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An Ghníomhaireacht um Chaomhnú Comhshaoil

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Winners and Losers: Climate Change Impacts on Biodiversity in Ireland

SSTI
Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Environmental Protection Agency

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EPA Climate Change Research Programme 2007–2013

Winners and Losers: Climate Change Impacts on Biodiversity in Ireland

Climate Change Impacts on Biodiversity in Ireland: Projecting Changes and Informing Adaptation Measures

CCRP Report

Prepared for the Environmental Protection Agency

by

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The EPA Climate Change Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

1 Introduction to the Project

The climate envelope modelling described in this report represents a staged investigation into the possible impacts of climate change on the nature conservation resources of Ireland. It represents a significant piece of original research applying state-of-the-art methods for the first time in Ireland, and is an important step in trying to understand the complex interactions between climate, climate change, and species and habitats across the island. The work is one part of the wider research programme Co-ordination, Communication and Adaptation for Climate Change in Ireland: an Integrated Approach (COCOADAPT) funded by the Environmental Protection Agency (EPA).

2 The Project in Context

The prediction of climate-change-driven shifts in species and habitat distributions has so far been dominated by continental-scale studies at a 50 × 50 km grid-scale resolution. Many of these studies exclude topographic data and other important ecological variables such as geology, and fail to capture the detail of distributions at finer scales, with regional and landscape-scale applications essential for aiding conservation. Such missing data and scale limitations contribute to restricting confidence in species distribution model (SDM) projections.

In this work, a finer-meshed model grid (10 × 10 km) was employed and other important information was integrated in the predictive models developed. The work demonstrates that by collating some of the available database records in a unique way, the construction and application of more statistically sophisticated and machine-based SDMs than have previously been available for Ireland have been made possible.

3 Results Summary

3.1 Species modelling

The predictive accuracies of SDMs based on the area under the curve (AUC) and Cohen's Kappa performance statistics identified species that could be modelled successfully using a range of climate and topographical variables, but also highlighted those species with a poorer predictive performance (due to the absence of variables crucial to defining their distribution, inadequate distribution data, etc.). The addition of topographical information to basic climate variables resulted both in a significant improvement in the predictive capacity of the models and in more realistic spatially mapped model outputs. The performance of models was shown to vary with the modelling technique used and the distribution patterns of these species in Ireland and across Europe. Species belonging to the particularly vulnerable arctic-montane major biome group showed the greatest increase in model performance.

It is projected that many species in Ireland will experience significant changes to their ranges under future climate scenarios. Species with disjunct and narrow distributions are projected to experience the largest range changes, contracting and expanding, respectively. In general, moss, liverwort, and fern species will experience range contractions, while angiosperm species will see more variation in their response, with some angiosperms expanding while others contract. Species representative of arctic-montane, boreal-montane and boreo-arctic montane biomes will be most vulnerable to climate change. On the island of Ireland, these species will not have higher altitudes and latitudes to move to. Plant communities from many of Ireland's protected habitats are likely to see significant changes in their composition, with species moving in and out. Although not all species in the plant communities of these habitats were modelled, the following habitats may be the most vulnerable to climate change impacts:

- Upland habitats (siliceous and calcareous scree, siliceous and calcareous rocky slopes, alpine and subalpine heath);
- Peatlands (raised bog, blanket bog); and
- Coastal habitats (fixed dunes – combined with the additional threat of sea-level rise to coastal habitats).

3.2 Habitats modelling

The modelling was undertaken within a Generalised Linear Modelling (GLM) and Generalised Additive Modelling (GAM) framework, and consensus probabilities were assembled from the best performing models. Climate and topography-based models are presented which skilfully replicate the observed baseline distribution. The results suggest that both GLMs and GAMs applying climatic-based variables are useful predictors of active blanket bog and wet heath distribution in particular. In general, climate is the primary controlling factor in the distribution of the habitats, although the inclusion of elevation variables is also an important component in the models. When the climate change data are applied to project changes of climate space for the habitats, the models overall are capturing an altitudinal component of change superimposed on a latitudinal gradient, although the specific changes to areas of suitable climate space vary for each habitat type.

3.3 Key messages

Results here reinforce the strongly emerging global consensus in conservation science, whereby rapid climate change is widely considered to be the defining conservation issue for this generation. The effects of climate change are increasingly apparent from evidence-based assessments in countries and continents around the globe. These climate-driven changes will profoundly affect our ability to conserve species and the habitats on which they depend.

Inherent uncertainties associated with climate change projections underpin any impact assessment. Nevertheless, the underlying message should remain clear:

- Widespread changes are already occurring in natural systems and these will continue;
- These changes will accelerate in scope and scale in the coming decades due to greenhouse gases already in the atmosphere;
- The scale and extent of changes will continue to accelerate over longer timescales if greenhouse gas emissions continue unabated or increase; and
- Conservation decisions will have to be made based on longer timescales than has traditionally been the case.

The ecological impacts associated with climate change will not occur in isolation; rather climate-driven changes will combine with, and exacerbate, existing stresses on Ireland’s natural systems. An understanding of those interactions will become increasingly critical in defining and implementing effective conservation measures. As a result, conservation in an era of climate change will require that not only are the environmental problems of the past acknowledged and addressed, but that those of an increasingly uncertain future are also anticipated and prepared for.

4 Specific Recommendations

Based on the results of the project, some Ireland-specific recommendations for the conservation sector are provided. These are:

1. The Habitats Directive requires regular assessment and reporting on the conservation status of species and habitats listed in the Directive’s Annexes I, II, IV, and V. These assessments highlight the main threats to these species and habitats. Potential climate change impacts now need much greater priority in the assessment and management of Natura 2000 (N2K) sites in Ireland if appropriate actions to protect vulnerable species and habitats are to be implemented in time. To date, data concerning climate change projections have not been incorporated into these assessments. Future assessments should ensure that the latest data and state-of-the-art modelling techniques are used to project climate change impacts and that outputs from these should be used to directly inform these assessments and recommendations.

2. The composition of plant communities in N2K sites in the future is likely to be different from today. A more dynamic approach to habitat classification and what is deemed to be a high quality habitat will be required to account for these changes. The likelihood of occurrence of novel species assemblages in the future is high and the conservation sector will need to be prepared to amend its conservation objectives accordingly.

3. Species will experience changes in their ranges (due to changes in areas of suitable climate) in the future, moving to higher latitudes and altitudes. The maintenance and promotion of connectivity in the wider landscape and between N2K sites is vital to ensure that species can reach new areas of suitable climate space. The creation of green infrastructure (sustainable landscape management approaches which enable natural processes to take place and thereby increase resilience of ecosystems) will help maintain a heterogeneous landscape, facilitating dispersal of species to these new areas of suitable climate and habitat.

4. Restoration of degraded habitats will improve the extent, integrity and resilience of vulnerable habitats such as blanket and raised bogs with knock-on benefits for species dependent on such habitats.

5. Given the significant distances between some of Ireland’s designated sites, the role of well-designed agri-environment measures in non-protected areas (mainly agricultural areas) will be critical in maintaining heterogeneity and connectivity in the wider landscape.

6. Future biodiversity conservation planning and management will require a more dynamic approach to site designation and protection. The identification of current sites where species will be able to persist in the future, sites where species will migrate to in the future, and areas that connect these sites will underpin long-term planning. More flexibility in the designated site network than is currently present will be required to achieve effective planning and management to adapt to and mitigate the worst of climate change. It will most likely be necessary to designate some new sites.

7. Ireland’s species and habitats currently face a multitude of threats including land-use change, habitat fragmentation and the introduction of non-native species. The conservation sector will increasingly need to consider the cumulative effects of these current pressures in the context of future impacts of climate change.

8. Some species in the future will not be capable of migrating to new areas of suitable climate and habitat or adapting to new conditions. If future conservation objectives deem these species to be a priority, then assisted migration (translocation) to areas with suitable climate and habitat may be necessary to avoid extinction.

9. It is recommended to focus limited conservation resources on those species and habitats in Ireland that are most vulnerable. The current research has identified many of these and they are referred to in the report.

10. Long-term monitoring and research are central to the detection and quantification of climate change impacts on Ireland’s vulnerable species and habitats and should be integrated as a core part of management planning at the site level. This monitoring (of species distribution, habitat quality, etc.) will aid long-term survival of species through the identification and rapid implementation of appropriate conservation management actions. Long-term monitoring will also ensure that current designated sites are effectively protecting the species and habitats intended, encouraging limited resources to be used more efficiently. Monitoring is also critical for improving and validating model-based projections.

11. Future biodiversity modelling requires further refinement of the techniques used in this study. A more integrated approach incorporating dispersal models, biotic interactions and land-use change scenarios is essential to provide more realistic range change projections. More research and a retention and extension of the capacity developed here are needed to ensure that the tools required

to provide the conservation sector with the best projections are available.

As well as considering climate change adaptation, a number of other cross-cutting themes need to be integrated for the strategic management of our natural capital. These include:

- Impacts of non-native species;
- The role of biodiversity in ecosystem functioning and ecosystem service provision;
- Habitat and ecosystem management;
- Monitoring of biodiversity and evaluation of actions;
- Conservation of genetic and native species diversity; and
- Socio-economic issues.

A brief synthesis of guiding principles based on current knowledge and conservation best practice is also provided (Appendix 1) which complements the specific recommendations outlined above.

1 Introduction

1.1 Observed Changes in Natural Systems

Globally, there is evidence that species are shifting their ranges in response to changes in regional climates (Fischlin et al., 2007), that species are altering their phenology (Jones et al., 2006; Fischlin et al., 2007; Donnelly et al., 2008), and that some species are facing extinction, or have become extinct (Fischlin et al., 2007). Further evidence of climate change impacts includes changes in species altitudinal and geographical ranges (Fischlin et al., 2007) and changes to population density, community structure, species genetics and evolution (Fischlin et al., 2007). Therefore, developing effective adaptation strategies to offset the climate change threats to species persistence will be critical in maintaining species and genetic diversity (Thuiller et al., 2008).

1.2 A European Policy and Conservation Context

The changing relationship between biodiversity and climate has profound implications for the economic and social well-being of all countries, and maintaining healthy ecosystems will buffer against some of the impacts of climate change. However, species–environment relationships are complex and more information on these linkages is needed to inform spatial planning policy for climate change adaptation. There is widespread recognition that protected area networks such as the Natura 2000 (N2K) network will become increasingly important refuges for habitats and species in a warming climate.

Europe has the world’s most extensive network of conservation areas; however, historically, sites have been selected without taking into account the effects of climate change (Araújo et al., 2011). The Emerald Network extends the N2K network and allows for implementation of its principles beyond the European Union (EU). The N2K and the Emerald networks are the two major instruments of the Pan-European Ecological Network (PEEN), promoted under the Pan-European Biological and Landscape Diversity Strategy (PEBLDS) (Araújo, 2009b). While these terrestrial protected areas in Europe may act as buffers against climate change, the protected areas network is likely to be no more effective in retaining suitable climate conditions for Habitats Directive species than the surrounding landscape (Araújo, 2009b). However, the extent to which European conservation areas are effective in protecting biodiversity is subject to ongoing research (e.g. Dimitrakopoulos et al., 2004; Gaston et al. 2006; Araújo et al., 2007; Maiorano et al., 2007; Jackson et al., 2009).

Addressing data gaps and the more streamlined integration of data in spatial planning is a key component in informing and implementing the current European Commission (EC) Biodiversity Strategy and Biodiversity Action Plan (BAP) and its proposed follow-up actions. Recent commitments from the EC also emphasise the close inter-relationship between climate change and biodiversity and the need for an integrated approach to policy development. Crucially however, decisions have to be underpinned by the best available science. There is also recognition that the ecological impacts associated with climate change do not exist in isolation, but combine with and exacerbate existing stresses on natural systems. Understanding those interactions is critical for designing effective conservation measures.

A major challenge is to enhance the coherence of the N2K network via extended habitat networks and linkages to increase the overall spatial coverage of natural and semi-natural habitats (Gaston et al., 2008). Measures proposed to increase resilience include plans to expand protected areas, maintain varied and functional ecosystems, and preserve habitat quality (Hopkins et al., 2007; Mitchell et al., 2007), as well as planning on the basis of the functional connectivity of habitats rather than simple structural connectivity. This can be considered as a form of anticipatory adaptation, since, as climatic conditions become unsuitable, a species either adapts to and tolerates the changes to its environment, moves its range to track suitable climate, or faces a high extinction risk (Jump and

Peñualas, 2003; Engler et al., 2009). Even species not directly affected by a changed climate may not be able to compete with species whose expansion is facilitated by it (Engler et al., 2011).

Indications are that protected areas are expected to retain climatic suitability for species better than unprotected areas, but in fact N2K areas retain climate suitability for species no better and sometimes less effectively than unprotected areas (Araújo et al., 2011). Compounding all of these challenges, uncertainty is perhaps the single most characteristic facet of a climate scenario, and is one that climate science continues to come to terms with (Morgan et al., 2009). Consequently, in any impact assessment, it must remain as a compounding and underlying element, even if not explored in further detail here. Nonetheless, the underlying message should be clear – widespread changes are already occurring which will continue and accelerate in scope and scale in the next few decades due to greenhouse gases already in the atmosphere. They will also expand over longer time horizons if greenhouse gas emissions continue unabated. Therefore, conservation decisions will have to be made based on longer timescales (e.g. over several decades) than has traditionally been the case.

1.3 Reducing Climate Change Impacts on the Biodiversity of Key Protected Areas

Despite knowledge gaps and uncertainty in relation to conservation planning under a changing climate, a number of general habitat types can be identified as key areas for intervention:

1. The first category is that of stationary refugia, or range retention areas, identified as regions where species are most likely to survive despite climate changes. Such stationary refugia escape the more dramatic climate changes, maintaining climate variation within the range of tolerance of most species and, hence, allow species to persist through short-distance dispersal (e.g. Newton, 2003; Araújo, 2009).

2. The second category is that of displaced refugia, where species are able to find suitable habitats after they have been displaced by climate change from their original location. Typically these are areas at the leading edge of species ranges and their distribution can be inferred using bioclimatic envelope models (e.g. Levinsky et al., 2007; Huntley et al., 2008).

3. The third category comprises regions of high connectivity that allow species to track climate changes through dispersal. This has been extensively explored, and some work has begun to develop quantitative approaches for identification of dispersal routes between protected areas under climate change (e.g. Williams et al., 2005; Phillips et al*.*, 2008; Vos et al., 2008). However, it must be remembered that species dispersal ability can vary considerably.

Any policy initiatives geared to mitigating climate change impacts on biodiversity need to identify and manage these three types of areas. However, in the fragmented landscapes of Ireland there are few remaining areas of stationary refugia and, hence, policy initiatives will have to focus on the latter two options. Therefore, concerted efforts are required to integrate protected areas into wider landscapes, seascapes and sectors through the use of connectivity measures such as the development of ecological networks and ecological corridors. Similarly, the restoration of degraded habitats and landscapes is required to address climate change impacts and increase resilience to climate change.

In order to ensure that biodiversity projects take more explicit account of the impacts of climate change, six guiding principles have been identified for UK conservation practice (Hopkins et al., 2007), based on a wider international consensus. These principles factor in sound conservation practice aimed at ensuring the best possible outcome in the face of limited knowledge and the imponderable future effects of climate change. Given the analogous biogeographical and landscape contexts of both countries, these are also largely relevant to Ireland (see Box 2 of Hopkins et al., 2007).

1.4 Statistical and Bioclimatic Envelope Modelling

Various modelling approaches have been developed to convert observations of species at point locations into predictive maps (see, e.g., Table 2 in Coll et al., 2011). These have been extensively reviewed (e.g. Araújo and Guisan 2006; Heikkinen et al. 2006; Elith and Leathwick, 2009). Bioclimatic envelope models (BEMs) can be considered as a special case of niche-based models or species distribution models (SDMs) (Guisan and Zimmermann, 2000; Austin, 2002; Guisan and Thuiller, 2005; Heikkinen et al., 2006). SDMs correlate current species distributions with climate and environmental variables, which then can be used to project spatial shifts in species climatic envelopes according to selected climate change scenarios (e.g. Thuiller et al., 2005; Huntley et al., 2008). However, developing reliable applications of SDMs requires considerable knowledge of the factors influencing the accuracy of model predictions (Heikkinen et al., 2006).

The limitations of SDMs are recognised and largely derive from their static correlative nature; however, they are easy to use. A fundamental issue for the application of SDMs in the context of vulnerability analysis is that they can only give information about *exposure* to climate stress, not sensitivity (House et al., 2010). In other words, SDMs do not provide any process information or information on feedbacks within ecosystems once the climate becomes unsuitable. Nonetheless, SDMs can provide a valuable first approximation of climate change impacts at broad geographic scales where climate is the primary constraint on the distribution (Pearson and Dawson, 2003; Heikkinen et al., 2006; Ellis et al*.,* 2007).

These and related issues for the SDMs applied here are explored throughout the remainder of this report in an Ireland-specific context. However, it should be borne in mind that many factors other than climate influence the distribution of species (Hampe, 2004; Franklin, 2009). In particular, the predictive performance of the models has been shown to vary with the modelling technique used (Heikkinen et al., 2006; Syphard and Franklin, 2009; Virkkala et al., 2010), geographic distribution (Marmion et al., 2008), species traits (Syphard and Franklin, 2009; Hanspach et al., 2010), and the environmental information included (Syphard and Franklin, 2009; Ashcroft et al., 2010; Virkkala et al., 2010). Nevertheless, a number of studies show that the inclusion of topographical variables has the potential to increase the accuracy (Luoto and Heikkinen, 2008; Trivedi et al., 2008; Virkalla et al., 2010). A schematic representation of the approach adopted here is provided in Fig. 1.1 overleaf.

1.5 Aims and Objectives

Specific aims and objectives include:

- To apply state-of-the-art SDMs to project possible future changes in the range of elements of Ireland's biodiversity due to climate change and to assess the performance of a range of modelling techniques when topographical variables are added. A similar range of techniques is also applied to a number of priority habitats using a modified approach to model construction and evaluation.
- To project changes in the distribution of climate space associated with a range of species and habitats of conservation interest in Ireland under projected future climate change, and to assess the potential implications for plant communities associated with habitats protected under the Habitats Directive.
- To discuss the results of these model projections in the context of the future conservation management of Ireland's protected habitats and the implications for climate change adaptation strategies, as well as to identify refinements for future work.

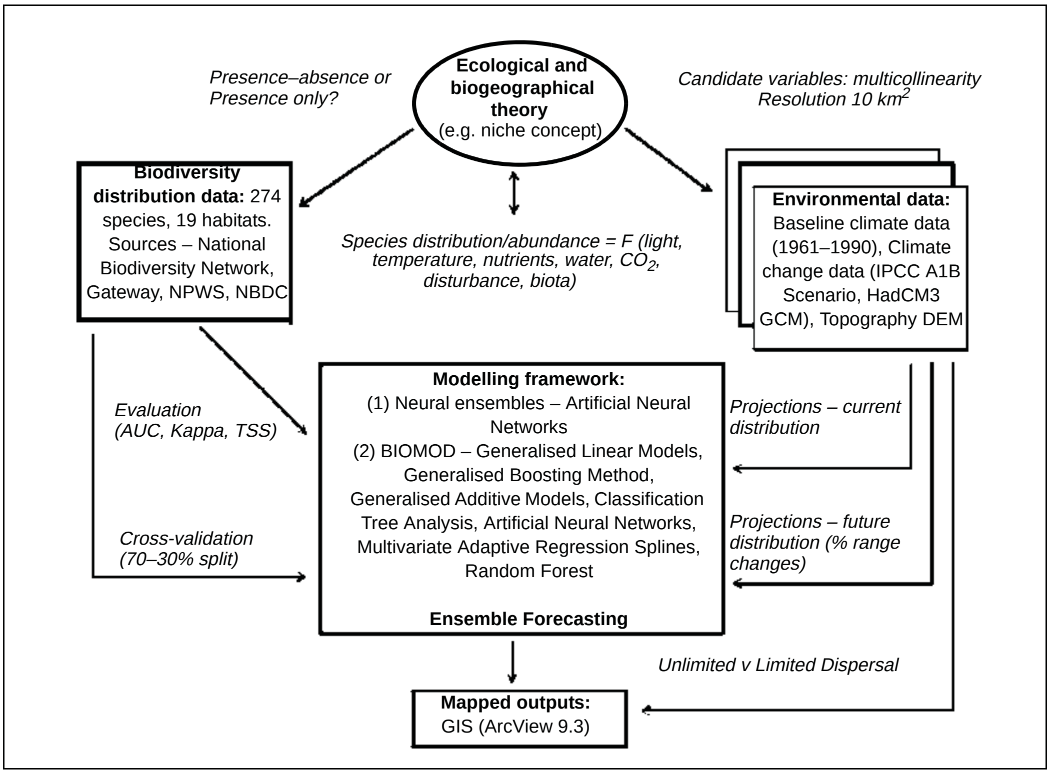

Figure 1.1. Conceptual framework outlining the key components of species distribution modelling. Biogeographical and ecological theory and concepts underpin the approach and identify the characteristics of species and environmental data required for calibration which can then be applied to produce a map of predicted and projected species distribution using climate data (adapted from Franklin, 2009). NPWS, National Parks and Wildlife Service; NBDC, National Biodiversity Data Centre; AUC, area under the curve; IPCC, Intergovernmental Panel on Climate Change; HadCM3, Hadley Centre Coupled Model, vers. 3; GCM, Global Climate Model; DEM, digital elevation model.

2 Methodology

2.1 Study Area

The study area covers ca 84,421 km^2, with altitudes ranging from sea level to 1,038 m a.s.l. (Corrán Tuathail, Co. Kerry). Much of the island is lowland, partly surrounded by mountains, with a characteristic temperate oceanic climate. Mean monthly temperatures range from 6–6.5°C in January to 15–15.5°C in July (Rohan, 1986). On average, annual precipitation totals range between 750 mm and 1,000 mm in the drier eastern half of the country, compared with more than 3,000 mm per year in parts of the western mountains.

2.2 Climate and Climate Change Data

2.2.1 1961–1990 Baseline climate data

A quality-controlled gridded data set of 1961–1990 climate data was used to construct the predictive models for the baseline period. These 10 × 10 km resolution data are derived from monthly climate data for 560 precipitation stations and 70 temperature stations interpolated via polynomial regression with an inbuilt adjustment for elevation (Sweeney and Fealy, 2002, 2003; Fealy and Sweeney, 2007). Variables used included mean, minimum and maximum monthly temperatures, and mean monthly precipitation; derived bioclimatic variables used included, for example, net annual rainfall, mean winter temperature, and continentality index (Appendix Table 1 of the End of Project Report).

2.2.2 Climate change data

The ENSEMBLES project provides state-of-the-art climate change information and aims to quantify and reduce the uncertainty in regional climate change projections (Van der Linden and Mitchell, 2009). This approach recognises that reliance on the output from a single Global Climate Model (GCM) leaves significant potential for gross under or overestimation of the associated risks, which may result in poor decision making and increase the risk of maladaptation (Fealy, 2010).

Met Éireann provided data from the HadCM3L GCM dynamically downscaled via the high resolution limited area model (HIRLAM) and the regional atmospheric model (RCA3), which was part of Ireland’s contribution to ENSEMBLES (McGrath and Lynch, 2008). The model output employed was from an A1B Emission Scenario at a horizontal resolution of 14 km and this was processed in-house to yield new outputs at 10 km resolution.

As part of the A1 storyline and scenario family, the A1B (Balanced) storyline describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income (IPCC, 2007).

2.3 Priority Species and Habitat Data Sets for Ireland

Data on the distribution of all Annex I (Habitats Directive) priority habitats and species on a 10 × 10 km grid were provided by the National Parks and Wildlife Service (NPWS). The NPWS maps are based on a combination of habitat and species distribution maps and are supported by NPWS surveys (NPWS, 2008). Though these are to some degree incomplete and none fully depict the national resource of habitats and species (NPWS, 2008), data of this resolution are appropriate for the modelling undertaken in the current study. The NPWS data were complemented by data for Northern Ireland (NI) Annex I reporting for priority habitats and species from the Joint Nature Conservancy Council (JNCC) (JNCC, 2007) database. This work is the first to bring together these combined data for developing a predictive modelling capacity. Also, as these data sources are national repositories, they are highly reliable and the geo-referencing of the data is likely to be excellent.

2.4 Species Data and Selection Criteria

In total, 274 species and 19 habitats were modelled (Appendix Tables 2 and 3 of the End of Project Report). Species and habitats are either currently protected by the Habitats Directive in Ireland or are plant species listed as characteristic of plant communities across a range of terrestrial habitats protected under the Habitats Directive (Appendix Table 3 of the End of Project Report). No data were sourced or used for the broader distribution of the species and habitat types outside Ireland (e.g. Europe, Asia, or North America). It is recognised that it would be better modelling practice to include data from these wider distributions, as Ireland is likely to encompass only a small range of the species tolerances for particular variables. It is also recognised that adding such data is likely to considerably improve some of the model test statistics. However, the added expense and effort of including such wider distribution data were beyond the resources available to the project. Nevertheless, it is recognised that this is an area where there is room for improvement were further funding available to future projects.

Vascular plants and bryophytes accounted for the bulk of the species modelled: 213 and 56, respectively. Data for the Irish fauna were either less reliable (e.g. under-recorded), unavailable or otherwise unsuitable. Species were also grouped according to other categories, including major taxonomic groups, plant taxonomic groups, distribution and biogeographical elements (Table 2.1). The biogeographical element was divided into major biome and eastern limit categories after Hill et al. (2004) for vascular plants and Hill et al. (2007) for bryophytes. Species data were largely obtained from the National Biodiversity Network (NBN) Gateway (NBN Gateway, 2008), while data for bryophytes were obtained from the NPWS (NPWS, 2010).

2.5 The Modelling Grid

The NBN provided the 10 × 10 km grid which was developed in partnership with the JNCC. This provided a framework to reference the climate and climate change data to the same grid as the biological and environmental data. Presence (1) and absence (0) matrices were constructed for the species and habitats of interest from the relevant data records and referenced to the other information. Grid-based applications have become near-universal as they allow the construction of models bringing together different tiers of climatic and environmental information. However, most SDM projections are based on continental-scale studies at a 50 × 50 km resolution. The COCOADAPT work, therefore, represents a finer-scaled approach using climate and elevation variables at a more regionally relevant scale.

Table 2.1. Modelling results are aggregated ecologically according to selected categories, including major taxonomic groups, plant taxonomic groups, distribution in Ireland and biogeographical element (number of species belonging to each group is shown in parentheses).

Taxon	Plants	Distribution	Biogeographic element	
			Major biome	Eastern limit
Vascular plant (213)	Angiosperm (202)	Wide (151)	Arctic-montane (23)	Hyperoceanic (12)
Bryophyte (56)	Liverwort (16)	Narrow (57)	Boreo-arctic montane (14)	Oceanic (41)
Invertebrate (1)	Moss (40)	Disjunct (74)	Wide-boreal (17)	Suboceanic (24)
Mammal (1)	Fern (7)	Intermediate (11)	Boreal-montane (30)	European (70)
Lichen (3)	Clubmoss (4)		Boreo-temperate (59)	Eurosiberian (34)
	Lichen (3)		Wide-temperate (7)	Eurasian (14)
			Temperate (69)	Circumpolar (70)
			Southern temperate (27)	
			Mediterranean-Atlantic (19)	

2.6 Topographic Data

To produce the topographic data, the range in elevation variables was calculated for each grid cell from a global digital elevation model (DEM) (GTOPO30) with a horizontal grid spacing of 30 arc s (approximately 1 km). Mean, maximum and minimum elevations were also derived from the DEM and the data referenced to the climatic data sets. Further topographical variables were extracted according to the habitat and ecological factors deemed specific to the species. These included area greater than 350 m, area greater than 500 m, mean slope, area occupied by aspects facing north-west, north and north-east, and other combinations of these variables (Appendix Table 4 of the End of Project Report). Hawth's Tools, an extension to ArcGIS, was used to carry out the polygon in polygon analysis (Beyer, 2004).

2.7 SDM

2.7.1 Principles governing variable selection

A sound conceptual underpinning is essential for model building and the accurate prediction of species distributions. Therefore, model formulation in this study's work was underpinned by:

1. A sound understanding of the 'species niche concept' (Hutchinson, 1957); and

2. Knowledge of the specific environmental variables that govern the distribution of species, with the latter also reliant on expert knowledge (Franklin, 2009).

According to Austin and Van Niel (2011), plant growth and distribution as modelled by environmental and biological variables can be conceptually summarised by the simple formulation below:

Species distribution/abundance = *f* (light, temperature, nutrients, water, CO_2, disturbance, biota)

To build the best possible models, it is essential to relate the variables selected to the ecophysiological process they are intended to represent, and to identify what assumptions have been made about those variables not included (Austin and Van Niel, 2011). Guisan and Zimmermann (2000) highlight four key steps in statistical modelling which guided the approach taken:

1. Conceptual model formulation;

2. Statistical model formulation;

3. Calibration (fitting or estimation); and

4. Evaluation.

2.7.2 Predictor variable selection and data splitting

A wide range of climatic and topographic variables was evaluated for possible inclusion in the SDMs (Appendix 3 Tables 1 and 4 of the End of Project Report). All variables were screened for collinearity using variance inflation factors (VIFs), with a VIF value greater than 5 used as a working threshold (Zuur et al., 2007) for discarding collinear terms. However, knowledge of species ecology also informed the final variable selection. Models were tested until only variables deemed to be ecologically sensible and non-collinear variables were used in the final models. Finally, the models were tested using climatic variables only, or a combination of climatic and topographic variables to establish the effects of topographic variables on the distribution of species, and to investigate the effects on predictions of disregarding these variables (Virkalla et al., 2010).

Since independent evaluation data were not available for much of the species data, data sets were randomly divided into 'training' and 'testing' data prior to the modelling. The predictive power for the derived models was examined based on an evaluation data set, spatially mixed on a random split of 30% with the calibration data set (70%). The predictive performance of the models was evaluated using the area under the curve (AUC) of a receiver operating characteristic (ROC) plot (Fielding and Bell, 1997), together with Cohen's Kappa statistic (K). Model performance was considered to be excellent when $K > 0.75$, good when $K = 0.40–0.75$ and poor when $K < 0.40$ (Landis and Koch, 1977). The interested reader is directed to Appendix 1 of the End of Project Report where more detail on the various technical and statistical performance measures used in the modelling is provided.

3 Results

3.1 Layout Summary

This chapter is structured into two main subsections and interested readers are also directed to Appendix 2 of the End of Project Report to aid interpretation:

(i) Evaluation of the performance of the SDMs used to project the changes for species distributions. These are further subdivided into three main areas examining:

- Model performance characteristics between the different model families (Appendix 2 of the End of Project Report);
- Projected range changes for focal species; and
- The implications of the above for community structure.

(ii) Evaluation of the performance of the habitat BEMs (hereafter referred to as HDMs) with reference to the baseline data using the performance test measures (Appendix 2 of the End of Project Report). The fitted baseline HDMs are mapped alongside the observed distribution of the habitats to provide a comparison.

- The ‘best’ HDMs are calibrated prior to applying the climate change data. Projected changes are presented alongside the baseline results. Potential changes to the climate space relative to the HDM-projected baseline are described and interpreted.
- To avoid overlap with the reporting on modelling, a description of the habitats is provided in Appendix 3 of the End of Project Report (Supplementary Information 1). These are duplicated from the information supplied to the EC by the NPWS in the 2008 Assessment Report (NPWS, 2008). Additional information has been supplied for some of the habitats by Cross (2006).

3.2 Results (i)

3.2.1 Model performance

Overall, 156 of the 293 species and habitats modelled achieved excellent or good predictive performance scores for AUC and/or Kappa. However, the Neural Ensembles (NE) model predictive performance significantly improved with the addition of topographic variables to the basic climate variables (Table 3.1) – significantly more models recorded excellent scores for AUC and Kappa ($p < 0.0001$) with climate and

Table 3.1. Comparison of performance (AUC and Kappa statistics) of models using Neural Ensembles for species distribution and habitats using climate and ecology versus climate only variables. Mean (standard error of mean) performance statistics also given.

Performance category	AUC		Kappa	
	Climate and ecology	Climate only	Climate and ecology	Climate only
Excellent	66	38	7	3
Good	84	89	108	78
Fair	84	89		
Poor	45	69	172	206
Fail	8	2		
Mean (SE)	**0.867 (0.006)**	**0.828 (0.007)**	**0.477 (0.01)**	**0.401 (0.011)**

AUC, area under the curve.

topography than for climate variables alone; 81% and 78% of the species and habitats modelled, respectively, showed significant improvements in AUC ($p < 0.0001$) and Kappa ($p < 0.0001$) with addition of topographical data. The species of the arctic-montane biome showed greatest increases in overall model performance ($p < 0.01$).

Figure 3.1 demonstrates the benefits of including specific additional ecological (geological, topographical and habitat) variables in species distribution models, highlighting spatially mapped NE model outputs for three case study species (*Geomalacus maculosus*, *Salix herbacea*, *Mastigophora woodsii*). There is a clear refinement of projected ranges of species when topographic variables are included in the models (Fig. 3.1). Projected areas of suitable climate space decrease when areas with suitable environmental conditions and habitat become a constraint on the model. For example, in the case of *Geomalacus maculosus* (Kerry Slug), only areas with suitable climate, geology (Devonian sandstone) and habitat (oak-dominated woodland and unimproved oligotrophic open moor or blanket bog) remained in the mapped projected ranges – a more accurate reflection on its future distribution. For *Mastigophora woodsii* (Woods' Whipwort), this refinement highlights the probably critical distribution of this species in the future. For *Salix herbacea* (Dwarf Willow), the influence of additional topographical variables resulted in a projected future range that included grid cells with higher elevations.

Significant differences were found between the predictive performances of the seven modelling types applied in this study. The interested scientific reader is directed to Appendix 2 of the End of Project Report where the technical and statistical measures used to evaluate the baseline distribution models are reported, including a further series of figures.

3.2.2 *Projected range changes*

In this section, only results of species and habitats with sufficiently high model predictive performance ($n = 156$) are presented. Overall, there was a mean loss of range (33%) for all species under a limited dispersal scenario, while under an unlimited dispersal scenario, a mean increase in range of 24% was shown (Table 3.2). In models using only climate variables, the latter value increased to 54%, again highlighting the importance of additional topographic variables in refining model outputs.

The species distribution patterns in Ireland and across Europe were shown to have an effect on the projected changes in the ranges of the species. In particular, under a limited dispersal scenario, species with disjunct distributions (mean contraction = –43%) had significantly higher contractions in their range when compared with species with wide distributions (mean contraction = –26%) ($p < 0.05$) (Fig. 3.2a). Under an unlimited dispersal scenario, species with disjunct distributions still underwent range contractions (mean contraction = –1.5%), which was significantly lower than for species with narrow distributions (mean range expansion = 90%) ($p < 0.001$). Species with narrow distributions were also projected to see significantly higher range expansions compared with species having wide distributions (mean range expansion = 4%) ($p < 0.001$) (Fig. 3.2a) under an unlimited dispersal scenario and demonstrated the largest potential for range expansions. Significant differences between the projected range changes of species belonging to different major biomes under a limited dispersal scenario were also shown (Fig. 3.2b). For example, species belonging to the boreal-montane biome had significantly higher range contractions (mean = –50%) when compared with species belonging to the temperate biomes (mean contraction = –25%) ($p < 0.05$) (Fig. 3.2b). No significant differences were found for species grouped according to major biome under an unlimited dispersal scenario (Fig. 3.2b), or for species grouped according to their eastern limit under either dispersal scenario (Fig. 3.2c).

The projected range changes of a selection of habitats (directly modelled) protected under the Habitats Directive are presented in Fig. 3.3. Overall, a mean range contraction of 22% was shown for all habitats, ranging from a 5% contraction for wet heath (WH), a 60% contraction for juniper scrub, a 26% contraction for calcareous rock slopes to a 94% contraction for orchid-rich (calcareous) grasslands under limited dispersal scenarios.

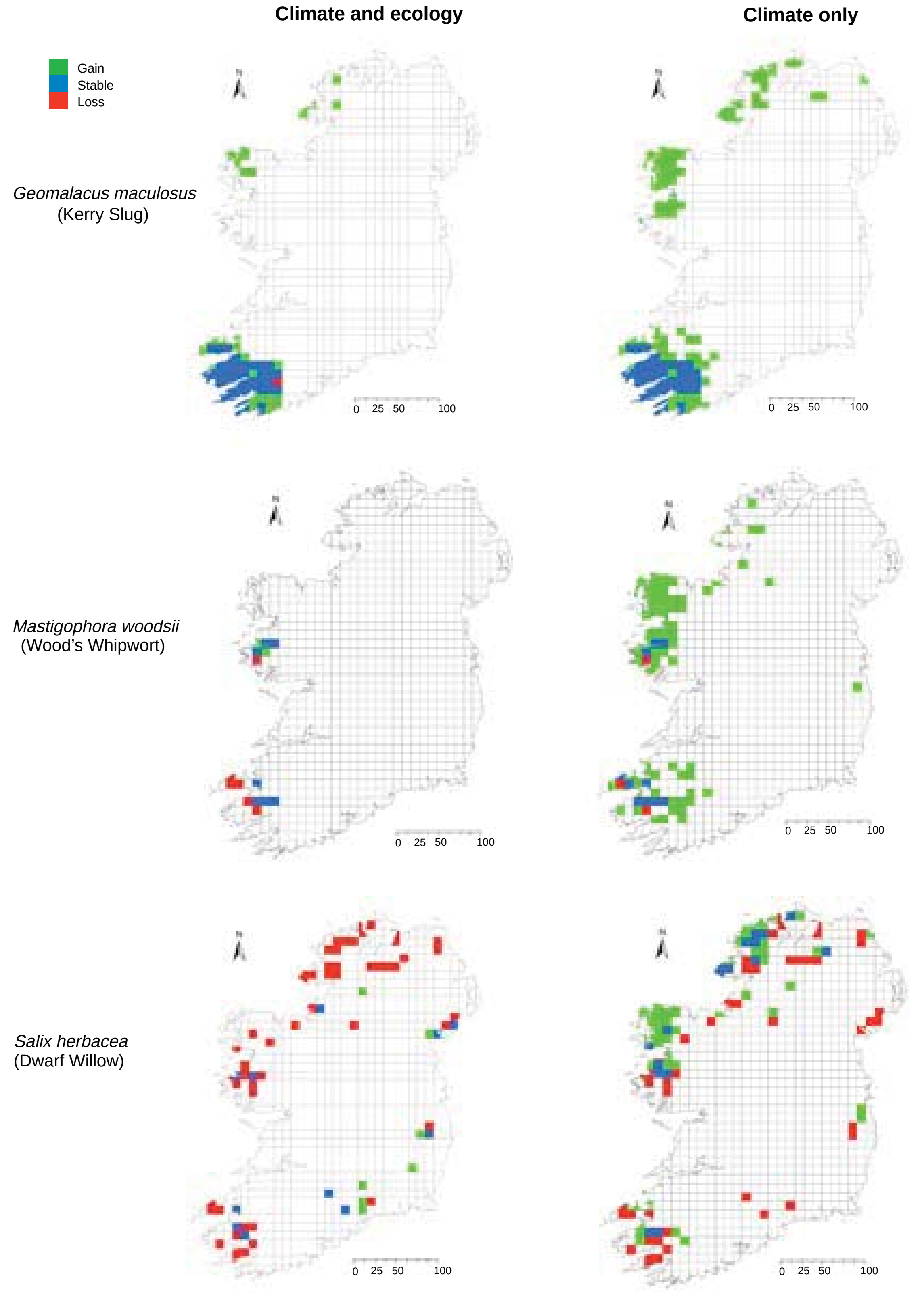

Figure 3.1. Comparison of spatially mapped Neural Ensembles model outputs for three case study species (*Geomalacus maculosus*, *Salix herbacea*, *Mastigophora woodsii*) for models with and without additional ecological (topographical) variables, highlighting refinement of projected ranges of species when additional variables are included in the models.

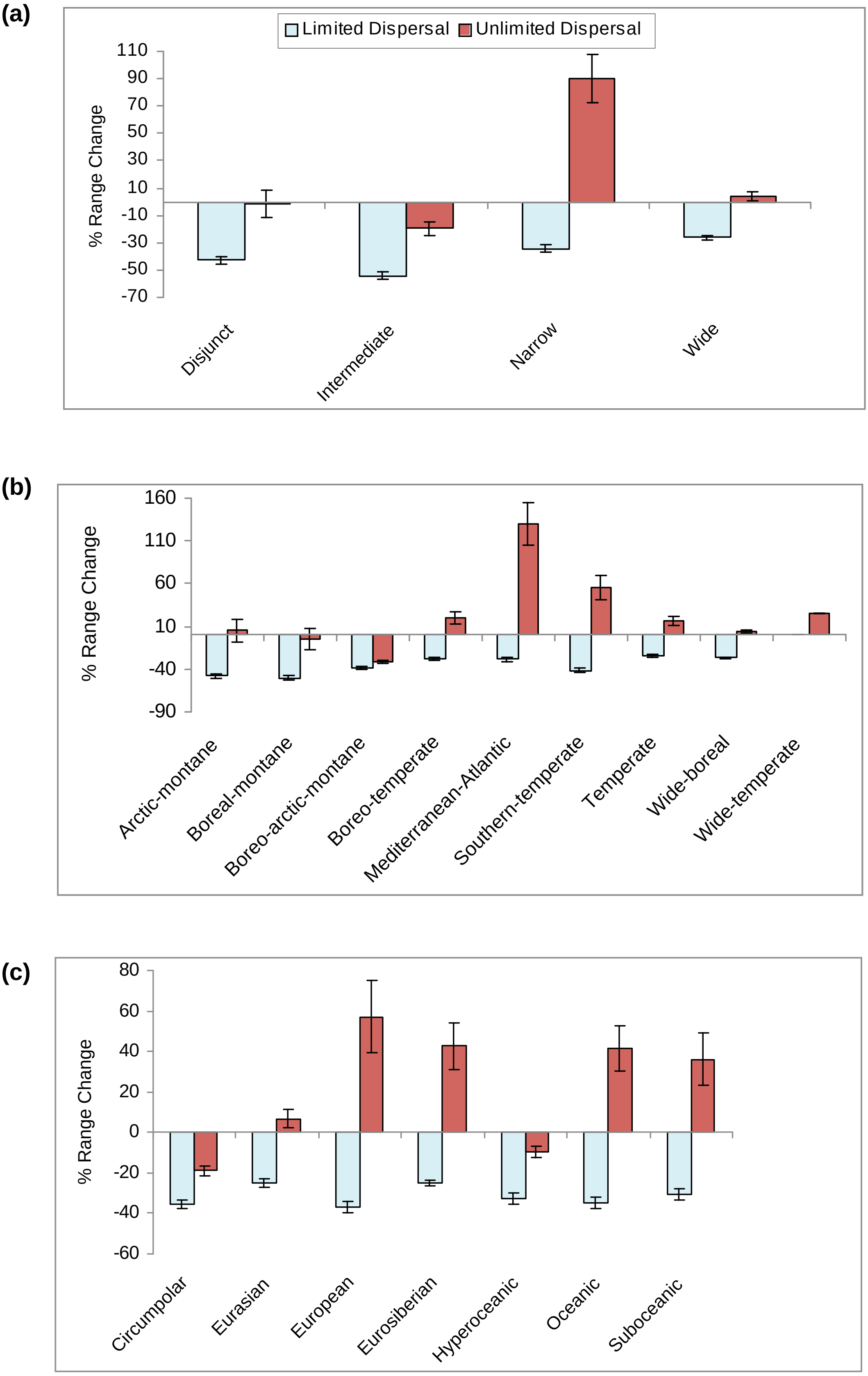

Figure 3.2. Association of species ecology: (a) distribution in Ireland, (b) major biome (biogeographic element/European distribution), and (c) eastern limit (biogeographic element/European, Asian, and North American distribution). Standard errors of the mean are shown by vertical bars.

Table 3.2. Summary statistics (mean, minimum, maximum values) of projected range changes (n = 156 of high performance models).

	Climate and ecology			Climate only		
	Mean (SE)	**Maximum**	**Minimum**	**Mean (SE)**	**Maximum**	**Minimum**
AUC	0.867 (0.002)	0.994	0.726	0.828 (0.002)	0.993	0.343
Kappa	0.477 (0.003)	0.817	0.113	0.401 (0.003)	0.852	0.001
Observed (grid cells[1])	242 (6)	933	2	242 (4)	933	2
Predicted (grid cells)	250 (6)	934	1	272 (4)	939	3
Gain (grid cells)	65 (2)	381	0	87 (2)	445	0
Loss (grid cells)	56 (1)	333	0	61 (1)	328	0
Stable (grid cells)	195 (5)	934	0	212 (4)	939	0
% Range change (limited dispersal)	–33 (1)	0	–100	–33 (1)	0	–100
% Range change (unlimited dispersal)	24 (3)	1067	–100	54 (3)	1714	–100

SE, standard error of mean; AUC, area under the curve.
[1] Grid cells = 10 × 10 km modelling grid cells based on Irish National Grid.

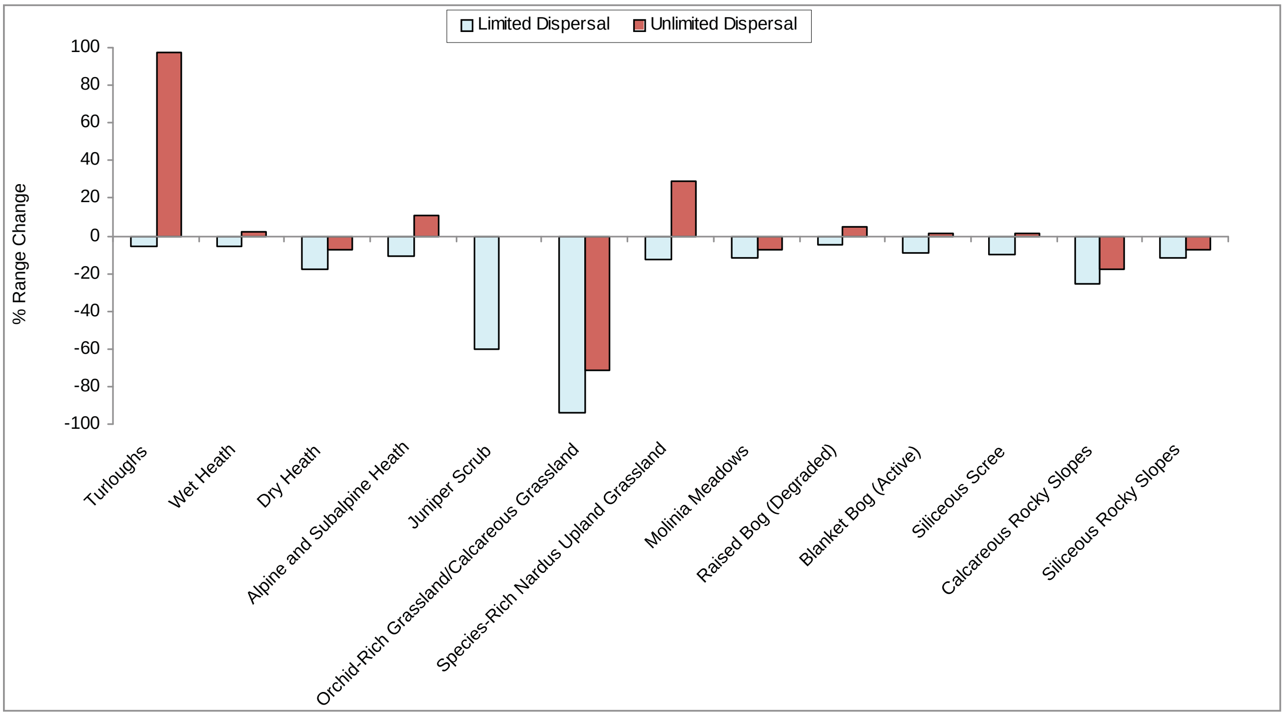

Figure 3.3. Projected range changes (%) for habitats protected under the Habitats Directive using a direct habitat modelling approach under limited and unlimited dispersal scenarios.

3.2.3 Community composition changes

Table 3.3 outlines the range change summary statistics for species characteristic of plant communities found in habitats protected under the Habitats Directive. As in the previous section on projected range changes, only results of species and habitats with sufficiently high model predictive performance are presented. Using this indirect

Table 3.3. Summary statistics of range changes of plant species characteristic of plant communities in habitats protected under the Habitats Directive (indirect habitat modelling approach using characteristic plant species) under unlimited and limited dispersal scenarios.

Habitat	CORINE habitat code	n (total)	Unlimited dispersal scenario					Limited dispersal scenario				
			Mean	SE	Median	Minimum	Maximum	Mean	SE	Median	Minimum	Maximum
Wet Heath	4010	8 (11)	9	13	8	–54	68	–33	12	–21	–85	0
Dry Heath	4030	4 (8)	14	17	14	–23	52	–15	9	–8	–45	–1
Alpine and Subalpine Heath	4060	6 (11)	–23	16	–20	–72	38	–38	13	–34	–81	–3
Juniper Scrub	5130	6 (9)	14	7	8	–3	38	–7	4	–4	–27	0
Orchid-Rich Grassland/Calcareous Grassland*	6210	13 (30)	151	90	3	–66	1066	–38	9	–25	–95	0
Species-Rich *Nardus* Upland Grassland*	6230	4 (10)	33	7	29	20	52	–17	5	–17	–27	–5
***Molinia* Meadows**	6410	4 (21)	12	11	4	–3	44	–17	3	–15	–27	–9
Lowland Hay Meadows	6510	4 (20)	–1	1	–1	–6	2	–8	3	–7	–17	–2
Raised Bog (Active)*	7110	8 (13)	10	17	7	–87	93	–40	12	–35	–95	–2
Raised Bog (Degraded)	7120	11 (13)	–10	9	3	–87	25	–36	9	–26	–95	–2
Blanket Bog (Active)*	7130	22 (34)	–1	8	3	–67	100	–38	5	–32	–91	–2
Siliceous Scree	8110	8 (12)	11	35	–16	–72	253	–46	10	–44	–81	–3
Calcareous Scree	8120	6 (11)	40	46	–1	–60	253	–42	10	–43	–75	–9
Calcareous Rocky Slopes	8210	6 (10)	0	24	0	–77	81	–44	12	–49	–77	–9
Siliceous Rocky Slopes	8220	13 (20)	51	53	–16	–72	629	–33	7	–25	–81	–3
Limestone Pavement*	8240	14 (28)	91	47	7	–21	522	–15	5	–7	–64	0
Perennial Vegetation of Stony Banks	1220	6 (10)	11	6	14	–15	29	–16	7	–11	–44	–0
Vegetated Sea Cliffs	1230	8 (12)	34	34	13	–59	260	–32	8	–27	–72	–0
Marram Dunes	2120	5 (9)	34	36	–5	–12	177	–31	11	–43	–55	0
Fixed Dunes*	2130	3 (11)	–6	31	–7	–59	48	–62	14	–50	–90	–46

*Priority Annex I Habitats.
CORINE, Co-ORdination of INformation on the Environment; SE, standard error of mean.

approach to investigate potential impact on habitats, mean changes in the ranges (areas of suitable climate space) of +24 and –31% under unlimited and limited dispersal scenarios, respectively, were calculated. Under an unlimited dispersal scenario, range changes ranged from expansions of 150% for orchid-rich grassland to contractions of 23% for alpine and subalpine heath, with 25% of habitats showing potential areas of suitable climate space decreasing (Fig. 3.4). Under a limited dispersal scenario, the five habitats projected to lose more than 40% of their range (and therefore implying that they are composed of the most vulnerable species assemblages) were raised bog (active), fixed dunes, siliceous scree, calcareous scree and calcareous rocky slopes (Fig. 3.4).

Within these mean values of range change aggregated for each habitat, much variation in the response of individual species that compose these plant communities was shown. All habitats included species projected to experience both range contractions and expansions with the mean values of these range changes, aggregated for each habitat, shown in Fig. 3.4. The range changes of individual species characteristic of plant communities in each habitat are further detailed in the End of Project Report available online (http://erc.epa.ie/safer/reports). For example, under unlimited dispersal scenarios some species belonging to upland habitats, such as siliceous scree, are projected to experience range expansions of >200% (e.g. *Saxifraga rosacea*, *Cladonia furcata*), while other species in those plant communities are projected to experience range contractions of >50% (e.g. *Salix herbacea*). Under a limited dispersal scenario, species were shown to either experience little or no change or range contractions. The results highlight that not all species in plant communities and habitats will experience the same climate change impacts and it is likely in the future that species may move into and out of plant communities and habitats of conservation value that exist today, creating new species assemblages with consequences for strict habitat classification.

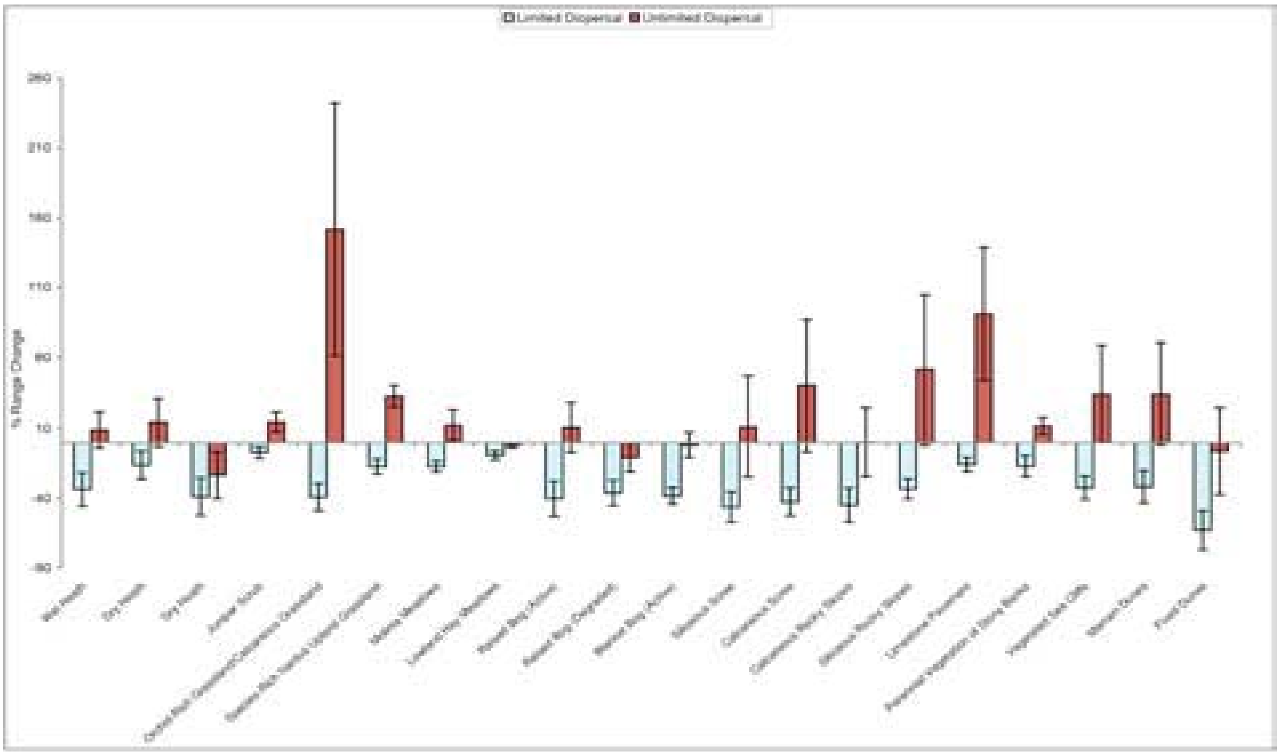

Figure 3.4. Mean projected range changes of plant species characteristic of plant communities in habitats protected under the Habitats Directive under unlimited and limited dispersal scenarios. Standard errors of the mean are shown by vertical bars (see Appendix Table 3 of the End of Project Report for plant community details).

3.3 Results (ii)

3.3.1 Wetland habitat modelling using generalised linear models (GLMs) and generalised additive models (GAMs)

The interested reader is directed to Appendix 2 of the End of Project Report, where the technical and statistical measures used to evaluate the baseline habitat models are reported. These include a further series of figures and tables.

3.3.2 Projecting future changes from the habitat models

The climate signal was applied to the baseline HDMs and following refitting of the GLMs and GAMs, the new probability scores for each 10 × 10 km grid cell were computed. The changes with respect to the baseline are summarised in Table 3.4 and the consensus model projections were used to create the future distribution maps for the four habitats (Figs 3.5–3.8).

3.3.2.1 Projected changes: WH climate space

The projected changes of climate space for the WH habitat indicate that the model is capturing an altitudinal component of change superimposed on a latitudinal gradient (Fig. 3.5), and associated with this there is:

- A loss and fragmentation of suitable climate space in the south and west offset by potential gains in the north and east;

Table 3.4. Summary of suitable climate space changes for wetland habitats based on projections from the consensus models assuming an unlimited dispersal scenario relative to the baseline simulation for the 10 × 10 km grids.

CORINE habitat type and code	**Change relative to baseline (10 × 10 km grids)**		
	Gain	**Loss**	**Net change**
Wet Heath 4010	83	86	**–3**
Degraded Raised Bog 7120	23	73	–**50**
Active Blanket Bog 7130	45	114	–**69**
Rynchosporion Depressions 7150	227	129	+98

CORINE, Co-ORdination of INformation on the Environment.

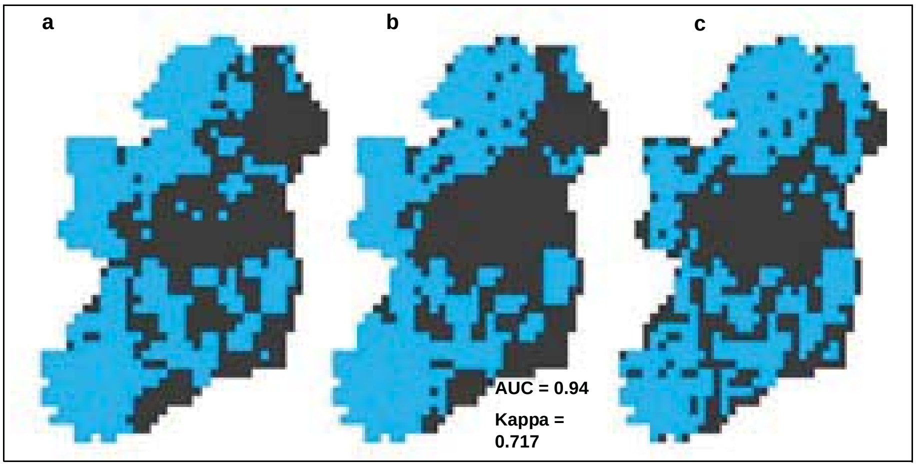

Figure 3.5. Wet heath habitat distribution on 10 × 10 km grid: (a) National Parks and Wildlife Service and Joint Nature Conservancy Council observed, (b) Climate Model (CM) baseline modelled, and (c) CM 2050s climate space projected. Blue squares denote habitat presences, black squares absences.

- A marked expansion of climate space for eastern and northern inland uplands; and
- A contraction of suitable climate space to higher altitude areas associated with a marked loss of lower elevation climate space in the south-east and south-west.

3.3.2.2 Projected changes: degraded raised bog (DRB) climate space

The projected changes for the DRB habitat indicate a loss and fragmentation of suitable climate space (Fig. 3.6):

- There is a marked contraction of climate space around the Central Plain, with substantial losses and fragmentation at the southern edge of the distribution; and
- Although the model projects gains in various individual 10 × 10 km squares, it should be recalled that HDMs are correlative and take no account of process information, including a prior record of the habitat being present.

3.3.2.3 Projected changes: active blanket bog (ABB) climate space

The projected changes for the ABB habitats reflect some of the projected changes for the WH habitat due to the altitudinal and latitudinal gradients of change captured in the model. However, there are also differences (Fig. 3.7):

- There are more projected losses of climate space for low-lying southern and western coastal areas; and
- Suitable climate space (CS) remains in the north-west and the north, with some expansions of climate space projected.

3.3.2.4 Projected changes: rynchosporion depressions (RD) climate space

Considerable gains in climate space for the RD habitats are projected although there is a contrasting latitudinal pattern (Fig. 3.8):

- The model projects an expansion of climate space to the north and east, whereas in the south, south-west and parts of the west marked losses and fragmentation of climate space are indicated; and
- While the model projects a potential expansion of climate space for northern uplands (the habitat is currently rare above 300 m), it also appears to be projecting losses above this elevation for southern and western uplands.

Given the close association of the RD habitat with other wetland habitat types (WH and ABB), these results make sense biogeographically, i.e. for these three wetland habitats there appears to be a clear altitudinal component of change superimposed on the latitudinal pattern of change.

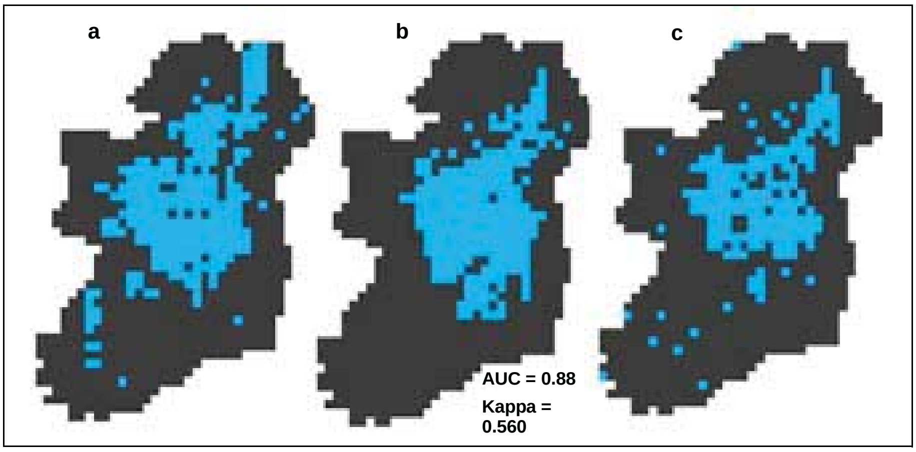

Figure 3.6. Degraded raised bog habitat distribution on 10 × 10 km grid: (a) National Parks and Wildlife Service and Joint Nature Conservancy Council observed, (b) Climate Model (CM) baseline modelled, and (c) CM 2050s climate space projected. Blue squares denote habitat presences, black squares absences.

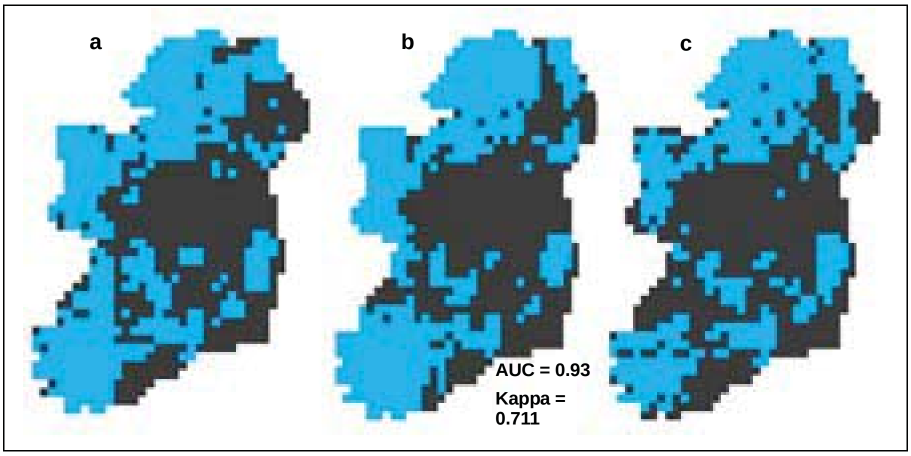

Figure 3.7. Active blanket bog habitat distribution on 10 × 10 km grid: (a) National Parks and Wildlife Service and Joint Nature Conservancy Council observed, (b) Climate Model (CM) baseline modelled, and (c) CM 2050s climate space projected. Blue squares denote habitat presences, black squares absences.

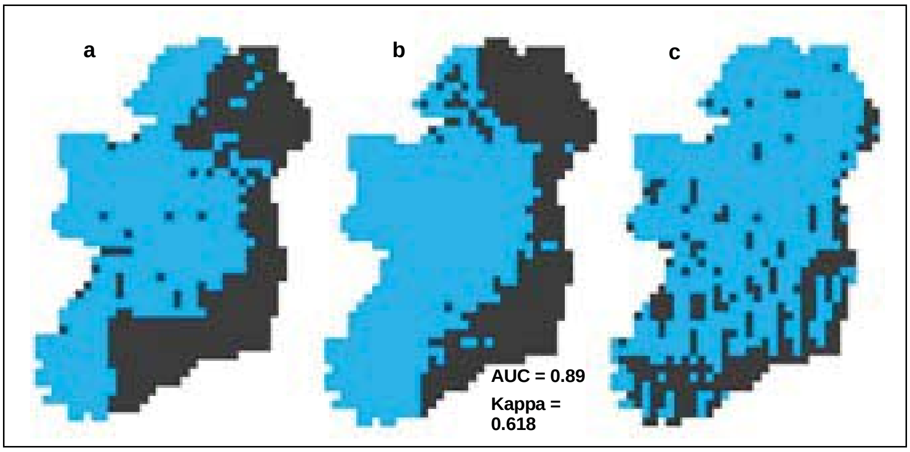

Figure 3.8. Rynchosporion depressions habitat distribution on 10 × 10 km grid: (a) National Parks and Wildlife Service and Joint Nature Conservancy Council observed, (b) Climate Model (CM) baseline modelled, and (c) CM 2050s climate space projected. Blue squares denote habitat presences, black squares absences.

4 Discussion

4.1 SDM Performance and Projected Range Changes for Species, Plant Communities and Habitats

Ireland's biodiversity is currently facing a multitude of threats including land-use change, habitat fragmentation and the introduction of non-native species. Future conservation strategies will increasingly need to consider the potential impacts of a changing climate, in particular shifts in the ranges of species. This project used a range of SDM techniques to assess the potential impacts of climate change on the future distribution of Ireland's vulnerable vascular plants, bryophytes and a selection of other species. In particular, this study examined species characteristic of plant communities of habitats protected under the Habitats Directive.

The results yield clear evidence that many species, those currently with and without direct protection, and many of our protected habitats and their plant communities are likely to experience negative consequences of climate change. The outputs of the models also project that many species could experience potential range expansions. However, it is uncertain that these species will have the capacity to disperse fast enough to keep up with shifting areas of suitable climate.

For most species globally, and no less so in Ireland, there is little knowledge on the physiological factors that govern their distribution. This study, therefore, used SDM to provide valuable insight into potential climate change impacts of these species using broader climatic and environmental variables as proxies to a variety of ecophysiological processes. This, coupled with the ability to model high numbers of species, underpinned the reasons for using SDMs in the current study (Pearson and Dawson, 2003). Many factors, other than climate, are known to influence the distribution of species (Hampe, 2004; Franklin, 2009). The use of additional topography variables improved the model performance of most species modelled in the current study though it was shown to be most valuable for species usually found in upland habitats (Luoto and Heikkinen, 2008). For case study species such as *Geomalacus maculosus*, additional variables concerning the geological and habitat requirements also greatly improved the model performance, in particular when future projections were examined spatially. The model results obtained here indicate that species distributions are governed by a range of biotic and abiotic factors found at a range of spatial scales, and in general reinforce the results of other work (e.g. Pearson and Dawson, 2003; Trivedi et al., 2008). At large continental scales, species distributions are shaped by the macroclimate, whereas at smaller regional or landscape scales, where conservation policies usually focus, factors such as topography modify the macroclimate to produce an altitudinal climatic gradient, along which species are distributed. This study also showed the predictive performance of SDM to vary with modelling technique used (Heikkinen et al., 2006; Syphard and Franklin, 2009), and that more recent techniques, such as random forest (RF), NE and the general boosting method (GBM), performed better than other techniques, such as classification tree analysis (CTA) and multivariate adaptive regression splines (MARS) (Virkkala et al., 2010).

Geographic distribution patterns at Irish and European levels were also found to be an important control of model predictive performance in the current study. Marmion et al. (2008) showed that species with limited geographic ranges and specialist species with strict ecological requirements model better that those with wide geographic ranges and a wider ecological tolerance. In the current study, species with narrow and disjunct distributions outperformed species with a wide distribution. Species distribution at the European level was also shown to be an important factor in model performance, with species belonging to the arctic-montane group in particular associated with better predictive performance compared with the other major biomes This may reflect certain species traits associated with species in these biomes (Syphard and

Franklin, 2009; Hanspach et al., 2010) or may reflect the disjunct nature of their distribution mostly found in high latitudes and altitudes in Ireland (Hodd and Sheehy Skeffington, 2011).

However, approximately 45% of the species modelled did not produce models of acceptable quality. This is most likely due either to their ubiquitous (wide) distribution and, therefore, occurrence in a broad range of bioclimatic regions or to the absence of specific environmental (soils, land use, etc.) variables important to their distribution. It is, therefore, vital that, to make the best use of SDMs, uncertainties associated with model performance (technique, ecology, geographic distribution, etc.) are fully understood. There is a need to understand whether the variation in model predictive performance reflects biogeographical or ecological differences of different species or whether it is more a product of the statistical or spatial techniques used (Marmion et al., 2008).

Overall, this study showed that, under a limited dispersal scenario, the mean range for all species modelled would contract by 33%, while, under an unlimited dispersal scenario, the mean range for all species would expand by 24%. A review of other studies shows that species at higher latitudes and altitudes tend to suffer the largest range contractions (Virkalla et al., 2008; Engler et al., 2011). This was confirmed in the results of this study as specific groups of species emerged from the data as being more at risk to potential changes in the climate, most notably species with disjunct distributions and those species belonging to the boreal-montane and arctic-montane biomes. Many of these species are found in Ireland's uplands and have restricted distribution (Hodd and Sheehy Skeffington, 2011). Further evidence for this trend was shown when species with distributions more typical of lower latitudes and altitudes were projected to experience significant expansions in ranges. These included species with narrow distributions in Ireland, mostly falling into the Mediterranean-Atlantic and Southern-Atlantic major biomes.

As has been discussed in many papers, there are many limitations to the predictive power of SDMs, in particular the ability of species to disperse (Brooker et al., 2007). Many of the plant species modelled in this study either have low dispersal ability, reproduce vegetatively or have little information recorded about their capacity to disperse. Consequently, the models do not have the capacity to make projections that include specific dispersal data, and in any event the dispersal data are not available to test this further. The authors suggest that the rate at which climate change is projected to progress is unlikely to provide sufficient time for many species to disperse to new areas of suitable climate and habitat, and they suggest that the results in the current study concerning limited dispersal scenarios results are likely to be closest to reality. They also demonstrated the importance of incorporating additional topographical variables on range change projections. Mean range expansions decreased from 54% to 24% when these variables were included in the models. This limitation extends to more than just additional ecological/topographical variables. It highlights the importance of developing better integrated models in the future that link SDMs with dispersal models, biotic interactions and land-use scenarios.

The results also demonstrated that all species in plant communities and habitats will not respond in the same fashion to the climate change projections applied here; rather they will respond in different ways based on individual requirements. Consequently, it is likely in the future that species will move into and out of plant communities and habitats of conservation value that exist today, creating new species assemblages with consequences for strict habitat classification. Species that currently only exist in unique assemblages may be replaced by widespread species, expanding, for example, from lowland to upland areas in the future, leading to a modelled realisation of this vegetation, as has been observed in Scotland (Britton et al., 2009). This will have major consequences for the species that N2K sites were set up to protect. Future designation of sites and the management of current sites need to incorporate projected climate change impacts, and develop appropriate adaptation and mitigation strategies. This may require a more dynamic system to designating sites as species move through the landscape.

In summary, the model results suggest that the following species and habitats are the most threatened:

- Species with disjunct (negative) and narrow (positive) distributions are projected to experience the largest range changes.
- In general, moss, liverwort and fern species will experience range contractions, while angiosperm species will see more variation in their response, with some angiosperms expanding while others contract.
- Species representative of arctic-montane, boreal-montane and boreo-arctic montane biomes will be more vulnerable to climate change. On the island of Ireland these species will not have higher altitudes and latitudes to move to.
- Plant communities from many of Ireland’s protected habitats are likely to see significant changes in their composition, with species moving in and out. It will be required therefore to incorporate climate change projections into the conservation management of all habitats. Although not all species in the plant communities of these habitats were modelled, our results suggest that the following habitats may be the most vulnerable to climate change impacts: upland habitats (siliceous and calcareous scree, siliceous and calcareous rocky slopes, alpine and subalpine heath), peatlands (raised bog, blanket bog), and coastal habitats (fixed dunes – additional threat of sea level rise to coastal habitats).

4.2 The GLM and GAM Habitat Results in Context

For the better performing models, the proportion of deviance explained (D^2) scores are similar to those obtained by Parviainen et al. (2008) applying GAMs to species data in Finland. For example, their plant species GAMs were explaining on average 54.0% of the variation in occurrence (Parviainen et al*.,* 2008). However, in terms of future model refinement for Irish habitats and species, these results are encouraging as the GAMs applied in the Finnish work contained more environmental information than was incorporated in the models here, including land-cover and geology variables.

Generally some of the variables included in the models reflect two primary properties of the climate (energy and water availability) with known roles in imposing constraints upon habitat and species distributions as a result of widely shared physiological limitations (e.g. Whittaker et al., 2007; Araújo et al., 2011). However, for future habitat modelling, there is scope to refine and improve the models by the inclusion of, for example, more refined topography and land-cover variables. Obvious candidates for the WH and ABB habitats would be slope, angle and aspect information. It has been suggested that local topography may create important local climatic refugia for species that are important even in studies of very large areas (e.g. Ohlemuller et al., 2008; Coll, 2010; Austin and Van Niel, 2011). Therefore, future models may benefit from incorporation of some, for example, light measure, since it is estimated that differences in light regimes between north- and south-facing aspects in temperate latitudes can produce differences in temperature equivalent to a shift of 200 km polewards (Austin and van Niel, 2011). There is also scope to incorporate some form of temperature lapse rate adjustment to refine future model development for upland areas (Coll et al., 2010). The modelling grid here would lend itself to this approach as the data extracted from the DEM provide both the mean elevation and the elevation range for each 10 × 10 km cell, and, hence, would allow an adjustment for temperature variables to be made.

Conversely, but for similar reasons, i.e. insufficient other environmental information in the models, the D^2 values for the fen and mire habitat models offer pointers to future improvement if other relevant data are incorporated in subsequent models. Thus, for example, for the fen and mire habitats, integrating data on surface and subsurface hydrology may provide better results.

In the case of the active raised bog (ARB) results, the habitat distribution is typified by a spatially aggregated pattern in the Midlands extending to the north through the border areas into Northern Ireland. This affects the matrix structure of the data, specifically there are relatively few binary presences compared with the absences, an issue compounded by the spatial clustering of the presence data. It appears that zero inflation is affecting the ability of the fitted GLM and GAM to accurately predict the proportion of occurrences. This is reflected in the low sensitivity scores, despite the good performance based on the true skill statistic (TSS) and AUC scores for the models. Logistic regression (LR) in particular is highly sensitive to unequal group sizes (prevalence) (Homer and Lemeshaw, 1989; Fielding and Bell, 1997; Coll et al., 2011), and LR performance is known to be poor at relatively low frequencies of presence (Nielson et al., 2008; Marmion et al., 2009; Jones et al., 2010). LR and other GLM methods are also known to be sensitive to spatial autocorrelation (de Frutos et al., 2007; Dormann, 2007), and other applications of GLM and GAM to species data report more accurate results when the spatial clumping is low (Marmion et al., 2009). Results here support this as the GLMs and GAMs performed better for the other (more spatially disaggregated) habitat types, and suggest that future work on ARB habitats would benefit from explicit refinements to the modelling framework incorporating routines to deal with spatial autocorrelation (e.g. Dormann et al., 2007). Nonetheless, a clear conclusion from the range of discrimination measures is that the distribution of Ireland’s WH and ABB habitats, in particular, can be modelled with some success.

4.3 Applying and Extending Probabilistic Projections for Informing Robust Adaptation Decisions on Habitats

The rigorous selection routines applied to the variables used in the baseline SDMs and the subsequent calibration to assess performance provide a useful tool for the conservation sector. Since the bulk of method development was geared towards producing thoroughly evaluated baseline models, these lend themselves to informing robust adaptation options. Thus, for example, although only the downscaled output from one GCM and scenario has been used to project climate space changes, the methods lend themselves to using outputs from different GCMs and regional climate models (RCMs) across a range of scenarios to encapsulate uncertainty. Overall, these can be applied in a framework that allows the identification of adaptation strategies that are robust (i.e. insensitive) to climate change uncertainties.

By working with probabilities, a number of choices are made available to inform adaptation options for the sector. In terms of the SDMs themselves, different cut threshold probabilities could be applied for different conservation management decisions; for example, the Sensitivity-Specificity or Maximum Kappa threshold may be more appropriate than the 0.5 threshold applied here in aiding different types of decision (e.g. Liu et al., 2005; Jimenez-Valverde and Lobo, 2007; Freeman and Moisen, 2008; Freeman, 2011). However, and of greater value to practitioners, multiple climate change data can be fitted to the SDMs and changes in the distribution of the spatial probabilities assessed via the frequency distributions associated with different climate change projections. It is, therefore, possible to envisage a situation where there may be a spatial clustering of critical thresholds for any given habitat or species across a range of GCM and RCM outputs, or a grouping within certain climate change scenarios. Arising from this, vulnerable areas within the overall range can be readily identified and management intervention strategies implemented. Conversely, by identifying robust areas within the distribution range of the focal habitat or species, areas where less intervention is likely to be needed can also be identified, thereby enabling the targeting of resources to the more vulnerable areas.

A related and important point is that, ultimately, maps will typically have multiple and somewhat conflicting management applications. Providing users with a continuous probability surface may, therefore, be more versatile by not only allowing threshold choice to be matched with map use, but also allowing the user to distinguish between a map’s discrimination and its calibration (Freeman and Moisen, 2008). This also offers greater flexibility to the end-user as evaluation can be carried out on this probability surface, rather than on particular classification maps. In addition, providing the user with the probability surface allows an examination of calibration, which can be critical to some ecological applications, and is impossible to determine from a classification map (Freeman and Moisen, 2008). For clarity of interpretation, the maps produced here are simply CM-generated presence and absence maps based on the 0.5 cut threshold as a typical default and one which is widely applied in the literature. However, probability surface maps can be readily generated using outputs from any of the individual models using any combination of the other 11 different threshold options specified in, for example, Freeman (2011).

Although the limitations and assumptions of SDMs are considered throughout, they do have value in informing conservation decisions. If, for example, the management aim is to assess landscape connectivity for a habitat or species on a first-pass basis, carefully evaluated and calibrated SDMs providing multiple probabilities from different climate change outputs would identify ‘pinch points’ and areas where a further evaluation of landscape permeability is required as part of a wider adaptation assessment. Although the 10 × 10 km modelling grid lacks the landscape-scale information required for a full assessment, by providing a probability-led assessment, SDMs can be used to help identify the spatial distribution of robust and vulnerable cells across a range of climate change scenarios derived from different GCMs and RCMs. Refined SDMs applied in this way can provide a targeted decision support tool to direct land managers to individual or grouped cells requiring detailed site assessments at a sub-10 × 10 km grid resolution, with the necessary landscape detail incorporated. Essentially then, if an ensemble-based approach from multiple GCM/RCM outputs is applied via a range of consensus-based SDMs and if cells are consistently identified where there is a contraction or expansion of climate space, locations requiring a more detailed assessment should be clear for any given habitat or species.

4.4 The Habitat Modelling in Context – Wider Synergies of Climate Change Impacts and Threats to Wetland Systems

4.4.1 Ecosystem service provision from wetlands

Ireland’s peatlands and wetlands are highly valued as a distinctive type of semi-natural habitat and include many areas with protective designations and, in common with all wetland areas, are important providers of ecosystem services (Maltby, 2010). In terms of ecosystem services, peatlands provide a regulating function by absorbing and retaining atmospheric pollutants which would otherwise degrade water quality in downstream areas, although this can cause damage to the peatland ecosystem itself (Maltby, 2010).

Peat also provides a high density of carbon I storage, as well as taking up carbon from the atmosphere and acting as a long-term carbon sink in areas where peat is forming. More importantly from a carbon cycle perspective is the amount of carbon that has accumulated in peat over many millennia. Extensive erosion of peat leads to losses of particulate and dissolved organic carbon (POC and DOC) and fine sediments, and could potentially release the remnant heavy metals and other pollutants built up since the Industrial Revolution (House et al., 2010). Declining acid deposition, increased temperatures, atmospheric carbon dioxide and land management could also increase the amount of DOC loss from peat to surface waters (Freeman et al*.*, 2001, 2004; Monteith et al., 2007; Clark et al., 2010; Yallop et al., 2010). Silting of reservoirs and changes in water quality would lead to rising water treatment costs that could result in some sites no longer being cost-effective for water supply. The hydrological functioning of peat soils can influence peak river flows and flooding, although very high rainfall quickly leads to saturation and increased run-off (Bonn et al*.*, 2009; Holden, 2009), while increased rainfall and temperature are implicated in recent observed increases in carbon flux (Billett et al., 2010).

However, exploring such complex feedbacks would require dynamic process-based models that interactively couple organic soils and vegetation dynamics. Currently, there are no such fully coupled models for vegetation on organic soils; most vegetation dynamic models only deal with vegetation on mineral soils. Therefore, while the results obtained from the HDMs are useful and informative, they should be considered a first-pass assessment, not least since the overall vulnerability of bog and wetland habitats in Ireland arises from the effects of a changing climate being superimposed on other drivers of change (Byrne et al., 2003; Jones et al., 2006; Donnelly et al., 2008).

4.4.2 Habitat and biodiversity vulnerability

Loss of high quality wetlands will lead to direct loss of important wetland biodiversity through physical removal of the habitats and their associated plant and invertebrate species, while degradation may lead to reduced species diversity and local extinction of rare or sensitive species (Scally et al., 2010). More generally, degradation and loss of all types of unprotected wetlands may have secondary impacts on the biodiversity value of the remaining wetlands through increased isolation of the remaining habitat and reduced permeability of the surrounding landscape (Scally et al., 2010).

Until now it has been unclear how vulnerable peatland and wetland systems in Ireland are to climate change on a regional basis. The improved insight into the possible climatic vulnerability of the habitats modelled here can help inform ‘climate-proof’ future management and restoration strategies for these habitats and the services their ecosystems provide. However, an important caveat for the application of HDMs in the context of vulnerability analysis is that they can only give information about *exposure* to climate stress, not sensitivity (House et al., 2010). In other words, HDMs do not provide any process information or information on feedbacks within ecosystems once the climate becomes unsuitable. Although methods that concentrate on the vulnerability of a wetland to climate change are useful, vulnerability should also be considered in a broader sense. Climate change is often an added or cumulative pressure on many wetlands; vulnerability assessments should, therefore, address the ability of a wetland to cope with a range of impacts from all externally driven forces (Gitay et al., 2011).

4.5 Synthesis and Implications for Future Research

Considerable progress has been made and substantial capacity developed over the lifetime of this project; these relate both to the spatial data assembled and the methods developed and applied for the first time in Ireland. However, the caveat that still applies more generally to SDMs must remain, that is, compared with process-based simulation models, SDMs are quite intuitive but also simplistic (Jeschke and Strayer, 2008). Also, while they offer a good approximation of what could happen to biodiversity in the short to medium term, a remaining major limitation of SDMs is that they do not incorporate sufficient other information. This includes, for example, the population dynamics determining species distribution, and information relating to the abundance, population structure, and local extinction risk that might lead to misleading extinction rates (Thuiller et al., 2008).

Another caveat is that statistical relationships with climatic variables do not necessarily imply causal relationships; thus, species and habitat distributions may only respond to some of the many climatic drivers used in the models, whereas the real distribution may respond to other variables that were not used, for example climatic extremes such as frost days and high intensity rainfall. Nonetheless, as has been the case for ecology more generally (Jeschke and Strayer, 2008), the model development here has applied a number of sophisticated techniques that can support and inform Ireland’s wider conservation effort based on current best practice. In so doing, a considerable resource has been built for the future. However, to be useful in continuing to inform long-term management options, the models and methods need to be improved and refined in light of ongoing developments.

Remaining constraining issues include, for example, the fact that a model that accurately predicts the current distribution of a species or habitat may not accurately predict the potential future distribution (Pearson et al., 2006). Conversely, models that are less accurate in predicting current distributions may be more accurate in predicting future distributions. One factor that may contribute to this is that indices of accuracy, such as AUC and TSS, give equal weight to false positives and false negatives (Jones et al., 2010). However, the calibration routines for the habitat HDMs have gone at least some way towards tackling this issue for the models presented here. Despite this, the environmental data and possible further information omitted and the lack of a finer-scale grid limit full confidence in the results. Further knowledge about the factors influencing the accuracy of predictions from different modelling applications in an Ireland-specific context is still required. Based on this work, improving the accuracy of SDMs will only occur through ongoing refinement and testing.

Overall, the results from the habitat HDMs provide a good quantitative description of relationships between the distribution of some key wetland habitats and climate for the baseline period. In addition, climate-based models are presented that skilfully replicate the observed baseline distribution. The results suggest that both GLMs and GAMs applying climatic-based variables are useful predictors of ABB and WH distribution in particular. In general, climate is the primary controlling factor in the distribution of the habitats at the scale modelled here, although the inclusion of elevation variables is also an important component in the models.

Maintaining and extending the data resource acquired via projects such as this is a widely recognised need, and decision makers, planners, researchers, and their respective organisations, should adopt a strategic view to information management (Gioia, 2010). Despite the difficulties, a common commitment to working towards best practice information management principles, both within and between organisations, is required (Gioia, 2010). By forging such links Ireland will be better equipped to tackle new or complex questions as they arise. The need to understand the effects of climate change on biodiversity is a prime example.

It should also be borne in mind that most of the actions that can be taken to protect species and habitats from climate impacts are similar to those currently being implemented to counter other pressures on natural systems (Dale et al., 2000; Hulme, 2005). Nevertheless, climate change vulnerability assessments facilitate adaptation planning, and should be considered in conjunction with, for example, the guiding principles in Hopkins et al. (2007). Specifically, vulnerability assessments help in:

- Identifying which species or systems are likely to be most strongly affected by projected changes; and
- Understanding why these resources are likely to be vulnerable, including the interaction between climate shifts and existing stressors (Glick et al., 2011).

The authors suggest that this work has gone some considerable way to inform climate change adaptation strategies for a whole range of species and for specific key habitats.

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Acronyms

a.s.l.	Above sea level
ABB	Active blanket bog
ARB	Active raised bog
AUC	Area under the curve
BAP	Biodiversity Action Plan
BEMs	Bioclimatic envelope models
CM	Climate Model
CORINE	Co-ORdination of INformation on the Environment
CS	Climate space
CTA	Classification tree analysis
DEM	Digital elevation model
DOC	Dissolved organic carbon
DRB	Degraded raised bog
EC	European Commission
EU	European Union
GAMs	Generalised additive models
GBM	General boosting method
GCM	Global Climate Model
GLM	Generalised linear model
HDM	Habitat distribution model
HIRLAM	High resolution limited area model
JNCC	Joint Nature Conservancy Council
LR	Logistic regression
MARS	Multivariate adaptive regression splines
N2K	Natura 2000
NBN	National Biodiversity Network
NE	Neural Ensembles
NPWS	National Parks and Wildlife Service
PEBLDS	Pan-European Biological and Landscape Diversity Strategy
PEEN	Pan-European Ecological Network
POC	Particulate organic carbon
RCM	Regional climate model

RD	Rynchosporion depressions
RF	Random forest
ROC	Receiver operating characteristic
SDM	Species distribution model
TSS	True skill statistic
VIF	Variance inflation factor
WH	Wet heath

Appendix 1 Guiding Principles from Current Knowledge

A brief synthesis of the guiding principles that complement this study's specific recommendations is provided here. These lay out a common series of measures to steer best practice in helping natural systems adapt to a changing climate. The following five overarching principles are evident:

1. **Reduce other, non-climate stressors**
   Address other conservation challenges – habitat destruction and fragmentation, pollution, and invasive species. Stress reduction will increase the resilience of the systems.

2. **Manage for ecological function and protection of biological diversity**
   Healthy, diverse ecosystems will be better able to withstand the impacts of climate change. Enhance ecosystem resilience by protecting biodiversity among different functional groups, among the species within function groups, and variations within species and populations to maintain species richness more generally.

3. **Establish habitat buffer zones and wildlife corridors**
   Improve and, if necessary 'engineer', habitat connectivity to facilitate species migration and range shifts in response to changing climate conditions.

4. **Implement proactive management and restoration strategies**
   Efforts that actively facilitate the ability of species, habitats and ecosystems to accommodate climate change, for example enhancing/restoring wetland development and hydrology, accretion, and translocating species to protect highly valued species or ecosystems when other options are insufficient.

5. **Increase monitoring and facilitate management under uncertainty**
   Uncertainty about future climate change impacts and the effectiveness of proposed management strategies is unavoidable. Careful monitoring of ecosystem health linked to management approaches that accommodate uncertainty will be required.

A number of related guiding principles for managing conservation adaptation are provided in, for example, Hopkins et al. (2007), and issues in relation to elements of the above have been explored previously as part of a gap analysis and review of Irish policy on biodiversity and climate change (Coll et al., 2009).

Appendix 2 Synopsis of Appendices in the End of Project Report

Full details of the modelling approaches used are provided in the appendices of the End of Project Report, published online. These provide information on the detail of the statistical methods used and the technical performance measures applied to assess model performance. A brief synopsis is provided here.

- **Appendix 1 provides the technical and statistical detail of the modelling methods, including:**
    - Species modelling using Artificial Neural Networks (ANNs) and model ensemble approaches (BIOMOD);
    - Habitat bioclimatic envelope modelling; and
    - Skill statistics to identify consensus-based models.
- **Appendix 2 provides the technical details used to assess the results, including:**
    - Statistical results for species distribution model (SDM) performance;
    - Generalised linear modelling of wetland habitats;
    - Generalised additive modelling of wetland habitats;
    - Model validation I: assessing predictive ability and discrimination;
    - Model validation II: parameter estimation for fitted models; and
    - Consensus models: habitat model selection criteria and model calibration.
- **Appendix 3 provides:**
    - Tables detailing the climate data used; and
    - Lists of the species modelled and information on species characteristic of the habitats modelled.
- **Appendix 4 provides:**
    - Supplementary information for the wetland habitat types modelled.

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomhnithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil, Pobal agus Rialtais Áitiúil.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail;
- scardadh dramhuisce.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

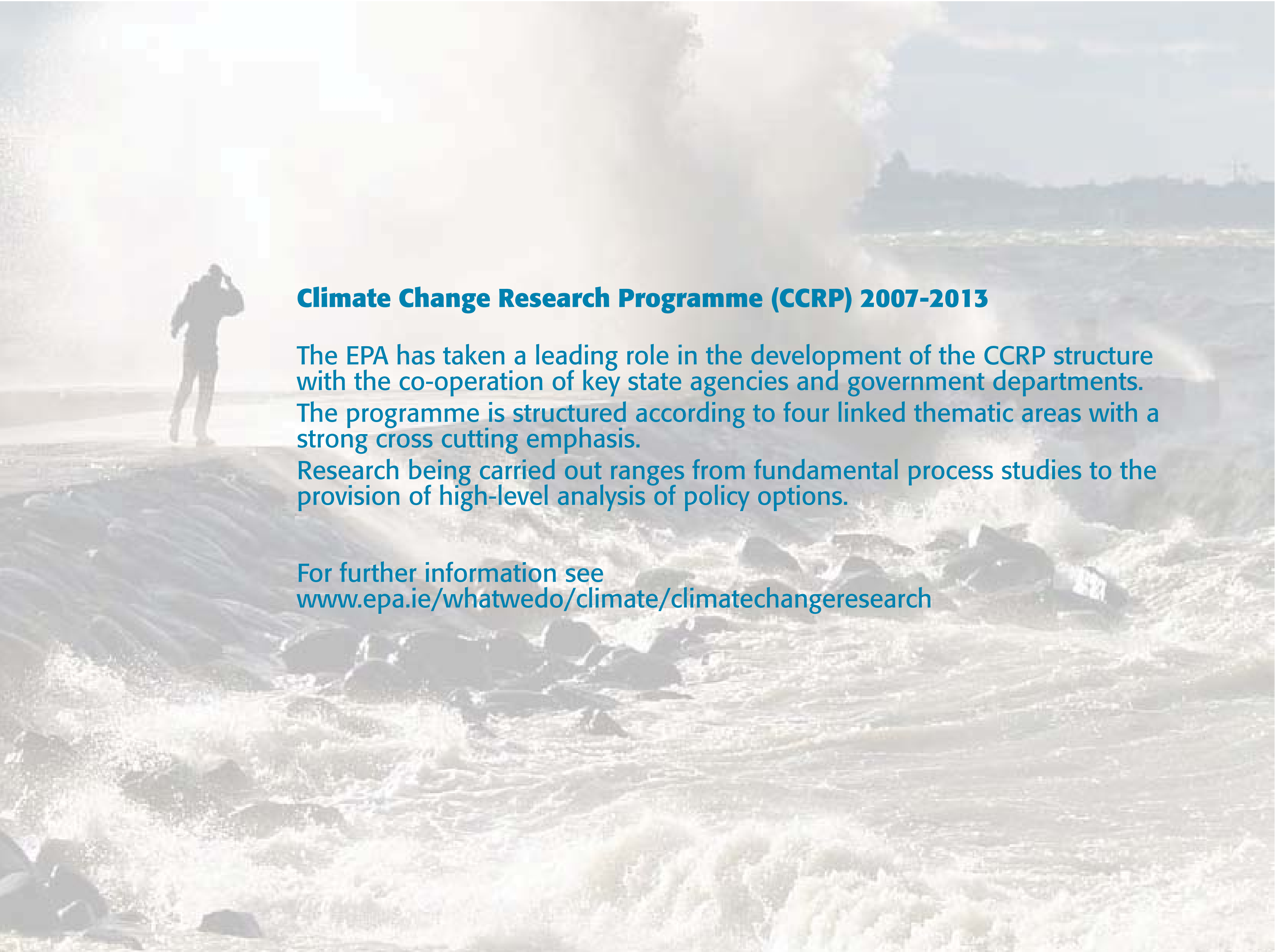
STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.



Climate Change Research Programme (CCRP) 2007-2013

The EPA has taken a leading role in the development of the CCRP structure with the co-operation of key state agencies and government departments.
The programme is structured according to four linked thematic areas with a strong cross cutting emphasis.
Research being carried out ranges from fundamental process studies to the provision of high-level analysis of policy options.

For further information see
www.epa.ie/whatwedo/climate/climatechangeresearch

Environmental Protection Agency
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Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government