value sites in which the number of species was maximised.

Finally, I used a combination of the plant distribution data, spatial environmental data, and a logistic regression method to build models to predict the distribution of the plant species of conservation concern group (SCC). These consisted of a model built using incomplete national data and a model built using a more complete plant dataset for County Waterford. The associations between the environmental data and SCC occurrence were examined and the predictive performance of both models was investigated using a reserved portion of the County Waterford data.

6.4 Summary of research findings

6.4.1 Spatial coverage provided by the plant data

Spatially explicit data on biodiversity are fundamental to conservation planning (Kukkala & Moilanen, 2013; Pressey & Bottrill, 2009). The mapping of the distributions of species is challenging because species can be detected only

through direct field surveys, unlike the more efficient remote sensing of broad ecosystems; therefore knowledge of species distributions is often incomplete (Ferrier et al. 2004). The research in Chapter 2 involved an investigation of the level of coverage provided by the tetrad-scale data for plants in Ireland where the vascular plant distribution data were collated and mapped at the tetrad scale. This was the first step in the research to show the level of coverage provided by the current distribution records, as has been completed in other areas (e.g. Dogan et al. 2011; Ferrier et al. 2004; Garzón-Machado et al. 2011). The data coverage turned out to be low with no coverage at all for approximately 70% of the island of Ireland (Chapter 2), and with a similar level of cover for some under-recorded taxa such as earthworms in Britain and Ireland, with just 32% cover in the Republic of Ireland (Carpenter et al. 2012). The tetrad-scale data were also unevenly distributed with only two counties in Ireland with a high level of data coverage. The number of species recorded in each tetrad cell varied, indicating that recording effort was not consistent.

6.4.2 The coincidence of plant species of conservation concern with designated areas

The coincidence of tetrads containing plant species of conservation concern with areas designated for the protection of biodiversity was also investigated (Chapter 2; Walsh et al. 2015). A conservative measurement revealed that between 22 to 40% of these tetrads were occurring outside of designated areas, which is largely consistent with findings in other regions (Gomez-Campo, 1997; Jackson et al., 2009; Blasi et al., 2011). The results for individual species show that there is considerable variation in the level of cover provided by designated areas. Some had good cover for example all of the locations of *Pilularia globulifera* were within designated areas which could indicate that the designated areas are helping to preserve certain species. In other cases all of the locations of individual species were occurring outside of designated areas for example *Adoxa moschatellina* and *Erica vagans*. The results showed that sites inside designated areas and in the landscape beyond designated areas may be important for the safeguarding of species of conservation concern. The results were similar to those for red listed species in the UK (Jackson et al.

2009) and support the assertion of the UK study that a dual conservation strategy would be appropriate, where both protected area management and conservation measures in the wider countryside could be used to conserve plant species. The plant species of conservation concern represent one group of plant species in Ireland but other species are also important to ecosystems (Gaston and Fuller, 2008). The subsequent research objectives were to investigate methods for the identification of the most important areas for plants, and the next section deals with the first of these, the scoring method.

6.4.3 Identifying priority areas using a scoring method

Biodiversity is not evenly distributed (Gaston 2000) and certain areas of the landscape are of more conservation value than others. The identification of these areas provides focus for conservation planning. Methods are required to objectively identify the priority areas so that the limited conservation resources can be targeted effectively. A variety of approaches have been undertaken to identify these areas such as identifying Key Biodiversity Areas (Eken et al. 2004), Important Bird Areas (Brown et al. 1995), and biodiversity hotspots (Myers et al. 2000). The Important Plant Area programme attempts to provide standardised criteria-based method for the selection of priority areas; however, the programme is focused on the identification of priority areas using criteria of global or regional rather than local importance (Anderson, 2002). Criteria-based methods for the identification of priority areas, such as Important Plant Areas, require sites to achieve set thresholds and can result in the selection of few sites where thresholds are strict. For example, in Northern Ireland where 48 candidate sites were proposed as Important Plant Areas only 4 were selected by the IPA methodology (NBG, 2015). The selection of so few Important Plant Areas indicated that the selection criteria may be too strict and I attempted to provide criteria that are more suitable for identifying priority areas in an Irish or other regional context. In Chapter 3 I developed a scoring method of prioritisation to identify priority areas for plants in Ireland. The output of the scoring method provided an index of conservation value for the entire

landscape for Ireland to match similar efforts in other areas (Burgess et al. 2006; Ture & Bocuk, 2010).

One of the guiding principles of conservation planning is for priority areas to sample as much of the biodiversity as possible within the area in question (Margules & Pressey, 2000). I used a method to select priority areas that was based on the accumulation of species in cells assigned high conservation value by the scoring method. This approach proved more effective in selecting priority areas with higher numbers of species than either selecting random or species-rich sites. These results supported the findings in other studies that compared similar selection methods (Chapter 3; Kati et al. 2004). The scoring method identified other areas in which the numbers of species that were represented was as good as in priority areas identified in other studies (e.g. Abellan et al. 2005; Blasi et al. 2011; Simaika & Samways 2009). In an Irish example, almost half of the priority areas identified in County Waterford coincided with local Important Plant Areas identified using a combination of expert knowledge and species criteria showing at least partial agreement with the local IPA approach though without the need of subjective lists of 'axiophytes' which are user-defined worthy species (Green & Fitzpatrick, 2008).

6.4.4 Complementarity-based approach to priority area identification

In the scoring method for spatial prioritisation (Chapter 3) the best sets of cells could achieve high species representation but the addition of further cells did little to increase the inclusion of species, showing that representation was being achieved in an inefficient manner. This is because the inclusion of species depends less on the conservation value or species richness of the site than on how well the sites complement each other in terms of the species that they contain; a principle known as complementarity (Kirkpatrick 1983). The lack of accounting for complementarity among the priority areas resulted in the selection of groups of areas that are inefficient at capturing species, in that many more areas were selected than was necessary to ensure species were represented. At times, definitive planning solutions are required for conservation problems such as minimising the number of priority areas or

maximising species representation within priority areas (Williams et al. 2004). This has led to the development of complementarity-based approaches to spatial prioritisation (Ferrier and Wintle, 2009). While a variety of complementarity-based methods exist (e.g. heuristic prioritisation methods) I used linear programming as a tool for the complementarity-based selection of priority areas. Unlike alternative methods, this approach can provide an optimal solution where the identified priority areas meet criteria that can be specified by the user. Linear programming was used to develop a complementarity-based approach for selecting priority areas that maximised species representation in as few sites as possible. The plant distribution data were used with this method to select the minimum number of cells that achieved a number of conservation objectives.

The use of the complementarity-approach for priority area selection in Ireland proved to be as efficient as in other studies (Chapter 4; e.g. Csuti et al. 1997; Marignani & Blasi, 2012; Williams et al. 1996). This showed that use of linear programming within complementarity-based methods can be used to inform conservation planning in Ireland by providing a variety of planning scenarios where much of the diversity of plant species could be included in a minimum of priority areas. The first linear programming methods presented in this research did not include any measure of the conservation value of the landscape, apart from the requirement to maximise species representation. As such the programs were free to choose from any of the sites regardless of their conservation value, as long as the representation requirements were met. In Chapter 4, I developed a method to include the conservation values of the scoring method from Chapter 3 in the linear programming approach to priority area identification. To my knowledge this is the first time that a value generated by a different prioritisation method has been included in an optimal method for site selection. This approach combined the strengths of both the scoring and complementarity methods of prioritisation in efficiently maximising both species inclusion and the collective conservation value of the priority areas.

Chapters 2 – 4 describe research that was conducted using the current known distribution of plant species in Ireland. However priority area identification was limited to the hectad-scale for Ireland and to two counties at the tetrad-scale due to the largely incomplete distribution data coverage at this scale.

6.4.5 Modelling the distribution of plant species of conservation concern

Chapter 5 featured the modelling of the species of conservation concern group of plants to produce predictive maps of the locations of this group at the tetrad-scale. Although rarer species such as the plant species of conservation concern would be expected have good distribution datasets there may still be locations where these species have not yet been recorded, especially as the plant distribution data are largely incomplete at this scale (Chapter 2). Conservation planning decisions based on these data will be relying on potentially incomplete information that could undermine the effectiveness of planning decisions. The availability of spatial environmental data and statistical software presents opportunities to model the distribution of species to address potential gaps in the knowledge of species distributions.

I used a species distribution modelling approach to model the distribution of the group of plant species of conservation concern (SCC) with a goal of predicting the distribution of this group of species in Ireland. A logistic regression approach taking a binary presence-absence response variable was selected as a suitable method for this analysis. This modelling approach attempted to characterise the conditions associated with the presence and absence of species, thereby enabling the prediction of species presence or absence in all areas for which there is available environmental data. Background data in the form of pseudo-absences can be used in logistic regression to characterise background environmental data when reliable species absence data are not available. The selection of pseudo-absences can be used to correct for potential bias associated with presence-only data, for example by selecting pseudo-absences so that they reflect the same selection bias as the presence data (Phillips et al. 2006); however in the case of species of conservation concern in Ireland the models required a large number of background data to

adequately characterise the landscape. So in this respect the findings of Chapter 5 show that it may be more appropriate to include a large number of background data in the form of pseudo-absences to characterise the landscape of larger study areas such as the Republic of Ireland. These research findings support recommendations in the literature for the inclusion of large numbers of background data in species distribution modelling (Barbet-Massin et al. 2012).

The ability of the logistic regression models to predict plant species of conservation concern was found to be similar to the performances of species distribution models in other studies. Although the model performances were good the research also support the assertion of Parviainen et al. (2009) that predictive maps arising from species distributed modelling should be inspected as the predictive maps from models of similar predictive ability can differ; as was the case of the predictive mapping for County Waterford in Chapter 5. Here, one of the models was used to produce a national predictive map of plant species of conservation concern. Not only does this output represent an improvement in the knowledge base for conservation planning but it also provides guidance to where future plant surveys could be targeted for the recording of members of this species group.

The species distribution modelling was used to predict areas of high probability of the presence of the species of conservation concern. The earlier identified priority areas occur in similar locations to the high probability areas and this could be due to underlying factors such as land-use, or due to the influence that the species group has in the methods used for the identification of priority areas. Unlike the prioritisation methods that are dependent of good data coverage, the modelling approach can be applied across all areas. This raises the question of whether a species modelling approach might be better for the identification of important areas of plant diversity than the prioritisation methods of chapters 3 & 4. However, the priority area identification methods include other plant species in addition to the species of conservation concern and those sites will better represent the overall plant diversity of Ireland. Also, despite the good predictive performances of the species distribution models in County

Waterford I would not recommend the immediate use of predicted probability values of SCC occurrence for Ireland. The species distribution modelling of SCC (or other groups of plants) would need to be improved to bring the model to the standard of existing species distribution modelling studies in Ireland such as those conducted for badger (Byrne et al. 2011) and freshwater pearl mussel populations (Wilson et al. 2010).

6.5 Main conclusions

It is important to have a good understanding of the spatial distribution of biodiversity as gaps in this information pose a major challenge for conservation planning (Ferrier 2002). For most regions, biodiversity data will not be complete because the time and costs associated with exhaustive surveys are usually prohibitive (Bombi et al. 2011). This was seen to be the case for the tetrad distribution records in Ireland apart from two counties where more thorough surveying had been conducted. The low level of tetrad coverage provided by the plant records limited where priority areas could be identified at this scale and where the species distribution modelling could be validated using well surveyed areas. Protected areas might also be playing a role in the persistence of plant species of conservation concern but conservation measures should also be directed to the locations outside of protected areas as many of the locations of these species occur in part or fully outside of designated areas (Chapter 2, Walsh et al. 2015).

The prioritisation methods proved more successful in selecting priority areas than the Important Plant Areas selection in Northern Ireland at least in the numbers of areas selected. In this respect the prioritisation methods may be more suitable for the identification of priority areas in Ireland or other regions as the Important Plant Area criteria are so restrictive that they do not give sufficient guidance for priority area selection for Ireland. Importantly, and as restated throughout this thesis, the methods of identification for the more important areas of plant diversity were not intended to provide a finalised selection of

reserves but to instead identify areas that could complement existing protected areas, Important Plant Areas, and the legislative protection of species. However, given the scale at which this research was conducted it may be more appropriate to conduct further investigation into the factors underlying the tetrad scale results. Grid-based distribution maps such as the hectad and tetrad-scale maps generated in this research are not likely to correspond to relevant sites on the ground (Eken et al. 2004). While records at a finer scale than hectad or tetrad would be more desirable for planning these would likely be even more incomplete given the increasing levels of effort that would be required to survey at those scales. The priority areas identified at the hectad or tetrad level could be instead used to highlight broader areas of high conservation value for further investigation.

The scoring method of prioritisation can provide an index of conservation value across the entire landscape that may be more useful for planning decisions by identifying high value sites that might not feature using other methods (e.g. Important Plant Areas) where they might narrowly fail to meet the criteria thresholds. Conservation management plans are not always implemented all at once and it is more common that decisions are made over relatively long periods of time (Pressey et al. 2007). In cases such as this the definitive priority area solutions offered by a complementarity approach would not be appropriate as these areas must also be assigned together as a group if they are to fulfil planning requirements.

The linear programs in Chapter 4 focus on guaranteeing that species feature at least once within the selected priority areas. In some cases this level of representation may be inadequate as the risk of local extinction may be high (Williams 2008). A preferred approach in conservation planning is to include multiple representations of each species (or other natural features) within a set of sites (Cabeza & Moilanen, 2001) to reduce extinction risk through increased population sizes and support for population dynamics (Williams 2008). This approach can be implemented in the linear programming approach by increasing the requirement of species representation within the program

constraints; though the success of this approach would be dependent on having enough locations of that species in the chosen study area.

Biodiversity conservation tends to place greater emphasis on rarer species (Chan et al. 2006) however ecosystem services are maintained in a large part by high plant species diversity including relatively common species (Isbell et al. 2011). The identified priority areas often coincided with areas of higher predicted probability of species of conservation concern. I believe that the prioritisation methods of chapters 3 and 4 are more suitable than the distribution modelling of species of conservation concern for the identification of priority areas in Ireland. The inclusion of the more common species in addition to the species of conservation concern in the prioritisation methods makes it likely that priority area selection is focused to important sites that are more representative of the flora of Ireland.

A drawback of the distribution models (at least in respect to the species of conservation concern group) is that the climate variables initially included in the model building process did not feature in the final models. This therefore prevents prediction of the impact of climate change on distributions using these models. Species distribution modelling could however still factor in the identification of priority areas by providing new species distribution inputs for the prioritisation methods so that areas outside of current well surveyed regions could be identified. Improvements to the species distribution models could begin by modelling groups of species, such as community-level modelling (Ferrier & Guisan, 2006), with more similar ecological niches than the varied SCC group. These could be investigated to see if these would have stronger associations with independent environmental data and if they could provide better predictive performances. Some of these could potentially show relationships to climate variables allowing investigations of the impact of climate change. Alternatively, the more demanding approach of modelling the distributions of individual species could be undertaken.

6.6 Limitations of research

This research is based on collections of records of vascular plants. The data were collected by various individuals and organisations and were almost certainly subject to well-known collection biases, such as bias towards easily accessible sites and towards charismatic species (Possingham et al., 2000). The distribution data in Chapter 2 indicate that the data are biased in terms of the areas that were selected for recording and also feature inconsistent levels of recorder effort. The range of cover provided by the tetrad scale data is patchy in Ireland and there is a large area without any tetrad scale records (approximately 70%). Undoubtedly, these areas will contain species that would impact on the outcomes of the research conducted in this study; however the hexad-scale data have more complete coverage and can still offer some input to conservation planning. All species datasets are imperfect (Pressey and Cowling, 2001) and botanical surveys are subject to bias (Rich & Woodruff, 1992). The lack of an effort to account for bias in the plant distribution data must be taken into consideration when evaluating the research presented in this thesis. Bias in species records can be reduced by the use of controlled, systematic collection methods (Rich & Woodruff, 1992). Alternatively bias in the data can be corrected, for example by correcting for the amount of time spent surveying and the number of recorders involved (Petrik et al. 2010). In addition to these approaches the species data can be weighted to account for sample bias in the collection of records (Phillips et al. 2009). Any future research relating to the plant distribution data for Ireland should attempt to account for any bias in the species records.

The methods for the collection of vascular plant records used a geographic recording system based on the Irish National Grid. Each species was recorded as occurring in a particular grid cell. The coincidence of grid cells containing species of conservation concern with designated areas was investigated in Chapter 2. In many cases the grid cells partially overlapped with the irregular shaped designated areas and a conservative measurement of the level of coincidence treated any cell that had partial overlap with designated areas as

being inside that area. Although a less conservative approach was also undertaken it is not possible in these cases to know if a species is truly occurring inside or outside of a designated area. This issue could be addressed using modern GPS or mobile technology to allow the reporting of more accurate locations of species. The issue for conservation planning is likely related to how the distribution data are reported in addition to the scale of recording, e.g. point data are often collected for plant records but may be scaled to the coarser grid records before being released for any subsequent analyses of the distributions. The use of grid-scale data in conservation planning can offer a compromise between the level of data coverage and resolution of the distribution records.

In general, scoring methods of prioritisation such as the method outlined in Chapter 3 are easy to construct, implement and explain than other prioritisation methods (Ferrier and Wintle, 2009), however there is no standard scoring method in the literature and studies use human value judgements in choosing criteria and in calculating values (Gorrod, 2006). The primary disadvantage of any scoring method of prioritisation is an inability to guarantee or maximise species representation within the selected priority areas. On the other hand, complementarity-based methods of spatial prioritisation that use tools such as linear programming are less transparent, more difficult to construct and are limited to solving relatively simple conservation problems (Moilanen, 2008) such as guaranteeing species representation. Other considerations such as examining how species depend on the spatial arrangement of sites are not amenable to prioritisation approaches that use linear programming (Haight & Snyder, 2009). In this study the spatial prioritisation methods are limited to relatively simple conservation planning problems. Both the mapped distribution of plant records (Chapter 2) and the priority area identification methods (Chapters 3 & 4) provide a snapshot of plant diversity in Ireland, while the modelling approach of Chapter 5 is limited to current predicted distributions. In all of these chapters, no consideration is given to any change in species distribution over time, which should factor into conservation planning (Possingham et al., 2009). Other important components of biodiversity (e.g.

important ecological processes, intact species assemblages) or threats (Burgess et al., 2006; Visconti et al. 2010) were not included in the prioritisation methods featured in this thesis. Spatial components of priority area selection such as the distance and connectivity between the areas (Williams et al., 2004) can also feature in spatial prioritisation. Spatial factors of this kind can be addressed using linear programming approaches (e.g. Williams et al., 2004; Billionet, 2012) however these are more complicated to construct and solve compared to those concerned with species representation alone.

6.7 Future Research

While the methods developed in this study provide spatial information of relevance for conservation planning, further research is required to determine what other relevant information about plant species in Ireland should be considered and how these should be addressed. Such information should include consideration of threats to plant species by using, for example, threat indices (Burgess et al., 2006) or by identifying important areas of biodiversity that are likely to be lost due to threats (Visconti et al., 2010). Connectivity among priority areas allows interaction between sub-populations and is of importance to ecosystem functions and the distribution of species (Lindenmayer et al., 2008). This concept should also be considered in the identification of priority areas (Blowes & Connolly, 2012) as too should the resilience of networks of these areas to the effects of climate change (Carroll et al., 2010).

The distribution of habitat indicator species, which features as a criterion of the scoring method, could be further investigated to determine the predominant habitat types that are occurring in cells. The availability of guides to habitats that include lists of species indicative of different habitats (e.g. Fossitt 2000) would allow species records to be separated by associated habitat type. This new spatial data could act as a surrogate for a habitat map and cells containing important habitats (e.g. Annex I habitats; semi-natural habitats) could be assigned higher weighting within the scoring method. The new habitat

information could subsequently be included in a linear programming tool to maximise the representation of habitats within the selected priority areas.

The number of solutions to the linear programs in this study was limited and it may be more appropriate to use an iterative programming approach to find a larger number (or all) of the possible solutions in each of the scenarios. An examination of the frequency with which individual cells feature in solutions could provide information on the importance of each cell to various conservation planning problems. Other algorithmic approaches, such as heuristic algorithms, can provide solutions for more challenging conservation planning; however these provide near-optimal solutions, where the solutions are close to but not guaranteed to be the best solution. Where the use of linear programming in complementarity approaches only provides one solution, the heuristic approaches can provide a large number of near-optimal solutions. The future identification of priority areas of plant conservation should consider including an investigation of the use of a heuristic approach (e.g. Marxan (Ball et al. 2009)) as the difference in performance between the linear programming and heuristic approaches is dependent on the dataset (Moilanen & Cabeza 2001).

6.8 Concluding remarks

The methods and evident in this thesis suggest that the best way to prioritise areas for conservation or for further research would be to use a species distribution modelling approach as shown in Chapter 5 to predict distributions of plant species. These distributions could then feature as an input to a scoring method of prioritisation as outlined in Chapter 3 (or an improved version of it) to assign conservation value to all areas in the landscape. A complementarity-based approach using linear programming could then be used to select the sets of cells that would most efficiently maximise species representation and cell conservation value. Further research could incorporate other relevant information (e.g. species specific threats, impact of climate change) in the scoring method and the linear programming approach could be explored to include spatial design elements such as connectivity in the priority area

networks. These methods would provide a valuable tool to assist conservation planners in developing strategies to efficiently target limited conservation resources to the most important areas of plant diversity in Ireland.

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Appendix 1: Coincidence of individual species with designated areas

Table 1a: The number of tetrads occupied by each individual Red Data Book species and the coincidence of the tetrads with designated areas. (DA – Designated Area, # Tetrads = number of tetrads the species occurred in).

Species	# Tetrads	In DA	Outside DA
<i>Achillea maritima</i>	4	4	0
<i>Adoxa moschatellina</i>	2	0	2
<i>Agrostemma githago</i>	15	9	6
<i>Ajuga pyramidalis</i>	11	9	2
<i>Alchemilla alpina</i>	1	1	0
<i>Allium schoenoprasum</i>	7	7	0
<i>Alopecurus aequalis</i>	9	4	5
<i>Anacamptis morio</i>	46	32	14
<i>Anthemis arvensis</i>	2	1	1
<i>Arabidopsis petraea</i>	2	2	0
<i>Arenaria ciliata</i>	5	5	0
<i>Asparagus prostratus</i>	11	11	0
<i>Asplenium obovatum</i> subsp <i>lanceolatum</i>	8	8	0
<i>Asplenium septentrionale</i>	1	1	0
<i>Astragalus danicus</i>	5	5	0
<i>Betonica officinalis</i>	24	21	3
<i>Bromus racemosus</i>	31	27	4
<i>Calamagrostis epigejos</i>	8	5	3
<i>Calamagrostis stricta</i>	6	6	0
<i>Callitriche truncata</i>	2	2	0
<i>Campanula trachelium</i>	23	19	4
<i>Cardamine amara</i>	63	29	34
<i>Cardamine impatiens</i>	2	2	0
<i>Carduus nutans</i>	18	13	5
<i>Carex depauperata</i>	1	1	0
<i>Carex divisa</i>	5	5	0
<i>Carex magellanica</i>	5	3	2
<i>Carex pauciflora</i>	3	2	1
<i>Centaurea cyanus</i>	33	15	18
<i>Centaurium littorale</i>	2	2	0
<i>Centaurium pulchellum</i>	14	14	0
<i>Cephalanthera longifolia</i>	14	12	2
<i>Cirsium heterophyllum</i>	2	1	1
<i>Clinopodium acinos</i>	17	8	9

Species	# Tetrads	In DA	Outside DA
<i>Colchicum autumnale</i>	7	7	0
<i>Cryptogramma crispa</i>	7	4	3
<i>Deschampsia setacea</i>	18	16	2
<i>Draba incana</i>	29	25	4
<i>Elatine hydropiper</i>	29	24	5
<i>Epilobium alsinifolium</i>	1	1	0
<i>Epipactis phyllanthes</i>	4	2	2
<i>Equisetum hyemale</i> × <i>ramosissimum</i> = <i>E</i> × <i>moorei</i>	13	9	4
<i>Equisetum pratense</i>	28	10	18
<i>Erica ciliaris</i>	3	3	0
<i>Erica mackayana</i>	7	7	0
<i>Erica vagans</i>	1	0	1
<i>Erigeron acris</i>	41	24	17
<i>Eriophorum gracile</i>	25	24	1
<i>Filago minima</i>	57	33	24
<i>Filipendula vulgaris</i>	15	14	1
<i>Frangula alnus</i>	50	44	6
<i>Galeopsis angustifolia</i>	11	5	6
<i>Geranium purpureum</i>	10	7	3
<i>Geranium rotundifolium</i>	27	16	11
<i>Geranium sylvaticum</i>	1	1	0
<i>Gnaphalium sylvaticum</i>	19	10	9
<i>Groenlandia densa</i>	40	27	13
<i>Gymnocarpium robertianum</i>	3	3	0
<i>Hammarbya paludosa</i>	21	18	3
<i>Helianthemum nummularium</i>	1	1	0
<i>Helianthemum oelandicum</i> subsp <i>piloselloides</i>	5	5	0
<i>Hierochloe odorata</i>	1	1	0
<i>Hordeum secalinum</i>	25	24	1
<i>Hottonia palustris</i>	2	1	1
<i>Hydrilla verticillata</i>	1	1	0
<i>Hyoscyamus niger</i>	8	7	1
<i>Hypericum canadense</i>	22	13	9
<i>Hypericum hirsutum</i>	11	4	7
<i>Hypochaeris glabra</i>	2	1	1
<i>Hypopitys monotropa</i> agg	4	4	0
<i>Hypopitys monotropa</i> subsp <i>hypophegea</i>	1	1	0
<i>Inula salicina</i>	2	2	0

Species	# Tetrads	In DA	Outside DA
<i>Juncus compressus</i>	3	3	0
<i>Kickxia elatine</i>	38	27	11
<i>Lamiastrum galeobdolon</i> subsp <i>montanum</i>	2	1	1
<i>Lathyrus japonicus</i> subsp <i>maritimus</i>	11	9	2
<i>Ligusticum scoticum</i>	22	22	0
<i>Limonium recurvum</i> subsp. <i>Pseudotranswallian</i>	1	1	0
<i>Limosella aquatica</i>	22	12	10
<i>Lolium temulentum</i>	2	2	0
<i>Lotus subbiflorus</i>	12	9	3
<i>Lycopodiella inundata</i>	4	4	0
<i>Melampyrum sylvaticum</i>	8	8	0
<i>Mentha pulegium</i>	7	7	0
<i>Mertensia maritima</i>	17	17	0
<i>Minuartia recurva</i>	2	2	0
<i>Misopates orontium</i>	6	4	2
<i>Najas flexilis</i>	56	51	5
<i>Oenanthe pimpinelloides</i>	11	10	1
<i>Ornithopus perpusillus</i>	23	19	4
<i>Orobanche rapum genistae</i>	16	7	9
<i>Orthilia secunda</i>	1	1	0
<i>Papaver hybridum</i>	1	0	1
<i>Persicaria vivipara</i>	4	3	1
<i>Pilularia globulifera</i>	18	18	0
<i>Poa alpina</i>	3	3	0
<i>Poa palustris</i>	18	15	3
<i>Polygonum maritimum</i>	3	3	0
<i>Polystichum lonchitis</i>	22	20	2
<i>Potentilla fruticosa</i>	20	17	3
<i>Pseudorchis albida</i>	29	19	10
<i>Puccinellia fasciculata</i>	16	15	1
<i>Pyrola media</i>	11	4	7
<i>Pyrola rotundifolia</i>	16	9	7
<i>Pyrola rotundifolia</i> subsp <i>maritima</i>	3	3	0
<i>Pyrola rotundifolia</i> subsp <i>rotundifolia</i>	9	5	4
<i>Ranunculus fluitans</i>	5	2	3
<i>Rorippa islandica</i>	36	22	14
<i>Rubus chamaemorus</i>	1	0	1
<i>Rumex maritimus</i>	11	4	7

Species	# Tetrads	In DA	Outside DA
<i>Salix phylicifolia</i>	4	4	0
<i>Salvia verbenaca</i>	12	9	3
<i>Sanguisorba officinalis</i>	13	13	0
<i>Sarcocornia perennis</i>	9	9	0
<i>Saussurea alpina</i>	12	10	2
<i>Saxifraga aizoides</i>	32	31	1
<i>Saxifraga hartii</i>	2	2	0
<i>Saxifraga hirculus</i>	19	17	2
<i>Saxifraga nivalis</i>	1	1	0
<i>Saxifraga oppositifolia</i>	29	27	2
<i>Scandix pecten veneris</i>	1	1	0
<i>Schoenoplectus triqueter</i>	14	12	2
<i>Scleranthus annuus</i>	10	7	3
<i>Scrophularia umbrosa</i>	11	4	7
<i>Sibthorpia europaea</i>	8	6	2
<i>Silene acaulis</i>	9	9	0
<i>Simethis mattiazzii</i>	8	8	0
<i>Spiranthes romanzoffiana</i>	57	37	20
<i>Teesdalia nudicaulis</i>	3	3	0
<i>Trichomanes speciosum</i>	47	43	4
<i>Trifolium glomeratum</i>	2	2	0
<i>Trifolium subterraneum</i>	2	2	0
<i>Trollius europaeus</i>	6	4	2
<i>Tuberaria guttata</i>	14	14	0
<i>Vicia lathyroides</i>	10	9	1
<i>Vicia orobus</i>	16	9	7
<i>Viola hirta</i>	15	10	5
<i>Viola lactea</i>	16	10	6
<i>Viola persicifolia</i>	18	18	0

Table 1b: The number of tetrads occupied by each individual Flora Protection Order species and the coincidence of the tetrads with designated areas. (DA – Designated Area, # Tetrads = number of tetrads the species occurred in).

Species	# Tetrads	In DA	Outside DA
<i>Achillea maritima</i>	4	4	0
<i>Allium schoenoprasum</i>	6	6	0
<i>Alopecurus aequalis</i>	9	4	5
<i>Arabidopsis petraea</i>	2	2	0
<i>Arenaria ciliata</i>	5	5	0
<i>Asparagus prostratus</i>	11	11	0
<i>Asplenium obovatum</i> subsp <i>lanceolatum</i>	8	8	0
<i>Asplenium septentrionale</i>	1	1	0
<i>Astragalus danicus</i>	5	5	0
<i>Betonica officinalis</i>	24	21	3
<i>Calamagrostis epigejos</i>	6	5	1
<i>Callitriche truncata</i>	2	2	0
<i>Cardamine impatiens</i>	1	1	0
<i>Carex depauperata</i>	1	1	0
<i>Carex divisa</i>	4	4	0
<i>Centaurium pulchellum</i>	14	14	0
<i>Cephalanthera longifolia</i>	14	12	2
<i>Clinopodium acinos</i>	17	8	9
<i>Colchicum autumnale</i>	7	7	0
<i>Deschampsia setacea</i>	18	16	2
<i>Epilobium alsinifolium</i>	1	1	0
<i>Equisetum hyemale</i> × <i>ramosissimum</i> = E × <i>moorei</i>	13	9	4
<i>Eriophorum gracile</i>	25	24	1
<i>Filago minima</i>	27	19	8
<i>Galeopsis angustifolia</i>	11	5	6
<i>Gnaphalium sylvaticum</i>	5	4	1
<i>Groenlandia densa</i>	38	25	13
<i>Gymnocarpium robertianum</i>	3	3	0
<i>Hammarbya paludosa</i>	17	15	2
<i>Helianthemum nummularium</i>	1	1	0
<i>Hordeum secalinum</i>	25	24	1
<i>Hydrilla verticillata</i>	1	1	0
<i>Hypericum canadense</i>	22	13	9
<i>Hypericum hirsutum</i>	9	3	6
<i>Inula salicina</i>	2	2	0
<i>Lathyrus japonicus</i> subsp	11	9	2

maritimus			
Species	# Tetrads	In DA	Outside DA
<i>Limosella aquatica</i>	22	12	10
<i>Lotus subbiflorus</i>	12	9	3
<i>Lycopodiella inundata</i>	3	3	0
<i>Mentha pulegium</i>	4	4	0
<i>Mertensia maritima</i>	9	9	0
<i>Minuartia recurva</i>	2	2	0
<i>Misopates orontium</i>	6	4	2
<i>Najas flexilis</i>	56	51	5
<i>Papaver hybridum</i>	1	0	1
<i>Persicaria vivipara</i>	4	3	1
<i>Pilularia globulifera</i>	18	18	0
<i>Pseudorchis albida</i>	24	16	8
<i>Puccinellia fasciculata</i>	16	15	1
<i>Pyrola rotundifolia</i> subsp <i>maritima</i>	3	3	0
<i>Sanguisorba officinalis</i>	11	11	0
<i>Sarcocornia perennis</i>	9	9	0
<i>Saxifraga hartii</i>	2	2	0
<i>Saxifraga hirculus</i>	17	15	2
<i>Saxifraga nivalis</i>	1	1	0
<i>Schoenoplectus triqueter</i>	14	12	2
<i>Scleranthus annuus</i>	4	3	1
<i>Simethis mattiazzii</i>	8	8	0
<i>Spiranthes romanzoffiana</i>	40	27	13
<i>Trichomanes speciosum</i>	43	39	4
<i>Trifolium glomeratum</i>	2	2	0
<i>Trifolium subterraneum</i>	2	2	0
<i>Trollius europaeus</i>	6	4	2
<i>Vicia orobus</i>	14	8	6
<i>Viola hirta</i>	15	10	5
<i>Viola lactea</i>	16	10	6

Table 1c: The number of tetrads occupied by each individual Northern Ireland Wildlife Order and Northern Ireland Priority species and the coincidence of the tetrads with designated areas. (DA – Designated Area, # Tetrads = number of tetrads the species occurred in).

Species	# Tetrads	In DA	Outside DA
<i>Adoxa moschatellina</i>	1	0	1
<i>Ajuga pyramidalis</i>	3	3	0
<i>Anacamptis morio</i>	1	1	0
<i>Andromeda polifolia</i>	9	6	3
<i>Calamagrostis epigejos</i>	2	0	2
<i>Calamagrostis stricta</i>	6	6	0
<i>Carex elongata</i>	13	13	0
<i>Carex magellanica</i>	5	3	2
<i>Carex pauciflora</i>	3	2	1
<i>Centaurium littorale</i>	2	2	0
<i>Centunculus minimus</i>	6	6	0
<i>Ceratophyllum submersum</i>	3	1	2
<i>Cirsium heterophyllum</i>	2	1	1
<i>Cochlearia officinalis</i> subsp. <i>scotica</i>	3	3	0
<i>Coeloglossum viride</i>	36	21	15
<i>Crambe maritima</i>	6	6	0
<i>Cryptogramma crispa</i>	7	4	3
<i>Dactylorhiza traunsteinerioides</i>	2	2	0
<i>Dryas octopetala</i>	5	4	1
<i>Elatine hydropiper</i>	29	24	5
<i>Epipactis palustris</i>	11	8	3
<i>Epipactis phyllanthes</i>	2	1	1
<i>Frangula alnus</i>	5	4	1
<i>Fumaria purpurea</i>	2	2	0
<i>Galium uliginosum</i>	1	1	0
<i>Gentianella campestris</i>	8	5	3
<i>Geranium pratense</i>	8	6	2
<i>Geranium sylvaticum</i>	1	1	0
<i>Hammarbya paludosa</i>	5	3	2
<i>Helminthotheca echioides</i>	2	0	2
<i>Hierochloa odorata</i>	1	1	0
<i>Hottonia palustris</i>	1	1	0
<i>Hypochaeris glabra</i>	2	1	1
<i>Hypopitys monotropa</i> agg.	2	2	0
<i>Juniperus communis</i>	15	12	3

Species	# Tetrads	In DA	Outside DA
Lathyrus palustris	5	5	0
Ligusticum scoticum	8	8	0
Limonium binervosum agg.	1	1	0
Lycopodiella inundata	1	1	0
Melampyrum sylvaticum	8	8	0
Mentha pulegium	3	3	0
Mertensia maritima	8	8	0
Neotinea maculata	3	1	2
Neottia nidus-avis	20	9	11
Oenanthe fistulosa	49	39	10
Ophrys apifera	11	9	2
Orobanche hederæ	1	1	0
Orthilia secunda	1	1	0
Platanthera bifolia	46	20	26
Polystichum lonchitis	2	2	0
Primula veris	4	1	3
Pseudorchis albida	5	3	2
Pyrola media	11	5	7
Ranunculus fluitans	5	2	3
Rubus chamaemorus	1	0	1
Ruppia cirrhosa	10	4	6
Sagina subulata	1	1	0
Salix myrsinifolia	12	10	2
Salsola kali subsp. kali	4	4	0
Sanguisorba officinalis	2	2	0
Saxifraga aizoides	6	6	0
Saxifraga hirculus	2	2	0
Saxifraga oppositifolia	1	1	0
Scleranthus annuus	6	4	2
Silene acaulis	1	1	0
Sisyrinchium bermudiana	5	4	1
Sium latifolium	52	41	11
Sorbus hibernica	11	5	6
Sorbus rupicola	3	3	0
Spiranthes romanzoffiana	14	10	4
Stellaria palustris	47	38	9
Teesdalia nudicaulis	3	3	0
Trichomanes speciosum	5	5	0
Trollius europæus	4	2	2
Vicia lathyroides	2	1	1

Appendix 2: A list of the Flora Protection Order species in the plant distribution data.

Flora Protection Order Species		
Achillea maritima	Cephalanthera longifolia	Hydrilla verticillata
Allium schoenoprasum	Clinopodium acinos	Hypericum canadense
Alopecurus aequalis	Colchicum autumnale	Hypericum hirsutum
Arabisopsis petraea	Cryptogramma crispa	Inula salicina
		Lathyrus japonicus subsp. maritimus
Arenaria ciliata	Deschampsia setacea	
Asparagus officinalis subsp. prostratus	Epilobium alsinifolium	Limosella aquatica
Asplenium obovatum subsp. lanceolatum	Equisetum hyemale x ramosissimum = E. x moorei	Lotus subbiflorus
Asplenium septentrionale	Eriophorum gracile	Lycopodiella inundata
Astragalus danicus	Filago minima	Mentha pulegium
Betonica officinalis	Galeopsis angustifolia	Mertensia maritima
Calamagrostis epigejos	Gnaphalium sylvaticum	Minuartia recurva
Callitriche truncata	Groenlandia densa	Misopates orontium
Cardamine impatiens	Gymnocarpium robertianum	Najas flexilis
Carex depauperata	Hammarbya paludosa	Papaver hybridum
Carex divisa	Helianthemum nummularium	Persicaria vivipara
Centaureum pulchellum	Hordeum secalinum	Pilularia globulifera
		Pseudorchis albida
		Puccinellia fasciculata
		Pyrola rotundifolia subsp. maritima
		Sanguisorba officinalis
		Sarcocornia perennis
		Saxifraga granulata
		Saxifraga harti
		Saxifraga hirculus
		Saxifraga nivalis
		Schoenoplectus triquet
		Scleranthus annuus
		Simethis mattiazii
		Spiranthes romanzoffiana
		Trichomanes speciosum
		Trifolium glomeratum
		Trifolium subterraneum
		Trollius europaeus
		Vicia orobus
		Viola hirta
		Viola lactea

Appendix 3: A list of Red Data Book species in the plant distribution data.

Red Data Book Species

Achillea maritima	Deschampsia setacea	Hypopitys monotropa agg.	Pyrola rotundifolia subsp. maritima
Adoxa moschatellina	Draba incana	Hypopitys monotropa subsp. hypophegea	Pyrola rotundifolia subsp. rotundifolia
Agrostemma githago	Elatine hydropiper	Inula salicina	Ranunculus fluitans
Ajuga pyramidalis	Eleocharis parvula	Juncus compressus	Ranunculus tripartitus
Alchemilla alpina	Epilobium alsinifolium	Kickxia elatine	Rorippa islandica
Allium schoenoprasum	Epipactis phyllanthes	Lamiastrum galeobdolon subsp. montanum	Rubus chamaemorus
Alopecurus aequalis	Equisetum hyemale x ramosissimum = E. x moorei	Lathyrus japonicus subsp. maritimus	Rumex maritimus
Anacamptis morio	Equisetum pratense	Ligusticum scoticum	Salix phylicifolia
Anthemis arvensis	Erica ciliaris	Limonium recurvum subsp. humile	Salvia verbenaca
Arabidopsis petraea	Erica mackayana	Limonium recurvum subsp. pseudotranswallianum	Sanguisorba officinalis
Arenaria ciliata	Erica vagans	Limosella aquatica	Sarcocornia perennis
Arenaria norvegica subsp. norvegica	Erigeron acris	Lolium temulentum	Saussurea alpina
Asparagus officinalis subsp. prostratus	Eriophorum gracile	Lotus subbiflorus	Saxifraga aizoides

Asplenium obovatum	Euphorbia peplis	Lycopodiella inundata	Saxifraga granulata
subsp. lanceolatum	Filago minima	Matthiola sinuata	Saxifraga hartii
Asplenium septentrionale	Filipendula vulgaris	Melampyrum sylvaticum	Saxifraga hirculus
Astragalus danicus	Frangula alnus	Mentha pulegium	Saxifraga nivalis
Betonica officinalis	Galeopsis angustifolia	Mertensia maritima	Saxifraga oppositifolia
Bromus racemosus	Geranium purpureum	Minuartia recurva	Scandix pecten-veneris
Calamagrostis epigejos	Geranium rotundifolium	Misopates orontium	Scheuchzeria palustris
Calamagrostis stricta	Geranium sylvaticum	Najas flexilis	Schoenoplectus triquetra
Callitriche truncata	Gnaphalium sylvaticum	Oenanthe pimpinelloides	Scleranthus annuus
Campanula trachelium	Groenlandia densa	Ornithopus perpusillus	Scrophularia umbrosa
Cardamine amara	Gymnocarpium dryopteris	Orobanchae rapum-genistae	Serratula tinctoria
Cardamine impatiens	Gymnocarpium robertianum	Orthilia secunda	Sibthorpia europaea
Carduus nutans	Hammarbya paludosa	Papaver hybridum	Silene acaulis
Carex depauperata	Helianthemum nummularium	Persicaria vivipara	Simethis mattiazzii
Carex divisa	Helianthemum oelandicum	Pilularia globulifera	Spiranthes romanzoffiana
Carex magellanica	subsp. piloselloides	Poa alpina	Taraxacum gotlandicum
Carex pauciflora	Hierochloa odorata	Poa palustris	Teesdalia nudicaulis
Centaurea cyanus	Hordelymus europaeus	Polygonum maritimum	Trichomanes speciosum
Centaureum littorale	Hordeum secalinum	Polystichum lonchitis	Trifolium glomeratum
Centaureum pulchellum	Hottonia palustris	Potentilla fruticosa	Trifolium subterraneum
Cephalanthera longifolia	Hydrilla verticillata	Pseudorchis alba	Trollius europaeus
Cirsium heterophyllum	Hyoscyamus niger	Puccinellia fasciculata	Tuberaria guttata
Clinopodium acinos	Hypericum canadense	Pyrola media	Vicia lathyroides
Colchicum autumnale	Hypericum hirsutum	Pyrola rotundifolia	Vicia orobus
Cryptogramma crispa	Hypochaeris glabra		Viola hirta
			Viola lactea

Viola persicifolia

Appendix 4: A list of Northern Ireland Wildlife Order/Priority species in the plant distribution data

Northern Ireland Wildlife Order/Priority species

Adoxa moschatellina	Eleocharis parvula	Juniperus communis	Pyrola media
Ajuga pyramidalis	Epipactis palustris	Lathyrus palustris	Ranunculus fluitans
Anacamptis morio	Epipactis phyllanthus	Ligusticum scoticum	Rubus chamaemorus
Andromeda polifolia	Erica vagans	Limonium binervosum agg.	Ruppia cirrhosa
Betonica officinalis	Erigeron acris	Limosella aquatica	Sagina subulata
	Euphrasia officinalis subsp. anglica		
Calamagrostis epigejos	Euphrasia salisburgensis	Luzula pallescens	Salix myrsinifolia
Calamagrostis stricta	Frangula alnus	Lycopodiella inundata	Salsola kali subsp. kali
Carex elongata	Fumaria purpurea	Melampyrum sylvaticum	Sanguisorba officinalis
Carex magellanica	Galium uliginosum	Mentha pulegium	Saussurea alpina
Carex pauciflora	Gentianella campestris	Mertensia maritima	Saxifraga aizoides
Centaurium littorale	Geranium pratense	Neotinea maculata	Saxifraga hirculus
Centunculus minimus	Geranium sylvaticum	Neottia nidus-avis	Saxifraga oppositifolia
Ceratophyllum submersum	Gymnocarpium dryopteris	Oenanthe fistulosa	Scleranthus annuus
Cirsium heterophyllum		Ophrys apifera	Silene acaulis
Cochlearia officinalis subsp. scotica	Hammarbya paludosa		
Coeloglossum viride	Helminthotheca echioides	Orobanchae hederaceae	Silene gallica
Crambe maritima	Hierochloa odorata	Orthilia secunda	Sisyrinchium bermudiana
Cryptogramma crispa	Hordelymus europaeus	Pilularia globulifera	Sium latifolium
Dactylorhiza		Platanthera bifolia	Sorbus hibernica
traunsteinerioides	Hottonia palustris		
Dryas octopetala	Hypochaeris glabra	Polystichum lonchitis	Sorbus rupicola
Elatine hydropiper	Hypopitys monotropa agg.	Primula veris	Spiranthes romanzoffiana
		Pseudorchis albida	Stellaria palustris
			Teesdalia nudicaulis
			Trichomanes speciosum
			Trollius europaeus
			Vicia lathyroides

Viola persicifolia

Appendix 5: A list of Annex I habitat indicator species in the distribution data.

Annex I Habitat Indicator Species

Achillea maritima	Coeloglossum viride	Juncus subnodulosus	Pyrola rotundifolia subsp. maritima
Achillea millefolium	Colchicum autumnale	Juniperus communis	Quercus petraea
Achillea ptarmica	Conopodium majus	Juniperus communis subsp. nana	Quercus petraea x robur = Q. x rosacea
Aconitum napellus	Corylus avellana	Knautia arvensis	Quercus robur
Aconitum napellus sens.lat.	Crambe maritima	Lamium album	Ranunculus acris
Adiantum capillus-veneris	Crataegus monogyna	Lathyrus japonicus subsp. maritimus	Ranunculus aquatilis
Aegopodium podagraria	Crepis biennis	Lathyrus linifolius	Ranunculus aquatilis sens.lat.
Agrostis canina	Crepis capillaris	Lathyrus palustris	Ranunculus baudotii
Agrostis canina sens.lat.	Crepis paludosa	Lathyrus pratensis	Ranunculus bulbosus
Agrostis capillaris	Crithmum maritimum	Lemna minor	Ranunculus flammula
Agrostis stolonifera	Cryptogramma crispa	Lemna trisulca	Ranunculus fluitans
Alchemilla alpina	Cynosurus cristatus	Leontodon hispidus	Ranunculus omiophyllus
Alchemilla glabra	Cystopteris fragilis	Leontodon saxatilis	Ranunculus peltatus
Alisma lanceolatum	Daboecia cantabrica	Lepidium latifolium	Ranunculus penicillatus subsp. penicillatus
Alliaria petiolata	Dactylis glomerata	Leucanthemum vulgare	Ranunculus penicillatus subsp. pseudofluitans
Alnus glutinosa	Dactylorhiza fuchsii	Leymus arenarius	Ranunculus repens
Alnus incana	Dactylorhiza maculata	Ligusticum scoticum	Ranunculus trichophyllus
Alopecurus pratensis	Dactylorhiza maculata subsp. ericetorum	Limonium binervosum agg.	Rhamnus cathartica
Ammophila arenaria	Dactylorhiza	Limonium humile	Rhinanthus minor

Anacamptis morio	Anacamptis pyramidalis	traunsteinerioides	Limosella aquatica	Rhynchospora alba
			Linum bienne	Rhynchospora fusca
Anagallis tenella		Deschampsia cespitosa	Linum catharticum	Rorippa islandica
Andromeda polifolia		subsp. alpina	Littorella uniflora	Rorippa palustris
Anemone nemorosa		Deschampsia flexuosa	Lobelia dortmanna	Rosa spinosissima
Angelica archangelica		Deschampsia setacea	Loniceria periclymenum	Rubia peregrina
Angelica sylvestris		Diphysastrum alpinum	Lotus corniculatus	Rubus chamaemorus
Antennaria dioica		Draba incana	Lotus pedunculatus	Rubus fruticosus agg.
Anthoxanthum odoratum		Drosera anglica	Luronium natans	Rubus saxatilis
Anthyllis vulneraria		Drosera intermedia	Luzula campestris	Rumex crispus
Aphanes arvensis		Drosera rotundifolia	Luzula multiflora	Rumex hydrolapathum
Aphanes arvensis agg.		Dryas octopetala	Luzula sylvatica	Rumex sanguineus
Arabidopsis petraea		Dryopteris affinis	Lycopodiella inundata	Ruppia maritima
Arabis hirsuta		Dryopteris dilatata	Lycopus europaeus	Sagina maritima
Arctostaphylos uva-ursi		Dryopteris filix-mas	Lysimachia nemorum	Sagina nodosa
Arenaria serpyllifolia		Eleocharis acicularis	Lysimachia punctata	Salicornia europaea
Armeria maritima		Eleocharis multicaulis	Lysimachia vulgaris	Salix alba
Arrhenatherum elatius		Eleocharis palustris	Lythrum salicaria	Salix aurita
Artemisia maritima		Eleocharis parvula	Malva arborea	Salix cinerea
Arum maculatum		Eleocharis quinqueflora	Malva moschata	Salix cinerea sens.lat.
		Elytrigia atherica		
Asperula cynanchica		Elytrigia juncea subsp.	Mentha aquatica	Salix fragilis
Asplenium adiantum-nigrum		boreoatlantica	Menyanthes trifoliata	Salix herbacea
Asplenium ceterach		Elytrigia repens	Mercurialis perennis	Salix repens
Asplenium marinum		Empetrum nigrum	Mertensia maritima	Salsola kali
Asplenium ruta-muraria		Epilobium hirsutum	Minuartia recurva	Samolus valerandi
Asplenium scolopendrium		Epilobium palustre	Minuartia verna	Sanguisorba officinalis
Asplenium trichomanes		Epilobium parviflorum	Molinia caerulea	Sarcocornia perennis
		Epipactis atrorubens		

Asplenium viride	Epipactis palustris	Mycelis muralis	Saussurea alpina
Aster tripolium	Equisetum fluviatile	Myosotis ramosissima	Saxifraga aizoides
Atriplex glabriuscula	Equisetum palustre	Myosotis scorpioides	Saxifraga hartii
Atriplex laciniata	Equisetum telmateia	Myrica gale	Saxifraga hypnoides
Atriplex littoralis	Erica ciliaris	Myriophyllum alterniflorum	Saxifraga nivalis
Atriplex portulacoides	Erica cinerea	Myriophyllum spicatum	Saxifraga oppositifolia
Atriplex prostrata	Erica mackayana	Myriophyllum verticillatum	Saxifraga rosacea
Avenula pubescens	Erica tetralix	Nardus stricta	Saxifraga stellaris
Bellis perennis	Erica vagans	Narthecium ossifragum	Schedonorus pratensis
Berula erecta	Eriophorum angustifolium	Neotinea maculata	Schoenoplectus lacustris
Beta vulgaris subsp. maritima	Eriophorum gracile	Neottia ovata	Schoenoplectus lacustris
Betula pubescens	Eriophorum latifolium	Nuphar lutea	subsp. lacustris
Bidens tripartita	Eriophorum vaginatum	Oenanthe lachenalii	Schoenus nigricans
Blackstonia perfoliata	Erodium lebelii	Oenanthe pimpinelloides	Scilla verna
Blechnum spicant	Eryngium campestre	Ononis repens	Scorzoneroides autumnalis
Blysmus rufus	Eryngium maritimum	Ophioglossum vulgatum	Sedum acre
Brachypodium pinnatum	Eupatorium cannabinum	Ophrys apifera	Sedum anglicum
Brachypodium pinnatum sens.lat.	Euphorbia paralias	Ophrys insectifera	Sedum rosea
Brachypodium sylvaticum	Euphorbia peplis	Orchis mascula	Selaginella selaginoides
Brassica oleracea	Euphrasia frigida	Origanum vulgare	Senecio aquaticus
Briza media	Euphrasia officinalis agg.	Oxalis acetosella	Senecio jacobaea
Bromopsis erecta	Euphrasia salisburgensis	Oxyria digyna	Senecio sarracenicus
Bromus hordeaceus	Festuca ovina	Parapholis incurva	Senecio vulgaris
Bromus racemosus	Festuca ovina agg.	Parapholis strigosa	Serratula tinctoria
Buxus sempervirens	Festuca rubra	Parnassia palustris	Sesleria caerulea
Cakile maritima	Festuca rubra sens.lat.	Pedicularis palustris	Silene acaulis
Callitriche platycarpa	Festuca rubra subsp. juncea	Pedicularis sylvatica	Silene dioica
Callitriche stagnalis	Festuca vivipara	Persicaria amphibia	Silene flos-cuculi
			Silene uniflora

Callitriche stagnalis sens.lat.	Ficaria verna	Persicaria hydropiper	Silene vulgaris
Calluna vulgaris	Filipendula ulmaria	Persicaria lapathifolia	Sium latifolium
Calystegia sepium	Filipendula vulgaris	Persicaria maculosa	Solanum dulcamara
Calystegia soldanella	Frangula alnus	Persicaria minor	Solidago virgaurea
Campanula rotundifolia	Fraxinus excelsior	Persicaria vivipara	Sorbus aria agg.
Cardamine amara	Galium palustre	Petasites hybridus	Sorbus aucuparia
Cardamine pratensis	Galium saxatile	Phalaris arundinacea	Sparganium natans
Carex acutiformis	Galium uliginosum	Phegopteris connectilis	Spartina maritima
Carex arenaria	Galium verum	Phleum arenarium	Spergularia marina
Carex bigelowii	Gentiana verna	Phleum pratense	Spergularia media
Carex binervis	Gentianella amarella subsp. hibernica	Phleum pratense sens.lat.	Spergularia rupicola
Carex buxbaumii	Gentianella campestris	Phragmites australis	Spiranthes spiralis
Carex canescens	Geranium lucidum	Picea abies	Spirodela polyrhiza
Carex caryophyllea	Geranium robertianum	Pilosella officinarum	Stachys palustris
Carex demissa	Geranium sanguineum	Pilularia globulifera	Suaeda maritima
Carex diandra	Geranium sylvaticum	Pimpinella major	Subularia aquatica
Carex dioica	Geum rivale	Pimpinella saxifraga	Succisa pratensis
Carex divisa	Glaux maritima	Pinguicula lusitanica	Symphytum officinale
Carex echinata	Glechoma hederacea	Pinguicula vulgaris	Taxus baccata
Carex extensa	Gnaphalium uliginosum	Pinus mugo	Teucrium scorodonia
Carex flacca	Gymnadenia conopsea	Pinus sylvestris	Thalictrum alpinum
Carex hirta	Gymnadenia conopsea agg.	Plantago coronopus	Thalictrum minus
Carex lasiocarpa	Gymnocarpium robertianum	Plantago lanceolata	Thymus polytrichus
Carex lepidocarpa	Hammarbya paludosa	Plantago maritima	Tragopogon pratensis
Carex limosa	Hedera helix	Platanthera bifolia	Trichophorum cespitosum
Carex nigra	Helianthemum oelandicum	Platanthera chlorantha	Trichophorum germanicum
Carex pallescens	subsp. piloselloides	Poa alpina	Trifolium pratense
Carex panicea	Heracleum sphondylium	Poa pratensis	Trifolium repens
	Holcus lanatus		

Carex pauciflora	Honckenya peploides	Poa pratensis sens.lat.	Trifolium scabrum
Carex pendula	Hordeum secalinum	Poa trivialis	Triglochin maritima
Carex pilulifera	Hyacinthoides non-scripta	Polygala serpyllifolia	Tripleurospermum maritimum
Carex pulicaris	Hydrocharis morsus-ranae	Polygala vulgaris	Trisetum flavescens
Carex remota	Hydrocotyle vulgaris	Polygonum maritimum	Trollius europaeus
Carex rostrata	Hymenophyllum wilsonii	Polystichum aculeatum	Tuberaria guttata
Carex strigosa	Hypericum maculatum subsp. obtusiusculum	Polystichum lonchitis	Tussilago farfara
Carex sylvatica	Hypericum pulchrum	Polystichum setiferum	Ulex europaeus
Carex viridula sens.lat.	Hypericum tetrapterum	Populus nigra	Ulex gallii
Carlina vulgaris	Hypochaeris radicata	Potamogeton lucens	Ulmus glabra
		Potamogeton lucens x gramineus = P. x angustifolius	
Carum verticillatum	Ilex aquifolium	Potamogeton pectinatus	Urtica dioica
Catapodium marinum	Imperatoria ostruthium	Potamogeton perfoliatus	Utricularia australis
Centaurea nigra	Inula crithmoides	Potamogeton polygonifolius	Utricularia intermedia
Centaurea scabiosa	Inula salicina	Potamogeton praelongus	Utricularia minor
Centaurium pulchellum	Iris pseudacorus	Potentilla anglica	Utricularia ochroleuca
Centunculus minimus	Isoetes echinospora	Potentilla anserina	Utricularia vulgaris
Cerastium diffusum	Isoetes lacustris	Potentilla erecta	Utricularia vulgaris sens.lat.
Chenopodium rubrum	Isolepis setacea	Potentilla sterilis	Vaccinium myrtillus
Cicendia filiformis	Juncus acutiflorus	Poterium sanguisorba	Vaccinium oxycoccos
Cicuta virosa	Juncus acutus	Primula veris	Vaccinium vitis-idaea
Cirsium dissectum	Juncus articulatus	Primula vulgaris	Valeriana officinalis
Cirsium heterophyllum	Juncus bufonius	Prunus spinosa	Veronica officinalis
Cirsium oleraceum	Juncus bufonius sens.lat.	Pseudorchis albida	Vicia cracca
Cladium mariscus	Juncus bulbosus	Pteridium aquilinum	Viola canina
Cochlearia danica	Juncus conglomeratus	Puccinellia distans	Viola palustris
Cochlearia officinalis	Juncus effusus	Puccinellia fasciculata	Viola persicifolia
Cochlearia officinalis sens.lat.	Juncus gerardii		Viola reichenbachiana

Cochlearia officinalis subsp. scotica	Juncus maritimus	Puccinellia maritima	Viola riviniana
Cochlearia pyrenaica subsp. alpina	Juncus squarrosus	Pyrola rotundifolia	Viola tricolor subsp. curtisii
			Zannichellia palustris
			Zostera marina
			Zostera marina var. stenophylla
			Zostera noltii

Appendix 6: A list of the semi-natural habitat indicator species in the plant distribution data.

Semi-natural Habitat Indicator species			
Achillea millefolium	Carlina vulgaris	Juncus articulatus	Ranunculus aquatilis sens.lat.
Adiantum capillus-veneris	Centaurea nigra	Juncus bufonius	Ranunculus baudotii
Aesculus hippocastanum	Chrysosplenium oppositifolium	Juncus bufonius sens.lat.	Ranunculus flammula
Agrostis canina	Circaea lutetiana	Juncus bulbosus	Ranunculus penicillatus
Agrostis canina sens.lat.	Cirsium palustre	Juncus compressus	Ranunculus repens
Agrostis capillaris	Cladium mariscus	Juncus conglomeratus	Rhynchospora alba
Agrostis stolonifera	Cochlearia officinalis	Juncus effusus	Rosa agrestis
Alchemilla alpina	Cochlearia officinalis sens.lat.	Juncus foliosus	Rosa arvensis
Alisma plantago-aquatica	Comarum palustre	Juncus gerardii	Rosa caesia
Allium ursinum	Conopodium majus	Juncus inflexus	Rosa canina
Alnus glutinosa	Corylus avellana	Juncus inflexus x effusus = J. x diffusus	Rosa canina agg.
Alopecurus geniculatus	Crambe maritima	Juncus maritimus	Rosa micrantha
Alopecurus pratensis	Crataegus monogyna	Juncus squarrosus	Rosa mollis
Ammophila arenaria	Crithmum maritimum	Juncus subnodulosus	Rosa mollis agg.
Anacamptis pyramidalis	Cynosurus cristatus	Juniperus communis	Rosa obtusifolia

Anagallis tenella	Cystopteris fragilis	Knautia arvensis	Rosa rubiginosa agg.
Anemone nemorosa	Cytisus scoparius	Lathyrus pratensis	Rosa sherardii
Angelica sylvestris	Daboecia cantabrica	Lemna gibba	Rosa spinosissima
Anisantha sterilis	Dactylis glomerata	Lemna minor	Rosa stylosa
Antennaria dioica	Dactylorhiza incarnata	Lemna trisulca	Rosa tomentosa
Anthoxanthum odoratum	Dactylorhiza incarnata agg.	Leontodon hispidus	Rubia peregrina
Anthriscus sylvestris	Dactylorhiza kerryensis	Leontodon saxatilis	Rubus fruticosus agg.
Anthyllis vulneraria	Dactylorhiza maculata	Leucanthemum vulgare	Rumex acetosella
Apium nodiflorum	Dactylorhiza maculata subsp. ericetorum	Leymus arenarius	Rumex sanguineus
Arctostaphylos uva-ursi	Daucus carota	Limonium humile	Salicornia dolichostachya
Armeria maritima	Deschampsia cespitosa	Littorella uniflora	Salicornia europaea
Arrhenatherum elatius	Deschampsia flexuosa	Lobelia dortmanna	Salicornia fragilis
Arum maculatum	Diphasiastrum alpinum	Lolium perenne	Salix alba
Asplenium adiantum- nigrum	Drosera anglica	Lonicera periclymenum	Salix aurita
Asplenium ceterach	Drosera anglica x rotundifolia = D. x obovata	Lotus corniculatus	Salix caprea
Asplenium ruta-muraria	Drosera intermedia	Luzula sylvatica	Salix cinerea
Asplenium scolopendrium	Drosera rotundifolia	Lycopus europaeus	Salix cinerea sens. lat.

Asplenium trichomanes	Dryas octopetala	Lysimachia nemorum	Salix cinerea subsp. cinerea
Asplenium trichomanes subsp. quadrivalens			
Aster tripolium	Dryopteris dilatata	Lythrum salicaria	Salix cinerea subsp. oleifolia
Athyrium filix-femina	Dryopteris filix-mas	Melampyrum pratense	Salix fragilis
Atriplex glabriuscula	Eleocharis palustris	Mentha aquatica	Salix herbacea
	Eleogiton fluitans	Menyanthes trifoliata	Salix purpurea
	Elytrogia juncea subsp. boreoatlantica		
Atriplex laciniata	Empetrum nigrum	Mertensia maritima	Salix repens
Atriplex littoralis	Epipactis palustris	Molinia caerulea	Salix triandra
Atriplex longipes	Equisetum fluviale	Myosotis discolor	Salix viminalis
Atriplex portulacoides	Equisetum palustre	Myosotis laxa	Salsola kali
Atriplex prostrata	Erica cinerea	Myosotis scorpioides	Sambucus nigra
Avenula pubescens		Myrica gale	Sanicula europaea
		Myriophyllum alterniflorum	
Bellis perennis	Erica tetralix		Saxifraga aizoides
			Schedonorus
Berula erecta	Eriocaulon aquaticum	Myriophyllum spicatum	arundinaceus
	Eriophorum		Schoenoplectus
Beta vulgaris	angustifolium	Nardus stricta	lacustris
Betula pendula	Eriophorum gracile	Narthecium ossifragum	Schoenoplectus
Betula pubescens	Eriophorum vaginatum	Neotinea maculata	lacustris subsp. lacustris
Betula pubescens subsp. tortuosa	Eryngium maritimum		Schoenus nigricans
		Nuphar lutea	
			Scilla verna
Blackstonia perfoliata	Eupatorium cannabinum		
Blechnum spicant	Euphorbia paralias	Nymphaea alba	Scutellaria galericulata
		Oenanthe crocata	Sedum rosea

Bolboschoenus maritimus	Euphrasia micrantha	Oenanthe lachenalii	Sesleria caerulea
Brachypodium sylvaticum	Fagus sylvatica	Parnassia palustris	Silene flos-cuculi
Briza media	Festuca filiformis	Pedicularis palustris	Silene vulgaris
Bromopsis ramosa	Festuca ovina	Pedicularis sylvatica	Solidago virgaurea
Cakile maritima	Festuca ovina agg.	Persicaria amphibia	Sorbus aucuparia
Calluna vulgaris	Festuca ovina subsp. hirtula	Phalaris arundinacea	Sparganium emersum
Caltha palustris	Festuca ovina subsp. ovina	Phleum pratense	Sparganium erectum
Calystegia sepium	Festuca rubra	Phleum pratense sens.lat.	Stachys palustris
Cardamine pratensis	Festuca rubra sens.lat.	Phragmites australis	Suaeda maritima
Carex acuta	Festuca rubra subsp. rubra	Pinguicula lusitanica	Succisa pratensis
Carex acutiformis	Festuca vivipara	Pinguicula vulgaris	Taxus baccata
Carex aquatilis	Filipendula ulmaria	Pinus sylvestris	Teucrium scorodonia
Carex arenaria	Fraxinus excelsior	Plantago lanceolata	Thymus polytrichus
Carex bigelowii	Galeopsis angustifolia	Plantago maritima	Tilia cordata
Carex binervis	Galium aparine	Poa pratensis	Tilia platyphyllos
Carex canescens	Galium palustre	Poa pratensis sens.lat.	Tragopogon pratensis
Carex diandra	Galium saxatile	Poa trivialis	Trichophorum cespitosum
Carex dioica	Galium verum	Polygala serpyllifolia	Trifolium dubium
Carex distans	Gentiana verna	Polystichum setiferum	Trifolium pratense
Carex dicticha	Geranium robertianum	Populus alba	Trifolium repens
Carex divisa	Geranium sanguineum	Populus tremula	Triglochin maritima
Carex echinata	Geum urbanum	Potamogeton crispus	Triglochin palustris

Carex flacca	Glyceria fluitans	Potamogeton gramineus	Tripleurospermum
Carex hirta	Glyceria maxima	Potamogeton natans	maritimum
Carex hostiana	Gymnadenia conopsea	Potamogeton obtusifolius	Trisetum flavescens
Carex lasiocarpa	Gymnadenia conopsea agg.	Potamogeton pectinatus	Typha latifolia
Carex leporina	Hedera helix	Potamogeton perfoliatus	Ulex europaeus
Carex limosa	Heracleum sphondylium	Potamogeton polygonifolius	Ulex europaeus x gallii = U. x breoganii
Carex nigra	Hippuris vulgaris	Potentilla anserina	Ulex gallii
Carex oederi	Holcus lanatus	Potentilla erecta	Umbilicus rupestris
Carex panicea	Honckeyia peploides	Potentilla reptans	Urtica dioica
Carex paniculata	Huperzia selago	Potentilla sterilis	Utricularia australis
Carex pilulifera	Hyacinthoides non- scripta	Poterium sanguisorba	Utricularia intermedia
Carex pseudocyperus	Hydrocotyle vulgaris	Primula vulgaris	Utricularia minor
Carex pulcaris	Hypericum pulchrum	Prunella vulgaris	Utricularia ochroleuca
Carex punctata	Hypochoeris radicata	Prunus spinosa	Utricularia stygia
Carex remota	Ilex aquifolium	Pteridium aquilinum	Vaccinium myrtillus
Carex riparia	Iris pseudacorus	Puccinellia maritima	Vaccinium vitis-idaea
Carex rostrata	Isoetes lacustris	Quercus petraea	Valeriana officinalis
Carex vesicaria	Jasione montana	Quercus robur	Veronica beccabunga
Carex viridula sens.lat.	Juncus acutiflorus	Ranunculus aquatilis	Veronica montana
			Veronica officinalis
			Vicia sepium
			Viola palustris
			Viola reichenbachiana
			Viola riviniana

Appendix 7: List of native species in the plant distribution data

Native Species	Dryopteris dilatata	Narthecium ossifragum	Rumex conglomeratus Rumex conglomeratus x crispus = R. x schulzei
Achillea maritima	Dryopteris filix-mas	Nasturtium microphyllum	Rumex crispus
Achillea millefolium	Dryopteris filix-mas x affinis = D. x complexa	Nasturtium microphyllum x officinale = N. x sterile	Rumex crispus subsp. littoreus
Achillea ptarmica	Dryopteris oreades	Nasturtium officinale	Rumex crispus subsp.
Adiantum capillus-veneris	Dryopteris remota	Nasturtium officinale agg.	uliginosus
Agrimonia eupatoria	Echium vulgare	Neottia maculata	Rumex crispus x obtusifolius = R. x pratensis
Agrimonia procera	Elatine hexandra	Neottia cordata	Rumex hydrolapathum
Agrostis canina	Elatine hydropiper	Neottia nidus-avis	Rumex hydrolapathum x obtusifolius = R. x weberi
Agrostis canina sens.lat.	Eleocharis acicularis	Neottia ovata	Rumex maritimus
Agrostis capillaris	Eleocharis multicaulis	Nuphar lutea	Rumex obtusifolius
Agrostis stolonifera	Eleocharis palustris	Nymphaea alba	Rumex obtusifolius x sanguineus = R. x duftii
Agrostis vinealis	Eleocharis palustris subsp. palustris	Odontites vernus	Rumex sanguineus
Aira caryophyllea	Eleocharis palustris subsp. vulgaris	Odontites vernus subsp. serotinus	Rupia cirrhosa
Aira praecox	Eleocharis palustris x uniglumis	Oenanthe aquatica	Rupia maritima
Ajuga pyramidalis	Eleocharis parvula	Oenanthe crocata	Sagina apetala
Ajuga reptans	Eleocharis quinqueflora	Oenanthe fistulosa	Sagina apetala subsp. apetala

Ajuga reptans x pyramidalis =			
A. x pseudopyramidalis	Eleocharis uniglumis	Oenanthe fluviatilis	Sagina filicaulis
Alchemilla alpina	Eleogiton fluitans	Oenanthe lachenalii	Sagina maritima
Alchemilla filicaulis	Elymus caninus	Oenanthe pimpinelloides	Sagina nodosa
Alchemilla filicaulis subsp. vestita	Elytrigia atherica	Ononis repens	Sagina procumbens
Alchemilla glabra	Elytrigia atherica x juncea = E. x acuta	Ophioglossum azoricum	Sagina subulata
Alchemilla glaucescens	Elytrigia campestris	Ophioglossum vulgatum	Sagittaria sagittifolia
Alchemilla xanthochlora	Elytrigia juncea subsp. boreoatlantica	Ophrys apifera	Salicornia dolichostachya
Alisma lanceolatum	Elytrigia repens	Ophrys insectifera	Salicornia emerici
Alisma plantago-aquatica	Elytrigia repens x atherica = E. x drucei	Orchis mascula	Salicornia europaea
Alliaria petiolata	Elytrigia repens x juncea = E. x laxa	Oreopteris limbosperma	Salicornia fragilis
Allium ursinum	Empetrum nigrum	Origanum vulgare	Salicornia pusilla
Allium vineale	Epilobium alsinifolium	Ornithopus perpusillus	Salicornia ramosissima
Alnus glutinosa	Epilobium hirsutum	Orobanche alba	Salix aurita
Alnus glutinosa x incana = A. x pubescens	Epilobium hirsutum x parviflorum = E. x subhirsutum	Orobanche hederaceae	Salix aurita x repens = S. x ambigua
Alopecurus aequalis	Epilobium montanum	Orobanche rapum-genistae	Salix aurita x viminalis = S. x fruticosa
Alopecurus geniculatus	Epilobium montanum x obscurum = E. x aggregatum	Orthilia secunda	Salix caprea
Alopecurus pratensis	Epilobium obscurum	Osmunda regalis	Salix caprea x cinerea = S. x reichardtii
Ammophila arenaria	Epilobium obscurum x palustre = E. x schmidtianum	Oxalis acetosella	Salix caprea x cinerea x viminalis = S. x calodendron

Anacamptis morio	Epilobium palustre	Oxyria digyna	Salix caprea x viminalis = S. x smithiana
Anacamptis pyramidalis	Epilobium parviflorum	Parapholis incurva	Salix cinerea subsp. cinerea
Anagallis arvensis	Epilobium parviflorum x montanum = C. x limosum	Parapholis strigosa	Salix cinerea subsp. oleifolia
Anagallis tenella	Epilobium parviflorum x obscurum = E. x dadicum	Parentucellia viscosa	Salix cinerea x aurita = S. x multinervis
Andromeda polifolia	Epilobium parviflorum x palustre = E. x rivulare	Parietaria judaica	Salix cinerea x myrsinifolia
Anemone nemorosa	Epipactis atrorubens	Parnassia palustris	Salix cinerea x phyllicifolia = S. x laurina
Angelica sylvestris	Epipactis helleborine	Pedicularis palustris	Salix fragilis x pentandra = S. x meyeriana
Antennaria dioica	Epipactis palustris	Pedicularis sylvatica	Salix herbacea
Anthoxanthum odoratum	Epipactis phyllanthos	Pedicularis sylvatica subsp. hibernica	Salix myrsinifolia
Anthriscus caucalis	Equisetum arvense	Pedicularis sylvatica subsp. sylvatica	Salix pentandra
Anthriscus sylvestris	Equisetum arvense x palustre = E. x rothmaleri	Persicaria amphibia	Salix phyllicifolia
Anthyllis vulneraria	Equisetum fluviatile	Persicaria hydropiper	Salix viminalis x caprea x aurita = S. x stipularis
Anthyllis vulneraria subsp. lapponica	Equisetum fluviatile x arvense = E. x litorale	Persicaria maculosa	Salix viminalis x cinerea = S. x holosericea
Anthyllis vulneraria subsp. vulneraria	Equisetum fluviatile x palustre = E. x dycei	Persicaria maculosa x hydropiper = P. x intercedens	Salsola kali
Aphanes arvensis	Equisetum hyemale	Persicaria minor	Salsola kali subsp. kali
Aphanes arvensis agg.	Equisetum hyemale x ramosissimum = E. x moorei	Persicaria mitis	Salvia verbenaca

Aphanes australis	Equisetum hyemale x variegatum = E. x trachyodon	Persicaria vivipara	Sambucus nigra
Apium graveolens	Equisetum palustre	Petasites hybridus	Samolus valerandi
Apium inundatum	Equisetum palustre x telmateia = E. x font-queri	Phalaris arundinacea	Sanguisorba officinalis
Apium nodiflorum	Equisetum pratense	Phegopteris connectilis	Sanicula europaea
Apium nodiflorum x inundatum = A. x moorei	Equisetum sylvaticum	Phleum arenarium	Sarcocornia perennis
Aquilegia vulgaris	Equisetum telmateia	Phleum bertolonii	Saussurea alpina
Arabidopsis petraea	Equisetum variegatum	Phleum pratense	Saxifraga aizoides
Arabidopsis thaliana	Erica cinerea	Phleum pratense sens.lat.	Saxifraga harti
Arabis hirsuta	Erica erigena	Phragmites australis	Saxifraga hirculus
Arbutus unedo	Erica mackayana	Pilosella officinarum	Saxifraga hirsuta
Arctium minus agg.	Erica mackayana x tetralix = E. x stuartii	Pilularia globulifera	Saxifraga hypnoides
Arctium nemorosum	Erica tetralix	Pimpinella major	Saxifraga nivalis
Arctostaphylos uva-ursi	Erigeron acris	Pimpinella saxifraga	Saxifraga oppositifolia
Arenaria ciliata	Eriocaulon aquaticum	Pinguicula grandiflora	Saxifraga rosacea
Arenaria leptoclados	Eriophorum angustifolium	Pinguicula lusitanica	Saxifraga spathularis
Arenaria norvegica subsp. norvegica	Eriophorum gracile	Pinguicula vulgaris	Saxifraga spathularis x hirsuta = S. x polita
Arenaria serpyllifolia	Eriophorum latifolium	Pinguicula vulgaris x grandiflora = P. x scullyi	Saxifraga stellaris
Arenaria serpyllifolia subsp. serpyllifolia	Eriophorum vaginatum	Plantago coronopus	Saxifraga tridactylites
Armeria maritima	Erodium cicutarium agg.	Plantago lanceolata	Schedonorus arundinaceus
Arrhenatherum elatius	Erodium lebellii	Plantago major	Schedonorus giganteus
Arrhenatherum elatius var. bulbosum	Erodium maritimum	Plantago major subsp. intermedia	Schedonorus pratensis
Artemisia maritima	Erophila glabrescens	Plantago maritima	Scheuchzeria palustris

Arum maculatum	Erophila majuscula	Platanthera bifolia	Schoenoplectus lacustris
Asparagus officinalis subsp. prostratus	Erophila verna	Platanthera chlorantha	Schoenoplectus lacustris subsp. lacustris
Asperula cynanchica	Erophila verna sens. lat.	Poa alpina	Schoenoplectus tabernaemontani
Asperula cynanchica subsp. cynanchica var. densiflora	Eryngium maritimum	Poa annua	Schoenoplectus triquetra
Asplenium adiantum-nigrum	Euonymus europaeus	Poa humilis	Schoenus nigricans
Asplenium adiantum-nigrum x onopteris = A. x ticinense	Eupatorium cannabinum	Poa pratensis	Scilla verna
Asplenium ceterach	Euphorbia hyberna	Poa pratensis sens. lat.	Scirpus sylvaticus
Asplenium marinum	Euphorbia paralias	Poa trivialis	Scorzoneroideides autumnalis
Asplenium obovatum subsp. lanceolatum	Euphorbia peplis	Polygala serpyllifolia	Scorzoneroideides autumnalis var. pratensis
Asplenium onopteris	Euphorbia portlandica	Polygala vulgaris	Scrophularia auriculata
Asplenium ruta-muraria	Euphrasia arctica	Polygonum aviculare	Scrophularia nodosa
Asplenium scolopendrium	Euphrasia arctica subsp. borealis	Polygonum aviculare agg.	Scrophularia scorodonia
Asplenium septentrionale	Euphrasia arctica x officinalis	Polygonum maritimum	Scrophularia umbrosa
Asplenium trichomanes	Euphrasia confusa	Polygonum oxyspermum subsp. raii	Scutellaria galericulata
Asplenium trichomanes subsp. quadrivalens	Euphrasia frigida	Polypodium cambricum	Scutellaria galericulata x minor = S. x hybrida
Asplenium trichomanes subsp. trichomanes	Euphrasia micrantha	Polypodium interjectum	Scutellaria minor
Asplenium viride	Euphrasia nemorosa	Polypodium interjectum x cambricum = P. x shivasiae	Sedum acre
Asplenium x confluens	Euphrasia officinalis agg.	Polypodium vulgare	Sedum anglicum
Aster tripolium	Euphrasia officinalis subsp. anglica	Polypodium vulgare sens. lat.	Sedum rosea

Astragalus danicus	Euphrasia officinalis subsp. monticola	Polypodium vulgare x cambricum = P. x font-queri	Selaginella selaginoides
Athyrium filix-femina	Euphrasia officinalis subsp. pratensis	Polypodium vulgare x interjectum = P. x mantoniae	Senecio aquaticus
Atriplex glabriuscula	Euphrasia pseudokernerii	Polystichum aculeatum	Senecio erucifolius
Atriplex laciniata	Euphrasia rostkoviana	Polystichum aculeatum x lonchitis = P. x illyricum	Senecio jacobaea
Atriplex littoralis	Euphrasia rostkoviana x anglica	Polystichum lonchitis	Senecio jacobaea x aquaticus = S. x ostenfeldii
Atriplex longipes	Euphrasia salisburgensis	Polystichum setiferum	Senecio squalidus x viscosus = S. x subnebrodensis
Atriplex patula	Euphrasia scottica	Polystichum setiferum x aculeatum = P. x bicknellii	Senecio sylvaticus
Atriplex portulacoides	Euphrasia tetraquetra	Polystichum setiferum x lonchitis = P. x lonchitiforme	Senecio vulgaris
Atriplex prostrata	Festuca altissima	Populus tremula	Sesleria caerulea
Avenula pubescens	Festuca filiformis	Potamogeton alpinus	Sherardia arvensis
Baldellia ranunculoides	Festuca ovina	Potamogeton alpinus x lucens = P. x nerviger	Sibthorpia europaea
Barbarea vulgaris	Festuca ovina agg.	Potamogeton alpinus x perfoliatus = P. x prussicus	Silene acaulis
Bellis perennis	Festuca rubra	Potamogeton alpinus x praelongus = P. x griffithii	Silene dioica
Berula erecta	Festuca rubra sens.lat.	Potamogeton berchtoldii	Silene flos-cuculi
Beta vulgaris	Festuca rubra subsp. juncea	Potamogeton berchtoldii x natans = P. x variifolius	Silene latifolia x dioica = S. x hampeana
Beta vulgaris subsp. maritima	Festuca rubra subsp. Litoralis	Potamogeton coloratus	Silene uniflora
Betonica officinalis	Festuca vivipara	Potamogeton coloratus x berchtoldii = P. x lanceolatus	Silene vulgaris
Betula pendula	Ficaria verna	Potamogeton crispus	Simethis mattiazzii

Betula pendula x B. pubescens = B. x aurata	Ficaria verna subsp. fertilis	Potamogeton filiformis Potamogeton filiformis x pectinatus = P. x suecicus Potamogeton friesii Potamogeton gramineus Potamogeton gramineus x perfoliatus = P. x nitens Potamogeton lucens Potamogeton lucens x gramineus = P. x angustifolius Potamogeton lucens x perfoliatus = P. x salicifolius Potamogeton natans Potamogeton natans x gramineus = P. x sparganiifolius	Sisyrinchium bermudiana Sium latifolium Solanum dulcamara Solidago virgaurea Sonchus arvensis Sonchus asper Sonchus oleraceus
Betula pubescens Bidens cernua Bidens tripartita	Filago minima Filago vulgaris Filipendula ulmaria	Potamogeton obtusifolius Potamogeton pectinatus Potamogeton perfoliatus Potamogeton perfoliatus x crispus = P. x cooperi Potamogeton polygonifolius Potamogeton praelongus Potamogeton praelongus x crispus = P. x undulatus	Sorbus aucuparia Sorbus devoniensis Sorbus hibernica Sorbus rupicola
Blackstonia perfoliata Blechnum spicant	Filipendula vulgaris Fragaria vesca	Potamogeton angustifolium Sparganium emersum Sparganium erectum Sparganium erectum subsp. erectum	
Blysmus rufus	Frangula alnus	Potamogeton pusillus	Sparganium erectum subsp. microcarpum
Bolboschoenus maritimus Botrychium lunaria	Fraxinus excelsior Galeopsis bifida		
Brachypodium pinnatum Brachypodium pinnatum sens.lat. Brachypodium sylvaticum Briza media	Galium aparine Galium boreale Galium elongatum Galium odoratum		
Bromopsis erecta Bromopsis ramosa Bromus commutatus	Galium palustre Galium saxatile Galium saxatile x sternerii		
Bromus hordeaceus Bromus hordeaceus subsp. feronii	Galium sternerii Galium uliginosum		

Bromus hordeaceus subsp. thominei	Galium verum	Potamogeton x lintonii	Sparganium erectum subsp. neglectum
Bromus hordeaceus x lepidus = B. x pseudothominei	Galium verum x mollugo = G. x pomeranicum	Potentilla anglica	Sparganium erectum subsp. oocarpum
Bromus racemosus	Gentiana verna	Potentilla anglica x reptans = P. x mixta	Sparganium natans
Butomus umbellatus	Gentianella amarella subsp. hibernica	Potentilla anserina	Spergularia marina
Cakile maritima	Gentianella campestris	Potentilla erecta	Spergularia media
Calamagrostis epigejos	Geranium columbinum	Potentilla erecta subsp. strictissima	Spergularia rubra
Calamagrostis stricta	Geranium lucidum	Potentilla erecta x anglica = P. x suberecta	Spergularia rupicola
Callitriche brutia	Geranium molle	Potentilla fruticosa	Spiranthes romanzoffiana
Callitriche brutia subsp. hamulata	Geranium pratense	Potentilla reptans	Spiranthes spiralis
Callitriche hermaphroditica	Geranium purpureum	Potentilla sterilis	Spirodela polyrrhiza
Callitriche obtusangula	Geranium robertianum	Poterium sanguisorba	Stachys palustris
Callitriche palustris	Geranium rotundifolium	Poterium sanguisorba subsp. sanguisorba	Stachys sylvatica
Callitriche platycarpa	Geranium sanguineum	Primula veris	Stachys sylvatica x palustris = S. x ambigua
Callitriche stagnalis	Geranium sylvaticum	Primula vulgaris	Stellaria alsine
Callitriche stagnalis sens.lat.	Geum rivale	Primula vulgaris x veris = P. x polyantha	Stellaria graminea
Callitriche truncata	Geum rivale x urbanum = G. x intermedium	Prunella vulgaris	Stellaria holostea
Calluna vulgaris	Geum urbanum	Prunus avium	Stellaria media
Caltha palustris	Glaucium flavum	Prunus padus	Stellaria pallida
Calystegia sepium	Glaux maritima	Prunus spinosa	Stellaria palustris

Calystegia sepium subsp. roseata	Glechoma hederacea	Prunus spinosa x domestica = P. x fruticans	Suaeda maritima
Calystegia sepium x silvatica = C. x lucana	Glyceria declinata	Pseudorchis albid	Subularia aquatica
Calystegia soldanella	Glyceria fluitans	Pteridium aquilinum	Succisa pratensis
Campanula rotundifolia	Glyceria fluitans x notata = G. x pedicellata	Puccinellia distans	Symphytum officinale
Campanula trachelium	Glyceria maxima	Puccinellia fasciculata	Taraxacum agg.
Cardamine amara	Glyceria notata	Puccinellia maritima	Taraxacum amarellum
Cardamine flexuosa	Gnaphalium sylvaticum	Pulicaria dysenterica	Taraxacum ancistrolobum
Cardamine hirsuta	Gnaphalium uliginosum	Pyrola media	Taraxacum arenastrum
Cardamine impatiens	Groenlandia densa	Pyrola minor	Taraxacum argutum
Cardamine pratensis	Gymnadenia conopsea	Pyrola rotundifolia	Taraxacum atactum
Carduus crispus subsp. multiflorus	Gymnadenia conopsea agg.	Pyrola rotundifolia subsp. maritima	Taraxacum aurosulum
Carduus tenuiflorus	Gymnadenia conopsea subsp. borealis	Pyrola rotundifolia subsp. rotundifolia	Taraxacum boeckmanii
Carex acuta	Gymnadenia conopsea subsp. conopsea	Quercus petraea	Taraxacum brachyglossum
Carex acutiformis	Gymnadenia conopsea subsp. densiflora	Quercus petraea x robur = Q. x rosacea	Taraxacum bracteatum
Carex appropinquata	Gymnocarpium dryopteris	Quercus robur	Taraxacum britannicum
Carex aquatilis	Gymnocarpium robertianum	Radiola linoides	Taraxacum cambricum
Carex aquatilis x nigra = C. x hibernica	Hammarbya paludosa	Ranunculus acris	Taraxacum cophocentrum
Carex arenaria	Hedera helix	Ranunculus aquatilis	Taraxacum cordatum
Carex bigelowii	Hedera helix subsp. helix	Ranunculus aquatilis sens. lat.	Taraxacum croceiflorum
Carex binervis	Hedera hibernica	Ranunculus auricomus	Taraxacum cyanolepis
Carex buxbaumii	Helianthemum nummularium	Ranunculus baudotii	Taraxacum degelii

Carex canescens	Helianthemum oelandicum	Ranunculus bulbosus	Taraxacum densilobum
Carex caryophyllea	subsp. piloselloides	Ranunculus circinatus	Taraxacum drucei
Carex demissa	Hieracium sphondylium	Ranunculus flammula	Taraxacum dupidentifrons
	Hieracium anglicum	Ranunculus flammula subsp. minimus	Taraxacum ekmanii
Carex depauperata	Hieracium angustisquamum	Ranunculus flammula subsp. scoticus	Taraxacum euryphyllum
Carex diandra	Hieracium argentatum	Ranunculus flammula x reptans = R. x levenensis	Taraxacum exacutum
Carex dioica	Hieracium caledonicum	Ranunculus fluitans	Taraxacum excellens
Carex distans	Hieracium diaphanum		
Carex distans x hostiana = C. x muelleriana	Hieracium duriceps	Ranunculus hederaceus	Taraxacum expallidiforme
Carex disticha	Hieracium exotericum	Ranunculus lingua	Taraxacum exsertum
Carex divisa	Hieracium hebridense	Ranunculus omiophyllus	Taraxacum faeroense
Carex divulsa	Hieracium hypochaeroides	Ranunculus peltatus	Taraxacum fasciatum
Carex divulsa subsp. divulsa	Hieracium iricum	Ranunculus penicillatus	Taraxacum fulgidum
Carex divulsa subsp. divulsa x muricata subsp. pairae	Hieracium latobrigorum	Ranunculus penicillatus subsp. penicillatus	Taraxacum fulvicaarpum
Carex divulsa x remota = C. x emmae	Hieracium orcadense	Ranunculus penicillatus subsp. pseudofluitans	Taraxacum fulviforme
Carex echinata	Hieracium prenanthoides	Ranunculus repens	Taraxacum fusciflorum
Carex echinata x dioica = C. x gaudiniana	Hieracium rubiginosum		
Carex elata	Hieracium sabaudum	Ranunculus sceleratus	Taraxacum gelertii
Carex elongata	Hieracium sanguineum	Ranunculus trichophyllus	Taraxacum haematicum
		Ranunculus tripartitus	Taraxacum hamatiforme
Carex extensa	Hieracium scoticum	Raphanus raphanistrum subsp. maritimus	Taraxacum hamatum
Carex flacca	Hieracium scotostictum	Rhamnus cathartica	Taraxacum hamiferum
Carex hirta	Hieracium sparsifolium	Rhinanthus minor	Taraxacum haworthianum

Carex hostiana	Hieracium stewartii	Rhinanthus minor subsp. minor	Taraxacum inane
Carex hostiana x viridula = C. x fulva	Hieracium strictiforme	Rhinanthus minor subsp. monticola	Taraxacum insigne
Carex laevigata	Hieracium subcrocatum	Rhinanthus minor subsp. stenophyllum	Taraxacum laciniifrons
Carex lasiocarpa	Hieracium subleptostoides	Rhynchospora alba	Taraxacum lacistophyllum
Carex lasiocarpa x riparia = C. x evoluta	Hieracium uiginskysense	Rhynchospora fusca	Taraxacum lamprophyllum
Carex lepidocarpa	Hieracium umbellatum	Rorippa amphibia	Taraxacum landmarkii
Carex leporina	Hieracium umbellatum subsp. bichlorophyllum	Rorippa islandica	Taraxacum laticordatum
Carex limosa	Hieracium umbellatum subsp. umbellatum	Rorippa palustris	Taraxacum leucopodium
Carex magellanica	Hieracium vulgatum	Rorippa sylvestris	Taraxacum lingulatum
Carex muricata subsp. pairae	Hierochloa odorata	Rorippa sylvestris x amphibia	Taraxacum longisquameum
Carex nigra	Hippuris vulgaris	= R. x anceps	Taraxacum luteum
Carex nigra x elata = C. x turfosa	Holcus lanatus	Rosa agrestis	
Carex oederi	Holcus lanatus x mollis = H. x hybridus	Rosa arvensis	Taraxacum macrolobum
Carex otrubae	Holcus mollis	Rosa arvensis x canina = R. x irregularis	Taraxacum maculatum
Carex otrubae x remota = C. x pseudoaxillaris	Honckenya peploides	Rosa arvensis x micrantha = R. x vituperabilis	Taraxacum maculosum
Carex pallescens	Hordeum secalinum	Rosa caesia	Taraxacum marklundii
Carex panicea	Huperzia selago	Rosa caesia subsp. caesia	Taraxacum naevosiforme
Carex paniculata	Hyacinthoides non-scripta	Rosa caesia subsp. vosagiaca	Taraxacum nietoi
		Rosa canina	Taraxacum nordstedtii

Carex paniculata x appropinquata = C. x rotae	Hydrilla verticillata	Rosa canina agg.	Taraxacum obliquum
Carex paniculata x diandra = C. x beckmannii	Hydrocharis morsus-ranae	Rosa canina group 'Transitoriae'	Taraxacum oblongatum
Carex paniculata x remota = C. x boenninghausiana	Hydrocotyle vulgaris	Rosa canina x caesia = R. x dumalis	Taraxacum oxoniense
Carex pauciflora	Hymenophyllum tunbrigense	Rosa canina x obtusifolia = R. x dumetorum	Taraxacum pachymerum
Carex pendula	Hymenophyllum wilsonii	Rosa canina x sherardii = R. x rothschildii	Taraxacum palustre
Carex pilulifera	Hypericum androsaemum	Rosa canina x tomentosa = R. x scabriuscula	Taraxacum pannucium
Carex pseudocyperus	Hypericum canadense	Rosa micrantha	Taraxacum pannulatiforme
Carex pseudocyperus x rostrata = C. x justischmidtii	Hypericum elodes	Rosa mollis	Taraxacum pannulatum
Carex pulcaris	Hypericum hirsutum	Rosa mollis agg.	Taraxacum parnassicum
Carex punctata	Hypericum humifusum	Rosa obtusifolia	Taraxacum pectinatiforme
Carex remota	Hypericum maculatum subsp. obtusiusculum	Rosa rubiginosa agg.	Taraxacum piceatum
Carex riparia	Hypericum maculatum x perforatum = H. x desetangsii	Rosa rubiginosa x micrantha = R. x bigeneris	Taraxacum platyglossum
Carex riparia x vesicaria = C. x csomadensis	Hypericum perforatum	Rosa sherardii	Taraxacum polyodon
Carex rostrata	Hypericum pulchrum	Rosa sherardii x agrestis	Taraxacum procerisquameum
Carex rostrata x vesicaria = C. x involuta	Hypericum tetrapterum	Rosa sherardii x rubiginosa = R. x suberecta	Taraxacum pseudohamatum
Carex spicata	Hypochaeris glabra	Rosa spinosissima	Taraxacum pulchrifolium
Carex strigosa	Hypochaeris radicata	Rosa spinosissima x canina = R. x hibernica	Taraxacum quadrans

Carex sylvatica	Hypopitys monotropa agg.	Rosa spinosissima x mollis = R. x sabinii	Taraxacum sagittipotens
Carex vesicaria	Hypopitys monotropa subsp. hypophegea	Rosa spinosissima x rubiginosa = R. x biturigensis	Taraxacum sahalinianum
Carex viridula sens.lat.	Hypopitys monotropa subsp. Monotropa	Rosa spinosissima x sherardii = R. x involuta	Taraxacum sect. Celtica Taraxacum sect. Erythrosperma
Carlina vulgaris	Ilex aquifolium	Rosa stylosa	Taraxacum sellandii
Carum verticillatum	Inula crithmoides	Rosa stylosa x canina = R. x andegavensis	Taraxacum sinuatum
Catabrosa aquatica	Inula salicina	Rosa tomentosa	Taraxacum stenacrum
Catapodium marinum	Iris pseudacorus	Rubia peregrina	Taraxacum stenoglossum
Catapodium rigidum	Isoetes echinospora	Rubus acclivitatum	
Catapodium rigidum subsp. majus		Rubus adenanthoides	Taraxacum stictophyllum
Centaurea nigra	Isoetes lacustris	Rubus adscitus	Taraxacum subbracteatum
Centaurea scabiosa	Isolepis cernua	Rubus aequalidens	Taraxacum subcyanolepis
Centaureum erythraea	Isolepis setacea	Rubus albionis	Taraxacum subexpallidum
Centaureum littorale	Jasione montana	Rubus altiarcuatus	Taraxacum subhamatum
Centaureum pulchellum	Juncus acutiflorus	Rubus amplificatus	Taraxacum tenebricans
Centunculus minimus	Juncus acutus	Rubus anisacanthos	Taraxacum undulatiflorum
	Juncus articulatus		
Cephalanthera longifolia	Juncus articulatus x acutiflorus = J. x surrejanus	Rubus ariconiensis	Taraxacum undulatum
Cerastium arvense	Juncus bufonius	Rubus asperidens	Taraxacum unguilobum
Cerastium diffusum	Juncus bufonius sens.lat.	Rubus bartonii	Taraxacum xanthostigma
Cerastium fontanum	Juncus bulbosus	Rubus botryeros	Taxus baccata
Cerastium glomeratum	Juncus conglomeratus	Rubus boudicca	Teesdalia nudicaulis
	Juncus conglomeratus x effusus = J. x kern-reichgeltii	Rubus briggsianus	Teucrium scordium
Cerastium semidecandrum	Juncus effusus	Rubus britannicus	Teucrium scorodonia
Ceratocarpus claviculata			

Ceratophyllum demersum	Juncus foliosus	Rubus caesarius	Thalictrum alpinum
Ceratophyllum submersum	Juncus gerardii	Rubus caesius	Thalictrum flavum
Chamaemelum nobile	Juncus inflexus	Rubus calvatus	Thalictrum minus
	Juncus inflexus x effusus = J. x diffusus		
Chamerion angustifolium	Juncus maritimus	Rubus cardiophyllus	Thelypteris palustris
Chenopodium album	Juncus ranarius	Rubus chamaemorus	Thymus polytrichus
Chenopodium rubrum	Juncus squarrosus	Rubus cinerosiformis	Torilis japonica
Chrysosplenium oppositifolium	Juncus subnodulosus	Rubus cinerosus	Torilis nodosa
Cicendia filiformis	Juniperus communis	Rubus conjugens	Tragopogon pratensis
Cicuta virosa	Juniperus communis subsp. communis	Rubus dasyphyllus	Trichomanes speciosum
Circaea lutetiana	Juniperus communis subsp. nana	Rubus dentatifolius	Trichophorum cespitosum
Circaea lutetiana x alpina = C. x intermedia	Knaulia arvensis	Rubus drejeri	Trichophorum germanicum
Cirsium arvense	Koeleria macrantha	Rubus dumnoniensis	Trifolium arvense
Cirsium dissectum	Koeleria macrantha sens.lat.	Rubus dunensis	Trifolium campestre
Cirsium heterophyllum	Lamiaeum galeobdolon	Rubus echinoides	Trifolium dubium
Cirsium palustre	Lamiaeum galeobdolon	Rubus echinatus	Trifolium fragiferum
Cirsium palustre x C. arvense	Lamiaeum galeobdolon		
= C. x celakovskianum	subsp. montanum	Rubus errabundus	Trifolium glomeratum
Cirsium vulgare	Lathraea squamaria	Rubus fissus	Trifolium medium
	Lathyrus japonicus subsp. maritimus		
Cladium mariscus	Lathyrus linifolius	Rubus flexuosus	Trifolium micranthum
Clinopodium acinos	Lathyrus linifolius var. montanus	Rubus fruticosus agg.	Trifolium occidentale
Clinopodium ascendens	Lathyrus palustris	Rubus fusciculis	Trifolium ornithopodioides
Cochlearia anglica		Rubus gratus	Trifolium pratense
Cochlearia anglica x officinalis	Lathyrus pratensis		
= C. x hollandica	Lemna gibba	Rubus griffithianus	Trifolium repens
Cochlearia danica		Rubus hastiformis	Trifolium scabrum

Cochlearia danica x officinalis	Lemna minor	Rubus hebridensis	Trifolium striatum
Cochlearia officinalis	Lemna trisulca	Rubus hibernicus	Trifolium subterraneum
Cochlearia officinalis sens.lat.	Leontodon hispidus	Rubus hindii	Triglochin maritima
Cochlearia officinalis subsp. scotica	Leontodon saxatilis	Rubus hylocharis	Triglochin palustris
Cochlearia pyrenaica subsp. alpina	Lepidium heterophyllum	Rubus idaeus	Tripleurospermum maritimum
Coeloglossum viride	Leucanthemum vulgare	Rubus imbricatus	Trisetum flavescens
Colchicum autumnale	Leucojum aestivum	Rubus incurvatus	Trollius europaeus
Comarum palustre	Leymus arenarius	Rubus iricus	Tuberaria guttata
Conopodium majus	Ligusticum scoticum	Rubus laciniatus	Tussilago farfara
Convolvulus arvensis	Limonium binervosum agg.	Rubus lamburnensis	Typha angustifolia
Cornus sanguinea	Limonium humile	Rubus lanaticaulis	Typha latifolia
Corylus avellana	Limonium procerum	Rubus largifolius	Typha latifolia x angustifolia = T. x glauca
Crambe maritima	Limonium recurvum subsp. humile	Rubus latifolius	Ulex europaeus
Crataegus monogyna	Limonium recurvum subsp. portlandicum	Rubus lentiginosus	Ulex europaeus x gallii = U. x breoganii
Crataegus monogyna x laevigata = C. x media	Limonium recurvum subsp. pseudotranswallianum	Rubus leptothyrsos	Ulex gallii
Crepis capillaris	Limosella aquatica	Rubus letii	Ulmus glabra
Crepis paludosa	Linum bienne	Rubus leyanus	Umbilicus rupestris
Crithmum maritimum	Linum catharticum	Rubus lindleianus	Urtica dioica
Cryptogramma crispa	Lithospermum officinale	Rubus longithyriger	Urtica dioica subsp. galeopsisifolia
Cuscuta epithymum	Littorella uniflora	Rubus longus	Utricularia australis
Cynoglossum officinale	Lobelia dortmanna	Rubus melanodermis	Utricularia intermedia
Cynosurus cristatus	Lolium perenne	Rubus micans	Utricularia minor

Cystopteris fragilis	Lolium perenne x multiflorum	Rubus moylei	Utricularia ochroleuca
Cytisus scoparius	= L. x boucheanum	Rubus mucronulatus	Utricularia stygia
Cytisus scoparius subsp. maritimus	Lonicera periclymenum		
Daboecia cantabrica	Lotus corniculatus	Rubus nemorosus	Utricularia vulgaris
Dactylis glomerata	Lotus pedunculatus	Rubus nessensis	Utricularia vulgaris sens. lat.
Dactylorhiza fuchsii	Lotus subbiflorus	Rubus nobilissimus	Vaccinium myrtillus
Dactylorhiza fuchsii x	Luzula campestris	Rubus norvicensis	Vaccinium oxycoccos
Dactylorhiza fuchsii x			
incarnata = D. x kernerorum	Luzula multiflora	Rubus ordovicum	Vaccinium vitis-idaea
Dactylorhiza fuchsii x	Luzula multiflora subsp. congesta	Rubus pallidisetus	Valeriana officinalis
Dactylorhiza fuchsii x	Luzula multiflora subsp. hibernica	Rubus pallidus	Valerianella locusta
maculata = D. x transiens	Luzula multiflora subsp. multiflora	Rubus pascuorum	Verbascum thapsus
Dactylorhiza fuchsii x			
traunsteinerioides	Luzula pilosa	Rubus pistoris	Veronica anagallis-aquatica
Dactylorhiza incarnata	Luzula sylvatica	Rubus plicatus	Veronica arvensis
Dactylorhiza incarnata agg.	Lycopodiella inundata	Rubus plymensis	Veronica beccabunga
Dactylorhiza incarnata subsp. coccinea	Lycopodium clavatum	Rubus polyanthemus	Veronica catenata
Dactylorhiza incarnata subsp. cruenta	Lycopus europaeus	Rubus polyoplus	Veronica chamaedrys
Dactylorhiza incarnata subsp. incarnata	Lysimachia nemorum	Rubus prolongatus	Veronica montana
Dactylorhiza incarnata subsp. pulchella	Lysimachia nummularia	Rubus pruinus	Veronica officinalis
Dactylorhiza incarnata x			
kerryensis	Lysimachia vulgaris	Rubus purbeckensis	Veronica scutellata

Dactylorhiza incarnata x purpurella = D. x latirella	Lythrum portula	Rubus pyramidalis	Veronica serpyllifolia
Dactylorhiza kerryensis	Lythrum salicaria	Rubus questieri	Viburnum opulus
Dactylorhiza kerryensis var. kerryensis	Malva arborea	Rubus radula	Vicia cracca
Dactylorhiza kerryensis var. occidentalis	Matthiola sinuata	Rubus raduloides	Vicia hirsuta
Dactylorhiza maculata	Meconopsis cambrica	Rubus rhombifolius	Vicia lathyroides
Dactylorhiza maculata subsp. ericetorum	Medicago lupulina	Rubus riddelsdellii	Vicia orobus
Dactylorhiza maculata x incarnata = D. x carnea	Melampyrum pratense	Rubus robiae	Vicia sativa subsp. nigra
Dactylorhiza maculata x kerryensis = D. x dinglensis	Melampyrum sylvaticum	Rubus rossensis	Vicia sepium
Dactylorhiza maculata x purpurella = D. x formosa	Melica uniflora	Rubus rubristylus	Vicia sylvatica
Dactylorhiza maculata x traunsteinerioides	Mentha aquatica	Rubus rubritinctus	Viola arvensis x tricolor = V. x contempta
Dactylorhiza purpurella	Mentha arvensis	Rubus rufescens	Viola canina
Dactylorhiza purpurella x D. kerryensis	Mentha arvensis x aquatica = M. x verticillata	Rubus saxatilis	Viola canina x lactea = V. x militaris
Dactylorhiza traunsteinerioides	Menyanthes trifoliata	Rubus scaber	Viola canina x persicifolia = V. x ritschliana
Danthonia decumbens	Mertensia maritima	Rubus scabripes	Viola hirta
Daucus carota	Mibora minima	Rubus scissus	Viola lactea
Daucus carota subsp. gummifer	Milium effusum	Rubus segontii	Viola lutea
Deschampsia cespitosa	Minuartia recurva	Rubus septentrionalis	Viola odorata
Deschampsia cespitosa subsp. alpina	Minuartia verna	Rubus sprengelii	Viola palustris

Deschampsia cespitosa subsp. Parviflora	Moehringia trinervia	Rubus subinermoides	Viola palustris subsp. juressi
Deschampsia flexuosa	Molinia caerulea	Rubus tuberculatus	Viola persicifolia
Deschampsia setacea	Montia fontana	Rubus ulmifolius	Viola reichenbachiana
Dianthus armeria	Montia fontana subsp. amporitana	Rubus ulmifolius x caesioides	Viola reichenbachiana x riviniana = V. x bavarica
Digitalis purpurea	Montia fontana subsp. chondrosperma	Rubus vestitus	Viola riviniana
Diphysastrum alpinum	Montia fontana subsp. fontana	Rubus vigorosus	Viola riviniana x canina = V. x intersita
Draba incana	Montia fontana subsp. variabilis	Rubus viridescens	Viola riviniana x lactea
Drosera anglica	Myosotis discolor	Rubus waddellii	Viola tricolor subsp. curtisii
Drosera anglica x rotundifolia = D. x obovata	Myosotis laxa	Rubus warrenii	Vulpia bromoides
Drosera intermedia	Myosotis ramosissima	Rubus winteri	Vulpia fasciculata
Drosera rotundifolia	Myosotis scorpioides	Rubus wirralensis	Wahlenbergia hederacea
Dryas octopetala	Myosotis secunda	Rubus x pseudoidaeus	xDactylogymnadenia legrandiana
Dryopteris aemula	Myrica gale	Rumex acetosa	xDactylogymnadenia st-quintinii
Dryopteris affinis	Myriophyllum alterniflorum	Rumex acetosa subsp. acetosa	xSchedolium loliaceum
Dryopteris borrieri	Myriophyllum spicatum	Rumex acetosa subsp. hibernicus	Zannichellia palustris
Dryopteris cambrensis	Myriophyllum verticillatum	Rumex acetosella	Zostera marina
Dryopteris carthusiana	Najas flexilis	Rumex acetosella subsp. acetosella	Zostera marina var. stenophylla
Dryopteris carthusiana x dilatata = D. x deweveri	Nardus stricta	Rumex acetosella subsp. pyrenaicus	Zostera noltii