

## 2. Vulnerability Assessment and Adaptation Appraisal for Surface Water Resources

### 2.1 Introduction

Climate change has the potential to impact significantly on Irish water resources. The Intergovernmental Panel on Climate Change (IPCC) states in its Technical Report “Climate Change and Water” (Bates *et al.*, 2008) that changing climate over the past several decades can be associated with changes in a number of key components of the hydrological cycle. For instance, changes in annual and seasonal precipitation, intensity, and extremes, have been observed around the world (Bates *et al.*, 2008). These alterations can result in changes in annual and seasonal flow regimes and groundwater-surface water interactions. They, therefore, can affect raw water availability, which can in turn also affect water quality and biodiversity.

Precipitation changes will also not occur uniformly around the globe. Some locations will receive more rainfall, whereas other regions may suffer from extended drought periods. The impact of climate change on water resources and supply systems will not only depend on the geography and magnitude of changes in the hydrological system but also on the water supply system itself. Depending on the characteristics of water supply systems, the same change in climate may have different effects. For example, a resilient water supply system can be thought of as one with large excess capacity (Dessai and Hulme, 2007). Such a system has a high

resistance and even a large change in inputs will have little effect on the system. In contrast, in a system operating towards the limits of its capacity, even a small change in climate or a relatively infrequent extreme event can push it past a critical threshold.

Climate change assessments for Ireland to date suggest that climate change will alter catchment hydrology over medium and long time scales. In response to these anticipated changes it is important that adaptation focuses on identifying options that are equitable both locally and on a catchment scale. However, it is also important to recognise that climate change is but one pressure on water resources and management. Other factors include: population changes, changes in water demand, legislative changes (e.g. the Water Framework Directive or introduction of water charges) as well as infrastructural changes driven by policy (e.g. leakage reduction).

### 2.2 A Robust Approach to Adaptation

In responding to the challenge of adaptation, robust strategies have been identified as those that:

- are *low-regret*, in that they provide societal benefit under a wide range of climate futures,
- are *reversible*, in that they keep at a minimum the cost of being wrong,
- provide *safety margins* that allow for climate change in the design of current infrastructure or easy retrofitting,
- use *soft strategies* that avoid the need for expensive engineering and institutionalize a long term perspective in planning,
- reduce the decision time horizons of investments, and
- are *flexible* and mindful of actions being taken by others to either mitigate or adapt to climate change (Hallegatte, 2009 and Wilby & Dessai, 2010).

However, the movement to such an approach for adaptation necessitates a shift in how climate change information is used from a predict-and-provide, top-down approach, towards a bottom-up approach that allows climate scenarios to be used in exploratory modelling exercises that test the functionality of adaptation options to the uncertainties involved. Frameworks for robust adaptation and example applications in the water sector are beginning to emerge internationally and in Ireland (Dessai & Hume, 2007; Lopez *et al.*, 2009 and Hall & Murphy, 2012a). Key among these emerging examples is the usefulness of moving away from considering climate change impacts explicitly, but rather identifying where and when vulnerability to climate change may emerge and the application of frameworks for the identification and selection of robust adaptation options.

Adaptation measures need to be context specific and planned and implemented on international, national and regional levels. National planning and water management at the river basin scale can help to identify and understand current and future vulnerabilities. Individual river basins are the level at which detailed adaptation plans have to be implemented. In line with Matthews & Le Quesne (2009) we promote the application of a process-oriented “vulnerability thinking” instead of an “impacts thinking” approach in adaptation planning. A vulnerability thinking approach combines flexibility with planning over long time horizons, is adaptive, and recognises the uncertainty in projected changes in water availability.

### **2.3 A Framework and Decision Tool for Adaptation**

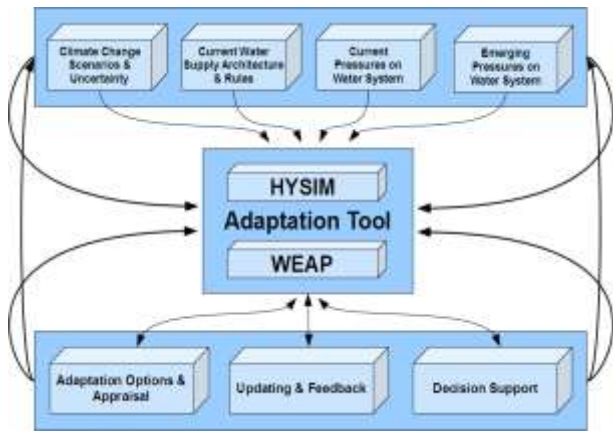
The adaptation framework used in this study is a stepwise process to framework consists of three circular processes (Figure 2.1) This recognises

that adaptation is an iterative feedback. The key components to the process that support decisions are vulnerability assessment and robust adaptation option appraisal (blue circle on the right). Within this circle the step of robust adaptation encompasses a circular framework (yellow cycle) for scenario-neutral adaptation planning adapted from Wilby & Dessai (2010). All these iterative adaptation processes as a whole are influenced by observational evidence, socio-economic and ecological pressures, as well as by uncertain future climate projections.

In operationalising this framework, the decision support tool depicted in Figure 2.2 couples a hydrological rainfall-runoff model (HYSIM) with a water-accounting model that accounts for the water supply system architecture and operating rules (WEAP). Uncertainty in future climate change impacts derived from future emissions of greenhouse gases, uncertainty in Global Climate Models (GCMs), downscaling techniques, and rainfall-runoff model uncertainties can be readily incorporated. The Water Evaluation And Planning (WEAP) model allows current water supply architecture and operating rules to be incorporated, along with current and emerging pressures on the water supply system. The flexibility of the tool means that as updated climate scenarios emerge from the next generation of global climate models and emissions scenarios, they can be incorporated. Most importantly, when used effectively, the tool can provide important information and appraisal of robust adaptation pathways to support crucial decisions.

### **2.4 Application of Approach**

In an illustrative application of the framework and tool, two contrasting case studies are summarised: in the wetter west the River Glora, a subcatchment of the River Moy, and in the drier



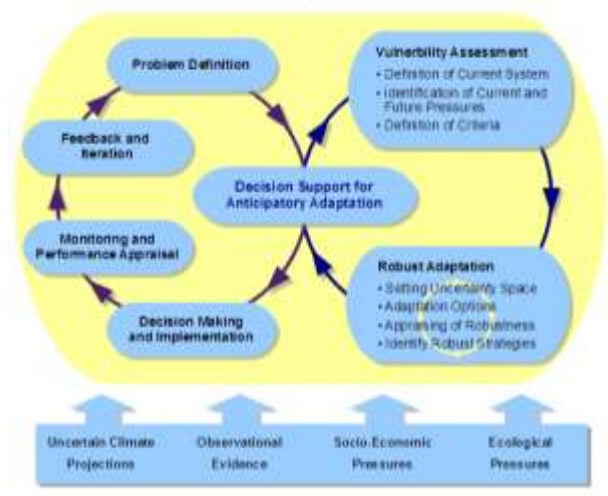
**Figure 2.1 Adaptation Framework for Planned Anticipatory Adaptation**

east the river Boyne. In both cases the framework is applied to examine the vulnerability of the water supply, and subsequently the degree of success of robust adaptation options in reducing future water stress is explored.

Specification of future climate employed the scenarios detailed in Sweeney et al. (2008) which represent six individual climate change scenarios derived from three Global Climate Models forced with two greenhouse gas emissions scenarios. The climate change scenarios were used to force a hydrological model in order to derive future changes in river flows and thus water availability. Where the

investigated surface water abstraction points have no locally measured stream flow records the hydrological model was used to model the river flows for each abstraction point individually. In such cases the model parameters were obtained according to the catchment's physical characteristics- parameters that required calibration against observations were conditioned using a split-sample, proxy-basin procedure. The Water Evaluation and Planning model Version 21 (WEAP21) was used to integrate simulated changes in catchment hydrology with water supply modelling in order to assess vulnerability and evaluate adaptation options. The water mass balances were calculated on node structures, which are linked to water supply and demand sites. The location of the individual water abstraction points was obtained from the 'National Abstractions Further Characterisation Project' for the Water Framework Directive conducted by CDM (2009). The amount of water abstracted is based on the individual water scheme's population and abstraction volume obtained from 'The provision and quality of drinking water in Ireland' report (EPA, 2009).

Water use scenarios were developed in order to appraise the vulnerability of current systems to climate change in tandem with changes in population and water demand. The scenarios were based on the individual water scheme's population and abstraction volume obtained from 'The provision and quality of drinking water in Ireland - A report for the years 2007-2008' (EPA, 2009) and from the 'National Abstractions Further Characterisation Project' for the Water Framework Directive conducted by CDM, (2009). Future scenarios for the abstraction points were based on population projections (CSO, 2008) while estimates of leakages were based on published values (Forfás, 2008; CDM, 2004).



**Figure 2.2 Schematic of the adaptation tool design showing the inputs and possible feedback mechanisms**

## 2.5 Case Study Application 1: River Boyne

Four future 'what-if-scenarios' were modelled;

- Scenario A—'Business as Usual'. The population of 2008 is extrapolated into the future using the CSO projections. Per capita water abstractions and supply infrastructure remain constant. The level of unaccounted for water is the national average of 43%.
- Scenario B—'Reduced Water Demand'. Increasing awareness in water conservation results in a stepwise annual per capita water demand reduction up to 5% by 2020. The level of unaccounted for water remains unchanged at 43%.
- Scenario C—'Reduced Leakages'. Improved water supply infrastructure results in an annual stepwise-reduced leakage level from 43% to 25% by the 2015. Daily per capita water demand remains unchanged on its 2008 level.
- Scenario D—'Reduced Demand and Reduced Leakages' Combination of Scenario B and Scenario C. Reduction of the per capita water demand and leakage reduction, as above.

Characterising water stress is difficult given that there are many equally important facets to water use, supply and scarcity (Brown and Matlock, 2011). Common indices are built around human water requirements (e.g. the Falkenmark Indicator), water resource vulnerability, indices incorporating environmental water requirements and others built on Life Cycle assessments and Water Footprinting. Here the Water Use-to-Resource Ratio (URR) was employed. This physical index of vulnerability is the water used (withdrawals) divided by the available water supply, on average and provides a local index of water stress. The index is divided into four categories as shown in Table 2.1.

**Table 2.1 Water Use-to-Resource Ratio (URR)**

Withdrawal / Q	<10%	10%–20%	20%–40%	>40%
Classification	No Stress	Low Stress	Stress	High Stress

The River Boyne catchment is located in the Eastern River RBD and extends over an area of ~2,692 km<sup>2</sup>. The catchment has an average elevation of 89m and ranges from zero to about 338m. On average the slopes are gentle with a mean slope of 1.6%. Flat and undulating lowlands are the prevailing physiographic feature with Grey Brown Podzolics being the principal soil class (30.6%), followed by Gleys (24.5%) and Minimal Grey Brown Podzolics (20.5%). The parent material of the dominating soils is Limestone Glacial Till (24%), Limestone Shale Glacial Till (21.6%) and Alluvium (12%); resulting in locally important aquifers underling about 68.6% of the catchment. The main land use types within the catchment are pastures (~79.4%) and arable land (~8%), as well as peat bogs (~4.2%), mainly located in the southern parts of the catchment. Table 2.2 shows the abstraction points analysed. Liscarthan and Kells show a high level of vulnerability to future water stress. Both are analysed in detail in Hall et al. (2012b). Summary results are provided here for the Kells abstraction.

**Table 2.2 Boyne Abstractions studied, Information Supply (CDM, 2009; EPA, 2009)**

Scheme Name	Scheme Code	Population Served	Volume (m <sup>3</sup> /day)
Athboy Water Supply	2300PU B1001	3000	2200
Drogheda	2100PU B1019	23077	27692
Kilcarn: Navan/Midmeath	2300PU B1016	5600	2800
Liscarthan: Navan/Midmeath	2300PU B1016	22400	11200
Oldcastle / Kells	2300PU B1011	2024	1447
Trim Water Supply	2300PU B1009	8000	3200

For both water abstraction points, all future scenarios in winter and spring remain below the low water stress threshold. In summer and autumn, all ranges of water stress are can be found within the different scenarios modelled. Generally, throughout the simulated time period, the number of simulations falling into the water stress categories increases over time for all water scenarios as the simulation length increases, as does the spread of the simulation outcomes. This increasing spread of data represents the increasing uncertainty ranges. Business as usual has the highest uncertainty ranges and the highest occurrence of simulations in the water stress categories. The number of simulations falling into water stress categories is subsequently reduced in water scenarios B and C resulting in a significant reduction in Scenario D.

Figure 2.3 presents the increase in the percentage of all summer simulations located in the High Water Stress Category for the Kells and Lisscarthan abstractions. It is clear that the frequency of High Water stress increases with time. While each adaptation measure is successful in reducing the frequency of high water stress it is evident from the results that such soft strategies alone may not be sufficient to avoid the occurrence of high water stress. More water demand and leakage reduction or additional measures may be necessary to increase the robustness of water supply to climate change.

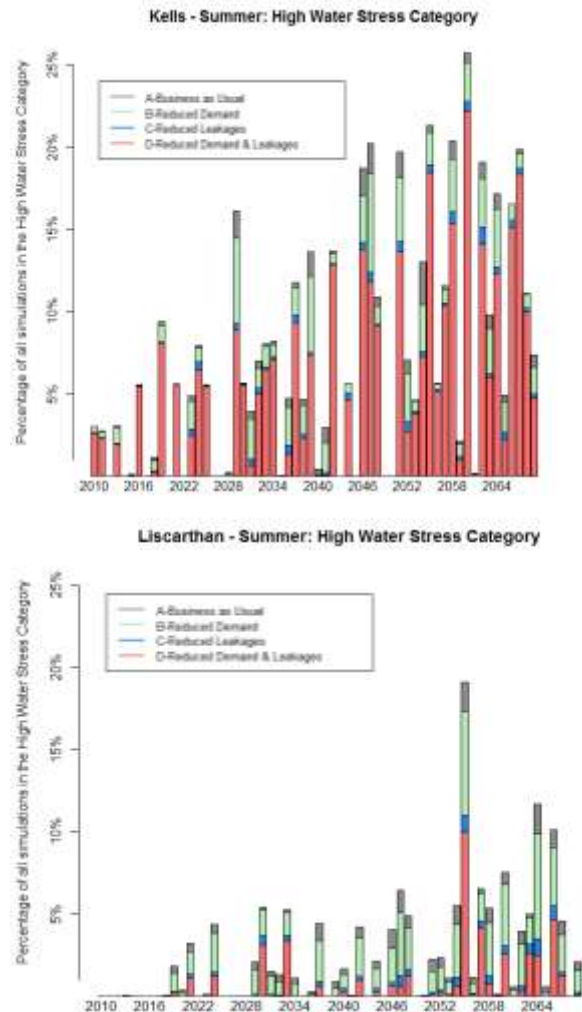


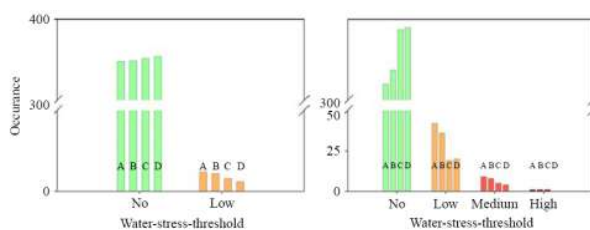
Figure 2.3 Percentage of all simulations in the High Water Stress Category for Kells and Lisscarthan

## 2.6 Case Study Application 2: Glore catchment

The modelling approach described above was applied to the River Glore sub-catchment located in the River Moy catchment, in the west of Ireland. The Glore catchment has an area of 64.72 km<sup>2</sup> and the elevation varies from 52 to 156 m. The main land cover of the catchment is pasture (44%) with 22% peat bogs. The dominant soils present in the catchment are well-drained degraded grey brown podzolics (47.7%), shallow brown earths (19.3%) and podzols (10.3%) as well as poorly drained basin peat (19.1%). The catchment is underlain by “regionally and locally important aquifers” but groundwater recharge rates are generally low with most of the catchment receiving 100-200mm

of replenishment per year (Working Group on Groundwater, 2008). The surface water abstraction site investigated in this study withdraws on average 814m<sup>3</sup> per day and serves a population of 3,989 people, resulting in an average daily water supply of 204 litres per capita (including losses through leakages).

For the 2020s, low-water-stress was detected for 11 out of 360 months in scenario A. The demand decreases in scenario B result in a reduction in the frequency of simulations falling within this category and were further reduced following implementation of scenarios C and D.



**Figure 2.4 Water-stress-threshold exceedance (number of months) of the 0.95-Quantile for the 2020s (right) and 2050s (left) for each scenario analysed.**

The frequency of months indicating water stress increases for the 2050s where ~14% of months indicate low water stress or higher. This is in line with progressive decreases in flow simulated for summer months under the climate change scenarios used. The adaptation options examined are successful in reducing the occurrence of water stress, where for example, the leakage reduction in scenario C reduces the frequency of months indicating low levels of water stress to 6.94%. All adaptation scenarios show a robust performance under the uncertainties incorporated in this modelling framework.

## 2.7 Conclusion and Recommendations

The modelling framework and tool developed in this research allows the identification of

vulnerability within water supply systems and the assessment of robust adaptation options. The tool derived is flexible and can be used with different threshold criteria and can be updated as new information and projections become available. For these case studies, climate change is likely to result in a reduction in the reliability and resilience, and an increase in the vulnerability, of the water supply. In many cases the reduction of leakage and demand is successful in reducing the occurrence of water stress. However, for some abstractions such soft strategies alone will not be sufficient to avoid high water stress and alternative supply sources may be required. Thus, consideration will need to be given to what is an acceptable level of residual risk once demand management options have been exhausted.

- From the case studies conducted, uncertainties for the future are high. These are related to climatic and non-climatic factors. Future adaptation planning in the water sector will need to account for this uncertainty.
- In the near term many elements of adaptation planning can be identified that are robust to uncertainty, particularly non-climatic factors such as demand and leakage control. It is recommended that such strategies should form an important aspect of adaptation planning in the near term.
- We promote the application of a process-oriented “vulnerability thinking” instead of an “impacts thinking” approach in adaptation planning. A vulnerability thinking approach combines flexibility with planning over long time horizons, as well as adaptive management, recognising the uncertainty in projected hydrological changes.
- Where investment in new infrastructure is required it is recommended that such infrastructure be subjected to a sensitivity analysis of performance under the full range of uncertainty associated with climate change.

### 3. Climate Change

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

#### 3.1 Introduction

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; 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 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).

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. As a result, conservation will require that not only are the environmental problems of the past addressed, but that those of an increasingly uncertain future are also a prepared for. Rapid climate change is widely considered to be the defining conservation issue for this generation and the inherent uncertainties associated with climate change projections underpin any impact assessment.

#### 3.2 Aims

- To apply state-of-the-art future climate scenarios to project possible impacts of climate change on Ireland's biodiversity to inform adaptation strategies.
- 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.

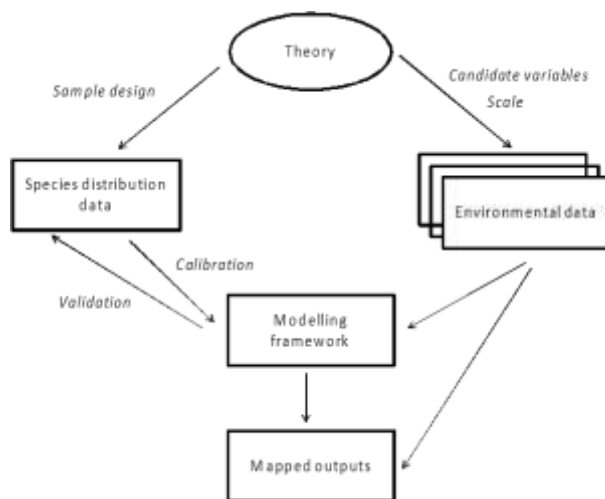
#### 3.3 Methodology

Relevant datasets of species and habitat distributions, together with other environmental data were obtained from available data sources as well as a number of key providers and merged to a common modelling grid. Observed climate and climate change data were then referenced to the biological and environmental data.

274 species and 20 habitats were modelled using established SDM techniques. The outputs from these models were improved by incorporating additional environmental and ecological data. Models were rigorously evaluated prior to fitting using the baseline climate data and other environmental information. Performance was evaluated using a range of commonly applied test measures. Figure 3.1. illustrates the conceptual framework outlining the key components of species distribution modelling. Biogeographical and ecological theory 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

To complement the machine-based model specification, a parallel approach was undertaken for selected wetland habitats using a manually-based approach to model construction and testing. A combination of SDM techniques was applied to the habitat data and the effects of different variable selection explored. To distinguish models constructed via this approach, these are referred to throughout as bioclimatic envelope models (BEMs) although the same principles are applied as for SDMs.



**Figure 3.1 Conceptual framework outlining the key components of species distribution modelling. (Source: adapted from Franklin, 2009)**

The SDMs and BEMs were re-fitted using climate change data (2031-2060) from a regional climate model (RCA3) dynamically downscaled from a global climate model (HadCM3) (McGrath *et al.*, 2008). The re-fitted models were used to project potential changes to climate space for the species and habitats following an evaluation of model spatial performance for the baseline period for selected case study species and habitats. Two dispersal scenarios, unlimited (where species can colonise all potential new areas) and fully limited (cannot colonise potential

new areas), were used to assess the ability of species to colonise new areas of suitable climate.

### 3.4 Key Findings

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

The predictive accuracies of SDM based on the Area Under the Curve (AUC) and 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 and other ecological variables 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 (Figure 3.2.)

The performance of models was shown to vary with the modelling technique used (Figure 3.3). Performance also varied for species in relation to the distribution patterns of these in Ireland as well as with species associated with major biogeographic groups across Europe (Figure 3.4).



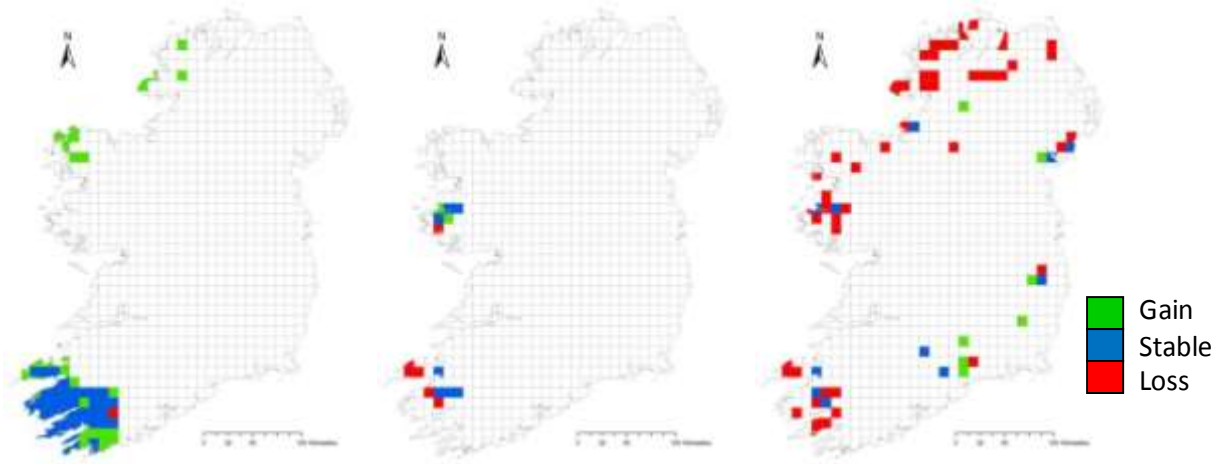


Figure 3.2 Spatially mapped species distribution model outputs for three case study species Kerry Slug, Wood's Whipwort and Dwarf Willow. The Kerry Slug is seen to experience range expansions, while the Wood Whiport and Dwarf Willow are shown to experience contractions, to higher latitudes and higher altitudes, respectively.

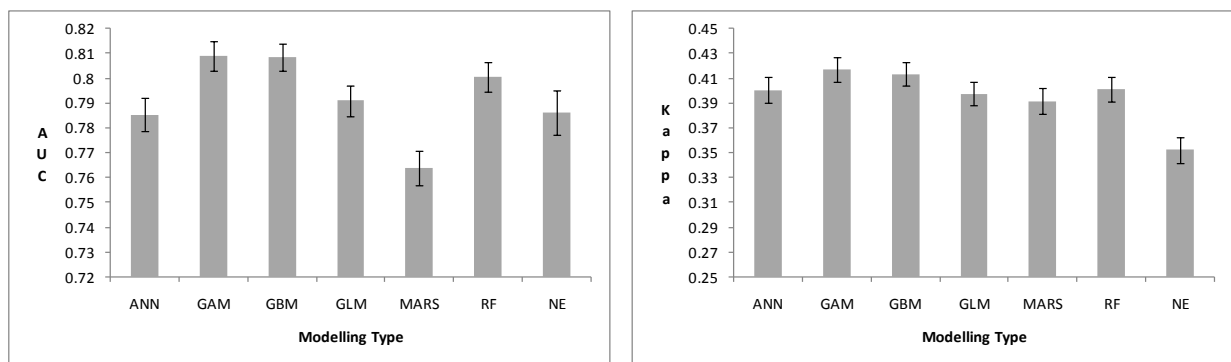
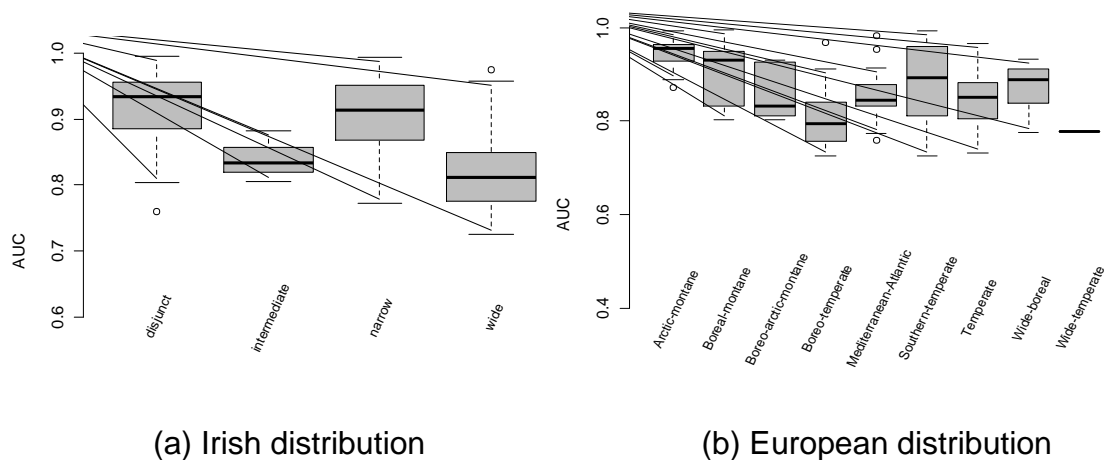


Figure 3.3 Comparison of the mean performance of each modelling type in terms of AUC (a) and Kappa (b) of each modelling type. Standard errors of the mean are shown by vertical bars. ANN = Artificial Neural Networks, GAM = Generalised Additive Models, GBM = Generalised Boosted Models, GLM = Generalised Linear Models, MARS = Multivariate Adaptive Regression Splines, RF = Random Forests, all of which were implemented in BIOMOD; and NE = Artificial Neural Networks implemented in Neural Ensembles



(a) Irish distribution

(b) European distribution

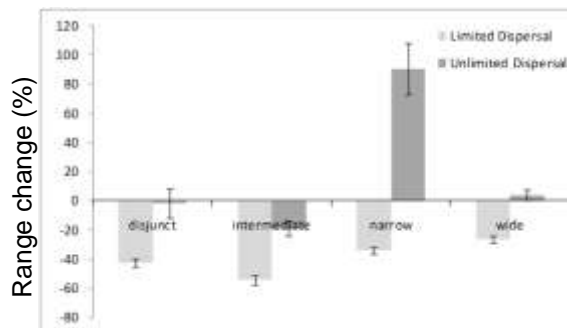
Figure 3.4 Predictive performance (AUC statistic) of the species distribution model (Neural Ensembles) for species in relation to (a) distribution in Ireland, and (b) major biome European distribution of the species

Species with disjunct and narrow distributions are projected to experience the largest range changes (Figure 3.5a). In general, moss, liverwort, and fern species are projected to experience range contractions. Some angiosperms may potentially expand their distribution, while the climate space associated with other species may contract. species at higher latitudes and altitudes tend to suffer the largest range contractions (Virkalla *et al.*, 2008; Engler *et al.*, 2011).

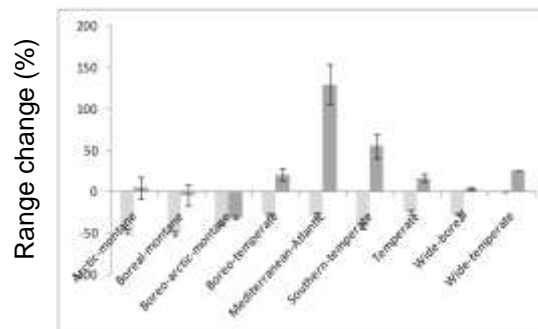
Species representative of Arctic-montane, boreal-montane and boreo-arctic montane biomes will be most vulnerable (Figure 3.5b). In Ireland these species will not have higher altitudes and latitudes to move to. While it might be expected that oceanic mountains would be buffered against climatic change by their more limited annual temperature range, by comparison with higher mountains such as the Alps, the lack of a permanent snow line zone limits the potential upward migration of species (Crawford, 2000), at least for marginal arctic-alpine species already near their southern range limit.

This potential upward migration is also likely for species with distributions more typical of lower latitudes and altitudes which were projected to experience significant expansions in ranges. These include species categorised in the Mediterranean-Atlantic and Southern-Atlantic major biomes. Thus, changes in climate leading to a reduction in the severity of the abiotic environment may lead to increased inter-specific competition associated with the invasion of species currently limited to lower elevations (Ellis and McGowan, 2006; Hodd and Sheehy Skeffington 2011). Shifts in the isotherm values associated with present maritime upland vegetation zones under selected scenarios of

climate change could be substantial (Coll *et al.*, 2010).



a) Irish distribution



b) European distribution

**Figure 3.5 Projected range changes under limited and unlimited dispersal scenarios in relation to (a) species distribution pattern in Ireland, and (b) major biome (biogeographic element/European distribution). Standard errors of the mean are shown by vertical bars**

Plant communities in many protected habitats are likely to see significant changes in their composition. 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).

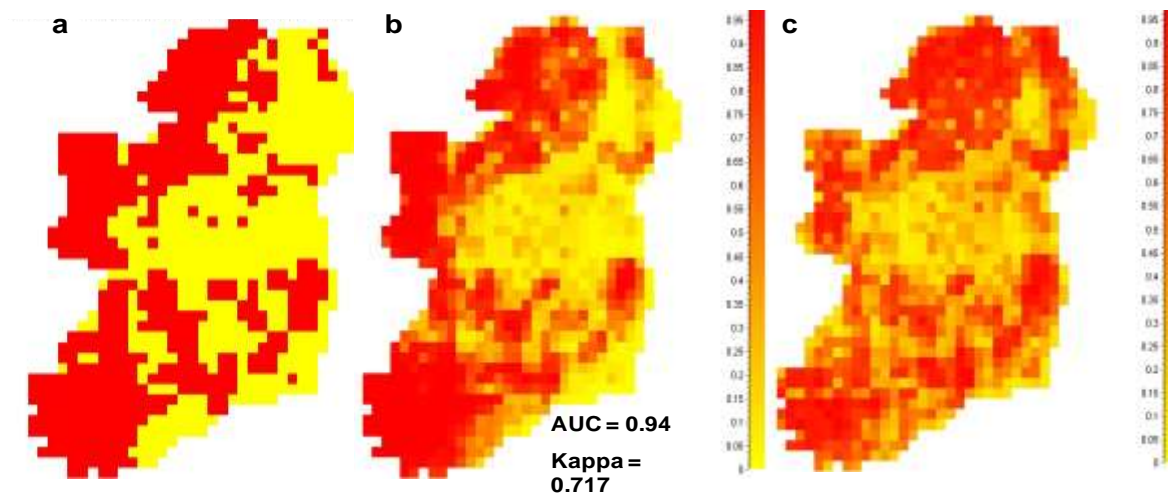


Figure 3.6 Wet heath habitat distribution on 10 x 10 km grid: a) NPWS and JNCC observed, b) Modelled baseline probability surface, c) 2050s climate space projected probability surface. Red squares denote habitat presences, yellow squares absences; scale bars denote the modelled probability of occurrence. The shading variation in the model-projected maps reflects the range of predicted probabilities for each of the grid cells

Of the key wetland habitats modelled, some were also found to be more vulnerable than others. For example, the climate space associated with the degraded raised bog and active blanket bog habitats contracted substantially more than the climate space associated with wet heath. However, the regional pattern of change varied for each of the habitats as an altitudinal pattern of projected changes was superimposed on a latitudinal gradient of change. This is illustrated with reference to the changes projected for the wet heath habitat; although there is little net loss of available climate space overall, the regional *distribution* alters (Figure 3.6).

### 3.5 Recommendations

1. Potential climate change impacts need much greater priority in the assessment and management of Natura 2000 sites if appropriate actions to protect vulnerable species and habitats are to be implemented in time. Future assessments should ensure that the latest data and climate modelling

techniques should be used to inform these assessments.

2. The composition of plant communities in Natura 2000 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 is required to account for these changes. The likelihood of new species assemblages in the future is high and the conservation sector will need to be prepared to amend its conservation objectives accordingly.
3. More research is necessary to understand the impacts of climate change on invasive species on ecosystems and ecosystem services. This should include greater understanding of the timescales over which particular species are projected to cause problems.
4. The maintenance and promotion of connectivity in the wider landscape and between Natura 2000 sites is vital to ensure species can reach new areas of

- suitable climate space. The creation of green infrastructure will help facilitate dispersal of species to these new areas.
5. Restoration of degraded habitats will improve the extent, integrity and resilience of vulnerable habitats such as blanket and raised bogs. This would include the reduction of grazing and trampling pressures.
  6. Given the significant distances between some 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.
  7. 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.
  8. 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 alongside the future impacts of climate change. A greater understanding through more research is required to understand the complex relationships between biodiversity, ecosystem functioning, ecosystem service provision and the consequences of environmental change.
  9. Some species will not be capable of migrating to new areas of suitable climate and habitat or of adapting to new conditions. If future conservation objectives deem these species to be a priority, then assisted migration to areas with suitable climate and habitat may be necessary to avoid extinction.
  10. 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 this study.
  11. Long-term monitoring and research is 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 will aid long-term survival of species through identification and rapid implementation of appropriate conservation management actions, and ensure that currently designated sites are protecting the species and habitats intended.
  12. More research and a retention and extension of the capacity developed here is needed to ensure that the tools required to provide the conservation sector with the best projections are available.
- Most of the actions that can be taken to protect species and habitats from these impacts are similar to those currently being implemented to counter other pressures on natural systems. Nevertheless, vulnerability assessments facilitate adaptation planning by identifying those species or systems that are likely to be most affected and contribute to understanding why these resources are vulnerable by elucidating the interaction between climate shifts and existing stressors (Glick *et al.*, 2011).