ICARUS
Irish Climate Analysis and Research Units

ENVIRO Centre

NUI MAYNOOTH

Department of Geography
Rhetoric House
NUI Maynooth
Co Kildare

tel: ++ 353 (1) 7084566
fax: ++ 353 (1) 7083573
web: http://icarus.nuim.ie

EnviroCentre
10 Upper Crescent
Belfast
BT7 1NT

t 028 90278330
f **028 90278334**
w *www.envirocentre.co.uk*
e *belfast@envirocentre.co.uk*

Biodiversity and Climate Change in Ireland

Briefing Paper

John Coll[1]
Cathy Maguire[2]
John Sweeney[1]

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[1] Irish Climate Analysis and Research Units, NUI Maynooth
[2] Envirocentre, Belfast

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1. Introduction

1.1 Background

The unprecedented social and economic changes experienced by Ireland over the past two decades has resulted in certain pressures on the environment increasing at a rate often exceeding that observed in other EU countries (EPA, 2008). Consequently, the four priority challenges identified by the EPA are:

- Limiting and adapting to climate change;
- reversing environmental degradation;
- mainstreaming environmental considerations;
- and complying with environmental legislation and agreements (EPA, 2008).

Therefore the commissioning of a briefing paper on the impacts of climate change on biodiversity in Ireland is timely, not least since the Biodiversity Forum concludes that climate change is having and will continue to have a huge bearing on biodiversity in Ireland. A knowledge review will also help inform the second National Biodiversity Plan (NBP) currently in development on the effects of climate change, invasive species and biosecurity, and in so doing will contribute to strategic national and local government policy planning over the next decade. With unprecedented levels of interest in biodiversity and the impacts of a changing climate, it has been recognised for some time that the state must take measures to develop or adapt existing national strategies and programmes for the conservation of biodiversity.

An obvious underpinning issue is that future climatic shifts could result in changes to species range dynamics which will reduce the relevance of present fixed protected areas for future conservation strategies. Historically, conservation planning has mostly focused on preserving pattern and has acted reactively. However, the conservation agenda is now moving on to consider adaptation to climate change, and a landscape approach is more applicable for testing strategies such as habitat re-creation, and assessing ecosystem resilience (Thuiller *et al*., 2008). There is also the need to assess and plan on the basis of functional connectivity rather than simple structural connectivity.

Implied in this is a further paradigm shift for conservation planning thinking. If unchecked climate change outstrips all possible available resources for new protected areas and as pathways for connectivity are exhausted, there may be a need to move away from the protected areas model in order to consider biodiversity conservation at the scale of all potentially available suitable landscape units and habitats. To illustrate the possible scale of the migration response for mobile species; recent work indicates an average 550km north-east range shift for European bird species in response to a 3° C end of century temperature increase (Huntley *et al*., 2007). Consequently we consider that as well as providing a timely status audit as to how well 'climate proofed' Ireland's designated site network is, we propose that we can usefully extend the findings by examining how landscape-scale impacts to designated sites may best be modelled for Ireland in future work.

Predicted negative effects of climate change for Ireland include changes in the distribution of species and the possible extinction of vulnerable species (EPA, 2008). Many aspects of Ireland's biodiversity are under threat, leading to habitat degradation and loss. The main threats arise from intensification of agriculture, poorly managed commercial forestry, peat extraction, land clearance and development, climate change and invasive alien species.

At a European level a recent European Environment Agency (EEA) report highlights that more action is needed towards halting biodiversity loss and maintaining the resilience of ecosystems because of their essential role in regulating the global climate system. Enhancing ecological coherence and the interconnectivity of the EU Natura 2000 network is key to the long-term survival of many species and habitats, for them to be able to adapt to a changing climate (EEA, 2008).

1.2 Rationale

Compelling evidence from around the globe indicates that species are already shifting their ranges in response to on-going changes in regional climates (Parmesan and Yohe, 2003; Root *et al.*, 2005; Walther *et al.*, 2005; Lavergne *et al.*, 2006), that species are altering their phenology (Menzel and Fabian, 1999; Visser and Holleman, 2001; White *et al.*, 2003; Zavaleta *et al.*, 2003: Jones *et al.*, 2006: Donnelly *et al.*, 2007) and that some species are facing extinction, or have become extinct (Parmesan, 2007; Pounds *et al.*, 2006; Foden *et al.*, 2007). Given the contemporary biodiversity crisis, effective conservation strategies that offset the climate change threats to species persistence will be critical in maintaining species and genetic diversity (Thuiller *et al.*, 2008).

These existing concerns are magnified since projected climate changes are likely to have an even greater impact on biota as the present century progresses (Berry *et al.*, 2002; Hill *et al.*, 2003; Thomas *et al.*, 2004; Thuiller *et al.*, 2005). Arising from these concerns there is a need in conservation planning to define at a landscape scale for any given region, the likely refugia corridors linking species' current and future ranges. In addition, conserving biodiversity as the climate changes is a two tiered challenge requiring adaptation (improved conservation strategies), together with mitigation.

There is considerable scientific consensus that the global climate is warming at a rate unprecedented in recent times and that warming trends are especially evident over northern hemisphere land areas and at high latitudes (Albritton *et al.*, 2001; Giorgi, 2005). In addition, numerous studies have shown that the most recent observations of changes in surface and free-atmosphere temperatures cannot be explained by (model-estimated) natural climate variability alone (Hegerl *et al.*, 2000; Barnett *et al.*, 2005).

However, there are significant remaining uncertainties in current predictions of future change at regionally and locally relevant scales. This is especially true for regions in North-western Europe and the North Atlantic, which are particularly challenging in terms of climate system understanding. Consequently planners are faced with a wide range of predicted changes from different models of unknown relative quality due to large, but unquantified, uncertainties in the modelling process (Cubasch *et al.*, 2001) (Section 2.1). Nonetheless, and despite these issues surrounding the detail of outputs from different models, NW Europe continues to be identified as a regional climate change 'Hot-Spot' (*senso* Giorgi, 2006).

Situated on the seaward western edge of north-western Europe and subject to both maritime and continental influences, the climate of Ireland is typified by spatial and temporal variability. These influences and the effects of the physical geography of the island produce a locally variable climate across the region. This variable climate contributes greatly to the biodiversity of the island, with a diverse mix of Atlantic, Arctic, Arctic-alpine and boreal elements occurring within a limited geographical area, and including many species on the edge of their global distributional range (Birks, 1997; Cross, 2006).

For example, the remaining woodlands of Ireland may be regarded as forming an extreme western and highly maritime extension of the west European transition or ecotone from Temperate Deciduous (Summer) Forest, through Boreal Coniferous Forest, to Boreal Deciduous Forest. Above the tree line and associated with the altitudinal decrease in temperature and increasing effects of wind, these communities are replaced by boreal alpine as well as sub-snowline and snowline associations where blanket bogs, heaths and dwarf shrub vegetation tend to be the dominants. It is this combination of highly variable local climates, together with many designated habitats of high conservation value being located in Ireland which necessitates the development of more locally relevant methods of climate change impact assessment for the biodiversity resource.

1.3 Aims and objectives

The aim of this briefing paper is to provide a review of available knowledge and the evidence base for policy on climate change and biodiversity. The specific objectives are:

- Provide an overview of the coherence, connectivity and resilience of National Parks, Nature Reserves, Natura 2000 sites and National Heritage Areas in order to maintain favourable conservation status of species and habitats in the face of the challenges presented by climate change.
- Make an initial assessment of the habitats and species in Ireland most at risk from climate change.
- Provide an overview of existing work which has been carried out on the potential impacts of climate change on biodiversity, including key habitats, and species.
- Assess synergies and gaps in the development of policies for climate change and biodiversity.
- Review climate change adaptation and mitigation policies and to report on the potential positive and negative impacts on biodiversity.
- Identify gaps and to make recommendations on how climate change considerations can be integrated into policy making in key sectors (including agriculture, forestry, inland waters, marine).
- Consider any emerging evidence of increased risk for the establishment of invasive alien species as a result of climate change.

2. Projected climate change impacts in Ireland

2.1 Climate change impacts: terrestrial environment

Superimposed on the biogeographical controls briefly outlined above, the landscapes of contemporary Ireland are the product of substantial human modification, and ongoing human activities will be important in shaping the evolution of the landscape. The overall effect of these historical changes has been to convert a largely deciduous forested landscape, broken up by raised bogs in the lowlands and more extensive areas of blanket bog in the west and on the mountains, into a largely grassland-dominated landscape with small, scattered stands of native woodland and an increasing area of coniferous plantation (Cross, 2006).

Therefore in undertaking a review of climate change and biodiversity it is vital to account for other drivers of change. The impacts of predicted climate changes on habitats and species will be superimposed on other human drivers of change such as habitat fragmentation, agricultural change, eutrophication and invasive species. For example, the intensification and specialisation of agricultural practises have led to widespread declines in farmland bird diversity across much of Europe (McMahon *et al.*, 2008).

Therefore here, as with many other countries, the principal contemporary threat to biodiversity is habitat degradation and loss. This is especially true for a culturally-shaped landscape such as Ireland. The key policy drivers affecting the agricultural landscape are:

- Reform of the Common Agricultural Policy
- Implementation of the Water Framework Directive
- Nitrate Vulnerable Zones
- Renewable Energy Policy

Some drivers already operating may have increasing impacts with time (e.g. current grazing regimes, summer concentrations of ground-level ozone, or nitrogen deposition), new drivers may also emerge and an extreme climatic event may completely overwhelm any climate-change impacts. Legislation changes (driven by social, economic or environmental factors) could drive land management changes, such as reform of the Common Agricultural Policy causing a drastic decline in sheep numbers. Likewise the economics of land-use in Ireland could alter management, such as a decline in traditional land management practises, or an increase in land managed for conservation (Section 7.2.1). In the latter case, management may also be influenced by trends in management or advances in ecological knowledge, and by social awareness again leading to legislation changes. The changing patterns of land ownership and use across Ireland may result in a greater diversity of management aims, making the upland landscape more heterogeneous. Events or changes outwith Ireland may influence habitats and species, such as a change in Arctic breeding areas affecting over-wintering migratory birds.

It should be noted that these different drivers for change can interact in different ways and may combine with climate change in an additive or counteractive way. Indeed, such unknown interactions may result in the most severe impacts. Given the potential for change arising from drivers such as those above, it is likely that such drivers may have greater impacts than climate change alone, certainly at least on a near term (2030s) horizon scan.

2.2 Climate change impacts: aquatic environment

Climate driven changes will also impact Ireland's marine, coastal, littoral and freshwater communities, thereby affecting the wider biodiversity resource. The interactions between weather, ocean currents and sea temperature are complex: thus the detailed response of biological systems to changes is difficult to assess.

A wealth of marine habitats supports a wide diversity of life around Ireland's coasts. This diversity is linked to the large scale movement of the North Atlantic Ocean's thermohaline circulation (THC). While the North Atlantic drift supplies warm waters on the west coast, cold sub-Arctic waters extend southwards to the Irish Sea to the east and juxtapose northern Boreal and southern Lusitanian marine species in a relatively small area.

Predicting changes in marine benthic habitats is difficult in Ireland due to the lack of data on species and habitat distributions, environmental requirements and understanding of how ecosystems function (Emblow *et al.*, 2003). In addition, no long-term datasets are available on species and habitats with which to examine patterns of marine environmental change over time (Emblow *et al.*, 2003). However, the MarClim study around UK coasts indicated that climate change is already having a profound impact on seashore indicator species (Laffoley *et al.*, 2005).

Harrison *et al.* (2001) examined the implications of climate change for the European marine environment, including five habitats of high conservation value which occur in Irish waters. They identified a range of direct and indirect effects which had to be considered (Table 1);

Table 1: Possible impacts on the marine environment considered by MONARCH (Harrison *et al.*, 2001) and other projects

Direct effects	**Indirect effects**
Sea-level rise	Change in thermohaline circulation*
Sea surface temperature change	Alteration in nutrient supply*
Increase in UV-B penetration*	Changes in wave climate*
	Changes in storminess*

*Insufficient evidence to predict likely scenarios

We have reviewed in summary form elsewhere (Annex Sections 1.2.1 – 1.2.3) evidence relating to prospective changes to some of these drivers. Given the present uncertainties surrounding the likely direction and magnitude of change for some of the key drivers, we conclude that as research continues and more sophisticated models continue to evolve, the scientific consensus is likely to change again over the coming decade. Therefore there has to be an ongoing and iterative engagement between the policy and scientific research community (Section 6) to review biodiversity conservation planning on an ongoing basis.

In terms of the biological impacts of the present projected changes around Ireland's coasts, it is considered that there will be changes in the relative distributions between southern and northern species assemblages. Although the arrival of exotic and invasive species in coastal and estuarine habitats will have further implications, not least since the wider changes in climate may favour their increased establishment (Emblow *et al.,* 2003). However, see Emblow *et al.* (2003) for a fuller review and a discussion of caveats related to data and knowledge gaps. Table 7.9 (pp 178) (Emblow *et al.* 2003) also provides a useful summary. While Harrison *et al.* (2001, Chapter 6) provide further information on e.g. the possible impacts on estuarine birds around Irish and UK coasts which complements Emblow *et al.*'s (2003) assessment.

With warmer sea temperatures affecting phytoplankton communities, the resulting decline in sand eel populations would adversely affect a wide range of seabirds (Arkell *et al.*, 2007). Around the coasts of the UK e.g. evidence of another year of seabird breeding failure appears to be emerging (MCCIP, 2008). This most recent crash follows a series of repeated annual breeding failures which are increasingly considered to be climatically linked (Thompson and Ollason, 2001; Fredriksen *et a*l., 2004a; Grosbois and Thompson, 2005; Harris *et al.*, 2005)

There appears to be a strong link between warm winters, low sandeel biomass and poor breeding seabird performance (Rindorf *et al.*, 2000; Arnott and Ruxton, 2002; Wanless *et al.*, 2004, 2005). Sea warming appears to be disrupting the community structure and abundance of zooplankton on which hatching sandeel larvae may depend for survival, growth and recruitment (Frederiksen *et al.*, 2004b; Wanless *et al.*, 2004, 2005; Fredriksen *et al.*, 2006). Worryingly, the evidence suggests these repeated annual breeding failures linked to climate change impacts on their food sources are already substantially reducing populations of certain species (MCCIP, 2008).

In summary therefore, associated with increased temperatures, there will be changes in the distribution of warm and cold water species in both coastal and offshore marine waters. Littoral and sub-littoral communities will be forced to respond to changing seasonal thermal regimes and light availability, a trend which will amplify over the century with increased warming. Irrespective of the direction of present climate change mitigation policies, the changes expected by the 2030s are already in train. To manage anticipated changes, there is increased impetus for an integrated coastal zone management system to be in place in order to better manage the drivers of change ahead of the 2030s.

Currently, the most challenging pollution issues relate to diffuse run off of pesticides and nutrient enrichment from agricultural land. With accelerated erosion triggered by a combination of exposure of the bare soil surface through human activity and extreme rainfall, farming practises in coastal areas will have to account for the increased frequency of seasonal heavy rainfall events expected by the 2030s.

However, it is not only the future mobilization of pollutants from terrestrial sources which will become an issue for marine organisms, but the resuspension of historically deposited pollutants already in the sediments of coastal systems (especially estuaries) as seasonally rougher seas increasingly perturb the coastline. With increases reported over the past fifteen years in the concentration of dissolved organic carbon (DOC) in upland freshwaters elsewhere, it is thought due to a combination of declining acid deposition and rising temperatures (e.g Evans *at al*., 2005). The combination of higher summer temperatures and seasonal precipitation changes by the 2020s has the potential to increase carbon supply to lochs and estuaries, with any increase in cloudiness of the water affecting levels of light and UV-B penetration. For example, Evans *et al*. (2005) report a step change in DOC mobilization from around 1996 for three of four monitored sites in Northern Ireland.

Perhaps more than for terrestrial settings, the direct impacts of climate driven change are likely to be more noticeable around the coasts and seas by the 2030s. It is not only the combination of localized changes to, for example, seasonal temperature and precipitation regimes that will drive change. Rather, prospective changes to wider hemispheric drivers such as the winter NAO, and it's influence on water mixing characteristics and storm tracking will increasingly impact Irish marine and coastal communities. However, the reader is again referred back to some of the discussion in Annex Section 1.2. The effectiveness of managing realignment and dealing with pollutant mobilization in the coastal zone by the 2030s will largely depend on the extent to which present policy can integrate the necessary long term planning in a national coastal strategy which also integrates biodiversity considerations.

Seasonal rainfall changes will impact on upland catchments, particularly those in the west likely to exhibit rapid run-off rates. With any increase in heavy rainfall events will be an associated increase in sediment load and the delivery of suspended solids to fresh water and estuarine systems. In an analogous setting elsewhere, it has been reported that excessive stream discharges are dislodging fish spawning grounds in north-west Scotland (Kerr and Ellis, 2001). Similarly, it is thought that changes to flood frequencies are affecting communities of the listed freshwater pearl mussel (*Margaritifera margaritifera*) around NW Europe (Hastie *et al*.; 2001, 2003).

Changes in the thermal environment will also directly impact upon some of Ireland's freshwater communities. In enclosed fresh water bodies, surface water temperatures will increase in response to higher summer temperatures. This will alter the mixing regime increasing thermal stratification (separation between surface and deeper waters which leads to deoxygenation) which will affect benthic and fish species. However, by the 2030s it is not so much mean seasonal changes which will drive such changes, but rather the increased likelihood of longer hot spells.

2.3 Climate change impacts: biodiversity and ecosystem services

In linking biodiversity and climate change issues, it is important to look beyond statutory obligations and notions of intrinsic worth. Biodiversity supports such diverse industries as agriculture, cosmetics, pharmaceuticals, pulp and paper, horticulture, construction and waste treatment. Consequently, the loss of biodiversity threatens our food supplies, opportunities for recreation and tourism, and sources of food, medicines and energy. However, there is a lack of knowledge regarding how ecosystems function and how biodiversity contributes to that function, across a range of scales, and it is generally considered that loss of biodiversity is likely to have a variety of effects on ecosystem function, resilience to change, the provision of goods and services and human well-being (Ferris, 2007).

In addition, the impact of losing elements of our biodiversity could deny future generations a wealth of cultural, scientific and commercial opportunities from new and emergent biotechnologies. Biodiversity is important for our health, for example as a source of pharmaceutical raw materials and also in terms of the quality of our food (Bullock *et al*., 2008), while fully functioning ecosystems provide us with healthy and productive environments which support the economy of rural and coastal areas.

Following the momentum inspired by the *Stern Review of the Economics of Climate Change*, the G8+5 ministers expressed the need to explore a similar project on the economics of the loss of ecosystems and biodiversity (European Communities, 2008). Arising from the initial work there is already a call for national accounting systems to be more inclusive in order to measure the human welfare benefits that ecosystems and biodiversity provide (European Communities, 2008).

Although only a preliminary and heavily conditioned figure, the current marginal value of ecosystems services in Ireland in terms of their contribution to productive output and human utility is estimated at over €2.6 billion per annum (Bullock *et al*., 2008). While this estimate rests on only a few key examples and necessarily omits other significant services such as e.g. the waste assimilation by aquatic biodiversity and benefits to human health (Bullock *et al*., 2008). Nonetheless, some provisional estimates of the economic contribution of biodiversity can be made across some sectors;

- Agriculture - ~ €1372 million per annum;
- Forestry - ~ €85 million per annum;
- Fisheries (catch) - ~ €180 million per annum;
- Aquaculture - ~€50 million per annum;
- Water quality - ~€385 million per annum;
- Human welfare - ~€330 million per annum (Bullock *et al*., 2008).

By comparison the outlay spent directly on biodiversity protection is highly disproportionate to the ecosystem service value biodiversity provides to the economy. For example, it is estimated that the National Parks and Wildlife Service spend ~€35 million per annum on protection, while the annual policy cost for the Rural Environment Protection Scheme (REPS) is ~€280 million.

Globally, tourism is one of the largest and fastest growing economic sectors and climate change is expected to have a range of direct (e.g. temperature rise) and indirect impacts. Wildlife tourism is growing in popularity and now generates substantial income for local economies around the world. For example, whale watching in Ireland was estimated to be worth €1,480,000 in direct revenues and €7,973,000 in indirect revenues in 1998 (Hoyt, 2000). While Ireland's recreational salmon fishery has been valued in excess of €100 million (CFB, 2000).

However, at regional and local scales there is little strategic planning in a locally based and highly fragmented sector due to a perception of climate change being a long-term global problem. At least part of Ireland's appeal for this growing sector is the richness and diversity of the habitats and species which contribute to the character of the landscape. There is therefore a need to assess the economic impact of possible biodiversity changes against new and emergent tourism markets of the future.

3. The Natura 2000 network in Ireland: coherence, connectivity and resilience

3.1 Summary of the resource (Republic of Ireland)

National Parks and Nature Reserves are areas designated for nature conservation and are in almost all cases entirely owned and managed by the National Parks and Wildlife Service (NPWS), constituting the most strictly protected conservation areas in the Republic of Ireland. There are currently 6 National Parks in the Republic of Ireland, which combined, cover 59,060 hectares (ha) (Craig 2001).

Natural Heritage Areas (NHAs) and Special Areas for Conservation (SACs) are designations that apply to areas of significant conservation value irrespective of ownership. The basic designation for wildlife is the NHA, defined as an area considered important for the habitats present or which holds species of plants and animals whose habitat needs protection (NPWS, 2008) (Figure 1).

To date, 75 raised bogs have been given legal protection, covering some 23,000 ha. These raised bogs are located mainly in the midlands; a further 73 blanket bogs, covering 37,000 ha, mostly in western areas are also designated as NHAs (NPWS, 2008) (Figure 1). There are also 630 proposed NHAs (pNHAs), which were published on a non-statutory basis in 1995, but have not since been statutorily proposed or designated.

The areas chosen as Special areas of Conservation (SAC) in Ireland cover an area of approximately 1, 337, 550 ha. Roughly 53% is land, the remainder being marine or large lakes and site areas range from ~0.01 ha to ~109, 000 ha. In addition, 121 Special Protection Areas (SPAs) have been designated since 1985, while 25 other sites enjoy legal protection and will shortly be designated as SPAs. It should be noted that many existing and future SPAs overlap with SACs (Figure 2).

3.2 Summary of the resource (Northern Ireland)

While at present there are no national parks in Northern Ireland, there is a ministerial commitment to work towards the establishment of national parks, and in particular towards a Mourne National Park. In parallel with the work on primary legislation, specific work progressing the proposal for a Mourne National park is underway and a Mourne National Park Working Party is working up boundary proposals.

At the present time 52 Special Areas of Conservation have been designated and a further candidate SAC submitted to the European Commission (EC) as the major part of Northern Ireland's contribution to Natura 2000 (Figure 3). These sites have already been declared Areas of Special Scientific Interest (ASSIs). SPAs and SACs together form the European wide network of sites known as Natura 2000.

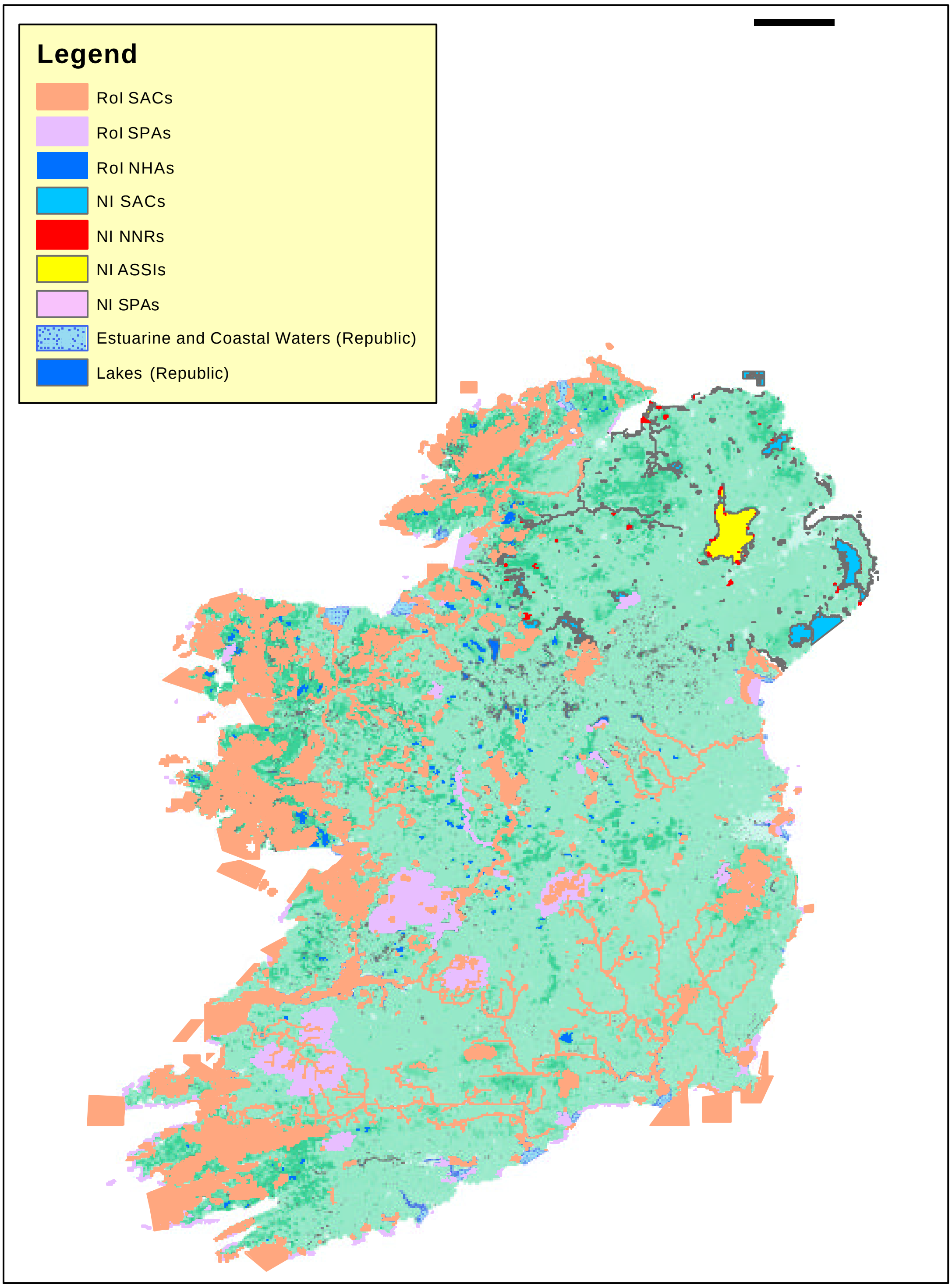

Figure 1: Outline map of Irish Natura 2000 site network. GIS shapefiles supplied by NPWS and the EPA (RoI) and the Department of the Environment (NI).

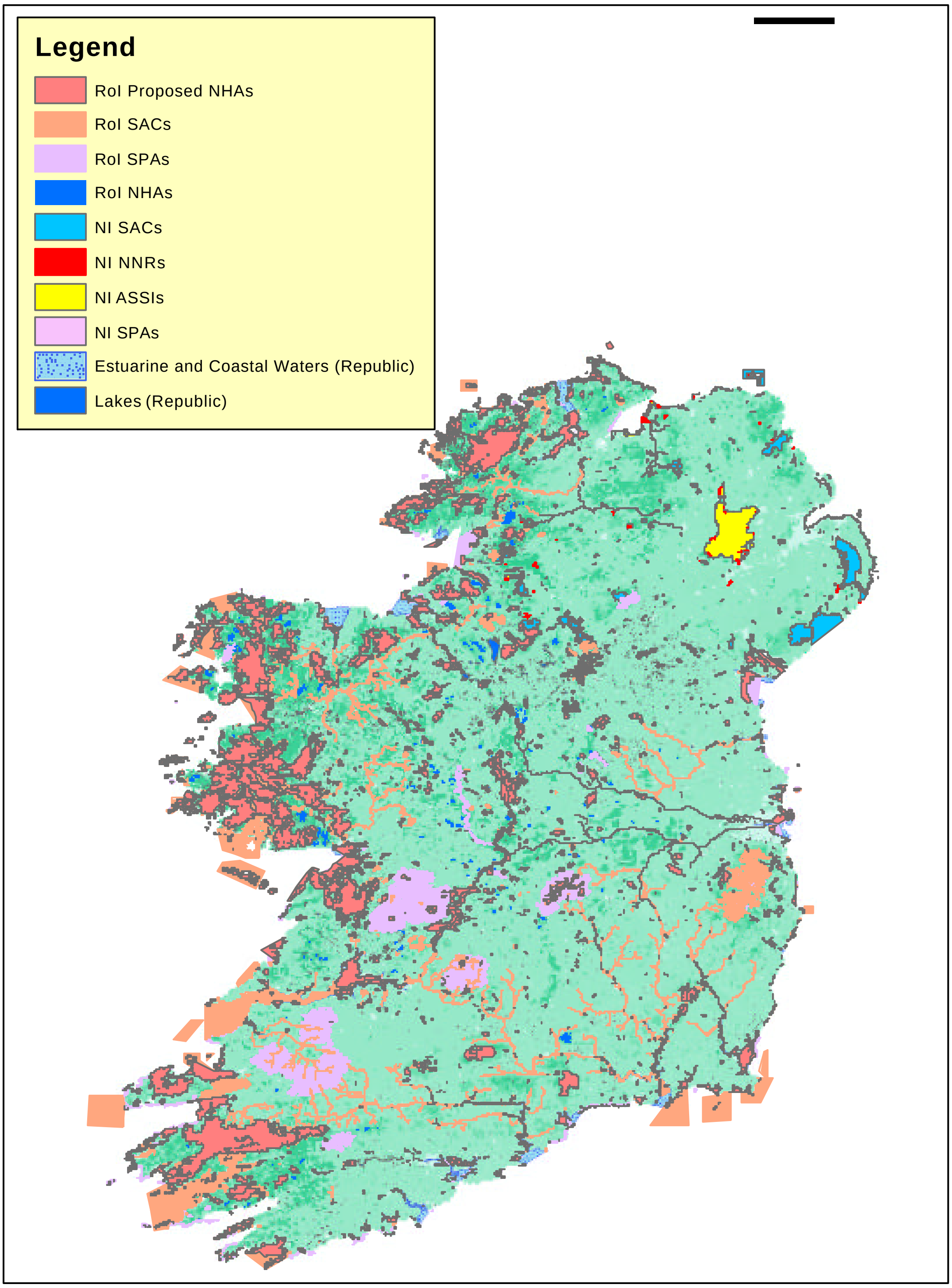

Figure 2: Outline map of Irish Natura 2000 network. Proposed NHAs (Republic of Ireland) overlain.

3.3 Structural connectivity: Natura 2000 network

It is clear from Figures 1 and 2 that there is considerable spatial overlap between sites within the various designations. This is particularly striking when the proposed NHAs for the Republic of Ireland (RoI) are overlain, particularly in relation to designated SACs (Figure 2). Another general feature is that there is more structural connectivity associated with western areas of the RoI, and to some extent around the coasts for both the RoI and Northern Ireland (NI). However, at the scale of the maps presented here, the areal extent of the designated sites reveals little of the detail of the landscape matrix and hence no real assessment of functional connectivity (Section 3.4).

In general, sites tend to reduce in spatial area and become more fragmented in the interior both sides of the border, this is not surprising as the designated areas are likely to be mirroring historical and contemporary patterns of settlement and land use. However, there is considerable structural connectivity associated with waterways and standing bodies of freshwater. This is likely to be significant when considering vectors which will facilitate the spread of aquatic invasive species associated with a changing climate (Section 7).

Since the projected seasonal changes to mean seasonal temperature and precipitation regimes for Ireland are not of a high magnitude by the 2030s (Annex Section 1.1). It seems reasonable to consider that providing there are no dramatic policy, social, economic or environmental changes, and with climate change occurring as indicated in the scenarios; there will probably be no major noticeable effects on the structural connectivity of many of the designated terrestrial sites, with the possible exception of some of the smaller sites embedded within other areas of land use (Section 3.4).

However, currently degraded habitats may continue to degrade, such as through substrate erosion. Any major increases in current degradation, or new large-scale structural impacts will probably be attributable to alterations to management regimes brought about by other driving forces, such as CAP reform (Section 6.2.1).

Nonetheless, extreme events may have a very unpredictable and profound impact, depending on their frequency and intensity, and deserve further consideration. An extreme climatic event may completely overwhelm any climate-change impacts associated with mean changes, perhaps even changing the direction of succession or change in a very different way. For example, and given the structural connectivity associated with waterways noted above, flood events could have implications for biota at a catchment scale. Similarly, extreme events may be localized in time and space, such as storms causing bog-burst or landslips.

By contrast, extended drought may affect habitats over a wide spatial scale and last for several years. For example, the unusually hot and dry summer of 2003 had a huge impact on biomass productivity in Europe, with more than a year's recovery time having been estimated (Ciais *et al.*, 2005). Even in the absence of other drivers and extreme events, and with no apparent change in many of the sites, there will still be a climate-induced momentum for change slowly building up in all communities that will exert increasing effects as the century progresses.

However, it is not adequate to consider the potential impacts of climate change on biodiversity in terms of structural changes to landscapes or habitats in isolation. There is also a need to consider how species and landscape interact, particularly in the intensively managed and fragmented landscapes of Ireland. Thus distinctions have to be made between the physical connectedness of habitats, and connectivity as a function of the ability of species to disperse through landscapes.

3.4 Functional connectivity: terrestrial sites

In order to halt the loss of biodiversity and meet other targets in the second Biodiversity Action Plan, there is a need to consider the impacts of climate change on species, both to understand their response and provision of potential adaptation measures. It is also vital to ensure that climate change adaptation and mitigation measures are not themselves harmful to biodiversity, and that increasingly an emphasis has to be placed on the importance of conserving biodiversity in the wider countryside, as well as in protected areas (EPA, 2008) (Section 1.1).

This is in addition to commitments in place which require reduction of the impacts of fragmentation, as well as further fragmentation that could potentially occur in the future associated with rapid climate change. The recognition of behaviour as a link between process and pattern in landscape ecology is exemplified by the concept of functional connectivity, i.e. the degree to which the landscape facilitates or impedes movement among resource patches.

However, at the level of landscape planning the issue is further complicated since a contrasting impact of climate change is that invasive species may be able to spread further. Therefore in order to protect native species assemblages, conservation interventions may be required to reduce connectivity for invasive species (Manchester and Bullock, 2000). Measures proposed to increase resilience in the face of biodiversity threats include expanded protected areas, varied and functional ecosystems and good habitat quality (Hopkins *et al*., 2007; Mitchell *et al*., 2007).

Consequently, when considering climate change adaptation measures the push and pull of these two conflicting management aims may best be considered in terms of re-building connectivity by way of engineering migration corridors in an already fragmented landscape. A key measure for increasing the speed at which species are able to respond to climate change is ensuring landscapes are permeable to species movement. Therefore there is a need to assess the dominant component of the landscape around and between protected areas.

The surrounding matrix has a significant impact on connectivity for many species in general. Semi-natural and extensive habitats are considered to be more conducive, or permeable, to species movement, while intensive land uses are regarded as less permeable, thereby reducing connectivity and effectively increasing ecological isolation

(Murphy and Lovett-Doust, 2004; Watts *et al.*, 2005). However, while functional connectivity is related to structural connectivity, it has to be defined in relation to an individual species' requirements (Tischendorf and Fahrig, 2000; Hilty *et al.*, 2006; Taylor *et al.*, 2006). Thus for individual species, a landscape is functional if it allows a species to carry out all its ecological functions including movement for foraging, mate finding and dispersal. A basic principle of functional connectivity is that some land covers or land uses are more permeable than others (Adriaensen *et al.*, 2003; Donald and Evans, 2006).

While techniques have been developed to proactively target biodiversity conservation at a variety of spatial scales and which can use a simple structural approach or a more complex functional one (BEETLE; Watt *et al.*, 2005, 2007). Their application remains limited by:

- the availability of high quality spatial and species data; and
- restricted information on the dispersal and landscape permeability function for most species (Watt *et al.*, 2007).

This serves to highlight that while the concept of connectivity is relatively straightforward, translating and implementing it in the realm of practical conservation is not (Crooks and Sanjayan, 2006). With the appropriate species and habitat data available, it is clear that some of these methods could be adapted for climate change impact assessment for a number of Irish habitats and be applied to the protected area network when combined with outputs from climate models**.** Ideally these would also be combined with experiments to determine the actual impact of model predictions providing a more robust evidence base for policy.

In summary, we need to develop a better understanding of spatial planning measures for Ireland which:

- predict and integrate the impact of future weather patterns on priority habitats and species;
- review the effectiveness of implementation of landscape-scale adaptation initiatives;
- link these to improved monitoring and recording programmes to facilitate model development.

One of the main shortcomings already identified in relation to managing Ireland's biodiversity is the lack of data to provide baseline and up to date information on the distribution and abundance of certain species and habitats (EPA, 2008). This lack of detailed high-resolution land cover and habitat data fit for national use hampers contemporary spatial planning measures relating to biodiversity, conservation and soil management (EPA, 2008). Issues like these contributed, at least in part, to a recent European review of Ireland's biodiversity concluding that the conservation status of many of the most important habitats and species gave cause for concern (EPA, 2008; Figure 3). However, see also the NPWS report (2008) for qualifications surrounding the habitat assessments summarized in Figure 3.

It is clear therefore that if Ireland is to begin to address the challenges of linking biodiversity conservation policy to climate change mitigation and adaptation measures, these already significantly under-resourced areas (EPA, 2008) must be addressed. This review underscores and emphasizes these existing concerns, since if even the most basic and fundamental research is to be undertaken in relation to climate change impacts, access to high resolution spatial and species monitoring data is essential. However, it should be emphasized that this is not a problem unique to Ireland. Species data can rarely be generated for all resolutions and all spatial extents, rather it tends to be available for large extents at coarse resolutions, or small extents at fine resolutions (Berry *et al.*, 2005). In addition, other criteria such as spatial representation, analytical soundness, measurability and potential inclusion in integrated assessment tools must also be considered (Erhard *et al.*, 2002).

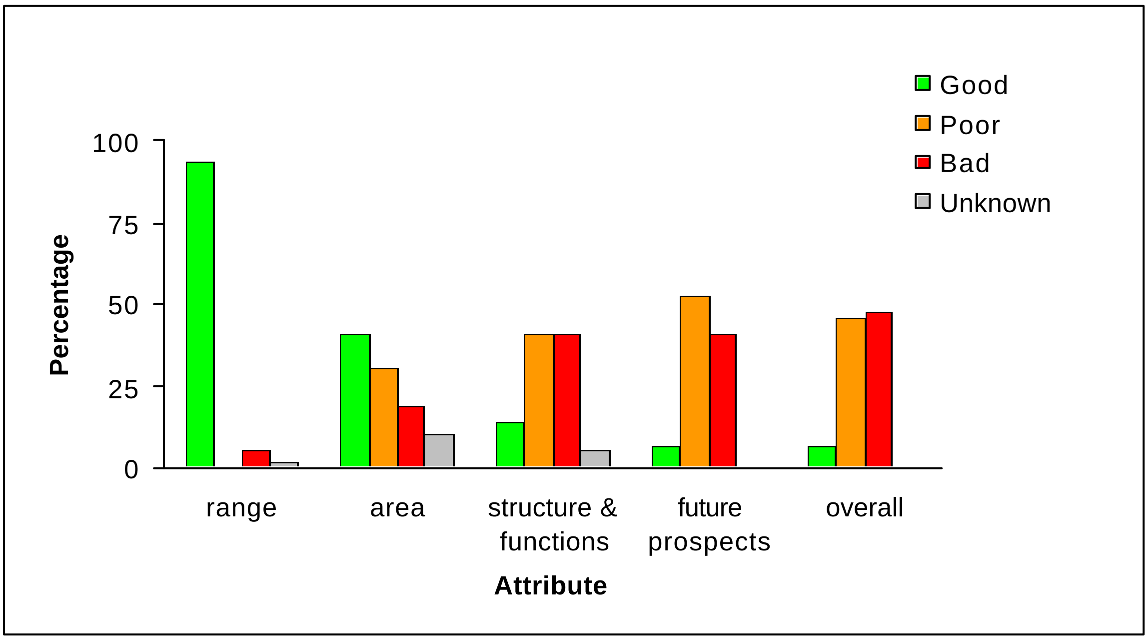

Figure 3: Summary of Conservation status for all Annexed habitats (Source: NPWS, 2008)

Access to improved spatial data must also be accompanied by scaled-up research improving knowledge of topics such as species-area relationships and conceptual developments in the application of island biogeography theory; a better understanding of meta-population dynamics and plant and animal responses to landscape-scale structures and processes; and an improved understanding of abiotic processes within landscapes and the spatial extent of different controls.

Therefore as the century progresses, and even allowing for the uncertainties (Annex Section 1.1), key considerations for conservation of the biodiversity resource (in addition to those identified above) are:

- Expanding our protected areas and buffering these within larger habitat restoration schemes. Conserving Ireland's peat bogs and restoring native woodland so they become both a useful future sequestration and conservation tool.
- These schemes would provide suitable conditions for existing populations, including space to move, as well as the space to accommodate new species in the future. Such schemes would contribute to continuing to provide vital ecosystem services such as carbon storage, water purification and flood management.
- The wider landscape must be permeable to species movements whether in an agricultural or urban context. Existing and future land-use policy should be reformed to secure and improve the site network in order to facilitate the delivery of a more permeable and resilient landscape.

3.5 Resilience: floodplains and river basin management

The vulnerability of wetlands to changes in climate depends on their position within hydrological landscapes. Hydrological landscapes are largely defined by the flow characteristics of ground water and surface water and by the interaction of atmospheric water, surface water, and ground water for any given locality or region. Assessment of these landscapes indicate that the vulnerability of all wetlands to climate change fall between two extremes: those dependent primarily on precipitation for their water supply are highly vulnerable, and those dependent primarily on discharge from regional ground water flow systems are the least vulnerable due to the greater buffering capacity of large ground water flow systems to climate change. Since most of the present water supply in Ireland comes from surface water, with between 20 and 25 percent supplied from groundwater (Charlton and Moore, 2003), Ireland's surface waters and the biological communities they support must therefore be considered as vulnerable to changes to seasonal precipitation regimes.

Wetland ecosystems are important because of the wide range of services which they perform, such as water regulation and purification (Millennium Ecosystem Assessment 2005) and carbon storage (Gorham 1991). Mitsch and Gosselink (1993) argue that hydrology is probably the most important determinant of the establishment and maintenance of specific wetland communities and wetland processes. Wetlands in Europe have already been identified as at risk from climate change through higher temperatures, greater evapotranspiration and altered precipitation amounts and patterns changing the hydrological regime (Hartig *et al.* 1997).

There is a general tendency for an enhanced seasonality of river flows in Ireland with projected climate changes:

- all areas will experience a decrease in summer runoff with a corresponding likelihood that the frequency and duration of low flows will increase in many areas;
- winter runoff is predicted to increase in the west, and particularly the north west, with a corresponding increase in the magnitude and frequency of flood events (Charlton and Moore, 2003; Charlton *et al.*, 2006).

These changes are linked to the projected changes to the spatial pattern of seasonal precipitation receipts across the country (Sweeney and Fealy, 2003, 2007).

Land use planning and land management and their effect on river flows are particularly critical. Improved management of floodplain meadows and other wetlands, removal of field drains, appropriate levels of grazing and improved woodland management in upland areas will all help to regulate water flow in a river catchment, and provide valuable habitats for wildlife. Therefore when considering the impacts of climate change it is also important to consider land use and human activity within the catchment, since these can have major impacts on the hydrological response to precipitation (Charlton and Moore, 2003; Charlton *et al.*, 2006).

In order to develop an appropriate management strategy to counteract climate change in streams, rivers and lakes, further consideration needs to be given to the impacts of (summer) low flow and more frequent flood events, as well as changes in water temperature. A linked meta-model approach has recently been used to investigate the impacts of climate and socio-economic change scenarios on water flows and wetland species in two contrasting UK regions, but perhaps raised more questions than it did answers about the assumptions and limitations of the approach (Harrison *et al.*, 2008).

3.6 Resilience: coastal and estuarine settings

Coasts are projected to be exposed to increasing risks, including erosion, due to climate change and sea-level rise. The effect will be exacerbated by increasing human-induced pressures on coastal areas (IPCC, 2007). Approximately 300km^2 of land along Ireland's coastline is at risk of inundation from rising sea levels (McElwain & Sweeney, 2007). In Ireland, a higher platform of wave attack will inevitably mean greater erosion of soft coastlines. About 1metre of land retreat can be anticipated on sandy coastlines in Ireland for every centimetre rise in sea level (McElwain and Sweeney, 2007). Therefore if we incorporate the uncertainty range projections advocated by Hulme *et al.* (2002) as a first order approximation, this could translate to the loss of 4-14 metres of soft coasts by the 2030s.

A rise in sea level effectively forces coastal habitats, such as sand dunes and mudflats, further in-land, although in some places the use of land and sea defences may prevent this landward migration of coastal habitats. The effective reduction in the area for the inter-tidal habitats often referred to as coastal squeeze affects species too. For example, migratory birds that rely on sand dunes and mudflats as staging and wintering posts may find their habitats reduced in area.

Around Ireland's coasts greater wave heights and storm surges may damage and remove sand dunes, machair, mudflats and shingle if these habitats are not allowed to migrate inland with changing coastal processes. These areas have a natural buffering effect, helping to absorb wave energy and may be viewed as natural protective strips around our coasts. However, the reader is also referred to some of the cautionary discussion in Annex Section 1.1 on climate model projections.

In coastal areas, as with all environments, there are subtle and cyclic interplays between physical processes and the biota exploiting the available habitats. Thus e.g. many soft coastlines undergo natural cycles of erosion and deposition linked to variations in sea level, sediment supply and wind and wave climate. These cycles may last from a few to many thousands of years and will be tracked by natural cycles of succession among colonising organisms. The obvious concern relating to climate change is that the rate and pace of changes will exceed the thresholds to which organisms are adapted.

Climate change is predicted to cause loss of inter-tidal habitat in low-lying areas e.g. coastal lagoons and estuaries (McElwain & Sweeney, 2007). Sand dune habitats and salt marshes are also vulnerable to sea-level and climate changes (IPCC, 2007). Recent modelling work in the UK suggests the most significant impacts are likely to be related to inter-tidal, saltmarsh and mudflat areas, which declined under all the sea-level rise scenarios considered (Gardiner *et al.*, 2007). Although the authors considered that compensation for these losses in some localities could be achieved through the creation of replacement habitat by the managed realignment of sea defences, often in conjunction with engineered sediment supply to raise inter-tidal surfaces to levels conducive to vegetation establishment (Gardiner *et al.*, 2007).

For Ireland, many of the low lying estuarine sandflats, mudflats and lagoons found along the southeast coast, some of which have been identified as SACs, could be threatened (EPA, 2008). These habitats provide rich feeding grounds for a variety of bird species as well as important nursery grounds for juvenile fish. For a fuller review of the possible impacts on native and over-wintering birds around Ireland's coasts, the reader is directed to the work of Emblow *et al.* (2003).

While the setting back of sea defences to more landward locations (managed realignment) is a response to the loss of saltmarsh and mudflat habitats, in many locations new defence lines impinge upon coastal grazing marsh areas which are themselves often designated (Lee, 2001; Nicholls and Wilson, 2001; Pethick, 2002). By contrast, other low-lying coastal habitats, saltmarsh and estuaries which are prevented from extending landwards due to the presence of some fixed or artificial boundary area also at risk (EPA, 2008).

For these environments, recent work has indicated that management choices, which can be linked to socio-economic futures have a greater potential impact on habitat viability than climate change. Therefore the choices that society makes will be key to the protection and conservation of biodiversity in the coastal zone (Richards *et al.*, 2008).

Consequently, there is a further need to identify and develop the tools that make it possible to manage Ireland's wetland and coastal ecosystems in the face of climate change. In addition, mechanisms are needed which allow climate change considerations to be integrated with management of human activities, identification of conservation sites, and the processes for monitoring, assessing and reporting on the status of habitats, species and ecosystems.

Further assessments are needed on the likely impact of the combined effects of ocean acidification and climate change, with the development of a composite index to track change. In summary, further research is required in a number of key areas including:

- Identifying constraints and opportunities and providing recommendations for optimal adaptation to climate change in coastal zones.
- Investigating the implications of climate change for the biodiversity of coastal wetlands.
- Improving understanding of the biodiversity impacts of managed retreat practices.
- Evaluating the biodiversity implications of building hard defences.
- Assess the implications of ocean acidification associated with climate change in relation to the impact on ecosystem function and the biodiversity of Irish coastal communities.

4. An initial assessment of habitats and species most at risk from climate change

While we have touched upon a number of related areas in the settings review above, here we intend to focus on habitats and species considered particularly vulnerable or at risk from climate change and for which assessments are available from the literature. We present these alongside an existing status review for Annexed habitats and species in order to provide an indication of climate change vulnerability alongside contemporary status audits.

4.1 Habitats

Below we provide a summary table taken from the NPWS (2008) assessment with an added column providing an indication of climate change impact knowledge status. We define vulnerability as the extent to which a natural or social system is susceptible to sustaining damage from climate change (IPCC, 2007). The footnotes beneath the table summarise the information sources.

Table 2: Assessment of each attribute and overall Conservation Status for Annexed Habitats (* indicates priority habitat). Definitions of the non-climate change terms are supplied in NPWS, 2008.

EU Code	Habitat Names (summarised)	Range	Area	Structure & Functions (Condition)	Future Prospects	Overall	Climate Change Vulnerability Assessment
1110	Sandbanks	Good	Good	Good	Poor	Poor	Unknown
1130	Estuaries	Good	Good	Unknown	Poor	Poor	Unknown
1140	Tidal Mudflats and Sandflats	Good	Good	Poor	Poor	Poor	Unknown
1150	Coastal Lagoons*	Good	Poor	Bad	Poor	Bad	Unknown
1160	Large Shallow Inlets and Bays	Good	Good	Unknown	Poor	Poor	Unknown
1170	Reefs	Good	Unknown	Poor	Poor	Poor	Unknown
1210	Annual Vegetation of Drift Lines	Good	Poor	Good	Poor	Poor	Unknown
1220	Perennial Vegetation of Stony Banks	Good	Poor	Poor	Poor	Poor	Unknown
1230	Vegetated Sea Cliffs	Good	Good	Poor	Poor	Poor	Unknown [1]
1310	Salicornia mud	Good	Poor	Poor	Poor	Poor	Unknown
1320	*Spartina* Swards	Good	Poor	Good	Poor	Poor	Unknown
1330	Atlantic Salt Meadows	Good	Poor	Poor	Poor	Poor	Unknown
1410	Mediterranean Salt Meadows	Good	Good	Poor	Poor	Poor	Unknown
1420	Halophilous Scrub	Good	Bad	Poor	Bad	Bad	Unknown
2110	Embryonic Shifting Dunes	Good	Poor	Poor	Poor	Poor	Unknown
2120	Marram Dunes (White Dunes)	Good	Bad	Bad	Bad	Bad	Favoured [1]
2130	Fixed Dunes (Grey Dunes)*	Good	Poor	Bad	Bad	Bad	Favoured [1]
2140	Decalcified Empetrum Dunes*	Good	Good	Bad	Poor	Bad	Unknown
2150	Decalcified Dune Heath*	Good	Good	Bad	Poor	Bad	Unknown
2170	Dunes with Creeping Willow	Good	Good	Poor	Poor	Poor	Unknown
2190	Humid Dune Slacks	Good	Poor	Poor	Bad	Bad	Unknown
2IAO	Machair*	Good	Poor	Bad	Bad	Bad	Low [1]
3110	Lowland Oligotrophic Lakes	Good	Good	Bad	Bad	Bad	Unknown
3130	Upland Oligotrophic Lakes	Good	Good	Bad	Bad	Bad	Unknown

3140	Hard Water Lakes	Good	Good	Bad	Bad	**Bad**	**Unknown**
3150	Natural Eutrophic Lakes	Unknown	Unknown	Unknown	Bad	**Bad**	**Unknown**
3160	Dystrophic Lakes	Good	Unknown	Bad	Bad	**Bad**	**Unknown**
3180	Turloughs*	Good	Good	Poor	Poor	**Poor**	**Medium-High [1]**
3260	Floating River Vegetation	Good	Good	Bad	Bad	**Bad**	**Unknown**
3270	Chenopodion rubri	Good	Good	Good	Good	**Good**	**Unknown**
4010	Wet Heath	Good	Unknown	Bad	Bad	**Bad**	**Medium [1]**
4030	Dry Heath	Good	Good	Poor	Poor	**Poor**	**Low [1]**
4060	Alpine and Subalpine Heath	Good	Poor	Poor	Poor	**Poor**	**Medium-High [1]**
5130	Juniper Scrub	Good	Poor	Poor	Poor	**Poor**	**Unknown**
6130	Calaminarian Grassland	Good	Good	Good	Poor	**Poor**	**High [1]**
6210	Orchid-Rich Grassland/Calcareous Grassland*	Good	Bad	Bad	Bad	**Bad**	**Unknown**
6230	Species-Rich Nardus Upland Grassland*	Good	Bad	Bad	Bad	**Bad**	**Unknown**
6410	Molinia Meadows	Good	Bad	Bad	Bad	**Bad**	**Unknown**
6430	Hydrophilous Tall Herb	Good	Good	Poor	Poor	**Poor**	**Unknown**
6510	Lowland Hay Meadows	Bad	Bad	Bad	Bad	**Bad**	**Low [1]**
7110	Raised Bog (Active)*	Bad	Bad	Bad	Bad	**Bad**	**Medium-High [1]**
7120	Degraded Raised Bogs	Good	Good	Poor	Poor	**Poor**	**Medium-High [1]**
7130	Blanket Bog (Active)*	Good	Bad	Poor	Bad	**Bad**	**Medium-High [1]**
7140	Transition Mires	Good	Good	Bad	Bad	**Bad**	**Unknown**
7150	Rhyncosporion Depressions	Good	Good	Good	Good	**Good**	**Unknown**
7210	Cladium Fens*	Good	Good	Bad	Bad	**Bad**	**Medium-High [1]**
7220	Petrifying Springs*	Good	Good	Bad	Bad	**Bad**	**Medium-High [1]**
7230	Alkaline Fens	Good	Good	Bad	Bad	**Bad**	**Medium-High [1]**
8110	Siliceous Scree	Good	Poor	Poor	Poor	**Poor**	**Unknown [1]**
8120	Calcareous Scree	Good	Poor	Poor	Poor	**Poor**	**Unknown**
8210	Calcareous Rocky Slopes	Good	Poor	Poor	Poor	**Poor**	**Unknown**
8220	Siliceous Rocky Slopes	Good	Poor	Poor	Poor	**Poor**	**Unknown**
8240	Limestone Pavement*	Good	Poor	Poor	Poor	**Poor**	**Unknown [1]**
8310	Caves	Good	Unknown	Good	Good	**Good**	**Unknown**
8330	Sea Caves	Good	Unknown	Good	Good	**Good**	**Unknown**
91A0	Old Oak Woodlands	Good	Bad	Bad	Bad	**Bad**	**Medium [1]**
91D0	Bog Woodland*	Good	Poor	Poor	Poor	**Poor**	**Medium-High [1]**
91E0	Residual Alluvial Forests*	Good	Bad	Bad	Bad	**Bad**	**Unknown**
91J0	Yew Woodlands*	Bad	Bad	Bad	Bad	**Bad**	**Unknown**

1 – Byrne *et al*. (2003)

For the interested reader seeking further information, the habitat distribution maps (NPWS, 2008) are available at:
http://www.npws.ie/en/PublicationsLiterature/HabitatsDirectivereport07/Habitats/

The approach is useful in identifying that climate change impacts may be superimposed on an already poor outlook for a number of priority habitats. Based on this initial qualitative assessment, the most vulnerable habitats overall appear to be;

- 7110 Raised Bog (Active);
- 7130 Blanket Bog (Active);
- 7210 Cladium Fens;
- 7220 Petrifying Springs;

- 3180 Turloughs;
- 91D0 Bog Woodland.

The exercise also indicates that priority habitats requiring further climate change impacts research appear to be;

- 1150 Coastal Lagoons;
- 2140 Decalcified Empetrum Dunes;
- 2150 Decalcified Dune Heath;
- 6210 Orchid-Rich Grassland/Calcareous Grassland;
- 6230 Species-Rich Nardus upland Grassland;
- 91E0 Residual Alluvial Forests;
- 91J0 Yew Woodlands.

4.2 Species

Again we provide a summary table taken from the NPWS (2008) assessment with an added column providing an indication of climate change impact knowledge status. We define vulnerability as above, and the footnotes beneath the table again summarise the information sources.

Table 3: Assessment of each attribute and overall Conservation Status for Annexed Species. Definitions of the non-climate change terms are supplied in NPWS, 2008.

EU Code	Species Name	Annex	Range	Population	Suitable Habitat	Future Prospects	Overall	Climate Change Vulnerability Assessment
1421	Killarney Fern (*Trichomanes speciosum*)	II, IV	Good	Good	Good	Good	**Good**	**Medium [1, 2]**
1528	Marsh Saxifrage (*Saxifraga hirculus*)	II, IV	Good	Good	Good	Good	**Good**	**Unknown [1, 2]**
1833	Slender Naiad (*Najas flexilis*)	II, IV	Good	Poor	Poor	Good	**Poor**	**Medium [1, 2]**
1393	Slender Green Feather-Moss (*Hamatocaulis vernicosus*)	II	Good	Good	Good	Good	**Good**	**Unknown**
1395	Petalwort (*Petalophyllum ralfsii*)	II	Good	Good	Good	Good	**Good**	**Unknown**
1376	Maerl (*Lithothamnion corralloides*)	V	Good	Unknown	Unknown	Poor	**Poor**	**Favoured [3]**
1377	Maerl (*Phymatolithon calcareum*)	V	Good	Unknown	Unknown	Poor	**Poor**	**Unknown**
1400	White Cushion Moss (*Leucobryum glaucum*)	V	Good	Good	Poor	Good	**Poor**	**Unknown**
1409	*Sphagnum* genus	V	Good	Good	Poor	Poor	**Poor**	**Unknown**
1413	*Lycopodium* species group	V	Good	Poor	Poor	Poor	**Poor**	**Medium [2]**
5113	*Cladonia* subgenus *Cladina*	V	Good	Good	Poor	Poor	**Poor**	**Unknown**
1013	Geyer's Whorl Snail (*Vertigo geyeri*)	II	Good	Poor	Poor	Poor	**Poor**	**Unknown**
1014	Narrow-mouthed Whorl Snail (*Vertigo angustior*)	II	Good	Poor	Poor	Poor	**Poor**	**Low [1]**
1016	Desmoulin's Whorl Snail (*Vertigo moulinsiana*)	II	Bad	Bad	Poor	Bad	**Bad**	**Unknown**
1024	Kerry Slug (*Geomalacus maculosus*)	II, IV	Good	Good	Good	Good	**Good**	**Favoured [1]**
1029	Freshwater Pearl Mussel (*Margaritifera margaritifera*)	II, V	Good	Bad	Bad	Bad	**Bad**	**High[4]**
1990	Nore Freshwater Pearl Mussel (*Margaritifera durrovensis*)	II, V	Bad	Bad	Bad	Bad	**Bad**	**High[4]**
1092	White-Clawed Crayfish (*Austropotamobius pallipes*)	II, V	Poor	Poor	Poor	Poor	**Poor**	**Unknown**
1065	Marsh Fritillary (*Euphydryas aurinia*)	II	Good	Poor	Poor	Poor	**Poor**	**Unknown**
1095	Sea Lamprey (*Petromyzon marinus*)	II	Poor	Poor	Poor	Poor	**Poor**	**Unknown**
1099	River Lamprey (*Lampetra fluviatilis*)	II, V	Good	Good	Good	Good	**Good**	**Unknown**
1096	Brook Lamprey (*Lampetra planeri*)	II	Good	Good	Good	Good	**Good**	**Unknown**
1102	Allis Shad (*Alosa alosa*)	II, V	Good	Unknown	Unknown	Unknown	**Unknown**	**Medium [5]**
5046	Killarney Shad (*Alosa fallax killarnensis*)	II, V	Good	Good	Good	Good	**Good**	**Medium [5]**
1103	Twaite Shad (*Alosa fallax fallax*)	II, V	Good	Bad	Unknown	Poor	**Bad**	**Medium [5]**
5076	Pollan (*Coregonus autumnalis*)	V	Good	Bad	Poor	Poor	**Bad**	**High[5]**
1106	Atlantic Salmon (*Salmo salar*)	II, V	Good	Bad	Poor	Poor	**Bad**	**Medium-High [1]**
1202	Natterjack Toad (*Bufo calamita*)	IV	Bad	Bad	Poor	Poor	**Bad**	**Low-Medium [1]**
1213	Common Frog (*Rana temporaria*)	V	Good	Good	Poor	Good	**Poor**	**Unknown**
1223	Leatherback Turtle (*Dermochelys coriacea*)	IV	Unknown	Unknown	Unknown	Poor	**Poor**	**Unknown**
1303	Lesser Horseshoe Bat (*Rhinolophus hipposideros*)	II, IV	Good	Good	Good	Good	**Good**	**Low [1]**
1309	Common Pipistrelle (*Pipistrellus pipistrellus*)	IV	Good	Good	Good	Good	**Good**	**Unknown**
5009	Soprano Pipistrelle (*Pipistrellus pygmaeus*)	IV	Good	Good	Good	Good	**Good**	**Unknown**

1317	Nathusius' Pipistrelle (*Pipistrellus nathusii*)	IV	Good	Good	Good	Good	**Good**	**Unknown**
1322	Natterer's Bat (*Myotis nattereri*)	IV	Good	Good	Good	Good	**Good**	**Unknown**
1314	Daubenton's Bat (*Myotis daubentoni*)	IV	Good	Good	Good	Good	**Good**	**Unknown**
1330	Whiskered Bat (*Myotis mystacinus*)	IV	Good	Good	Good	Good	**Good**	**Unknown**
1320	Brandt's Bat (*Myotis brandtii*)	IV	Good	Good	Good	Good	**Good**	**Unknown**
1326	Brown Long-Eared Bat (*Plecotus auritus*)	IV	Good	Good	Good	Good	**Good**	**Unknown**
1331	Leisler's Bat (*Nyctalus leisleri*)	IV	Good	Good	Good	Good	**Good**	**Unknown**
1334	Irish Hare (*Lepus timidus hibernicus*)	V	Good	Unknown	Poor	Good	**Poor**	**Unknown**
1355	Otter (*Lutra lutra*)	II, IV	Good	Poor	Good	Good	**Poor**	**Unknown**
1357	Pine Marten (*Martes martes*)	V	Good	Good	Good	Good	**Good**	**Low-Medium [1]**
1364	Grey Seal (*Halichoerus grypus*)	II, V	Unknown	Good	Good	Good	**Good**	**Unknown**
1365	Common (Harbour) Seal (*Phoca vitulina vitulina*)	II, V	Unknown	Good	Good	Good	**Good**	**Unknown**
1345	Humpback Whale (*Megaptera novaeangliae*)	IV	Unknown	Unknown	Unknown	Unknown	**Unknown**	**Unknown**
1349	Bottle-Nosed Dolphin (*Tursiops truncatus*)	II, IV	Good	Unknown	Good	Good	**Good**	**Unknown**
1350	Common Dolphin (*Delphinus delphis*)	IV	Good	Unknown	Good	Good	**Good**	**Unknown**
1351	Harbour Porpoise (*Phocoena phocoena*)	II, IV	Good	Good	Good	Good	**Good**	**Unknown**
2027	Killer Whale (*Orcinus orca*)	IV	Unknown	Unknown	Unknown	Unknown	**Unknown**	**Unknown**
2029	Long-Finned Pilot Whale (*Globicephala melas*)	IV	Unknown	Unknown	Unknown	Unknown	**Unknown**	**Unknown**
2030	Risso's Dolphin (*Grampus griseus*)	IV	Unknown	Unknown	Unknown	Unknown	**Unknown**	**Unknown**
2031	White-Sided Dolphin (*Lagenorhynchus acutus*)	IV	Good	Unknown	Good	Good	**Good**	**Unknown**
2032	White-Beaked Dolphin (*Lagenorhynchus albirostris*)	IV	Unknown	Unknown	Unknown	Unknown	**Unknown**	**Unknown**
2034	Striped Dolphin (*Stenella coeruleoalba*)	IV	Unknown	Unknown	Unknown	Unknown	**Unknown**	**Unknown**
2035	Cuvier's Beaked Whale (*Ziphius cavirostris*)	IV	Unknown	Unknown	Unknown	Unknown	**Unknown**	**Unknown**
2038	Sowerby's Beaked Whale (*Mesoplodon bidens*)	IV	Unknown	Unknown	Unknown	Unknown	**Unknown**	**Unknown**
2618	Minke Whale (*Balaenoptera acutorostrata*)	IV	Good	Unknown	Good	Good	**Good**	**Unknown**
2621	Fin Whale (*Balaenoptera physalus*)	IV	Good	Unknown	Good	Good	**Good**	**Unknown**
5020	Blue Whale (*Balaenoptera musculus*)	IV	Unknown	Unknown	Unknown	Unknown	**Unknown**	**Unknown**
5031	Sperm Whale (*Physeter catodon*)	IV	Unknown	Unknown	Unknown	Unknown	**Unknown**	**Unknown**
5033	Northern Bottlenose Whale (*Hyperoodon ampullatus*)	IV	Unknown	Unknown	Unknown	Unknown	**Unknown**	**Unknown**
2619	Sei Whale (*Balaenoptera borealis*)	IV	Unknown	Unknown	Good	Unknown	**Unknown**	**Unknown**
1348	Northern Right Whale (*Eubalaena glacialis*)	IV	Vagrant	Vagrant	Vagrant	Vagrant	**Vagrant**	**Unknown**
5029	False Killer Whale (*Delphinapterus lucas*)	IV	Vagrant	Vagrant	Vagrant	Vagrant	**Vagrant**	**Unknown**
2037	True's Beaked Whale (*Mesoplodon mirus*)	IV	Vagrant	Vagrant	Vagrant	Vagrant	**Vagrant**	**Unknown**
2622	Pygmy Sperm Whale (*Kogia breviceps*)	IV	Vagrant	Vagrant	Vagrant	Vagrant	**Vagrant**	**Unknown**
5029	Beluga/White Whale (*Delphinapterus leucas*)	IV	Vagrant	Vagrant	Vagrant	Vagrant	**Vagrant**	**Unknown**
5034	Gervais' Beaked Whale (*Mesoplodon europaeus*)	IV	Vagrant	Vagrant	Vagrant	Vagrant	**Vagrant**	**Unknown**

1 – Byrne *et al.* (2003)

2 – Wyse-Jackson (2008)

3 – Harrison *et al*. (2001)

4 – Hastie *et al*. (2001, 2003)

5 – FSBI (2007)

It should be noted that the Byrne et al. (2003) assessments are based on a later century horizon scan than we provide here. However, for consistency we apply their vulnerability ascription. While for the Marsh Saxifrage (*Saxifraga hirculus*) there are conflicting interpretations.

For the interested reader seeking further information, species distribution maps (NPWS, 2008) are available at:
http://www.npws.ie/en/PublicationsLiterature/HabitatsDirectivereport07/Species/

5. An overview of existing work

Below we provide a summary Table providing an overview of work which has been done in relation to biodiversity and climate change in Ireland. The interested reader is directed to the reference lists of the above for further information, as well as to the recent Bibliography of Clenaghan (2008).

Table 4: Summary of literature, biodiversity and climate change

Year	Author	Type	Notes
2001	Harrison *et al.* (MONARCH)	Report section	Impacts on species and habitats, UK and Ireland
2003	Byrne *et al*	Report section	Climate change and biodiversity assessment
2003	Emblow *et al.*	Report section	Climate change and the marine environment
2004	Donnely *et al.*	Journal paper	Climate change indicators for Ireland
2005	Berry *et al.* (MONARCH)	Report section	Impacts on species and habitats, UK and Ireland
2006	Jones *et al.*	Journal paper	Vegetation response to climate change
2007	Donnelly *et al.*	Report section	Climate change & changing phonologies in Ireland. Impacts on semi-natural ecosystems.
2007	Walmsley *et al.* (MONARCH)	Report section	Impacts on species, UK and Ireland
2007	Arkell *et al.*	Report	Cross-sector scoping, Northern Ireland
2007	Iremonger *et al.*	Report	Forest biodiversity
2008	Wyse-Jackson, P.	Report	List of climate change vulnerable plant species
2008	FBSI	Briefing paper	Climate change and the fishes of Britain and Ireland

6. Development of policies for climate change and biodiversity

In European policy a temperature increase of 2°C has emerged as the threshold for acceptable climate change and the benchmark temperature against which to consider atmospheric concentrations of greenhouse gases and emission reduction profiles. A 2°C rise in temperature equates to stabilisation at 450 ppm carbon dioxide equivalent (CO_2e) (Anderson and Bows, 2008). Climate change policy is informed by this 2°C threshold even though stabilising at 450 ppm CO_2e offers only a 46% chance of not exceeding 2°C (Meinshausen, 2006). Recent research by Anderson and Bows (2008) which examined the difference between empirical and modelled data on emissions since 2000 indicates that that given current emission trends (3% annual emission growth), 2°C may provide a reasonable guide for mitigation, but it is a misleading basis for informing adaptation policy which would be much better guided by stabilisation at 650 ppm CO_2e, equating to approximately a 4°C rise in temperature.

This review is taking place at a time when policy both in the Republic of Ireland and Northern Ireland is in development. In both jurisdictions the current policy framework does not take an integrated approach to climate and biodiversity. In the Republic of Ireland, key strategies such as the Biodiversity Strategy and the National Adaptation Plan are in revision and development respectively and are not likely to be forthcoming until next year.

In Northern Ireland, the policy framework is also in development and will be shaped by the Climate Change Bill which has just recently been passed by the UK parliament and will require the development of an adaptation programme. The Northern Ireland Climate Change Impacts Partnership (NICCIP) has been established to widen the understanding and knowledge of the impacts of climate change and necessary adaptation actions within Northern Ireland. Key objectives are to promote ownership across sectors and increase adaptation capacity. One objective of the research project on preparing for a changing climate in Northern Ireland (Arkell *et al.*, 2007) was to produce an adaptation strategy and identify the public sector bodies responsible for delivery. The research highlighted the lack of sector specific risk assessments for Northern Ireland and concluded that as a result awareness, willingness to change and a general sense of urgency to consider adaptation was lacking. The report also highlighted how research on impacts has not been carried through into policy and there has been no clear coordination of strategic planning within and between the bodies responsible to address climate change risks and adaptation. Last month the Environment Committee after hearing evidence from the Tyndall Centre based on the analysis in Anderson and Bows (2008) announced an inquiry into climate change, so there is some uncertainty over Northern Ireland policy at present whether targets from the Climate Change Bill will be adopted. In light of the Climate Change Bill and assembly inquiry, it is likely that there will be further development of the devolved policy agenda in the coming months.

In considering current policy and guidance, it is necessary to examine both the integration of climate change considerations into biodiversity policy and the integration of biodiversity considerations into climate change policy. The timing of the review coincides with an absence of key policies and strategies which makes it difficult to assess their effectiveness and what the impact will be on biodiversity. However, this lack of an integrated policy framework in combination with the timetable for policy development provides an opportunity for the synergies between these areas to be fully realized and reflected in a joined up policy framework.

6.1 Integration of climate change into biodiversity policies

The integration of climate change into biodiversity strategies and policies is proceeding and the revised Biodiversity Strategy will have climate change as a key theme. Many of the actions contained in the strategy will be focused at integrating biodiversity considerations into other policy areas and processes and this provides an opportunity to put in place actions integrating climate change considerations as well.

There are a range of other policies and plans focused on protecting and managing the biodiversity resource and these can also integrate climate change. Habitat action plans and species action plans can and do integrate climate change as a pressure and/or threat and contain management actions. Site management plans such as SAC conservation management plans also offer potential to integrate climate change more fully. At present these have a five year time frame (2005-2010) and integrating climate change considerations fully will require a longer time perspective and this could be addressed in the next round of plan development with specific consideration of the potential impact of climate change and the inclusion of mitigation actions into management plans and policies.

Public awareness campaigns on biodiversity have also been undertaken in both Northern Ireland (It's In Our Nature) and the Republic of Ireland (Notice Nature). Notice Nature targeted sectors with production of guidelines for construction, business and tourism. Although these do not specifically mention climate change and the need to factor in climate change considerations when planning to protect biodiversity. Given the level of uncertainty over specific impacts this may have been too complex an issue for these focused guidelines to include. However climate change should be incorporated more explicitly into any future phases of public awareness campaigns. Notice Nature also targeted the agricultural sector although the main provision for addressing biodiversity issues was through REPS.

6.2 Integration of biodiversity into climate change policies

There has been little to no integration of biodiversity issues into climate change policy to date in Ireland, however the National Climate Change Strategy recognizes the impacts of climate change on biodiversity. The National Climate Change Strategy also contains a commitment to produce a National Adaptation Strategy by 2009. This is in the very early stages of development and a steering group has now been established. The National Adaptation Strategy provides both an opportunity and a vehicle for integrating biodiversity and climate change issues and could direct the consideration of both into a wide range of strategies and plans including development plans and sector-specific guidance. For biodiversity issues there is a record of cooperation and collaboration on an island wide basis, it would also be beneficial to develop adaptation policies relating to biodiversity on a biogeographical basis.

6.3 Current mitigation and adaptation policy and positive and negative impacts on biodiversity

As adaptation policy is currently in development an assessment of the positive and negative impacts on biodiversity is difficult to do. Current mitigation actions including the use of REPS and biomass cultivation could have either positive or negative effects depending on how the policies are developed and implemented. There is also the EU policy dimension and certain sectors such as agriculture, fisheries and energy are largely integrated at an EU level through the single market and common policies and a recent green paper from the European Commission (EC, 2007) identifies a range of options for EU actions on adaptation.

However there are some current mitigation policies that are planned that could potentially have a negative impact on biodiversity unless the proper evaluations are undertaken. Specific actions include:

- The need for a Strategic Environmental Assessment (SEA) of renewable energy policy.
- REPS measures in general should be evaluated for their impacts on biodiversity and effectiveness.
- Changes in land use will need to be carefully assessed to ensure they are not impacting negatively on biodiversity.
- Sustainability Impact Assessments (SIAs) should be carried out to ensure biodiversity is taken into account in the development of renewable energy resources.
- Encouragement of biofuel crops that do not impact on biodiversity.

7. Gaps and sectoral policies

7.1 Communication and knowledge gaps

It has been recognized for a number of years that a clear policy framework is a prerequisite for the delivery of critical and coherent decisions relating to biodiversity policy (NPBR, 2003). There is also an urgent need to ensure that environmental policy making in general and biodiversity policy making in particular are informed by well-founded scientific knowledge (NPBR, 2003). However, as we have reviewed in preceding sections here difficult adaptation and mitigation decisions relating to projected changes in climate have to be taken despite significant scientific uncertainties. Consequently, as in a number of other sectors, there are substantial gaps between science and practice in the area of climate change and biodiversity.

A related problem arises from the innate tension between policy maker's expectations and the ability of science to deliver the outcomes required by policy, this is especially true in relation to biodiversity adaptation to climate change. These sorts of tensions can be attributed to;

(i) The acquisition rate of ecological (research) knowledge is slow relative to climate change. Consequently policy makers have to implement decisions on adaptation despite imperfect information.
(ii) Science and policy-maker communication also plays an important role. Thus while high level communication exists with respect to broad themes (e.g. the conservation of biodiversity during climate change), such broad themes may not be easily broken down into questions that can be readily tackled by scientific research (Sutherland *et al.*, 2006).

However, there is also a tension for the scientific community since the reductionist paradigm of classical science is not best suited to addressing the complexity inherent in conducting climate change impact assessments (CCIAs), but rather a systems-based approach linked across disciplines. Benefits arising from improved communications between the communities could include;

- more realistic expectations from policy makers on what science can deliver and a better definition of questions that can be addressed by scientists;
- a better recognition on the part of researchers of what constitutes genuine policy needs; and
- a recognition that applied research can also equate to good science.

Given the wider uncertainties and some of these innate tensions, an iterative engagement between science and policy which is both reflexive and outcome centered is envisaged as being the most appropriate way to proceed (Figure 4). Importantly, such a risk-averse decision making framework allows for a regular re-iteration of the problem and an ongoing re-evaluation of the objectives in light of any new or emerging scientific knowledge.

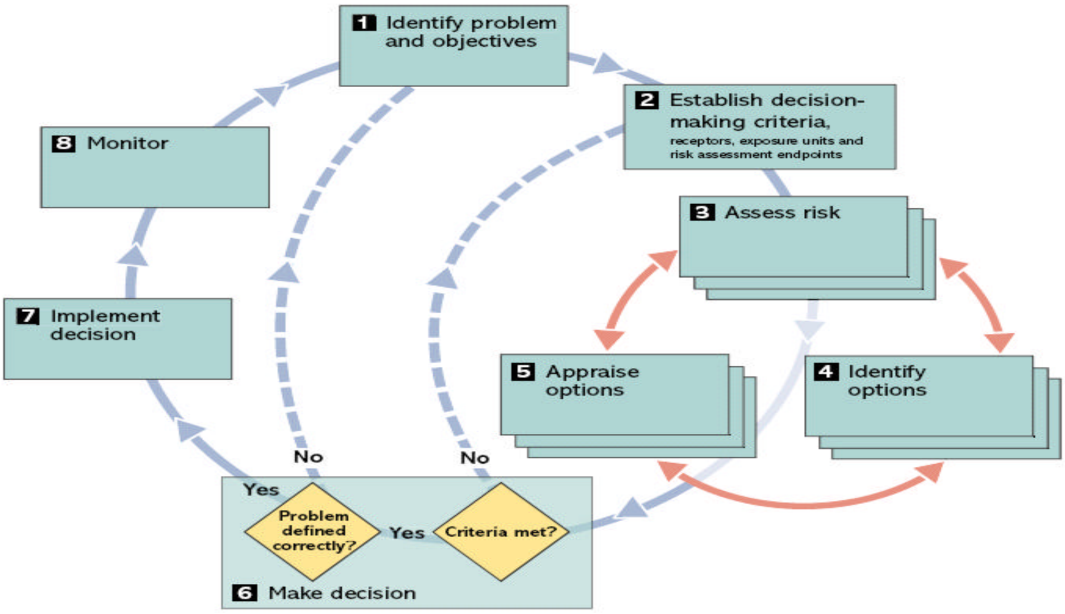

Figure 4: A framework to support good decision making in the face of climate change risk (Willows and Connell, 2003).

Aside from these very real communication issues, we also identify a further need to examine the cross-sectoral synergies of climate change and how these will impact upon biodiversity. Not least since despite the significant amount of climate related research in this sector, there is an apparent lack of co-ordination of policy development and strategic planning between the various responsible bodies to address climate change risks and adaptation (Arkell *et al.*, 2007).

Specifically, we see related climate change driven impacts in how the agricultural, forestry, water management and tourism sectors are managed as being particularly important in relation to future biodiversity conservation.

7.2 Cross-sector synergies

Below we identify a number of key sectors where we consider it essential that biodiversity and climate change considerations should be integrated into existing policy. We then briefly explore some of what we consider to be some of the key issues and likely drivers of change.

7.2.1 Agriculture

As the principal land use, farming has important linkages with the tourism and leisure industries, as well as having the dominant influence on the visual characteristics of Ireland's landscape. The total land area of Ireland is approximately 6.9 million hectares of which 4.3 million hectares or 62% is used for agriculture.

One major effect of the CAP Reform on the Irish landscape is likely to be a change in grazing systems. The current predominance of sheep grazing is largely due to subsidies received from the EU, as opposed to market forces. The introduction of Single Farm Payments, decoupling and removal of subsidies will likely result in a significant reduction in sheep numbers and a proportional increase in cattle grazing. Large changes in grazing such as these may alter the sward mix of grasslands on extensive systems as cattle are less discriminating grazers. However, there may also be some interaction with climate change impacts since wetter soils may be more vulnerable to erosion and compaction from cattle poaching under climate change.

A further effect of decoupling could be that due to market forces growers may choose to produce non-food crops. Oilseed rape, for example has numerous industrial applications, and large-scale expansion in land used for this purpose will alter the visual characteristics of the landscape. Cross Compliance and Good Agricultural and Environmental Condition (GAEC) requirements (as part of the CAP reform) will also instigate some changes in the visual landscape. These may be seen through changes in land management such as controlled grazing of cattle or re-afforestation.

The implementation of the Water Framework Directive and Nitrate Vulnerable Zones will undoubtedly change the soil and water environment in Irish farmland. The two major implications for farming in Ireland will be the control of diffuse pollution from agricultural sources and regulatory control of abstraction for irrigation purposes. These have the potential to alter the underlying characteristics of farmland through changes in the purity and volume of water in rivers and streams. Restrictions from these policy mechanisms on timing of water abstraction and application of fertilisers may conflict with agricultural needs under an altered climate.

The substitution of fossil fuels with the increasing use of renewable energy sources is now recognised by governments worldwide as a fundamental priority in reducing greenhouse gas emissions. The main sources of renewable energy will be wind power, biomass, hydro, tidal and wave energy. As a consequence the visual characteristics of the agricultural landscape could alter quite dramatically as land is used for afforestation and short rotation coppice for renewable purposes. Similarly, if government policy encourages the uptake of bio-energy; miscanthus and oilseed rape (used for bio-diesel) could radically alter the visual characteristics of the farming landscape, particularly if they replace grassland production. Climate change would improve the yields of some energy crops in Ireland.

As energy crops are still a relatively new venture in Ireland, the Department of Agriculture and Food is introducing measures to stimulate production at farm level at an estimated cost of €14 million over the period 2007–2009 (CAP, 2006). The measures include a new national payment of €80 per hectare to stimulate production of energy crops. At present, farmers can avail of an EU premium of €45 per hectare under the EU Energy Crops Scheme, to grow energy crops intended for use in the production of biofuels and biomass (CAP, 2006). Approximately 2,000 hectares was claimed under this in 2006. As an additional incentive, the new €80 national payment will be paid as a top-up to the existing €45 EU premium and increases the overall premium available to €125 per hectare (CAP, 2006).

It is clear that any or all of the above changes could have major implications for biodiversity. An obvious positive measure would be an expansion of REPS measures dealing with hedgerows, habitats, field margins, and biodiversity options such as the provision of nature corridors, species-rich grassland, tree planting and the environmental management of set-aside. While carbon sinks will be created primarily by Ireland's afforestation measures, these could be complemented significantly by support through REPS for the creation and maintenance of hedgerows e.g. In addition, the expansion of many of these existing REPS measures would help address a number of the connectivity issues in relation to climate change adaptation we have identified previously.

7.2.2 Forestry

The Republic of Ireland published a strategic plan for the forest sector in 1996 (DAFF, 1996) which involved increasing the forest cover dramatically. Ireland is one of the least forested countries in Europe, even though forestry plantations have increased forest cover from less than 1% of land cover to about 10% in the last century. The plan aims to increase this to 17% by 2030, mainly by planting new commercial forests at approximately 20,000 ha per year (Iremonger *et al*., 2007). This significant increase represents a large change in land use and land cover across Ireland, and has far reaching economic, social and ecological consequences.

As Ireland's forest authority, the Forest Service has a clear strategy for conserving and enhancing biodiversity in forests. The role of the Forest Service is to ensure that forestry practice in Ireland conforms to the principles of sustainable forest management (SFM), whereby forestry develops in a way that maximises its contribution to national economic and social well-being on a sustainable basis and is compatible with the protection of the environment (McAree, 2002). The Forestry Inspectorate is responsible for ensuring that all conditions relating to biodiversity are complied with in grant-aided forests, and it plays a pivotal role in the policing, monitoring and promotion of these important requirements (McAree, 2002).

However, in order to promote forest biodiversity and fully practice SFM, it is necessary to know what organisms are associated with the forest plantations, and what the manager should be aiming at. The various projects undertaken by Iremonger *et al.* (2007) concluded that forestry plantations can make a significant positive contribution to biodiversity in the landscape if properly planned and managed, and can have a negative effect if not. Another conclusion was that the promotion of biodiversity in forestry needs the support of good policies and practices (Iremonger *et al*., 2007).

The Planning and Management Tools for Biodiversity in a Range of Irish Forests (PLANFORBIO) research programme supports targeted forest biodiversity research in the contemporary Irish landscape (UCC, 2008). In keeping with government strategy to increase planting of forests that support a wealth of biodiversity throughout Ireland ongoing fieldwork as part of the wider project is concerned largely with mixed species plantations, while continuing to survey our native woodlands (UCC, 2008).

Obviously these sorts of programmes could be integrated as part of a wider collaboration examining what climate change could mean for biodiversity in Ireland's forests. We broach some of the strategic benefits such linkages could bring further in Section 9.2. In addition, and providing mixed species plantations comprise much of the new woodland, this would help address some of the connectivity issues explored in Sections 3.3 and 3.4, as well as the direct sequestration of atmospheric carbon dioxide.

7.2.3 Water Management

The Water Framework Directive (WFD) 2000/60/EC has significant interconnections and linkages with other EU legislation. These include:

- Environmental Assessment Directives; Environmental Impact Assessment (EIA) - 85/337/EEC as amended by 97/11/EC and 2003/35/EC;
- and Strategic Environmental Assessment (SEA) – 2001/42/EC;
- Public Participation Directive (2003/35/EC), and the Birds (79/409/EEC) and Habitats (92/43/EC) Directives (Bennet and Sheate, 2007).

It is clear that data issues remain uppermost in terms of the challenges faced by River Basin Districts (RBDs) and conservation bodies implementing the Birds and Habitats Directives. Baseline data from different processes, particularly in relation to conservation, need to be improved as a matter of urgency both in terms of quality of data gathered and its availability (Bennet and Sheate, 2007). We would consider that this is an imperative given the bleak outlook identified for some of our freshwater species in Table 3 above.

7.2.4 Tourism

We have briefly explored some of the issues here previously (Section 1.3) and conclude that wildlife tourism is a sector which is likely to continue to grow in the future. However, preservation of Ireland's landscape character and the restoration of degraded habitats are a key component in ensuring that future revenue streams from the tourism sector are maintained. Similarly, we envisage that restoration of landscape connectivity could be part of a win-win scenario in the context of wider biodiversity conservation, given the connectivity and buffering issues we explored in Sections 2.3 and 2.4. We also conclude that further research is needed into how patterns of tourism may change with a changing climate and what the implications of this are for biodiversity.

7.2.5 Other sectors

The growing impact on biodiversity of invasive species means it is necessary to also consider how those sectors which are key to reducing the threat from invasive species such as horticulture, aquaculture, the pet and aquaria trade and construction are considering climate change in policy making. The Invasive Species Ireland project which is jointly funded by NPWS and the Northern Ireland Environment Agency (NIEA) has started to produce Codes of Practice for these key sectors in combination with a programme of stakeholder engagement. Further incorporation of climate change considerations into the outputs of this project could be an effective way of raising awareness and getting actions taken by these sectors.

7.2.6 Gaps in policy making

A review of policy and guidance in key sectors has identified a lack of integrated policy on climate change and biodiversity. Some specific gaps include:

- Strategic Environmental Assessment of energy policy.
- Lack of guidance on integration of biodiversity and climate considerations into planning policy both at national and local level.
- Lack of guidelines for local authorities and other sectors on biodiversity and climate.
- Lack of biodiversity and climate change considerations in public procurement policies and practices.

There are a number of ways that these gaps can be addressed. One is the full implementation of the Strategic Environmental Assessment Directive which will strengthen biodiversity and climate considerations in sectoral policies. Another is the integration of climate proofing into Environmental Impact Assessment and ensuring that policy impact assessments address impacts on ecosystems supported by instruments that internalise the costs of damages to natural capital and ecosystem services (EC, 2007). However the key policy driver for addressing climate change and biodiversity could be achieved by ensuring that the National Adaptation Plan is integrated with and harmonized with the Biodiversity Strategy and that harmonisation of adaptation policy also takes place on an all-island basis.

8. Evidence for increased risk from invasive species as a result of climate change

There is a general scientific consensus that climate change is likely to favour invasive species, leading to new invasions and spread of already established invasive species. A recent review on climate change and invasive species prepared for the standing committee of the Bern Convention concluded that there is increasing evidence that climate change will affect the processes underlying biological invasions but that the current state of knowledge is not robust enough to make specific predictions (Capdevila and Zilletti, 2008). As highlighted in other sections of this review, ecosystems will differ in their responses to elevated CO_2 and temperatures and this is also the same for invasive species. Predictions need to be made on a species by species basis taking into account the biology and ecology of the species, the susceptibility of the habitat to invasion, the vulnerability of native biodiversity to climate change and the interactions between ecosystems and human activities.

Invasive species can also exacerbate the impacts of climate change by harming biodiversity in advance of direct climatic impacts. Climate change will interact with invasive species through different mechanisms such as changes in pathways and vectors, habitat alteration increasing vulnerability to invasion and changes in range distribution of potential and established invaders. Climate change will also influence propagule pressure, that is, the number and frequency of invasive species arriving in a particular habitat. Increases in mean temperature are also likely to lead to northward expansion of populations.

In terrestrial ecosystems climate change may affect the dynamics of invasions by causing changes in native ecosystems that increase their vulnerability to invasion and by favouring traits of specific invasive species. Temperature and length of growing season are key variables determining the distribution of invasive plant species. Changes in these could influence the reproductive capacity of species and even their reproductive strategies. In general models reveal that simulated climate change negative impacts on native ecosystems are likely to facilitate invasions (Thuiller *et al*., 2007). However it is imperative that experiments are also undertaken to evaluate invasive species responses to changes in variables such as elevated CO_2, temperature and precipitation regime to provide an evidence base for policy and decision making.

In the aquatic environment, climate change will affect many ecological processes and dispersal pathways and these will affect the success of invasive species. For marine distributions, extreme meteorological events may be as important as gradual climate changes. Extremes or sudden changes in temperature, salinity and turbidity may favour some exotic species. Changes to sea level, in combination with storm events, are likely to result in alterations to low lying areas and concomitant changes to water temperature, circulation, retention and sediment redistribution are likely to modify native species assemblages and could provide niches for exotics (Emblow et al., 2003). Recently there has been recruitment of the non-native Pacific oyster (*Crassostrea gigas*) in response to elevated summer temperatures. This species was introduced for aquaculture and water temperatures were considered to low for successful breeding. Recruitment has been documented in a number of sea lochs and research is now ongoing into the potential impact.

The Invasive Species Ireland (ISI) project which began in May 2006 aims to reduce the impact and threats from invasive species on the island of Ireland and is a joint initiative between the National Parks and Wildlife Service and the Northern Ireland Environment Agency. In Ireland, practical management of invasive species is challenging because of the cross-border implications of controlling introductions and spread. A pro-active stance is fundamental since prevention of introductions is demonstrably more cost-effective than reactive control or eradication measures. The ISI project has put in place practical steps that aim to minimise introductions, evaluated management and control measures, and laid the foundations for a cross-jurisdictional framework to respond to species introductions.

A key part of the project is to undertake a review of progress after two years and explore options for a way forward. Climate change was identified as a key issue that needs to be incorporated into the next phase of ISI, some specific actions that need to be undertaken include the revision of the risk assessments to incorporate climate change to identify species that will present a growing threat to native biodiversity in the context of climate change.

Invasive Species Ireland has carried out over 600 risk assessments on established and potential invasive species. This has identified a number of high risk species and their implications under the Habitats Directive and Water Framework Directive. The greatest threat will be to freshwater habitats and species which are already under the greatest pressure from invasive species and highly vulnerable to new invasions. Increasing impact of invasive species in aquatic habitats may also impact on the ecological status of waterbodies leading to a failure to meet the objectives of the Water Framework Directive.

There are a number of potential invasive species to Ireland who have not yet become established as they are temperature limited, this particularly applies to fish species such as carp species and Zander. It is likely that they could become established in the future as summer water temperatures become warm enough for successful breeding. A review of which species are expanding their ranges northwards in continental Europe and Britain would identify new potential invaders to Ireland.

Current management strategies and policies relating to invasive species need to incorporate climate change considerations to a greater extent than they currently do. This is particularly relevant for those sectors that import non-native species such as horticulture, the pet and aquaria trade and aquaculture. However there is an opportunity to do so in the next phase of Invasive Species Ireland and ensure that climate change is fully integrated into invasive species policy and plans and monitoring programmes. Conversely there is also a need to ensure that conservation policies adopted in response to climate change such as increasing connectivity and assisted migration do not inadvertently facilitate species invasions.

9. Capacity building and extending networks

In this section we identify some prospective strategic linkages which would improve information sharing in relation to wider initiatives elsewhere. We also provide a brief summary of the benefits which the suggested network affiliations may be able to provide.

9.1 Biodiversity forum links

In terms of Biodiversity Fora, there are a number of UK and European groups with various platforms for information sharing. One obvious candidate link would be to the UK Biodiversity Research Advisory group (UK BRAG). The stated aims of UK BRAG include:

- Identify, promote and facilitate biodiversity research to support UK and individual country biodiversity action plan commitments;
- Coordinate effective and efficient UK engagement with European biodiversity research issues, fulfilling the role of a national biodiversity research platform;
- Contribute to effective biodiversity research networking in the UK, leading to increased interdisciplinary capacity;
- Support knowledge transfer activities in relation to biodiversity research.
  [URL: http://www.jncc.gov.uk/default.aspx?page=3900]

There are also links to a wide set of publications which could help inform policy developments in Ireland, as well as wider links to European Networks. One possible candidate European link would be to the European Platform for Biodiversity Research Strategy (EPBRS). The EPBRS is a forum at which natural and social scientists, policy-makers and other stakeholders identify, structure and focus the strategically important research that is essential to:

- Use the components of biodiversity in a sustainable way;
- Maintain ecosystem functions that provide goods and services.
  [URL: http://www.epbrs.org/epbrs/]

9.2 The case for a biodiversity and climate change research forum and suggested links

Given the recurrent theme running throughout this report and echoed elsewhere of the need for improved data, there is a clear need for biodiversity and climate change research forum. As well as being an important information sharing platform in its own right, such a forum would facilitate data sharing between the various research groups. There is an obvious and emergent need for a metadata repository to further enable biodiversity impacts research and modelling on scales raging from the national via the landscape and site to the level of individual species.

The formation and maintenance of such a forum would also enable more effective partnership working and funding applications. Similarly, affiliation to wider biodiversity research networks would help identify emerging themes, initiatives and funding opportunities. For example, there is a cluster of European-funded projects at Agricultural Policy-Induced landscape changes: effects on biodiversity and Ecosystem Services.

[URL: http://agripopes.net/links.htm]. This includes links to for example, A Long-Term Biodiversity, Ecosystem and Awareness Research Network (ALTER-Net);

- ALTER-Net aims to help deliver on the 2010 target by promoting a better integrated and stronger European biodiversity research capacity resulting in the establishment of a lasting infrastructure for integrated ecosystem research, combining ecological and socio-economic approaches, and with greater emphasis on communication with relevant audiences.
  [URL: http://www.alter-net.info/]

This in turn provides links to other European research networks such as e.g. the European Long-Term Ecosystem Research Network [URL: http://www.lter-europe.net/].

10. Developing an indicator species monitoring network

A powerful information tool in tracking the impacts of climate change is the use of biodiversity indicators. Indicators of biodiversity can be viewed in three categories: structural, compositional and functional (Iremonger *et al*., 2007). At EU level, the European Commission is developing a headline set of biodiversity indicators with the European Environment Agency, to assess achievement of the 2010 target (EEA, 2007). Further development of indicators is needed at national level to inform the public and decision-makers on biodiversity, the effectiveness of conservation measures and progress made in halting biodiversity loss (EPA, 2008).

Although there appear to be numerous possibilities for indicators of the impact of climate change on the Irish environment, a review by Donnely *et al*. (2004) highlighted the difficulties involved in identifying an unambiguous set. Consequently they concluded that:

- the main problems relate to the absence of existing long-term data sets which can be extended into the future and from which trends can be observed;
- in addition, the overwhelming influence of factors other than climate change on particular indicator can reduce their significance and value; and
- currently the most effective impact indicator of climate change in Ireland appears to be phonological observations on tree developmental stages (Donnely *et al*., 2004).

This has led to further work reviewing the utility of tree phenology as an indicator (Donnely et al., 2006). Some authors have also considered that arctic-alpine associations may be useful a useful indicator generally (Nagy 2003, 2006).

There is consensus that the most climate change vulnerable species in Ireland are likely to be Arctic and Boreal relicts and mountain species (Byrne *et al*., 2003). 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 nival zone is insufficient in extent to accommodate any potential upward migration of species (Crawford, 2000, 2003). In addition, since many mountain plants are intolerant to competition, fast-growing lowland species with broad altitudinal and ecological ranges are predicted to expand at the cost of slow-growing competition-intolerant species with narrow habitat demands (Korner, 1999, 2003; Klanderud and Birks, 2003).

Consequently, a number of authors have argued (see e.g. Coll *et al*., 2005 and references therein) that these community associations in maritime uplands are likely to be particularly sensitive to climate change. Therefore and given the poor assessment reported in Table 3, there is a case to be made for initiating an ongoing monitoring programme of these communities as prospective indicators. However, there is also a need generally for widespread monitoring programmes to be initiated for a host of candidate indicator species and communities.

11. Concluding vision

Ireland's biodiversity is not a static resource; it is profoundly dynamic as a result of natural processes and events and of human use of the land. The legacy of fragmented landscapes and degraded habitats across our island remind us of the ecological consequences of a painful human history. Any vision of the future in a changed climate must include maintaining and enhancing Ireland's high quality remaining natural environment. Many of our ongoing environmental problems are at least in part a consequence of decisions confined to particular sectors or restricted areas. While our summary in Section 3 indicates that many of our priority habitats and species are in an already parlous state arising from historical and contemporary pressures, and for many we have no insight into what the impacts of climate change could mean. Targeted research is therefore a fundamental priority.

Despite the considerable uncertainties surrounding future climate projections (Annex 1), the rate and complexity of recent change in our climate is beyond our experience and there is consensus that future climates will not be like past climates. The implications of a changing climate for many of our native species are likely to be profound, there is therefore a real need to link and harmonize Ireland's policy response to climate change and biodiversity. In addition, there has to be a review of monitoring to assess whether existing systems are sufficiently sensitive to the effects of a changing climate and identify where new systems may be required.

However, and as we have highlighted here, the extent and complexity of many of the cross-cutting issues requires the involvement of all relevant interests to avoid decisions taken in isolation by a single sector, or with respect to an unduly limited area. Our findings here mirror those of other work. Hence we would re-iterate for example, that despite the significant amount of climate change impact research in relation to biodiversity, there does not appear to be any clear co-ordination of strategic planning within and between the various bodies responsible to address climate change risks and planning for adaptation (Arkell *et al.*, 2007). This also means that the links to other sectors, for example between biodiversity, fisheries, tourism and recreation, are potentially missed (Arkell *et al.*, 2007), although we provisionally address these and some wider communication issues in Section 5 above.

There is also a need for education and awareness raising, with a particular focus on the human impact on species and habitats and the scale of the likely impacts of a changing climate (Arkell *et al.*, 2007). Perhaps more importantly, we must engage people with the issues and encourage our young people to think beyond traditional barriers If we accept that biodiversity is the foundation of ecosystem services to which human well-being is intimately linked (RIA, 2008), then it follows that biodiversity conservation is profoundly linked to wider issues of social and generational equity under projections of climate change. Recent work has emphasized that poverty and the loss of ecosystems and biodiversity are inextricably intertwined, with most of the world's poor heavily reliant on ecosystem services (European Communities, 2008).

If Ireland is to effectively incorporate climate change adaptation and mitigation strategies into National Biodiversity Strategies and Action Plans (Wyse-Jackson, 2008). It follows that there must be improved coherence at national level between various plans and programmes affecting biodiversity, and that decision making at regional and local levels must mirror these high-level commitments for biodiversity (EPA, 2008) (Section 5). While such blithe recommendations are fine in principle and on paper, we have reviewed a number of the confounding practical issues and innate theoretical communication and expectation mismatch difficulties in Section 5.1.

In addition, we have identified an added value in having the various national and local biodiversity platforms forging and maintaining identified strategic links across Europe (Section 7.1). Similarly, we have identified a need for the formation of an Ireland-wide climate change and biodiversity research forum in order to improve information sharing between the appropriate agencies of state and the various research clusters. Again, we have identified wider European research networks to which such a forum could affiliate in order to facilitate engagement in wider European initiatives and to provide access to prospective additional funding streams (Section 7.2).

These sorts of findings do not preclude grass roots engagements and interactions, but rather demand it. Despite the Biodiversity Forum's role in increasing public awareness on biodiversity and a number of other awareness raising campaigns and initiatives across Ireland. A 2007 Euro-barometer report on attitudes of Europeans to biodiversity found that 52 per cent of those surveyed in Ireland had never heard of the term 'biodiversity', while 26 per cent had heard of it but did not know what it meant and only 22 per cent had heard of it and knew what it meant (EPA, 2008).

Similarly, by constructing climate change as a global problem, one that is distanced and un-situated relative to an individual's mental world, we make it easy for citizens to verbalise superficial concern with the problem, but a concern belied by little enthusiasm for behavioural change (Slocum, 2004; Lorenzoni *et al.*, 2007; Hulme, 2008). In doing so we have contributed to conditions that yield psychological dissonance in individuals: the contradictions between what people say about climate change and how they act (Stoll-Kleeman *et al.*, 2001; Hulme, 2008).

If we concede that in wildness is the preservation of the world (Thoreau, 1854) is one starting point on our long journey towards ecological consciousness, and if we consider that climate scenarios are socially contingent products of a post-normal science (*senso* Hulme and Dessai, 2008) as another view along our continuing journey. By linking climate change and biodiversity issues and actions, and through engaging the citizen in the gulf of debate informing the development of scientific and conservation thinking between these interpretations, we can only better inform all our futures.

For example, much has been made recently in both the scientific literature and the media of a 'tipping point' being exceeded in a climate context precipitating rapid climate change. However, in a balanced view, the human tipping points are likely to be more important, with a plethora of development choices and mitigation options available. Therefore while the inertia of the climate system commits us to some component of anthropogenic warming over the next few decades, present human activities have not yet entirely defined the magnitude of later century warming. As a result development pathway choices over the next couple of decades are more likely to influence the possible magnitude of end of century warming. This is not, however, a closing slop to complacency, the changes which will impact our biodiversity in the coming decades are already underway. What is required is improved policy planning linked to informed public debate to help better shape our island-wide response to a complex global issue.

12. Recommendations

This review contains a range of recommendations which are summarised here. We consider that integrating biodiversity and climate change adaptation and mitigation policy is an obvious priority and we have identified the development of the National Adaptation Strategy and the vehicle for taking this forward along with some of the integrated cross-sectoral policy needs we have identified here.

Specific recommendations include:

- Improve baseline data on the distribution of species and habitats
- Further develop the evidence base for policy through research combining modelling with experiments
- Carry out a fuller climate change vulnerability assessment for annexed habitats and species
- Identify indicator species, include in the Biodiversity Strategy indicator set and develop a indicator species monitoring network
- Develop strategic linkages with research fora
- Fully implement the Strategic Environmental Assessment Directive which will strengthen biodiversity and climate considerations in sectoral policies
- Integrate biodiversity and climate change policies in the Republic of Ireland through the National Adaptation Plan
- Harmonise adaptation policies on an all-island basis
- Integrate climate change considerations into management plans for the Natura 2000 network
- Ensure that climate change is fully integrated into invasive species policy and plans and monitoring programmes by including it as a requirement of the next phase of Invasive Species Ireland
- Develop sectoral specific adaptation policies
- Carry out a Strategic Environmental Assessment (SEA) of renewable energy policy
- Evaluate REPS measures for their impacts on biodiversity and effectiveness.
- Sustainability Impact Assessments (SIAs) should be carried out to ensure biodiversity is taken into account in the development of renewable energy resources
- Encourage biofuel crops that do not have a negative impact on biodiversity
- Develop guidelines for regional and local planning that incorporate biodiversity and climate change considerations

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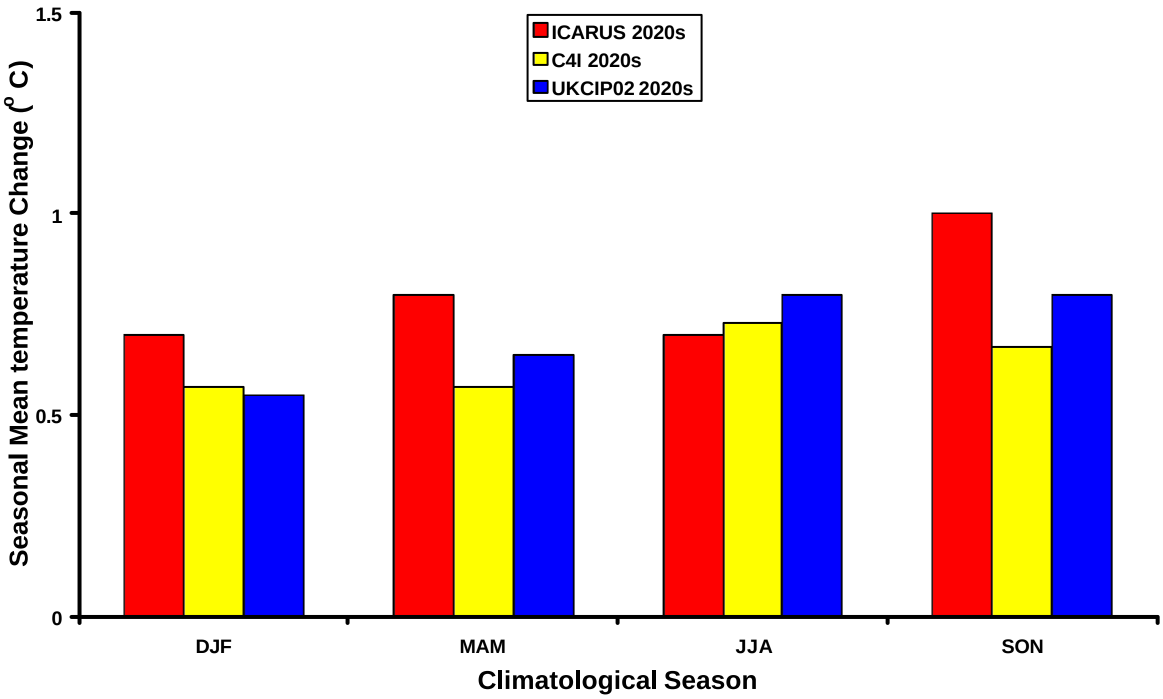
Annex 1: Projected climate changes for Ireland

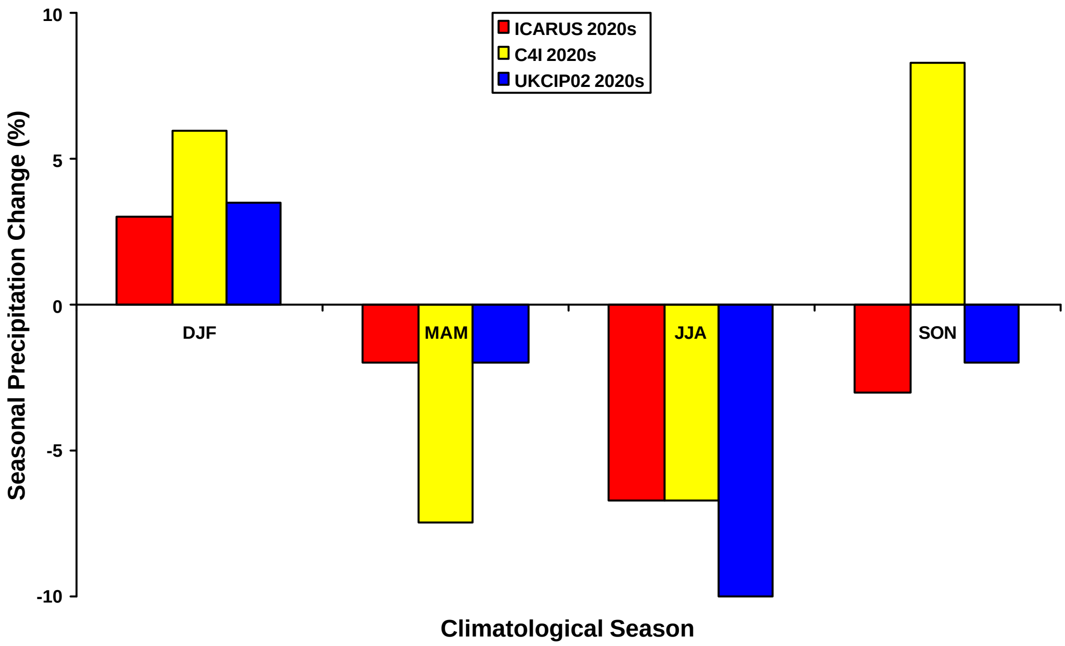
1.1 Climate model projections

A number of studies have applied selected Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (Nakicenovic *et al.*, 2000) to model climatic changes across Ireland at a regional scale. As viewed by climate researchers, a scenario is a coherent, internally consistent, and plausible description of a possible future state of the world (Carter *et al.*, 1994). A 'climate scenario' may form one component of a broader scenario of the future, and yet is itself informed by broader descriptions of the future world, for example, demographic trends, energy prices or greenhouse gas emissions (Hulme and Dessai, 2008).

Despite the different modelling approaches, models and scenario combinations used, there is some concordance of projected changes to mean seasonal temperature for the 2020s across Ireland (Figure 1). However, there are more disparities in the magnitude and sign for some of the projected seasonal precipitation changes for the island (Figure 2). In assessing the possible impacts on biodiversity, it is worth noting that the climate modelling community define the 2020s time-slice as 2021 – 2049. Therefore the median of this period coincides with our aim to focus on possible impacts based on a near term (2030s) horizon scan.



Annex Figure 1: Comparison of mean seasonal temperature change projections (° C relative to 1961-1990) for Ireland by the 2020s from different modelling groups. The spatial variation across the island captured by the different groups has been averaged.



Annex Figure 2: Comparison of mean seasonal precipitation change projections (% change relative to 1961-1990) for Ireland by the 2020s from different modelling groups. The spatial variation across the island captured by the different groups has been averaged.

In part these differences can be attributed to the different methods used, as well as the different scenarios. For example, the Irish Climate Analysis and Research Units (ICARUS) results (Fealy and Sweeney 2003, 2007) are the mean values of A2 and B2 scenario outputs obtained by statistically downscaled outputs from the ensemble mean of three Global Climate Models (GCMs). Whereas the Community Climate Change Consortium for Ireland (C4i) (McGrath *et al.*, 2008) and the United Kingdom Climate Change Impacts Programme 2002 (UKCIP02) (Hulme *et al.*, 2002) outputs are dynamically downscaled outputs obtained from a Regional Climate Model (RCM) nested within a driving GCM.

The difference between the C4i and UKCIP02 results are attributable to the different GCMs and RCMs used. Also, both the C4i and UKCIP02 projections are derived from weighted ensemble averages from the B2 family of scenarios with the emphasis more on local solutions to economic, social and environmental sustainability (Table 1). Whereas the A2 family of scenarios project a greater increase in global carbon dioxide (CO_2) emissions associated with different development trajectory assumptions (Nakicenovic *et al.*, 2000) (Table 1). The ICARUS results hence incorporate some of the greater temperature increases associated with this scenario relative to the more conservative assumptions (in CO_2 emissions terms) of the B2 family of scenarios.

Annex Table 1: Summary linking ICARUS, C4i and UKCIP02 climate change scenarios to other scenario developments (adapted from Hulme *et al.*, 2002)

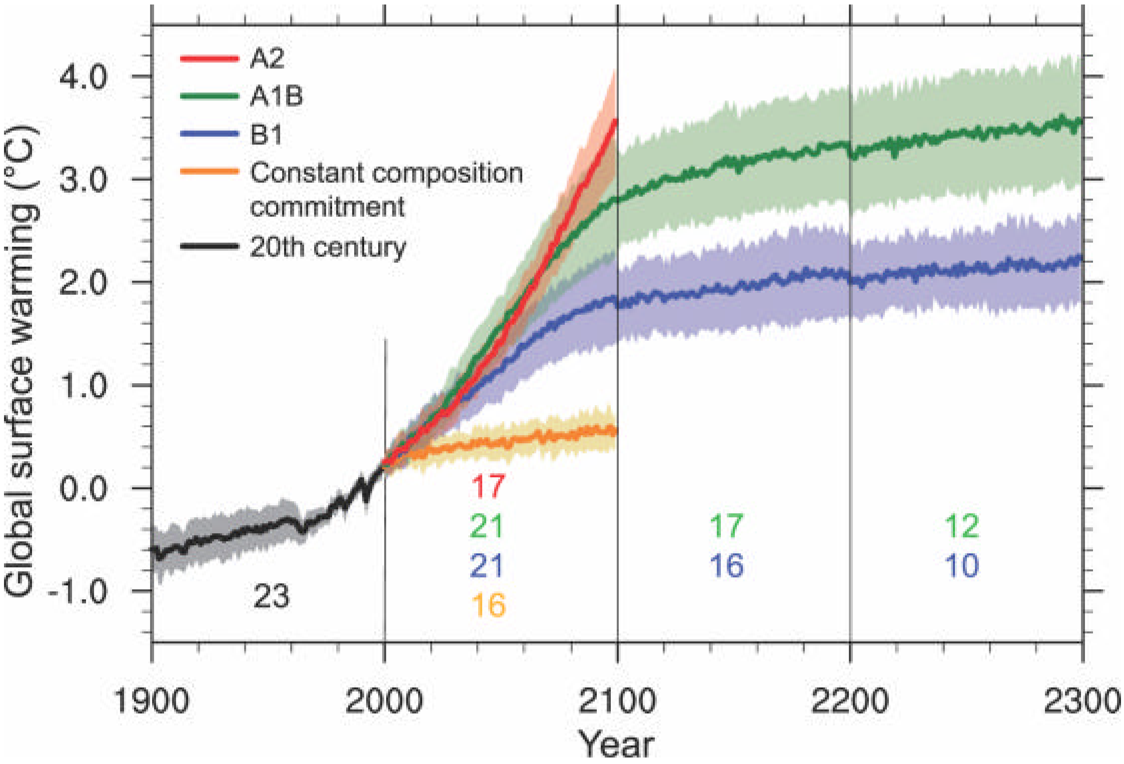
SRES[1] Storyline	**OST[2] Foresight Scenario**	**UKCIP98 Socio-economic Scenario**	**UK Environment Agency Scenario**	**UKCIP02 Climate change Scenario**
B1	Global Sustainability	Global Sustainability	Gamma	Low-Emissions
B2	Local Stewardship	Local Stewardship	Delta	Medium-Low Emissions
A2	Provincial Enterprise	National Enterprise	Alpha	Medium-High Emissions
A1F1	World Markets	World Markets	Beta	High Emissions

Notes:
[1] SRES: Special Report on Emissions Scenarios
[2] OST: UK Office of Science and Technology

Uncertainty is perhaps the single most sensitive facet of a climate scenario and one that climate science has struggled to come to terms with (Shackley and Wynne, 1996; Van der Sluijs, 1997; Van der Sluijs *et al.*, 1998; Moss and Schneider, 2000; Lahsen, 2005). Arising from this, an essential component of the communication and dissemination process for climate scenarios is to convey the range of assumptions, conflicts and compromises that have been made in their construction (Hulme and Dessai, 2008).

Amid these and other issues, and despite the advances offered by the climate modelling community, there are remaining concerns surrounding the validity of the socio-economic and development trajectory scenario assumptions used to derive the greenhouse gas (GHG) emissions scenarios driving the models. With the IPCC having decided there was no time to develop new scenarios for its 4th assessment report, the various modelling groups are using the same SRES scenarios used in the previous assessment (Schiermeier, 2006). This has led to criticism from many economists on the basis that the existing SRES scenarios rely on outdated economic theories which fail to reflect how lifestyle and energy demand in both rich and poor countries are likely to change (Schiermeier, 2006; Van Vuuren and O'Neill, 2006).

However, these concerns and criticisms largely relate to projections of change for later in the century. There is scientific consensus that the thermal inertia of the climate system commits us to the changes projected for the 2030s based on present GHG levels irrespective of mitigation measures in the intervening decades. Thus, for example, there is close agreement of globally averaged surface air temperature (SAT) multi-model mean warming for the early 21st century for concentrations derived from the three non-mitigated IPCC SRES B1, A1B and A2 scenarios (Meehl *et al.*, 2007). Therefore the warming averaged for 2011 to 2030 is affected little by different scenario assumptions or different model sensitivities (Meehl *et al.*, 2007). As a result, there is considerable convergence in the projections of climate change from the various models for this decade, with the later century divergence between the model results reflecting the increasing uncertainty (Figure 3).



Annex Figure 3: Multi-model means of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th-century simulation (Meehl *et al.*, 2007).

Given some of the scenario-related issues outlined here and given that other drivers of change will interact with climate change to impact biodiversity (Section 5), we consider our review here in the context of a near-term (2030s) horizon scan. Also, in recognition that the potential for developing synergies between climate change mitigation and adaptation has become a recent focus for both climate research and policy across sectors (Klein *et al.*, 2005). Here we have attempted to assess how an emergent policy on climate change and biodiversity might facilitate the successful integration and implementation of mitigation and adaptation measures for the island's biodiversity resource.

3.1 Summary knowledge review: other drivers

3.1.1 Sea level rise

Sea level is determined by changes in water volume or coastal elevation effected by the warming of the water (causing expansion) or by land movement; specifically for Ireland, isostatic readjustment causing land rebound after the last glaciation. Regional differences in climate-induced sea level rise can vary by up to +/- 50% and there is little agreement between climate models about these regional patterns of sea level rise, although Hulme *et al.* (2002) suggest that thermally driven changes in sea-level will be between +0.04 m and +0.14 m by the 2030s. However, while there is agreement that sea levels will rise as the planet warms, the complex dynamic and thermodynamic interactions of ocean, atmosphere and ice sheets are not fully understood.

There is also a considerable thermal inertia between atmospheric and abyssal ocean warming, for example it has been estimated that the modern ocean overturns once every ~1000 years (Adkins and Pasquero, 2004). However, other recent work indicates that dense water formed in both hemispheres is freshening in response to changes in the high latitude freshwater balance and rapidly transmitting the signature of changes in surface climate into the deep ocean (Rintoul, 2007). For a fuller account of the scientific issues and knowledge gaps in an Ireland-specific context, together with the likely impacts on the coastal zone, see the review by Fealy (2003).

3.1.2 Thermohaline circulation (THC) stability

Ocean currents cause significant geographical differences in the supply of heat to the atmosphere and regions around the North Atlantic Ocean have a mean annual surface air temperature that is 5–7^{o}C warmer than those at the same latitude in the Pacific (Stocker and Marchal, 2000). This can be attributed to the THC of the Atlantic Ocean moving warm, saline tropical waters northward, the Gulf Stream being part of this basin-scale circulation (Stocker and Marchal, 2000).

The existence of abrupt past climate changes has fuelled concern over the possibility of similar changes in future, particularly if anthropogenic climate change might trigger another instability of the circulation and a severe cooling over the North Atlantic and parts of Europe (Rahmstorf and Ganopolski, 1999; Rahmstorf, 1999, 2000; Srokosz and Gommenginger, 2002; Stouffer *et al.*, 2006). Despite these considerable uncertainties surrounding the stability and behaviour of the THC on varying timescales, consensus remains that a major ocean circulation change should be considered a 'low probability-high impact' risk, but emphasises that proper risk analysis is crucial for this type of non-linear climatic change (Rahmstorf, 2000; Hulme *et al.*, 2002; Schmittner *et al.*, 2005). While most GCMs simulate a weakening of the THC over the 21st century, none demonstrate a shut down by 2100 and overall warming is predicted to offset any cooling associated with this weakening (Hulme *et al.*, 2002; NERC, 2006).

3.1.3 Changes in storm and wave climate

There is strong evidence for increased wave heights in north east Atlantic waters and for increased occurrence of strong winds over the UK and adjacent regions from the 1960s to the present (Woolf and Coll, 2007). It is unclear whether recent behaviour is driven by climate change or is simply natural variation and whether substantial changes in storminess are likely in the 21st century (Woolf and Coll, 2007). Bacon and Carter (1991) inferred an increase in mean wave height of about 2% per year "over the whole of the North Atlantic in recent years, possibly since 1950" from observational data notably from Seven Stones Light Vessel (1962-1986). Recent analyses of a more extensive data set confirm a significant upward trend in wave heights in the North Atlantic, but only for the last 50 years and embedded within a pattern of multi-decadal variability over more than a century (Gulev and Hasse, 1999; Gulev and Grigorieva, 2004).

Wave heights in the North-East Atlantic and northern North Sea are known (from analysis of *in situ* data, satellite data and model reconstructions) to respond strongly and systematically to the behaviour of the North Atlantic Oscillation (NAO) (Woolf and Coll, 2007), which may also be interpreted as a regional manifestation of a wider Northern Annular Mode (NAM) of climate variability. The recent strong trend in the NAO (towards stormier conditions) is apparently unique in its history, but it is controversial whether this is a response to greenhouse gas forcing (Osborn, 2004). Many GCMs suggest a general trend towards the stormier tendency of NAO/NAM in the 21st century (e.g. Terray *et al.*, 2004; Miller *et al.,* 2006).

Factors related to the wind such as storminess and roughness of the sea are recognised to be very difficult to predict within climate change scenarios, with present confidence in GCM and RCM modelled wind field changes remaining low (Hulme *et al.*, 2002). However, a large number of analyses have now been conducted. Some analyses have focussed on general features of the storm track (strength and position) and related changes in regional indices such as the NAO and NAM (Woolf and Coll, 2007). Wolf and Woolf (2006) have shown the sensitivity of the wave climate to such changes. Other analyses have focussed on the number and intensity of extra-tropical cyclones and it is a feature of the analyses that different approaches suggest significantly different views of future storm climate (Woolf and Coll, 2007).

Many Global Climate Models suggest a general trend towards the stormier tendency of NAO/NAM in the 21st century (e.g. Terray *et al.*, 2004; Kuzmina *et al.*, 2005). Both a stronger storm track and a poleward displacement of that track are common features in studies of this kind (e.g., Miller *et al.*, 2006).

Whereas analyses primarily based on RCMs suggest different and mostly weaker changes in winds and storminess (e.g. Hulme *et al.*, 2002; Hanson *et al.*, 2004; Lozano *et al.*, 2004; Leckebusch *et al.*, 2006). An analysis of outputs from fifteen coupled GCMs forced by enhanced greenhouse warming experiments finds that there is a reduction in the total number of extra-tropical cyclones but an increase in the number of intense events (Lambert and Fyfe, 2006). With no apparent change in the geographical positions of the storm tracks, they conclude that there is no obvious shift in storm tracks associated with global warming (Lambert and Fyfe, 2006).

Considering these contradictory findings, downscaling via general structural changes in the atmosphere (such as shifts in NAO) may be more suitable for storminess than analysing winds in RCMs. Therefore and given that preference, the shift to stormy conditions suggested by Terray et al. (2004) and others should carry more weight than the contrary results from RCMs, but it is debatable (Woolf and Coll, 2006).

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