Climate change

Implications for Ireland's Marine Environment and Resources

April 2005

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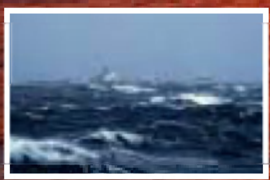

Marine Foresight Series
No.2

Marine Institute
Foras na Mara

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This report is one of a series prepared at the request of the Marine Institute as a contribution to the development of a comprehensive National Marine Research and Innovative Strategy (2006-2012). This strategy being prepared through the course of 2005 will identify the key actions needed to provide sustainable growth and development opportunites that will contribute to socio-economic progress and the protection of the marine environment. This report is designed to identify climate-induced impacts, and necessary related actions, that Foresight/Stateholder groups will have to take into account in preparing future R&D plans and programmes.

ISSN: 1649-590X

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Climate Change: Implications for Ireland's Marine Environment and Resources

Climate has always varied. However, the prospect of continuing global and regional climate change beyond that of normal climatic variation, due to a build-up of greenhouse gases in the atmosphere, is now a real possibility. This has potentially serious implications, and possibly some benefits, for the future development of our marine resources. Predicted changes include a greater incidence of storm damage and flooding in low-lying coastal areas and various impacts on marine life including modifications in primary production, food chains and geographical ranges of some species. Increased storm intensity may have significant implications for coastal structures, navigation as well as marine search and rescue operations. Changing marine ecosystems will also have real implications for environmental monitoring, protection and conservation strategies. While international actions to curtail or reduce the rate of climate change are of paramount importance, even if such actions succeed the levels of greenhouse gases currently in the atmosphere are likely to persist for several decades. We must, therefore, improve capacities to predict the types and rates of change and identify the adaptation measures that need to be applied in marine resource use and management. In the absence of policies and measures to prepare for and accommodate the changes, even the more moderate of the predicted scenarios will have significant social and economic impacts.

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Summary & Conclusions

The importance of marine climate

1. Ireland and Europe have become measurably warmer in the past two decades. This is confirmed by a large body of scientific data. The Intergovernmental Panel on Climate Change (IPCC) has concluded that this warming is mostly attributable to the build up of greenhouse gases (principally CO_2) in the atmosphere due to burning of fossil fuels and changes in land use. The long lifetimes of these gases in the atmosphere means that warming is likely to continue during the rest of this century despite current efforts to reduce emissions.

2. Climate change impacts for the marine environment include increases in sea temperature, storm intensity, wave height and sea level (as the oceans expand and ice melts), as well as possible changes in ocean currents. Such changes will have profound implications for marine life, including seafood species, our estuaries and coastal areas and the way we use them. Ireland's maritime communities and related socio-economic activities must be prepared to adapt to this changing climate regime and it is therefore essential to develop appropriate adaptation strategies.

3. Medium and long term development and investment strategies must take into account predicted climate impacts. Innovative policies and approaches to marine resource management are needed, guided by sound scientific knowledge and advice. This report examines existing knowledge regarding marine climate change and identifies associated management and scientific issues. It provides a basis for reviewing current practices in the use of marine and coastal areas, their associated resources and amenities, as well as related policies and scientific programmes.

Climate models and associated uncertainties

4. Global and regional climate models provide the most reliable basis for predicting future climate change scenarios. Predicted changes can then be assessed in order to develop appropriate strategies for managing adverse impacts. Models depend on time-series measurements of environmental conditions and, at present, gaps in the records at national and regional levels account for much of the uncertainty associated with model predictions. Nevertheless, the current generation of global and regional climate models provide remarkably accurate simulations of past climatic patterns and variations and are the best available tools for assessing likely future trends. Models need to be continuously developed and improved as new information from research and monitoring becomes available. The development of the regional climate modelling and prediction facility within Met Éireann will help in achieving this aim.

The driving forces

5. Predictions of climate-induced impacts on Ireland's marine environment stem from the following assumptions:

- Global warming, driven primarily by emissions of carbon dioxide (CO_2) to the atmosphere, will continue;
- Temperatures on land by 2055 will show increases up to 1.5°C in winter and 2.0°C in summer;
- A change in average rainfall by 2055 of +10% in winter and -10% to -40% in summer (greatest decrease in the south-east);
- An increase in sea levels similar to the global mean prediction of 0.49 ±0.08m by the end of the century; and
- An increase in the number of extreme events (e.g. more intense storms, hotter summers)

The likely consequences

6. These assumptions, based on the IPCC's Medium-High (A2) Emissions Scenario, suggest that within a few decades Ireland's marine ecosystems are likely to undergo significant changes in response to increased seawater temperatures, changes in near-shore salinities, more intense storms and possibly increases in sea level due to thermal expansion of the oceans and/or melting of the polar ice-cap.

7. Around the coasts, wetter winters leading to periodic flash floods, increased storm intensity and wave height combined with rising sea levels will accelerate erosion of soft shores and increase the incidence of flooding in low-lying areas. This will exacerbate trends that are already evident. In coastal areas exposed to prevailing south-westerly facing winds, structures on or near the shore such as houses, farm buildings, roads, piers and aquaculture facilities will be at greater risk from storm damage. Salt-marshes and lagoons will be inundated with greater frequency with resultant changes in their ecology.

8. In warmer seas some native species currently at the southerly limit of their ranges will tend to move north while species inhabiting warmer areas to the south will be encouraged to extend their range into Irish waters. Biodiversity is certain to be affected, changes in community structure perhaps being more likely than changes in the number of species. Seasonal temperature changes will alter the timing of spawning of both fish and invertebrate species; relocation of the spawning areas for some commercially important fish species must be expected. In near-shore shallow waters, extreme temperature events, even though transitory, will cause physiological stresses with concomitant losses of individual organisms and reductions in population size.

9. The timing and/or intensity of the spring phytoplankton bloom (already evident) will change. Corresponding changes in reproductive cycles of invertebrate food species and shifts in species distribution have the potential to disrupt established food chains with negative effects on growth and recruitment of larger predatory species including fish and marine mammals. Changes in growth and abundance of some commercially important seafood species are to be expected; yields from certain fisheries may decline at faster rates than before.

10. The changes may also open up possibilities for the development of new fisheries (e.g tuna) and new species for aquaculture as well as increased growth rates and productivity of some native species.

11. Increasing seawater temperature, in addition to salinity changes due to less summer rainfall and reduced river discharges, will further affect the distribution of species in estuarine and coastal waters including species that form part of the food supply for juvenile fish. Increases in wave energy during storm events will disrupt bottom-living communities in exposed locations.

12. The ability of marine organisms to adapt to changes in marine climate depends in part on how quickly the changes occur. In general, marine organisms have a high capacity to adjust to environmental changes that take place steadily over many generations, over centuries or millennia for example, but changes over several decades, as currently predicted, for most species would be difficult to accommodate. Species with short life cycles have greater adaptive capacities than long-lived species.

13. A summary of the possible impacts of climate change in Ireland's marine and coastal areas is given in Box 1.

Box 1: Summary of predicted marine impacts

The main concerns relate to changes in shore topography and inundations, especially from storm surges, as well as alterations to recruitment, growth and replacement of renewable aquatic resources. Extreme events are likely to occur more frequently and there will be a gradual underlying trend of ecological change brought about by increasing seawater temperatures. The predicted rate of change is speculative but if current predictions are correct there will be significant increases in sea temperatures to the south and east of Ireland by the middle of the present century. Predictions of climate-induced impacts on Ireland's marine environment stem from the following assumptions:

- Atmospheric warming, driven primarily by emissions of carbon dioxide (CO_2) to the atmosphere, will continue;
- Temperatures on land by 2055 will show increases up to 1.5°C in winter and 2.0°C in summer;
- A conservative estimate of change in average rainfall by 2050 is for an increase of +10% in winter and -10% to -40% in summer (greatest decrease in the south-east);
- An increase in sea levels similar to the global mean prediction of 0.49 ±0.08m by the end of the century; and
- An increase in the number of extreme events (e.g. more intense storms, hotter summers);

The effects of these changes on Ireland's marine and coastal areas are likely to include:

- Increased intensity of storms combined with changes in sea level leading to wave damage on soft shores, increased seasonal flooding and inundation of low-lying areas, interference with coastal developments and infrastructure and disruption of coastal habitats and fish nursery areas; increased storm intensity may also have implications for the design of aquaculture installations as well as for maritime transport, navigation and marine search and rescue operations;
- Reduced number of commercial fishing days in winter;
- An increase in mean seawater temperature leading to northerly shifts in the ranges of planktonic and other species, including migratory fish (e.g. pilchard, breams), enhanced recruitment of some native (e.g. mullet, bass) and non-native cultured species (e.g. Pacific oysters) and a decline in some wild populations (e.g. salmonids);
- In regard to biodiversity, species losses and new arrivals due to shifts in biogeographical range and greater incidence of invasions of non-native species;
- Increases in phytoplankton biomass throughout the year, changes in the timing and intensity of spring algal blooms and the structure of zooplankton communities with as yet unknown, but potentially substantive, consequences for marine food chains;
- Elevated summer and winter temperatures in shallow bays and inlets with corresponding changes in the structure and stability of marine plant and animal communities; and
- Changes in near-shore salinities, sediment loading and distribution due to alterations in river discharges and increasing sea level with potentially negative consequences for near-shore seafood production (e.g. aquaculture, nursery areas, traditional shellfish beds);

Climate is fundamentally important for the stability and maintenance of populations and food chains. Changes in climate will result in altered physical conditions that will include water circulation, stratification and nutrient supply. These effects may result in permanent or temporal changes to existing and evolving niches such as nursery areas and will either exclude or encourage species on the fringe of their natural distributions.

14. Ireland's marine climate is expected to change in the coming decades. Policies and strategies to better understand and manage these changes are imperative and need to be developed as a matter of priority. As climate model predictions are subject to uncertainty, a national strategy for adapting to changes in marine climate must allow for flexible responses depending on the rate and extent of change. The requirements to be addressed include:

Policy elements

- Ensuring that the planning of new developments and infrastructure in Ireland's marine and coastal areas takes into account the likely changes in marine climate by, *inter alia*, preparing guidance on managing infrastructure and development;
- Forging strong relationships with European institutes and agencies specialising in the investigation, modelling and prediction of climate change to avail of the latest findings for policy refinement and to develop indigenous expertise;
- Strengthening capacities for monitoring key marine climate indicators in accordance with international programmes e.g. European Global Ocean Observing System (EuroGOOS) and Global Monitoring for Environment & Security (GMES) initiative;

Scientific elements

- Development of marine climate recording instrumentation in accordance with agreed international approaches;
- Refining models of coastal margin vulnerability;
- Improving knowledge of relationships between climate, food chains, commercial and cultivated species;
- Greater vigilance with regard to the arrival of non-native species; and
- Promoting research and technology transfer into structural requirements for more robust on- and off-shore installations e.g. aquaculture, renewable energy, coastal infrastructure etc. suitable to Irish conditions.

15. As more information comes to light and predictions improve it will be necessary to review strategies for mitigating and accommodating changes in marine climate and to make adjustments that take account of new findings. For example, a major review and analysis of policy options in the fields of coastal planning and maritime industry development would be required in the event of a slowing down of the Gulf Stream, (and its northerly extension, the North Atlantic drift), due to continued salinity reduction in the Norwegian Sea. This could reverse warming in the N-E Atlantic and cause a significant cooling of the relatively warm climate presently experienced by northern Europe.

16. Although there will always be uncertainty regarding the precise effects of climate change on Ireland's marine environment, in the absence of policies and measures to prepare for and accommodate the changes even the more moderate of the predicted scenarios will have major social and economic impacts. It is imperative to develop a more focused programme of research and monitoring embracing key indicators of a changing marine environment as well as responses of living marine resources. In parallel with this, there is a need for a structured process for translating the findings of scientific investigations into policies and management actions, for example annual sessions of a multi-disciplinary advisory committee sponsored jointly by the relevant government departments and agencies. Such policies and actions will need to address approaches to species conservation, coastal land use and protection, as well as new approaches to aquaculture and fisheries. It is of utmost importance that all marine development and infrastructure programmes from now on take account of predicted climate change scenarios.

The need for action

Although there can be no certainty regarding the precise nature and rate of changes to Ireland's marine environment due to alterations in climate, in the absence of policies and measures to prepare for and accommodate the changes, even the more moderate of the predicted scenarios would have major social and economic impacts.

17. Recommendations for specific actions in the fields of management and science, designed to improve Ireland's capacities for evaluating changes in marine climate and adapting to the impacts of these changes, are given in Chapter 6 of the report.

Climate Change: Implications for Ireland's Marine Environment and Resources

1. Introduction

> ***"Climate change is the most serious problem we are facing today."***
> **Sir David King, UK Government Chief Scientific Advisor**

Climate has always varied. Recent warming has been associated with increased production of greenhouse gases, principally carbon dioxide. Should the apparent rate of change continue, it will have consequences for all sectors of the environment and present real challenges to human society. The manifestations of climate change include increasing temperature, changing patterns of wind and rainfall and associated ecosystem responses. Many traditional practices are finely adjusted to current climatic conditions, so any significant shift in these conditions will have significant impacts on society and the environment.

The oceans play a key role in the regulation of climate. They store, distribute and dissipate heat from solar radiation and exchange heat with the atmosphere. Consequently, the oceans are greatly affected by the climatic conditions they help to create. A proper understanding of the nature and effects of climate change can be gained only through careful observation of physical and biological features of the oceans in parallel with studies on land, in freshwater systems and in the atmosphere. Such observations are necessary not only to identify the nature and rate of climate change but also to predict likely future scenarios.

Life on Earth is to a significant extent determined by the physical factors that regulate climate. On land, very small differences in the ranges of temperature (e.g. daily, seasonally etc.), rainfall and wind strength, combined with local geological conditions, can separate one ecosystem from another with quite different species and communities. Likewise, in the sea, temperature, salinity, current and wave regimes - all related to climate - in combination with depth, seabed geology and topography determine the type and abundance of organisms present. Thus, a change in climate beyond that of normal climatic variation may force gradual changes in diversity and productivity of marine ecosystems. Abrupt changes may also occur.

Current model predictions of climate change in north-west Europe for the present century foresee a gradual warming accompanied by changes in patterns of wind and rainfall. Other avenues of research (Box 2) support a different scenario whereby a weakening of the warm North Atlantic surface currents (i.e. Gulf Stream/North Atlantic Drift) could lead to a marked and possibly rapid cooling of the climate of Ireland and north-west Europe that would have far more serious implications.

In October 2000, the Irish Government published a National Climate Change[1] Strategy that addresses human-induced causes of global warming, giving specific targets and deadlines for control of greenhouse gas emissions and carbon sequestration through increased forestation. The strategy does not address the monitoring of climate indicators or the management of climate change impacts.

In order for managers, senior scientists and policy-makers to evaluate different climate change scenarios, and to identify priorities for marine research and monitoring, it is important that they have available a concise summary of the existing evidence, predictions and potential effects on Ireland's marine environment and resources.

[1] Department of Environment & Local Government, 2000. National Climate Change Strategy, 89pp.

Box 2: Cooling of the North Atlantic - the worst case scenario?

[Based on Gagosian (2003)[2] and Dickson et al. (2002)[3]]

Most models of climate change in north-west Europe predict a gradual warming with associated changes in patterns of wind and rainfall. The influence of possible changes in ocean circulation is not considered in climate scenarios for the present century currently proposed by the Intergovernmental Panel on Climate Change (IPCC). However, the temperate climate of Ireland and north-west Europe is due mainly to the humid mild air conveyed into the region in association with the North Atlantic Drift, an extension of the Gulf Stream which is a warm surface current originating in the Gulf of Mexico and flowing north-east across the Atlantic. Without the Gulf Stream, temperatures in Ireland and north-west Europe would be 5°C or so cooler, with bitter winters at least as cold as those of the so-called Little Ice Age of the 17th to 19th centuries.

Although it seems contradictory that global warming could lead to a cooling of the warm ocean currents responsible for Ireland's mild climate, this is precisely what is suggested by recent research *(see footnotes)*.

The Gulf Stream and North Atlantic Drift are important parts of a global ocean circulation system (described as the Ocean Conveyor), which transports heat throughout the planet *(See diagram below)*. For the Gulf Stream to continue flowing northward, there must be a comparable, deep return current of cold dense water from the Nordic Seas. This occurs because the warm waters of the Gulf Stream lose moisture through evaporation and the sinking of the colder, heavier salt water forms a deep ocean current that drives the entire Ocean Conveyor; this is known as 'thermohaline circulation'.

Measurements show that the sub-polar seas bordering the North Atlantic have become noticeably less salty since the mid-1960s, especially in the last decade, possibly due to melting glaciers and/or increased precipitation. Analyses of ice cores and deep-sea sediments has shown that the Conveyor has abruptly slowed down or halted many times in the Earth's past. This has caused the North Atlantic region to cool significantly causing abrupt changes in climate i.e. within a few decades. Abrupt regional cooling would clearly have far greater policy implications than cooling that occurred after another century of global warming.

The degree of change in the thermohaline system necessary to significantly disrupt the Ocean Conveyor is unknown. There is a pressing need to intensify measurements of deep ocean currents and to improve understanding of the oceans' role in the hydrological cycle.

Source: McCartney, M. S., Curry R. G. & Bezdek H. F., 1996: *Oceanus*, 39, 19-23.

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[2]Gagosian, R. B., 2003. Abrupt Climate Change: Should we be worried? Prepared for a panel at the World Economic Forum, Davos, Switzerland. Woods Hole Oceanographic Institution, 15pp.

[3]Dickson B., Yasayaev, I., Meincke, J., Turrell, B., Dye, S. and Holfort, J., 2002. Rapid Freshening of the Deep North Atlantic Ocean over the Past Four Decades. Nature, Vol. 416, 832-837.

This document aims to summarise the status of current knowledge concerning climate change generally, discussing its significance for Ireland's marine environment and considering the implications for marine resource management. It draws extensively from recent reports on climate change indicators[4] and impacts[5] prepared for the Environmental Protection Agency but includes additional information of particular relevance to the marine environment.

Specifically, the document attempts to provide concise answers to the following questions:

- What is the evidence for climate change? (Chapter 2)
- What is the evidence for change in marine climate? (Chapter 3)
- What are the predictions and manifestations/impacts of climate change on the marine environment? (Chapter 4)
- What are the implications for management of marine areas and resources? (Chapter 5)
- How should we respond? (Recommendations) (Chapter 6)

[4] Sweeney, J., Donnelly, A., McElwain, L. & Jones, M., 2002. Climate Change: Indicators for Ireland (2000-LS-5.2.2-M1). Environmental Protection Agency, 54pp.

[5] Sweeney, J., Brereton, T., Byrne, C., Charlton, R., Emblow, C., Fealy, R., Holden, N., Jones, M., Donnelly, A., Moore, S., Purser, P., Byrne, K., Farrell, E., Mayes, E., Minchin, D., Wilson, J. & Wilson, J., 2003. Climate Change: scenarios and impacts for Ireland (2000-LS-5.2.1-M1. Environmental Protection Agency, 229pp.

2. Evidence for climate change

2.1 Global evidence

There is ample evidence to show that the Earth's surface temperature has increased significantly in the past 20 years. According to the Goddard Institute for Space Studies[6], global surface air temperature in 1997 was warmer than any previous year of the 20th century, marginally exceeding the temperature of 1995. The 1990s were significantly warmer than previous decades in the period of instrumental data, with the five warmest years of the century being 1990, 1991, 1995, 1997 and 1998 (Figure 1).

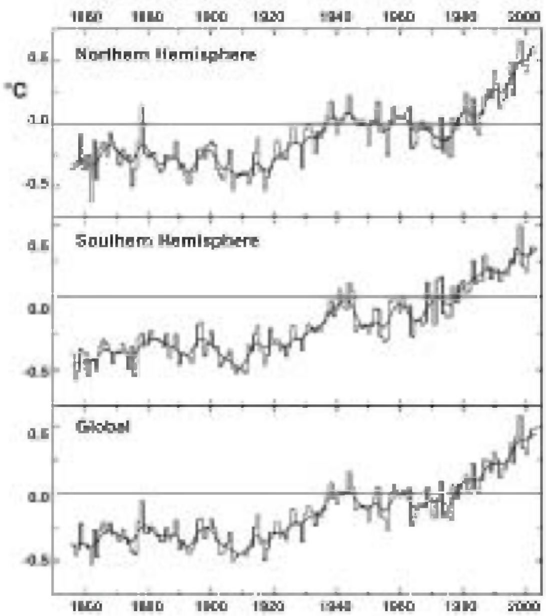

Figure 1: Annual-mean surface air temperature change, based on meteorological station network.

More recent research, including examination of ice cores and growth rings of ancient trees, shows that the Northern Hemisphere has been warmer since 1980 than at any time during the last 2000 years[7].

Similarly, the 3rd Assessment Report of the Intergovernmental Panel on Climate Change[8] (IPCC) concludes that global average temperature has increased by 0.6°C ± 0.2°C since 1860 with accelerated warming in the latter decades of the 20th century. The IPCC report also notes reductions in snow cover in the past 40 years with widespread retreat of ice cover, sea level rises of 0.1-0.2m and an increase in rainfall across temperate regions. A cumulative temperature increase of 1.6 - 6.0°C (since 1860) is projected by 2100, depending on greenhouse gas emission rates.

Although it is indisputable that temperatures are increasing globally, and there are clear manifestations of consequential changes to the environment, there remains a controversy regarding the extent to which the increase is due to human activities. At present the balance of scientific opinion points to increasing levels of atmospheric CO_2 as being responsible for the changes.

As the rate of future temperature increase is uncertain, there is much speculation regarding associated changes in regional climatic conditions and the implications for aquatic and terrestrial ecosystems. Although predictive models are increasingly sophisticated, they are predicated largely on assumptions regarding the trend in global warming which, in turn, are based on various scenarios for greenhouse gas emissions (principally CO_2).

2.2 Regional evidence

Although there are significant regional differences, most of Europe has experienced a mean temperature increase of about 0.8°C since 1900. During the decade 1981-1990, air temperature over most of Europe was exceptional, with yearly means up by 0.25-0.5°C with respect to the long-term average. The warming has been most apparent in a belt extending from Spain through central Europe into Russia. Temperature rise has been most marked during the winter period (Figure 2); evidence suggests that minimum temperature increases have been far larger than changes in maximum temperatures. In other words the diurnal temperature range is decreasing, which is consistent with evidence from other regions of the world. The geographical distribution of temperature trends shows greater warming (2°C per century) in the south-western part of Europe (Iberian Peninsula, south and central France) than in the British Isles or along the Baltic coastline (1°C per century).

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[6] http://www.giss.nasa.gov/research/observe/surftemp/1997.html
[7] Mann, M.E., Ammann, C.M., Bradley, R.S., Briffa, K.R., Crowley, T.J., Hughes, M.K., Jones, P.D., Oppenheimer, M., Osborn, T.J., Overpeck, J.T., Rutherford, S., Trenberth, K.E., Wigley, T.M.L., 2003. On Past Temperatures and Anomalous Late 20th Century Warmth, Eos, 84, 256-258
[8] IPCC, 2001. Climate Change 2001: Synthesis Report. Watson, R.T. and the Core Writing Team (Eds.) Intergovernmental Panel on Climate Change, Geneva, Switzerland, 184pp.

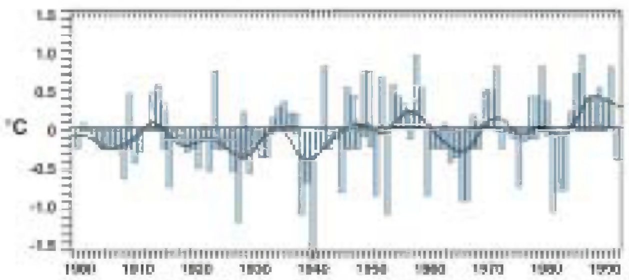

Figure 2: Annual winter (Dec.-Feb.) temperature anomaly over Europe during the period 1900-96 in relation to the long-term average[9].

Annual precipitation trends in the 20th century show enhanced precipitation in the northern half of Europe (i.e. north of the Alps to northern Fennoscandia), with increases ranging from 10% to almost 50%. By contrast, the region stretching from the Mediterranean to the Ukraine has experienced precipitation decreases as much as 20% in some areas. Whereas it is difficult to determine a meaningful trend in precipitation averaged across Europe, especially since the 1950s, there is an apparent trend towards reduced inter-annual variability, although not necessarily on a sub-regional or national basis.

2.3 Irish evidence

A recent report[4] examines Irish observational records and concludes that 'significant changes in Irish climate are occurring'. There has been an increase in mean annual temperature of 0.5°C during the 20th century, with a more rapid rise in the last decade. Significant decreases in frost frequency and increases in 'hot day' frequencies also occurred during this time and substantial increases in winter precipitation occurred in the north-west and a decrease of summer rainfall in the south-east, all changes consistent with the predicted trends from Global Climate Models (GCMs). Such matching indicates that contemporary modelling tools are suitable for assessing future impacts of climate change.

[9] Intergovernmental Panel on Climate Change, 1997. The Regional Impacts of Climate Change: An Assessment of Vulnerability. www.grida.no/climate/ipcc/regional/097.htm

3. Evidence for change in marine climate

There are very clear signs in recent decades that physical conditions across the marine areas of Ireland and Great Britain are changing in response to warming of the atmosphere. Although for some parameters the records are short, and spatial coverage limited, there can be little doubt that changes in sea temperature, wind strength and wave height are already sufficient to affect coastal ecosystems in certain areas. Evidence of an increase in sea surface temperature (SST) across the northern hemisphere is shown in Figure 3.

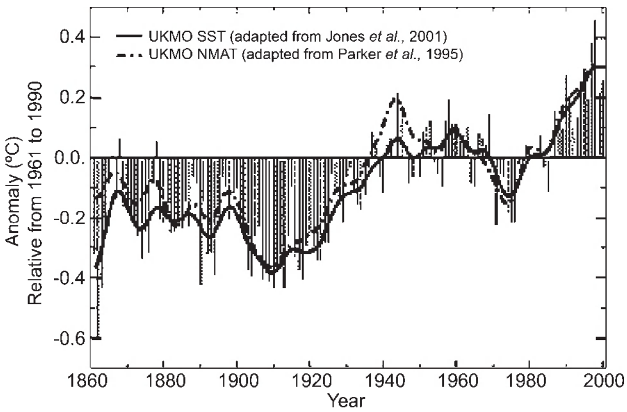

Figure 3: Sea-surface temperature anomaly time-series from an 1861 to 1990 average for the Northern Hemisphere[10].

3.1 Our principal climate indicator - the North Atlantic Oscillation (NAO)

Of all the factors that indicate climate variability in the north-east Atlantic region, in which Ireland is situated, the North Atlantic Oscillation (NAO) is by far the most influential and no discussion of marine climate can ignore the overriding importance of the NAO in this regard. A large part of the scientific literature on climatic variation across Ireland and the British Isles is dominated by model simulations of the NAO and its relation to weather patterns affecting both land and sea.

The NAO is a north-south alternation in the track of storms and depressions across the North Atlantic that impact upon the weather and climate of northern Europe. It is the dominant mode of winter atmospheric variability over the North Atlantic and accounts for more than one-third of the total variance in sea-level pressure. The NAO is measured by the difference between the mean winter sea level pressure at Gibraltar (or the Azores) and the mean winter sea level pressure at Iceland. The alternations are described as positive and negative phases (Figure 4).

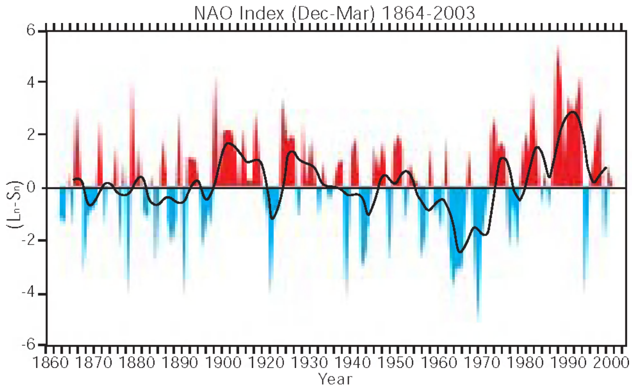

Figure 4: Winter North Atlantic Oscillation Index, 1864 to 2003 (from measurements at Iceland and Gibraltar)[11]

During a positive NAO, conditions are colder and drier than average over the north-west Atlantic (E. Canada to Greenland) and Mediterranean regions, whereas conditions in northern Europe, the Eastern United States and parts of Scandinavia are warmer and wetter than average.

A recognized feature of the NAO is its trend towards a more positive phase over the past 30 years, with a magnitude that seems to be unprecedented in the observational record[12].

Study of the NAO helps to increase the accuracy of long-term/seasonal weather forecasting. Much of the observed regional surface warming over Europe can be accounted for by the recent upward trend in the NAO index[13]. Thus, because the NAO is a natural phenomenon, it could be argued that much of the recent warming is not related to the build-up of greenhouse gases in the atmosphere. This viewpoint, however, ignores the possibility that anthropogenic climate change might influence modes of natural variability, perhaps making it more likely that one phase of the NAO is preferred over the other[12].

[10] World Meteorological Organization/United Nations Environment Programme. Climate Change 2001: The Scientific Basis.
[11] National Center for Atmospheric Research, Colorado. http://www.ncar.ucar.edu/
[12] Visbeck, M.H., Hurrell, J.W., Polvani, L. and Cullen, H.M., 2001. The North Atlantic Oscillation: past, present and future. Proc. Natl. Acad. Scxi. USA, 98 (23) 12876-12877.
[13] Hurrell, J.W., 1996. Geophys. Res. Lett. 23, 665-668

It has long been recognised that fluctuations in sea surface temperature and the strength of the NAO are related and that the North Atlantic ocean varies significantly according to the overlying atmosphere. Other ocean characteristics suggested as being influenced by the NAO[14] include:

- wind speed
- modulation of deep ocean temperature
- localised salinity changes
- the Atlantic storm track
- westerly wind strength
- significant wave height
- evaporation and precipitation patterns
- transport of the Labrador current
- Arctic sea ice

Physical and biological conditions in lakes are closely related to climate and can provide a useful measure of how waterbodies respond to changes in atmospheric pressure, temperature, wind and rainfall. Studies[15] on two lakes in the west of Ireland, for example, have shown that winter temperature and chlorophyll are correlated with the NAO, with lower chlorophyll level and higher temperatures occurring during positive NAO phases.

There is currently no agreement as to the processes responsible for observed low-frequency variations in the NAO. The absence of a demonstrated and suitable predictive model leads to uncertainty about future NAO variability. However, several current theories concerning the mechanisms underlying NAO variations, including the influence of tropical sea temperatures, suggest that the positive index phase might persist[12].

3.2 Observations from Irish and adjacent waters

Sea temperatures

The waters surrounding Ireland are ~7° to 8°C warmer than the average global sea surface temperature (SST) at the same latitude, principally due to the influence of the warm North Atlantic Drift, the main ocean current affecting the region. The prevailing south-westerly winds transfer heat from the sea to the land. Long-term records of sea surface temperatures (SST) around Ireland are sparse. The longest data set is from Malin Head where daily measurements of SST have continued since 1957. Any indication of a seasonal increase in SST at this location is tenuous; it shows a small increase from late winter to autumn during 2003/04 when compared with the 30-year average (Figure 5). However, evidence of warming over the past 15 years can also be found in the mean annual SST recorded at Malin Head; prior to 1995 the warmest year was 1989 but 1995 temperatures broke all previous records, rising to 17.5°C in August[16].

Scottish coastal sea temperatures have increased by ~1°C since the 1970s, with warming most apparent in winter[17]. Off-shore, sea surface temperatures increased by ~1° to 1.5°C. Minimum temperatures of oceanic waters off Scotland during the 1990s were the highest recorded during the 20th century, matching near-surface air temperature trends for the northern hemisphere. During the 1980s, sea temperature in the English Channel increased slightly but in the following decade there was an increase of almost 1°C, far greater than any change in the previous 100 years[18].

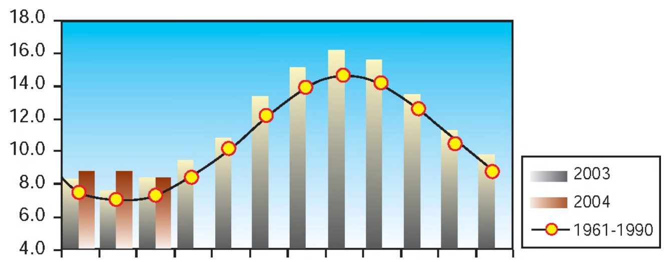

Figure 5: Average monthly sea surface temperatures at Malin Head compared to the 30-yr average (1961-1990), Met Éireann

[14] http://www.clivar.org/publications/other_pubs/iplan/iip/pd1.htm
[15] Jennings, E. et al, 2000. The North Atlantic Oscillation: Effects on Freshwater Systems in Ireland, Proc. Roy. Ir. Acad., No.3, 149-157.
[16] Met Eireann, 1995. Highest ever sea temperatures during summer 1995. Monthly Weather Bulletin, No.114, 20pp.
[17] http://www.snh.org.uk/strategy/sr-en07.htm
[18] Marine Biological Association, 2003. Marine biodiversity and climate change. http://www.mba.ac.uk/marclim

Salinity

There is insufficient information on temporal patterns of salinity in Irish waters to determine recent trends. Although data routinely collected by research cruises, when suitably processed, might be used for this purpose, the requisite standardised sampling protocols (e.g. times, locations, metadata) for trend analysis have yet to be introduced. However, data from the North Atlantic[19] do show changes in both temperature and salinity of the surface layers. Salinity changes in the Nordic Seas, with possible implications for the strength of the Atlantic circulation, have also been recorded *(See Box 2).*

In tropical ocean waters, researchers have measured a significant increase in salinity over the past 40 years, while oceans closer to the poles have become fresher[20]. These large-scale, relatively rapid oceanic changes suggest that recent climate changes, including global warming, may be altering the systems that regulate evaporation and precipitation and cycles fresh water around the globe.

Storminess

Storminess refers to the frequency of winds in excess of approximately 25 m/sec (Beaufort Force 10). A high winter NAO[21] index brings depressions into northwest Europe and with it patterns of higher rainfall and an increase in storms. At certain locations there is a high correlation (r = 0.8) between surface windspeed and the NAO . Figure 4 shows the variation in the NAO index; it is highly variable but shows an upward trend from the 1960s to the early 1990s. This is in agreement with the increasing number of severe gales experienced in the UK (and presumably Ireland) since the early 1970s[22]. In contrast, long-term records (1881-1998) clearly show high inter-annual variability in winter storminess over Ireland, the British Isles, Norwegian Sea and North Sea but no distinct long-term trend (Figure 6).

Records from the Armagh observatory show significant variations in storminess over the last 200 years, despite the sheltered inland nature of the site. Yet there is no evidence of increased storminess over the last 30 years. There is, however, an indication of a possible northwards movement of storm tracks over Ireland during the last 30 years.

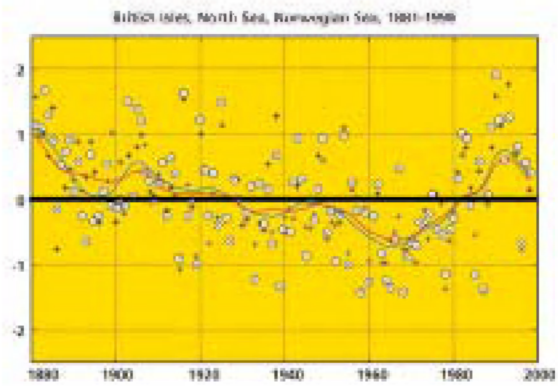

Figure 6: The observed storminess in the region of the British Isles, North Sea and Norwegian Sea showing long-term variations but no significant trend. Baseline is period average. Blue and circles: standardised annual 95% quantil, red and crosses 99% quantil of the pressure distribution within this region (curves 3-year running mean)[23].

Wave height

Measurements of wave height around Ireland and the British Isles by satellite altimetry show a strong seasonality, with exceptionally large average wave heights to the west and north of Ireland (i.e. off the Donegal coast) in winter. Waves west of Ireland, from 50ºN to 55ºN, had an annual mean extreme height of 11.1 metres during 1961-87 and were higher than 5.8m during 10% of the period. These heights increased by 0.3 and 0.7 m, respectively, over the period[24].

The inter-annual variability of winter wave climate is very high. Most of this variability can be described by a strong linear dependence on the NAO index[25]. This relationship may largely explain observations of

[19] Bönisch, G., J. Blindheim, J.L. Bullister, P. Schlosser and D.W.R. Wallace, (1997) "Long-term trends of temperature, salinity, density, and transient tracers in the central Greenland Sea". *J. Geophys. Res.,* 102 (C8), 18553-18571.
[20] Curry, R. Dickson, B and Yashayaev I., 2003. Massive Salinity Changes in Oceans. Nature, Vol. 426, 18/25, 926-829 .
[21] George, S. E., and M. A. Saunders, 2001. North Atlantic Oscillation impact on tropical North Atlantic winter atmospheric variability, *Geophys. Res. Lett.,* 28, 1015-1018.
[22] http://www.environment-agency.tv/ye/qu-ea-doc/s-enviro/stresses/1natural-for/3climate_change/1-3-1.html
[23] After Alexandersson et al, 1998, GAOS, 6, 97-120
[24] WASA, 1998. Changing waves and storms in the northeast Atlantic? Bull. Amer. Meteor. Soc., 79, 741-760.
[25] Woolf D.K., Cotton, P.D. and Challenor, P.G., 2003. Measurements of the offshore wave climate around the British Isles by satellite altimeter. Phil. Trans. R. Soc. Lond. A 361, 27-31.

increasing wave heights in the north-eastern Atlantic and northern North Sea during the latter decades of the 20th century. The Jericho project (see Annex) shows similar findings and suggests that coastal areas most likely to experience the greatest influence of increases in wave climate are those exposed to the largest waves such as Ireland's north-west coast.

Sea level

Sea level has been rising globally during the last century by a rate between 1-2 mm/yr[26]. This has been linked with the increase in global atmospheric temperature. The longest available records show that the rate of change during the 20th century was greater than the rate of change in the 19th century[27]. Global sea levels for the 21st century are predicted to change by 9 to 88 cm i.e. between 0.09 mm/yr and 8.8 mm/yr. The basis of the estimate consists of a large number of models with various hypotheses behind them. The apparent agreement between theoretical estimations and observed values is because the large ranges overlap.

An assessment of Ireland's overall vulnerability to sea level rise (SLR) based upon the IPCC Common Methodology supports Ireland's relatively low vulnerability to SLR, consistent with much of Northwest Europe[28]. Variation in the late Quaternary ice loading of Ireland has led to a north to south gradient in land movement (isostatic change), resulting in a predominantly emergent northern region and submergent to 'apparently stable' coastal environments to the south. Relative sea level rise (i.e. the net rise, discounting isostatic change) around Ireland and the British Isles averages ~1mm/year[29](about 10cm since 1900), although there are significant regional variations. A 50-yr record from Dublin port[30] indicates an annual rise of 1.6mm/yr. In general, however, records from Irish gauging stations are not sufficient to provide reliable indications of past changes in sea level around the Irish coasts[31].

At present there is insufficient evidence of the effects of climate warming on sea level and coastal changes around Ireland. However, there are circumstantial links between climatic changes and more frequent severe weather events (See following section) including flooding and storm damage in coastal areas. Although coastal flooding is sometimes mistaken for rising sea level, such events are mainly a result of storm surges associated with high tides and strong on-shore winds. Clearly, the impacts of storm surges are likely to increase as sea levels rise. Predictions concerning future sea level rise around Ireland are given in Chapter 4.

Extreme weather events

Unusually severe weather conditions, such as storm-force winds, persistent torrential rain or prolonged periods of drought can cause much economic damage and, in affected areas, may have implications for human

[26] Church, J.A., Gregory, J.M., Huybrechts, P., Kuhn, M., Lambeck, K., Nhuan, M.T., Qin, D., & Woodworth, P.L. (2001) Changes in sea level. Chapter 11 of the Intergovernmental Panel on Climate Change Third Assessment Report, Science Report, Cambridge University Press (2001), 638-689.
[27] Woodworth P.L., 1999. High waters at Liverpool since 1768: the UK's longest sea level record. *Geophysical Res. Letters*, 26, 1589-1592
[28] Devoy, R. J. N., (in press). Coastal vulnerability and the implications of sea-level rise for Ireland. *Journal of Coastal Research*, Special Issue, on European Vulnerability and Adaptation to Impacts of Accelerated Sea-level Rise. (From, Proceedings of SURVAS Expert Workshop, University of Hamburg, October 2000- http://www.survas.mdx.ac.uk)
[29] Woodworth, P., 1999. A review of the trends observed in British Isles mean sea level data measured by tide gauges. Geophysical Journal International 136, 651-670.
[30] http://reports.eea.eu.int/climate_report_2_2004/en/impacts_of_europes_changing_climate.pdf
[31] Devoy, R.J.N., 2000. Implications of accelerated sea-level rise (ASLR) for Ireland. Proc. SURVAS Expert Workshop on European Vulnerability to impacts of Accelerated Sea-Level Rise, Hamburg, 52-66. See also http://survas.mdx.ac.uk

health and welfare. Although the effects are often localised, such events are major factors in focusing public attention on climate. A recent example is the November 2002 flooding in the Dublin area (Tolka River), which led to 1358 insurance claims costing €50 million[32].

Extreme weather events have become an important political issue in Europe. Exceptionally high temperatures occurred in western Europe in 2003, causing various heat and drought-related impacts, both on human health and environment. Heatwaves are often accompanied by power failures, high levels of local air pollution, failures in water supply, forest fires and excess heat-related mortality. At the end of the hot 2003 summer, authorities reported high mortality figures[33]. Weather-related events in Europe cannot be attributed to climate change alone, but they show what may happen if current climate trends continue.

Prior to 1997, the largest loss incurred by Irish property owners from a single event was from Hurricane Charlie in August 1986. Insurance claims on that occasion amounted to approximately €47 million at today's value. Since the late 1990s, the incidence of damaging weather events has increased (Table 1).

Table 1: The cost to Irish property insurance companies of severe weather events since 1997[32]

YEAR	EVENT	COST
November 2002	Flood	€50 m
February 2002	Flood	€37 m
December 2001	Freeze	€30 m
November 2000	Flood	€51 m
December 1998/ January 1999	Storm	€56 m
December 1997	Storm	€84 m

The Irish Insurance Federation[32] has estimated that we can now reasonably expect one severe weather event each year, whereas in the past one might have assumed one such event every two, three or even five years. Much of the damage is incurred by property and infrastructure at or near the coasts. The impacts on marine life may include mortalities amongst shallow-water or intertidal organisms due to heat stress and disruption of benthic habitats and communities from wave action and sediment redistribution. At least one incident of mortalities amongst farmed fish, which occurred in Donegal Bay in 2003, may have been exacerbated by heat stress[34]. On the other hand warmer sea temperatures, especially during winter, are likely to reduce the incidence of cold weather events that have in the past caused harmful impacts on some shallow water species, including scallops[35].

Biological / Ecological Impacts

There have been few long-term studies of marine organisms in Irish waters[36] and, consequently, evidence of either biological or ecological change is scarce. There is a clear need to develop suitable indicators of biological change in the marine environment. Already two new breeding bird species - the Mediterranean gull and the little egret - have extended their range northwards into Ireland since the mid-1990s. During the 1980s and 1990s, new appearances of tropical or semi-tropical fish were recorded in British waters approximately every two years[37], culminating in 2001 with the appearance of both the big-eye thresher shark and the barracuda.

A recent major review[38] of the significance of rising sea temperatures to marine life of Britain and Ireland provides valuable information on critical temperature ranges for many benthic species and discusses their likely responses to the new conditions. Key points from this review are presented in subsequent sections of this report.

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[32] Irish Insurance Federation. Press Release, February 26th 2003.
[33] WHO (2003). Heatwaves: impacts and responses. Meeting document for the European Environment and Health Committee held in Prague, 9-10 October 2003 (EEHC9/Info.5). Prague, World Health Organization
[34] Cronin et al., 2004. Salmon mortalities at Inver and McSwyne's Bay finfish farms, County Donegal, Ireland during 2003. Mar. Env. Health Series, No. 15, 130pp.
[35] Minchin, D., 1985. Some considerations in the future management of escallops *(Pecten maximus)* in Connemara bays. 5th International Pectinid Workshop, La Coruna, Spain, 6-10 May 1985, 30pp.
[36] Emblow, C., Minchin, D., Mayes, E. and Wilson, J., 2003. Climate Change and the Irish Marine Environment. In: Climate Change: scenarios and impacts for Ireland (2000-LS-5.2.1-M1). Sweeney J. et al. (Authors). EPA, Environmental RTDI Programme 2000-2006, 229pp.
[37] Southeastern Fisheries Association, 2002. Strangers in the Seas. http://www.southeasternfish.org/Documents/strangers_in_the_seas.htm
[38] Hiscock, K., Southward, A., Tittley, I. and Hawkins, S., 2004. Effects of changing temperature on benthic marine life in Britain and Ireland. Aquatic Conserv: Mar. Freshw. Ecosyst. 14: 333-362.

The longest, although discontinuous, data series, from 1591, is based on fluctuations of the periodic fisheries for pilchard on the south coast of Britain, since related to climate change[39]. Similar patterns have been deduced for the south coast of Ireland[40] and for different pilchard species worldwide[41], so suggesting a worldwide response to changing conditions.

Spawning and larval development of several species leading to successful recruitment have been co-related with elevations of temperature. Abundant sets of spat of the native oyster occur in Tralee Bay when seawater temperatures in July exceed 18°C. In Lough Hyne, larval stages of the purple sea urchin (echinoplutei) and bivalve larvae are more abundant in July and August during warm summers. On the other hand, variations in the relative abundance of the purple sea-urchin in Lough Hyne[42] and of the cockle in Dublin Bay[43], studied over some decades, may be influenced by factors other than climate.

The apparent extended range of vagrant bony fish (teleosts) may reflect our previous lack of knowledge and poor recording, yet lists of species heretofore not previously recorded can provide useful datasets that reflect changes in the range of species[44].

For further evidence it is necessary to look elsewhere in the region, for example the North Sea[45]. Yet even here long-term data series are sparse. There is also the complication of separating climatic trends from sporadic weather events, as well as human activities. Cold winter events[46] have resulted in declines in both abundance and diversity of benthic species, whereas mild winters combined with eutrophication have led to increases in biomass. The impact of a cold event on biota may last for several years, until such time as a natural replacement takes place. Warmer temperatures may result in changes to intertidal communities. In one port area the barnacle *Balanus crenatus* was replaced locally by *Balanus amphitrite* but, following a period of cooling, the position was reversed[47].

Significant changes in Atlantic and North Sea phytoplankton[48], in particular alterations in the timing and intensity of spring blooms[49], and increases in phytoplankton biomass and zooplankton structure[50], are clear signs of a response to climate warming. Changes in primary and secondary production, combined with small changes in currents and circulation, may result in large swings in the recruitment of some commercial fish species[51] by affecting the proportion of eggs that

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39 Southward, A.J., Boalch, G.T. & Maddock, L., 1988. Fluctuations in the herring and pilchard fisheries of Devon and Cornwall linked to change in climate since the 16th century. Journal of the Marine Biological Society of the United Kingdom, 68: 423-445.
40 Minchin, D., 1993. Possible increases in mean temperature on Irish marine fauna and fisheries In: M.J. Costello and K.S. Kelly (eds). Biogeography of Ireland: past present and future. Occasional Publications of the Irish Biogeographical Society No 2. Pp 113-125.
41 Kawasaki, T., 1991. Effects of global climate change on marine ecosystems and fisheries. Pp 291-299 In: J. Jager and H.L. Ferguson (eds) Climate change: science, impacts and policy. Proceedings of the 2nd World Climate Conference. Cambridge University Press.
42 Kitching, J.A. & Thain, V.M., 1983. The ecological impact of the sea urchin Paracentrotus lividus (Lamarck) in Lough Ine, Ireland. Philosophical Transactions of the Royal Society. Series B: Biological Sciences 300: 513-552.
43 Wilson, J.G., 1993. The future for the cockle in Dublin Bay. Occas. Public'n of the Irish Biogeographical Soc. 2, 141-149.
44 Quigley D.T., Flannery, K. & O'Shea, J. 1993. Trigger fish in Irish waters: a biogeographical review. In: M.J. Costello and K.S. Kelly (eds). Biogeography of Ireland: past present and future. Occasional Publications of the Irish Biogeographical Society No 2. Pp127-140.
45 Clark, R.A. & Frid, C.L.J., 2001. Long-term changes in the North Sea ecosystem. Environ. Rev. 9: 131-187.
46 Dörjes, J., Michaelis, H., & Rhode, B. 1986. Long-term studies of macrozoobenthos in intertidal and shallow subtidal habitats near the island of Norderney (east Frisian coast, Germany). Hydrobiologia, 142: 217-232.
47 Naylor, E. 1965. Biological effects of a heated effluent in docks at Swansea, S. Wales. Proceedings of the Linnean Society, London 144, 253-268.
48 Edwards, M., Richardson, A., Batten, S. & John, A.W.G., 2004. Ecological Status Report: results from the CPR survey 2002/2003. SAHFOS Technical Report No.1, 8pp.
49 http://www.fisherycrisis.com/DFO/frozencod2.htm
50 Evans, F. & Edwards, A., 1993. Changes in the zooplankton community off the coast of Northumberland between 1969 and 1988, with notes on changes in the phytoplankton and the benthos. J. Exp. Mar. Biol. Ecol., 172: 11-31.
51 Shepard, J.G., 1990. Stability and the objectives of fishery management: the scientific background. Ministry of Agriculture, Fisheries and Food, Lowestoft, U.K. 16pp.

survive. The 'gadoid outburst' in the North Sea (~1963-1973) may have been due to a filling of the niche following the decline of herring as young cod share the same food. The subsequent decline of North Sea cod relates to a warming since the 1990's[52].

On the basis of marine plankton data gathered since 1946 in the Continuous Plankton Recorder (CPR) survey, changes have been identified in the species composition of copepods in the North Atlantic during the past four decades[53]. Southern species have migrated northwards in the eastern Atlantic along the coast of Europe, whereas northern or Arctic species have moved southwards in the western Atlantic off the coast of North America. These data are consistent with recent changes in climate, reflected by northern hemisphere temperature anomalies and the North Atlantic Oscillation. These findings demonstrate the importance of plankton monitoring in any programme to detect ecosystem responses to changes in climate.

At present there no proven links between the incidence of harmful algal species (e.g. toxin-producing species that can cause shellfish poisoning) and changes in marine climate. Nevertheless, because of the serious economic effects of shellfishery closures, and the increase in the number of known toxins in Irish waters, it is important that plankton research incorporates temporal and spatial surveys that will enable associations to be made between harmful algal events, the incidence of causative species and environmental changes (e.g. sea temperatures), should such associations exist. An extension of the CPR programme to fill gaps in the coverage of Irish near-shore waters would be most helpful in this regard.

[52] O'Brien, C.M., Fox, C.J., Planque, B. & Casey, J., 2000. Fisheries: Climate variability and the North Sea cod. Nature, 404: 142.
[53] Beaugrand, G., Reid P.C., Ibanez, F., Lindley, J. A. and Edwards, M., 2002. Reorganization of North Atlantic Marine Copepod Biodiversity and Climate, Science 2002 296: 1692-1694.

4. Predicted changes in Ireland's marine climate and their environmental impacts

> ***"Climate change costs could top $300billion annually worldwide"***
> ***Environmental News Service 09/02/01***

4.1 How will climate change affect Ireland as a whole?

Modelled climate scenarios[5] (e.g. medium-high emission scenario A2) based on the entire observational record for the period 1961-1990 suggest that by 2050 there will be:

- an increase in winter rainfall by 10%, expected to lead to flooding in the north and west;
- a 10-40% decrease in summer rainfall will decrease river, lake and reservoir levels;
- an air temperature increase in summer of up to 2°C; with typical midland temperatures up to 24.5°C;
- an air temperature increase of up to 1.5°C in winter; and
- a rise in sea levels, more extreme weather events and an increase in sea temperatures.

Increased evaporation in summertime would further reduce water availability and run-off from land to sea.

This is the background against which possible effects on the marine environment are evaluated.

4.2 Impacts on Ireland's marine and coastal environments

Current research programmes

The capacity to assess patterns and trends in climate is greatly dependent on the use of models and, in particular, the periods of time over which reliable data are available. Although good records exist for basic meteorological parameters such as air pressure, temperature, wind strength and direction, Irish marine data records are comparatively shorter and less extensive, emphasising the need to improve the recording of such key features as sea temperatures, sea levels and salinity. A number of Irish institutions are actively engaged in research into various aspects of marine climate change and potential effects on the marine environment and resources. Outlines of some important marine climate research programmes are given in the Annex to this report.

Sea Surface Temperature

Currently the most detailed predictions of changes in sea surface temperatures (SST) around Ireland and Great Britain, under various green-house gas emission scenarios, come from the UK Met Office's HadRM3 Model[54]. Other models also produce outputs for this region and assessments are made by comparisons between these outputs. Under the medium-high (A2) CO_2 emission scenario, all areas will show an increase in the temperature of coastal waters, with the shallowest seas such as the southern North Sea, English Channel and Irish Sea warming the most - by more than 3ºC by the 2080s. This 3ºC warming of surface water off the coast of southeast England is equivalent to about a three-month extension to the time period over which sea temperatures in this part of the UK reach, or exceed, the present August-September average of about 16ºC. Thus by the 2080s, average sea-surface temperatures would exceed the current mid-August to mid-September maximum for the five-month period from mid-June to mid-November. In contrast, the waters of the Atlantic Ocean northwest of Scotland and Ireland warm by less than 1ºC for the low emissions scenario over the same period.

> ***By the 2050s, under the A2 (medium-high) emissions scenario[8], the temperature of seawater around Ireland is predicted to increase by about 1-1.5°C and by the 2080s by 2-2.5°C in waters to the east, west and south[54].***

Temperature increases of this magnitude will affect both the diversity and abundance of marine life around the coasts. There is a broad range of possible changes from shifts in the timing and level of primary production *(see also Salinity right)*, changes in feeding patterns, growth, behaviour and disease resistance and reproductive success of individual species, to changes in predation, community structure and stability. However,

[54] Hulme,M., Jenkins,G.J., Lu,X., Turnpenny,J.R., Mitchell,T.D., Jones,R.G., Lowe,J., Murphy,J.M., Hassell,D., Boorman,P., McDonald,R. and Hill,S. (2002). Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK. 120pp

neither the exact nature of the changes nor their effects are readily predictable; they are likely to vary from location to location according to the degree and rapidity of temperature change and the influence of other climate-associated variables. Where physical change is slow, most biological communities in Ireland may be expected to adapt.

Salinity

The patterns of salinity in estuarine and coastal waters are part of the physico-chemical conditions that create vertical density gradients that in turn regulate the distributions of marine species. The strength and duration of stratification of the water column overlying the Continental Shelf determines the variability amongst plankton communities.

Although wind-driven currents predominate, part of the circulation on the Irish shelf is believed to be a function of pressure gradients resulting from density variations[55]. Most of the coastal and offshore waters to the south and west of Ireland show seasonal stratification, especially during early summer. The Irish Shelf Front, running approximately parallel to the west and south-west coasts, while having some thermal characteristics, is mainly a haline (salinity) front separating coastal waters from those of Atlantic origin. Such features have important roles in regulating primary production (including toxin-producing algae) and thence secondary production and marine food chains. More localised density gradients, such as the western Irish Sea gyre, may create physical conditions that sustain valuable fisheries e.g. Dublin Bay prawn *(Nephrops norvegicus)*[56]. Any substantive change in seasonal temperature (due to a general warming/cooling trend) could influence the formation, timing and stability of fronts and gyres, as well as associated current flows, resulting in a variety of biological changes that, from existing knowledge, are not readily predictable.

Through a process of down-scaling output from a global climate model (HadCM3) developed by the UK Met Office, and using emission scenarios for CO_2 and SO^2 outlined by the IPCC in 2001, Irish researchers have predicted changes in rainfall and run-off patterns that have potential to influence salinity of Ireland's coastal waters[57]. For periods up to 2090, the findings indicate a widespread reduction in annual run-off, most pronounced in the east and south-east. A slight increase is predicted for parts of the north-west. Summer run-off will be lower in all areas while winter run-off in the west will be greater with parallel increases in the magnitude and frequency of flood events.

The predicted fall in summer run-off could bring high saline water closer to shore during summer months and occasional incursions of species (stenohaline) that are less tolerant of salinity variations than the majority of estuarine and coastal species (euryhaline). More importantly, reduced summertime run-off could change the temporal pattern of nutrient supply from land, possibly affecting the timing of the spring bloom and reducing potential for primary production outside the spring period. Consequently, time-series datasets (e.g. from the CPR; see sections 3.2 & 6) are needed to enable the mapping of primary production at selected coastal sites.

Storminess and wind strength

The conclusions from a recent modelling study[58] undertaken by Irish and Danish institutes show that, in a greenhouse gases-induced warming climate, less storms are to be expected for northern parts of the N-E Atlantic margin (west coast of Ireland) although the intensity of storms will increase. With regard to wind speeds, the UKCIP[59] predictions indicate that, apart from areas off the south and east coasts of England where increases in wind speed can be expected, most of the British Isles will experience few changes in winter and spring. In summer and autumn, however, the wind speed can be expected to decrease as climate warms, especially off the west coasts of Britain and Ireland where reductions up to 10% are predicted. These patterns are consistent with the drier, more

[55] Boelens, R.G.V., Maloney, D.M., Parsons, A.P. & Walsh, A.R., 1999. Ireland's Marine and Coastal Areas and Adjacent Seas: an Environmental Assessment. Marine Institute, Dublin, 388pp.
[56] Hill, A.E., Brown, J. and Fernand, L., 1996. The western Irish Sea gyre: a retention mechanism for the Norway Lobster *(Nephrops norvegicus)*? Oceanologica Acta, 19, 357-368.
[57] Charlton, R.A. and Moore, S., 2003. The Impact of Climate Change on Water Resources in Ireland. In: *Climate Change: Scenarios & Impacts for Ireland,* (2000-LS-5.2.1-M1). ERTDI Report Series No.15, Environmental Protection Agency, 81-99.
[58] Lozano, I., R.J.N. Devoy, W. May and U. Andersen (2004). Storminess and vulnerability along the Atlantic coastlines of Europe: analysis of storm records and of a greenhouse gases induced climate scenario, Marine Geology 210, 205-225.
[59] Hulme, M., Jenkins, G.J., Lu, X., Turnpenny, J.R., Mitchell, T.D., Jones, R.G., Lowe, J., Murphy, J.M., Hassell, D., Boorman, P., McDonald, R. and Hill, S. (2002). Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK. 120pp

settled summers and more southerly winter depression tracks depicted under conditions of climate change.

Waves

Observations of increasing wave heights in the north-eastern Atlantic and northern North Sea during the latter decades of the 20th century can largely be explained by variations in the NAO. Although predictions of changes in weather patterns are not sufficiently reliable to permit confident projections of future coastal wave climate, coastal areas most likely to feel the greatest influence of future increases in wave climate are those exposed to the largest waves (e.g. Ireland's north-west coast) and areas with deep water close inshore (Figure 7).

Sea level

As noted in Section 3.2 above, global sea levels for the 21st century are predicted to change by 9 to 88 cm (Mean: 48cm) i.e. between 0.09 mm/yr and 8.8 mm/yr. Relative sea level for Ireland is rising at c.1mm/year on average (mainly due to isostatic forces[61]) though there are significant regional variations. In comparison to low-lying countries such as the Netherlands, Ireland, similar to much of north-west Europe, is considered to have relatively low vulnerability to sea level rise and at present there are no apparent effects of climate warming on sea level and coastal changes. Nevertheless, certain Irish coastal habitats are clearly susceptible to increases in sea level and storm surges.

As sea level changes are dependent on various other climate-related processes, especially inter-relationships between air and sea temperatures, precipitation and polar

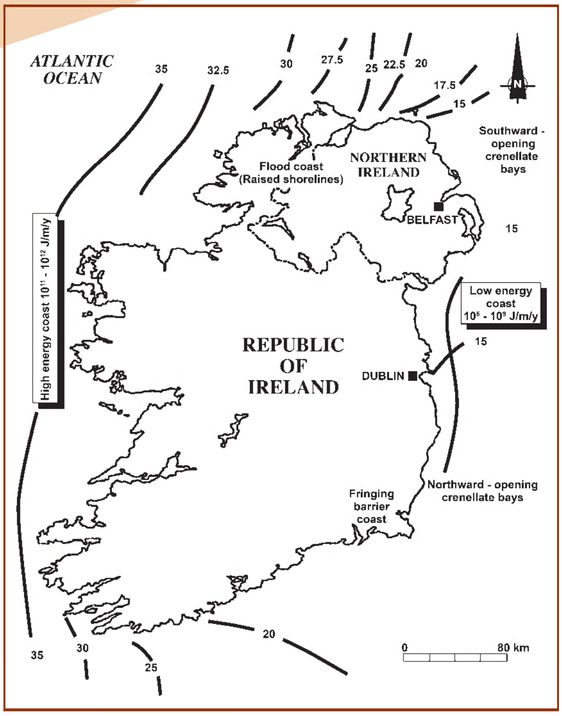

Figure 7: Ireland's coastal configuration and spatial differences in wave climate[60]

ice formation, predictions on regional sea-level changes carry a high level of uncertainty. A 1992 study estimated that relative sea level around Ireland could rise by as much as 46 cm in the next 30 years or so[62], depending on the rate of warming, melting of glaciers and ice caps and thermal expansion of the oceans. More recently, models based on the Medium-High (CO_2) Emissions scenario predict that by 2080 sea level increases around Ireland will range from 20-30 cm in the west and south-west, to 30-40 cm in the east[63]- significantly less than the 1992 estimates. If such rises were to materialise, many parts of the coast would begin to experience increased erosion, more frequent breaching of coastal defences and, in low-lying areas, increased flooding and the gradual loss (through erosion, inundation or siltation) of habitats and amenities.

The findings of a recent coastal vulnerability study of the Irish coastline, and associated social and economic implications, shows that about 30% of Ireland's coastal wetlands would be lost in the event of a 1m rise in sea (Table 2). The assessment was carried out by the

[60]Devoy, R.J.N., 1990. Implications of accelerated sea-level rise for Ireland. Proc. SURVAS Expert Wksp. On European vulnerability to impacts of accelerated sea-level rise, 52-58.
[61]Manifested by uplifting of the land mass that has continued since the melting of the Ice Age glaciers.
[62]Devoy, R., 1992. Climate, sea-level change and Ireland: the nature of the management problem, present and future. In: Coastal Engineering and Management: a workshop (Nov. 1990). Proc. edited by Devoy, R.J. & O'Mahony, A. Occas. Pub. Resource & Environ. Manag. Unit, University College Cork, No.2, pp.16-28 + figures.
[63]UKCIP

Table 2: *Vulnerability components for Ireland assuming a scenario of a 1m relative sea level rise to 2100, assuming the existing socio-economic situation.*

(These statistics for Ireland were included in the IPCC Third Annual Report (TAR), 2001 Review of 'Climate Change Statistics')

Impact categories†	**Component**	**Proportion/ Factor Scale**	**Vulnerability class** ***Low - Critical***
People affected (by coastal impacts) [(people/ total pop.) x 100%]	<250,000	<4.6%	Medium (1-10%)
People at risk (by e.g., SLR induced flooding) [(people x flood probability) / 1000]	<100,000 (from 1:100 yr flood)	1-8 people/ 1000	Low (<10 people/1000)
Capital value loss [(total loss / GNP) x 100%]	c. €140M (at agricultural land values)	c. 0.2% GNP*	Low (<1%)
Dry Land loss [(area / total area) x 100%]	<230km2	<0.3% Total area	Low (<3%)
Wetland loss [(area / total area) x 100%]	c. 800km2	c. 30% Wetland total	High (10-30%) [IPCC critical values: >30%]
Protection/adaptation costs‡ (for Republic of Ireland only) [(annual cost / GNP) x 100%]	Potential- c. €340M/yr Envisaged- <€10M/yr	c. 0.6% GNP* c. 0.02% GNP	High (0.25-1.0%) Low (<0.05%)

† The Impact Categories and outcome statistics shown are based on the recommended IPCC-CZMS (1992) Methodology for the calculation/ quantification of coastal vulnerability (the IPCC formula is shown).
‡ <4% of Ireland's coast is currently protected by built shore structures.
* GNP values were taken as for 1990 (or more recent, as available).

Coastal and Marine Resources Centre at University College Cork (UCC) where coastal impact assessment is a major focus of research.

4.3 Impacts on marine and coastal ecosystems

Any assessment of the broad range of impacts that might result from changes in marine climate will involve a degree of speculation.

The uncertainty of predictions

As knowledge in some areas of marine science is more uncertain than in others, predictions of the effects of climate change on coastal and marine ecosystems tend to be given with varying degrees of confidence[64]. There is some confidence in predictions of how increases in temperature will affect plant and animal physiology, abundances and distributions, dissolved oxygen concentrations and sea level. There is also some confidence in predictions of the effects of sea-level rise on shallow continental margins, including flooding of wetlands, shoreline erosion and enhanced storm surges. However, there is less confidence regarding temperature's influence on interactions amongst organisms and even less as to its effects on water circulation patterns. Consequently, assumptions made in the construction of climate models play an important part in the uncertainty of predictions.

There are various reasons why the effects of climate change on marine biota are difficult to predict.

[64] Kennedy, V.S., Twilley, R.R., Kleypas, J.A., Cowan Jnr, J.H. and Hare, S.R., 2002. Coastal and Marine Ecosystems & Global Climate Change. Pew Center (U.S.) Report No.8, 52pp.

Organisms will have different levels of tolerance to the imposed physical conditions and few will have the capability of actively avoiding these. Extreme events tend to reduce the range of a species[65]. Mortalities from cold events[66] and storms[67] also arise and affect species well within their geographical range. On the other hand, favourable conditions lasting for short periods (e.g. several years) can lead to an enhancement of numbers and an increase in range. There are many such natural perturbations, as well as impacts from anthropogenic interference. Consequently, biological variability can seldom be assessed in the absence of monitoring over long time periods. Not every species is suited to monitoring and some behavioural and other responses are difficult to study. Unfortunately, most long-term studies that have been undertaken were not designed to monitor changes in climate.

General implications

All aquatic ecosystems - coastal, estuarine and freshwater - will be affected by climate change over the coming century particularly those of lakes, lagoons and shallow bays where storm events may result in high turbidity, scouring and sediment redistribution. The beaching of living maërl and various molluscs such as scallops, loss of caged fish, damage to equipment and facilities (including servicing structures) for aquaculture and fishing, are likely to result in increased capital and other costs (e.g. insurance) thereby reducing incentives for investment. Management practices in coastal areas will need to adapt, involving cessation of capture of some stocks, enhancement of others and development of new fishery resources, including some for purposes other than human food, as in biotechnology, aquaria or animal food supplements. Increases in temperature are likely to favour development of aquatic leisure activities leading to competition with industries such as aquaculture.

Storm events may cause disturbance and mortalities amongst sediment communities at depths up to 50m[68] and even boulder communities at depths of 25m can be reduced following crushing of fixed organisms[69]. Thus, increased storminess will have implications for benthic communities exposed to storm swell.

Some of the effects of warmer seas may be beneficial to marine organisms. Increases of mean temperature during summer are likely to increase egg production in many invertebrate species and, if temperatures are sustained, a shorter planktonic period with reduced mortality is possible leading to increased settlement. Some molluscan fisheries may benefit but warmer conditions could also favour predators e.g. seastars. Existing oyster fisheries should have successful natural settlements provided that sea level changes do not greatly alter tidal flushing regimes.

Range extensions

As temperature is not the only factor controlling species distributions, increases in seawater temperature will not lead initially to an overall movement northwards of southern species or retreat northwards of northern species[38]. Gradual increases in temperature are likely to result in a reduction in the range of some coastal species with northerly distributions, as these are expected to become intolerant of changing conditions (for example the algae *Alaria esculenta*, *Odonthalia dentata;* the barnacle *Balanus balanoides* and the cod *Gadus morhua*)[70]; whilst northward increases in the range of other species are likely to take place (the alga *Bifurcaria bifurcaria*, the anemone *Anemone sulcata*, the barnacle *Balanus perforatus* and the fish *Sardina pilchardus*). Species whose ranges are presently on the south coast of Ireland or northern France, should have increased opportunities of becoming established in Ireland (Box 3). Some non-native molluscs presently in cultivation such as the Pacific oyster *Crassostrea gigas* may recruit to form significant settlements and opportunities for naturalisation of other useful species may also arise. Nevertheless, with all intentional species introductions for

[65]Crisp, D., 1964. The effects of the winter of 1962/63 on the British marine fauna. Helgoländer Wiss. Meeresunters., 10:313-327.
[66]Minchin, D., 1985. Some future considerations in the future management of escallops (Pecten maximus) in Connemara Bays. 5th International Pectinid Workshop, La Coruna, Spain, 6-10 May 1985, 28pp.
[67]Gibson, F.A., 1963. Mortality in marine animals during storms, January 1963. Irish Naturalists' Journal 14 (6): 118-119.
[68]Turner, S.J., Thrush, S.F., Pridmore, R.D., Hewitt, J.E., Cummings, V.J. & Maskery, M. 1995. Are soft sediment communities stable? An example from a windy harbour. Mar. Ecol. Prog. Ser. 120: 219-230.
[69]Minchin, D. (co-author this report), personal observation.
[70]Vincent, P., 1990. The biogeography of the British Isles. Routledge, London, 315pp.

Box 3: Changes in biogeographic range

The warm Lusitanian province lies south of Brittany from the Bay of Biscay and a Boreal province lies north of Scotland extending to Iceland and Norway, including the North Sea. Between lies a mixing of the two provinces which includes all Irish coasts. Conditions for boreal species are expected to become less favourable and some of these may no longer maintain populations in Irish waters but rather will develop a more northerly contracted range. Range extensions of species will be indicated both by planktonic species and those capable of swimming, particularly those that migrate. The transport of species with planktonic stages of short duration is facilitated by shipping, floating structures and leisure craft, via aquaculture transfers and attachment to flotsam. Consequently, range extensions of such species are most likely to be observed in port regions and at aquaculture sites.

purposes of culture or fishery development, the ICES Code of Practice[71] should be applied.

Species with life cycles that include a planktonic phase are likely to extend their distributions in line with isothermal changes[38]. Water masses, with different characteristics of temperature and salinity, tend to have specific plankton assemblages. Some of the species present can be used as indicators of water mass origin and historical records based on the continuous plankton recorder (CPR; see section 3.2) samples have enabled the monitoring of changes in plankton communities that reflect water movement as well as environmental conditions. A progressive increase in the movement of warm-water/sub-tropical species of plankton into the more temperate areas of the NE Atlantic is already apparant[48]. Offshore water masses may occasionally extend closer to shore and carry specific gelatinous zooplankton that includes siphonophores and oceanic medusa, such as *Pelagia noctiluca.* These could have consequences for the viable operation of fish culture, especially if cultivation extends further offshore where such gelatinous zooplankton are more frequent. Temperate gelatinous zooplankton is predicted to increase generally as a result of predicted warmer conditions and anthropogenic factors[72].

Fish that occasionally are recorded in Irish waters occurring close to the edge of their ranges are termed vagrants. Some, such as the bluefish *Pomatomus saltator* and the Tarpon *Tarpon atlanticus,* are rare in Irish waters and consequently their occurrence at present is of little significance. It is the occurrence of vagrant species that occur more frequently that is likely to provide useful information on change. The full ranges of seasonal vagrants are often blurred but, when all vagrant distributions are taken into account, a generalized pattern of shifting distributions may be obtained. The trigger-fish *Balistes carolinensis*[73] appears from the late summer to the autumn; it dies once sea temperatures fall below c. 12º C. This species as well as other seasonal surface water visitors normally occurring offshore (e.g., the skipper *Scomberesox saurus* and the sunfish *Mola mola*) have apparently increased in recent years and, through use of a standard recording scheme, could be useful indicators of climate change. Similar patterns in the northward movement of fishes have been noted from the Atlantic coast of France. This is of particular relevance where the recorded species are not part of a commercial fishery.

Impacts on fish

As water temperature increases, free-swimming species such as fish will be amongst the first to show changes in distribution. Examples are red mullet *Mullus surmuletus,* black sea bream *Spondyliosoma antharus*, the pilchard *Sardina pilchardus*, John Dory *Zeus faber* and cuttlefish *Sepia officinalis* which have all extended their distributions northwards in the past in response to temperature increases and are likely to do so again in future[38]. Marine distributions of salmonids are also thought to be dependent on temperature[74] and wild

[71]ICES, 2004. Code of Practice for the Introduction and Transfer of Marine Organisms (www.ices.dk)
[72]Purcell, J.E., 2004. Climate effects on jellyfish populations. North Pacific Marine Science Organisation 13th Annual Meeting, Honolulu, Hawaii, 16-24 October 2004.
[73]Quigley, D.T., Flannery, K. & O'Shea, J., 1993. Trigger fish in Irish waters: a biogeographical review. In: Biogeography of Ireland: past, present and future. M.J. Costello & K.S. Kelly (Eds). Occ. Publ. Ir. Biogeog. Soc., No.2, 127-140.
[74]Reddin, D.G. & Shearer, W.M., 1987. Sea-surface temperature and distribution of Atlantic salmon in the Northwest Atlantic Ocean. American Fisheries Society Symposium 1: 262-275.

salmon migrations may be compromised by increased temperature and reduced river flow arising from changes in precipitation. Salmonids, such as *Salmo salar* and *Salmo trutta*, are vulnerable to higher than normal temperatures at critical periods in their life-cycle. The immune system of salmonids is optimal at <15°C and becomes compromised at temperatures >20°C[75]. Already some Irish freshwater lakes and rivers are attaining temperatures >23°C in summer and some deep-water lakes have reached >19°C at depths over 35m.

Water table levels are expected to be lower and bogs may become less efficient in buffering stormwater discharges through rivers. This could lead to reduced water levels during summer, a condition that would be exacerbated by new water abstraction schemes designed to supply dryer regions towards the east coast. With reduced flows, migratory salmonids may be unable to ascend rivers and river temperatures and dissolved oxygen will, to an increasing extent, be influenced by air temperature. In general, species that move between marine and freshwater environments will be subject to a wider range of challenges. Extreme events may result in habitat alteration, particularly salmonid stream habitats.

The physiological effects of prolonged warmer water can lead to faster growth rates so that in the case of certain fishes, such as mullet, they enter the winter at a larger size and so become less vulnerable to predation, thereby enhancing their year-class strength.

Some fishery species may be expected to decline and to be replaced by others, for example by those with southern distributions and high replacement rates (i.e. pilchard). Recruitment of some species with early life stages dependent on lagoons and shallow bays, such as mullet *Chelon labrosus* and bass *Dicentrarchus labrax*, is likely to increase. Already some changes in the spawning behaviour of smelt *Osmerus mordax* in the Shannon Estuary have been noted to occur earlier in the year. Offshore, seasonal fisheries such as those for long-finned tuna *Thunnus alalunga* and silver bream *Brama brama* on the west coast of Ireland are likely to have longer exploitation periods. However, alterations to fisheries of this nature may not be entirely related to climate change.

Some nursery areas for fishes are likely to be modified through tidal inundation of low-lying land. The erosion of low lying areas (e.g. the Maharee isthmus in Tralee Bay) may lead to significant changes in water flow that could have impacts on local native oyster recruitment.

Aquaculture

Climatic changes, and in particular increases in temperature, will have both positive and negative implications for aquaculture that should be taken into account in developing future plans for the industry.

The marine cultivation of salmonids currently depends on the production of smolts from freshwater. Some of this production comes from Irish lakes. Since lakes are subject to warming, the long-term supply of smolts from these lakes may be compromised. A need for additional imports of smolts could result in increased production costs as well as a risk of importing salmonid diseases[76].

Cultivation of salmonids in shallow bays may be affected by spells of warm weather resulting in exposures to higher water temperatures and UV radiation, thereby promoting a move towards cooler, more open-water cultivation. Engineering of new cage designs may enable economic cultivation farther offshore but servicing costs will increase accordingly.

All evidence suggests that during warm summers the recruitment of many commercially managed invertebrates is enhanced. Multi-species spawning events can be triggered by increased insolation. Consequently, increased sea temperatures may result in more favourable conditions for the recruitment of some species. However, prolonged spawnings could also present marketing difficulties for

[75] Alabaster, J.S. & Lloyd, R. 1980. Water Quality Criteria for freshwater fish. Butterworths, London 297pp.
[76] Marine Laboratory Aberdeen, 2001. Epizootiological investigations into an outbreak of infectious salmon anaemia (ISA) in Scotland. FRS marine Laboratory Report No 13/01.

certain cultivated molluscs (i.e. mussels *Mytilus edulis*).

Changes resulting principally from coastal erosion and pulsed discharges from flood events may result in some areas becoming less suitable for molluscan culture. On the other hand, in some bays, and in the longer term, species such as the Pacific oyster *Crassostrea gigas* will be capable of generating recruiting populations, providing a cheaper source of spat. Already small numbers of this oyster recruit in south and west coast bays.

Summer mortalities of Pacific oysters, first noted in 1993 and associated with high temperatures, may become more frequent resulting in production problems. The cause of the mortalities in Ireland remains unclear. Elsewhere a relationship with warmer conditions and northward range extensions for some oyster pathogens are suspected[77].

Stress to farmed fish as a result of climate change (e.g. increased temperatures) could prolong infestations of pests, parasites and diseases. Pest species, parasites and diseases associated with more southern climes may begin to appear.

4.4 The overall position

A summary of predicted impacts of climate change on Ireland's marine environment and their principal effects is given in Box 4.

[77]Cook, T., Folli, M., Klinck, J., Ford, S. & Miller, J. 1998. The relationship between increasing sea surface temperatures and the northward spread of *Perkensis marinus* (Dermo) disease epizootics in oysters. *Estuarine and Coastal Shelf Science* 40: 587-597.

Box 4: Summary of predicted changes and impacts

The main concerns relate to changes in shore topography and inundations, especially from storm surges, as well as alterations to recruitment, growth and replacement of renewable aquatic resources. Extreme events are likely to occur more frequently and there will be a gradual underlying trend of ecological change brought about by increasing seawater temperatures. The predicted rate of change is speculative but if current predictions are correct there will be significant increases in sea temperatures to the south and east of Ireland by the middle of the present century. Predictions of climate-induced impacts on Ireland's marine environment stem from the following assumptions:

- Atmospheric warming, driven primarily by emissions of carbon dioxide (CO_2) to the atmosphere, will continue;
- Temperatures on land by 2055 will show increases up to 1.5°C in winter and 2.0°C in summer;
- A conservative estimate of change in average rainfall by 2050 is for an increase of +10% in winter and -10% to -40% in summer (greatest decrease in the south-east);
- An increase in sea levels similar to the global mean prediction of 0.49 + 0.08m by the end of the century (see section 4.2); and
- An increase in the number of extreme events (e.g. more intense storms, hotter summers);

The effects of these changes on Ireland's marine and coastal areas are likely to include:

- Increased intensity of storms combined with changes in sea level leading to wave damage on soft shores, increased seasonal flooding and inundation of low-lying areas, interference with coastal developments and infrastructure and disruption of coastal habitats and fish nursery areas; increased storm intensity may also have implications for the design of aquaculture installations/offshore platforms as well as for maritime transport, navigation and marine search and rescue operations;
- Reduced number of commercial fishing days in winter;
- An increase in mean seawater temperature leading to northerly shifts in the ranges of planktonic and other species, including migratory fish (e.g. pilchard, breams), enhanced recruitment of some native (e.g. mullet, bass) and non-native cultured species (e.g. Pacific oysters) and a decline in some wild populations (e.g. salmonids);
- In regard to biodiversity, species losses and new arrivals due to shifts in biogeographical range and greater incidence of invasions of non-native species;
- Increases in phytoplankton biomass throughout the year, changes in the timing and intensity of spring algal blooms and the structure of zooplankton communities with as yet unknown, but potentially substantive, consequences for marine food chains;
- Elevated summer and winter temperatures in shallow bays and inlets with corresponding changes in the structure and stability of marine plant and animal communities; and
- Changes in near-shore salinities, sediment loading and distribution due to alterations in river discharges and increasing sea level with potentially negative consequences for near-shore seafood production (e.g. aquaculture, nursery areas, traditional shellfish beds);

Climate is fundamentally important for the stability and maintenance of populations and food chains. Changes in climate will result in altered physical conditions that will include water circulation, stratification and nutrient supply. These effects may result in permanent or temporal changes to existing and evolving niches such as nursery areas and will either exclude or encourage species on the fringe of their natural distributions.

5. Implications for management of marine areas and resources

5.1 The case for action

It is important to recognise that an adaptive response to climate change, taking into account the uncertainties of current predictions, needs to be developed as soon as possible. The commitment given in the national strategy to controlling greenhouse gas emissions is necessary but there can be no assurance that such measures will indeed slow or reverse the changes that are now apparent. By being well prepared to make the necessary adaptations in environmental management and resource use, to an extent Ireland can mitigate or adjust to the more negative effects of climate change, should they occur.

A national response to climate change needs to embrace a range of policy, management and planning initiatives in addition to a strategy for the control of greenhouse gas emissions. It must be informed by a programme of scientific measurements and research to more accurately define trends in marine climate and associated responses of marine ecosystems, especially changes that affect productivity and diversity. To maximize its relevance to Ireland, this science programme must comprise both indigenous and international components.

It is imperative to incorporate climate change scenarios into all medium and long-term development and infrastructure plans. In parallel,

- **it will be necessary to establish a programme of scientific measurements and research to more accurately define trends in marine climate and associated biological responses, building on international programmes (e.g. EuroGOOS/GMES);**
- **the scientific programme should have indigenous and international components and contribute to improved climate models and predictions;**
- **the output from scientific measurements and research should be coupled to an ongoing review process that will translate scientific findings into management action; and**
- **management actions will need to embrace species and habitat conservation, coastal land use and protection, new approaches to aquaculture and fisheries, as well as marine safety and navigation issues.**

5.2 Key issues to be addressed

Physical parameters

There is a lack of good quality observational data required to track changes and to improve modelling and predictive capabilities. In general, records are too patchy i.e. too short and/or monitoring stations too widely spaced. A co-ordinated programme is required to extend measurements of basic marine climate indicators such as sea surface temperature, wind speed and direction, wave height, sea levels[78] and salinity both in space and time. While there are good records from land-based weather stations, there is a serious shortage of information on conditions at the coasts and offshore. The networks of data buoys and tide gauges need to be extended to provide greater resolution of sea conditions around Ireland.

Information on the characteristics of coasts exposed to the greatest fetch, waves and tides, low-lying areas most at risk from flooding and erosion, and physical changes to coastal areas and habitats, needs to be collected and reviewed on a systematic basis, taking into account climatic variations. This information will be valuable to local agencies and interests involved in the development and management of coastal areas and for purposes of Integrated Coastal Management (ICM) projects and County Development Plans.

A complete and accessible archive of marine climate and coastal zone data is a high priority. This should include data from dedicated surveys, ships, buoys, weather stations, research cruises and so forth. A permanent, managed and accessible national marine data archive, linked to similar European archives, should be established as soon as possible. Information from the archive should be made available free of charge to recognized scientific institutions and research groups. Regular bulletins summarizing patterns and trends in marine climatic conditions and tools for assessing and adapting to climate change, similar to those produced by the UK Climate Impacts Programme[79] should be made available to Planning Authorities.

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[78] A national network of tide gauge stations is currently being put in place by the Marine Institute.
[79] www.ukcip.org.uk

Marine Data Repository

The Marine Institute is making progress with regard to the publication of an online catalogue of datasets (www.marinedataonline.ie) and the establishment of a centralised repository of marine data holdings. The initial focus is on integration of physical oceanographic data with the intention of including biological data at a later date. Once integration has been achieved, the results of analysis will be integrated for further dissemination, e.g. monthly climatologies, distribution maps, etc. Links are being forged with similar initiatives throughout Europe via the SeaSearch consortium (EU funded Concerted Action). In addition the Marine Institute has adopted a Data Policy which provides a clear framework for the provision of data to end users (http://www.marine.ie/online+services/data+services/data+policy/index.htm).

Biogeography and species abundance

Trends in biological diversity and aquatic living resources are seldom predictable because these entities are subject to a wide range of human and other influences apart from climate change. To ascribe the dynamics of populations to climate alone is to dismiss the effects of wastes, dredging, fishing and other activities and the subtle influence of trophic interactions. The implications of climate change for living marine resources will principally relate to the impacts of increased temperatures, especially winter temperatures, allowing species intolerant of cold conditions to both survive and spread. There are also expected alterations to seasonal water runoff due to increased winter precipitation, dryer summers and extreme events such as severe storms. However, both cold events and hot spells, even though infrequent and of short duration, can also be important in regulating species distributions. Consequently, more information is needed on the biogeography of species in relation to climate change. This is addressed in part by the UK/Irish MarClim Programme (See Annex II). A recent contribution[38] to the MarClim Programme contains a detailed discussion of the potential effects of climate change on marine life of Britain and Ireland, based on temperature tolerances of different life stages. The overall conclusion of this study is that in warmer seas more species are likely to be gained than lost.

Knowledge of Ireland's marine biota is far from complete; new species continue to be described. Much of our existing knowledge has been gained from detailed surveys of specific areas such as Bantry Bay, Clare Island, Galway Bay, Lough Hyne, Mulroy Bay and Strangford Lough and special fishery research programmes and diving surveys. This patchy knowledge of biodiversity hampers abilities to predict and evaluate future changes to marine communities and to identify management priorities. Ireland, through its ratification of the International Convention on Biological Diversity[80] , is required to establish and maintain such records.

Several marine species are likely to expand their ranges further northward in Europe and some of these may reach Ireland. However, it is unlikely that their arrival will be due solely to changes in climate. The transmission of those without long pelagic life-stages over long distances may be dependent on carriage by ships or aquaculture products. This process will almost certainly result in additions of species to many localities. Movements are likely to include species native to continental Europe, but not yet present in Ireland, as well as non-native species such as the semi-tropical barnacle *Balanus amphitrite*, recruiting off the Belgian coast and known from ships and small craft arriving in Ireland. This barnacle and some other species could become significant fouling organisms on Irish shores. Areas most susceptible to colonisation will be shallow, sheltered coastal inlets. Reductions in the ranges of some more northerly (boreal) species will lead to a loss of some biota from Ireland.

There is a need to extend biological surveys - both in space and time - particularly of tidal and shallow-water communities where the earliest arrivals may be detected. A national inventory of marine flora and fauna should be established and adequate taxonomic training provided for this purpose. This work should build on past surveys such as the EU-funded BioMar project[81] that identified primary sites for biodiversity study

[80] Anon., 1998. National Report, Ireland: First National Report on the implementation of the Convention on Biological Diversity by Ireland. Department of Arts, Heritage, Gealteact and the Islands, Dublin. 120pp.
[81] www.ecoserve.ie/biomar/index.html

(Lough Hyne) and reference sites (Clare Island, Dublin Bay, Kenmare River, Kilkieran Bay, Mulroy Bay and Saltee Islands). Other sources of information include the MarClim project[96], the Atlas of Seaweeds of Britain and Ireland[82] and the Continuous Plankton Recorder (CPR) database[83].

Studies in Ireland of species whose occurrence and recruitment are likely to be influenced by climate change, and are under systematic examination at other European sites, should be encouraged. Recruitment and growth of some coastal species such as the grey mullet would appear to be related to temperature and would provide useful, cost-effective indices of climate change[84].

The frequency of appearance of vagrant fish, turtles and oceanic drift species should be catalogued and where possible related to other European data sets. Such occurrences provide long-term qualitative trends that may be related to altered combinations of wind, current and temperature patterns. Whereas there have been significant changes over time in the recording of vagrant species, partly resulting from better communications, such qualitative records provide valuable information. Unusual specimens captured by fishermen and aquarium operators should thus be systematically recorded.

> ***"Changes in the plankton will almost certainly have huge implications on commercial fisheries and so will have accompanying economic implications"***
>
> Science, 10th September 2004

Fishery resources

As a result of fishing intensity, many commercial fish stocks in Irish waters are harvested unsustainably and are at risk of suffering reduced reproductive capacity[85]. Climate change may have important impacts on the recovery of such stocks. At present, for example, Irish Sea cod stocks are in decline while at the same time there are notable northward shifts in planktonic species on which young cod feed; there are indications that replacement food species from the south may be less nutritious. Such northward movements in plankton may precede the more frequent appearance of fishes with more southerly distributions, presently appearing as by-catch, which could be the basis of future Irish fisheries (i.e. pilchard, breams, horse mackerel, red mullet, cuttlefish etc.).

Changes in marine climate will affect fisheries in other ways too. Stocks of commercial seafood species, for example, especially those having life stages in shallow water, are likely to be modified through changes in spawning time, appearance of larval and juvenile stages in relation to plankton succession, and physical and biological changes in nursery areas.

To monitor such changes it is recommended that young fish surveys used to assess stocks of plaice and gadoids should continue to embrace non-commercial by-catch species. The biomass of species such as red mullet *Mullus surmulletus* and various cephalopods may provide indices of change for little extra effort and, in conjunction with historical records, could be the basis of long-term time-series datasets. Pilchard may replace herring as a resource; monitoring the presence of both these species is advised as their occurrence in Irish waters has been cyclical. The use of plankton recorders during young fish surveys would help to elucidate the relevance of changes in plankton communities to year-class strength of commercial species.

Changes in freshwater discharge from rivers, increased turbidity and sediment transport will influence estuarine and shallow water nursery areas. For selected nursery areas, detailed records of freshwater inflows, temperature and salinity patterns, turbidity, bathymetry, substrate composition and benthic communities (especially seagrass beds) should be maintained through a combination of surveys and automated measurements. The current programme of insertion of fish passes[86] capable of recording salmonid movements and environmental parameters[87] is to be encouraged; further units could be built into new bridge sites. With regard to shellfish, studies of molluscan recruitment using settlement plates and collectors could provide a useful means of assessing variability in year-class strength.

[82]A Check-list and Atlas of the Seaweeds of Britain and Ireland (2003). Hardy, G and M.D. Guiry. Published by the British Phycological Society.
[83]www.sahfos.ac.uk
[84]Boelens, R.G.V., Gray, J.S. & Parsons, A.P., 2003. Review and Evaluation of Marine Environmental Impact Indicators and their Application in Ireland (DK/01/06). Marine Institute, 156pp.
[85]Anon. (2004): ICES Advisory Committee for Fisheries Management, ICES Advice 2004.
[86]www.marine.ie/scientific+services/monitoring/burrishoole+fish+census+/index.htm
[87]www.gft.ie

It seems likely that climate change will have less impact on deep-sea biota than on more coastal species, except perhaps where a life stage occurs near the sea surface. However, it is evident that during seasonal migrations there will be alterations to the residence time of some species off the west coast of Ireland.

Species introductions

Warmer seawater, and generally improving water quality in ports and harbours, will favour the establishment of species inadvertently introduced by shipping and aquaculture, as well as species that extend their ranges into Irish waters as a result of climatic changes. Some introduced species may have potential to displace indigenous species and/or to modify the structure or stability of established communities. Whereas in the past certain introduced species were unable to breed, changes in marine climate may allow such species to extend beyond their founder populations.

Entry points are likely to be sheltered estuaries, bays, inlets and natural harbours where ports, marinas and aquaculture practices exist. Until there is sterilization of ships' ballast water there will continue to be extensive transmissions of microbes and other biota and it is likely that hull fouling of both ships and leisure craft will remain a means of species transmission. Ireland should continue to contribute to international research and study groups established to address the problem of species transfer by shipping.

Regulation and, where relevant, use by industry of Codes of Practice[71] for the importation of aquatic living products, will considerably reduce the risk of non-native species becoming established. The potential effects on native species must also be taken into account. Public awareness of the supply chain for living organisms would enable more effective control. This could be accomplished through leaflets disseminated as part of coastal area management plans and programmes. The information provided needs to be reliable, up-to-date and should include the rationale for regulatory activities.

Port regions and areas where aquaculture products may be imported should be regularly examined for invasive species likely to colonise Irish waters. A vector analysis of transmission processes should be undertaken so that effective protocols for protecting the marine environment from harmful species can be developed and implemented via a standing national (i.e. multi-sectoral) invasive species forum.

Species for future cultivation

In view of the predicted rise in sea surface temperatures, there is good reason to review the suitability of species currently used or proposed[88] for aquaculture as well as the responses of pests and pathogens that can reduce aquaculture efficiency or productivity.

It would be prudent to examine high value species whose cultivation might become economically feasible either as a supplement or replacement for salmonid farming and to develop further mollusc cultivation opportunities. According to past experience, the time required in Ireland to bring previously uncultivated species to the level of commercial production may be considerable, depending on local conditions, development of expertise and perceived benefits of investment. For these reasons, trials with species that have potential for cultivation under various predicted marine climate scenarios should commence as soon as possible. In the case of imported species, it is imperative that assessment of the suitability of a species for culture in Ireland includes its potential for interaction (e.g. competition, predation etc.) with native species following either intentional or accidental release.

Based on the most recent information concerning likely future temperature regimes, species considered for cultivation should include those successfully cultivated further south e.g. in France (turbot *Psetta maxima*, bass *Dicentrarchus labrax*). Cod *Gadus morhua* and halibut *Hippoglossus hippoglossus*, currently under consideration for cultivation[88], could be compromised by increased seawater temperatures unless some new technology enables them to be cultivated in cooled water.

The diversification of shellfish species through aquaculture has been identified as an important objective for Ireland. The development of culture techniques for molluscs should be seen as a high priority to reduce dependency on oyster and mussel cultivation. For example, a species such as the clam *Nuttalia obscura*, a sediment-dwelling bi-valve, might be considered a potential candidate for development. Historically there have been serious declines in the production of different species of oyster. In warmer seas, Pacific oysters are likely to develop natural settlements that may compete with, and locally exclude, native oysters.

With regard to cage culture, it would be advisable to improve knowledge concerning the occurrence of gelatinous zooplankton and harmful algal events and to develop protective measures for reducing mortality. These matters may be of particular importance should cage culture of fish take place in offshore waters.

Caution regarding the control of pests, parasites and diseases is essential, especially in relation to stock movements. In the context of a changing European climate, and opportunities to develop new species for aquaculture, consideration should be given to the establishment of quarantine facilities suitably placed according to relative freedom from pests and pathogens. This would help in providing reliable, good quality stock to Ireland and other EU countries within similar climate zones. Such a facility could also be used to quarantine marine organisms for biotechnology purposes. Ireland may be a suitable location for a facility of this kind.

Marine environmental monitoring

An important consideration in the design of marine environmental monitoring programmes is the possibility that the characteristics of marine ecosystems could change significantly over time as a result of changes in climate. This will accentuate the problem of assessing trends in environmental quality as required by various national and international programmes. The recently introduced EU Water Framework Directive (WFD)[89], for example, requires monitoring to determine the ecological status of waterbodies (including estuaries and coastal waters) in relation to pre-selected reference values representing unperturbed conditions. If the 'baseline' conditions were to change to a degree, or at rates, beyond those normally expected from natural variation, it may be very difficult to assess compliance with the Directive.

For this reason it would seem sensible to build climate change indicators into the WFD and national marine monitoring programmes, to ensure that sufficient sites remote from human interferences are sampled and that the data are assessed regularly for trends that might be associated with key climate variables such as sea temperatures and the NAO index. Results from WFD monitoring should be integrated and assessed, as appropriate, with data from other monitoring and research activities including routine meteorological measurements obtained from buoys, satellites and research vessels.

[88] Anon., 2003. Report of the aquaculture working group on new species development. Department of Communications, Marine and Natural Resources, 56pp.
[89] EU, 2000. Directive of the European Council and of the Council 2000/60/EC establishing a framework for Community action in the field of water policy, 62pp + annexes.

6. Recommendations

> ***"Where there are threats of serious or irreversible damage, scientific uncertainty shall not be used to postpone cost-effective measures to prevent environmental degradation"***
> **1992 Rio Declaration on Environment and Development**

Although there will always be an element of uncertainty regarding the precise nature and rate of change to Ireland's marine environment due to alterations in climate, in the absence of policies and measures to prepare for and accommodate the changes even the more moderate of the predicted scenarios would have major social and economic impacts.

> ***A co-coordinated national climate change impacts programme to improve knowledge of the changes, and to manage their effects, should be a matter of priority.***

The programme should be prepared and implemented jointly by agencies and organisations with interests in, and responsibilities for, Ireland's marine and coastal environments and renewable marine resources.

The most authoritative basis for assessing the nature of climate change and managing its impacts is the output from mathematical models that simulate past climate patterns and predict future trends. The reliability of such models depends on the availability of time-series measurements of relevant climatic variables in the regions concerned. The longer and more complete the records, the more reliable the models will tend to be. There are significant gaps in the records at national and regional levels and these account for much of the uncertainty associated with current model predictions. In order to improve the basis of model predictions there is a need for concerted action designed to extend the measurement of key climate variables and indicators building on the relevant international plans and programmes (e.g. EuroGOOS/GMES).

Changes in climate could affect, *inter alia*, seafood production, water management and coastal land use. Impacts in one European region could have repercussions in other parts of the European Union. For this reason, strategies for mitigating and adapting to the negative effects of climate change on marine resources, and related scientific investigations, should be integrated as and where appropriate with those of other EU states. In this context, monitoring to measure changes in key marine climate indicators should be integrated with relevant European programmes to which Ireland could make a useful contribution. For a relatively small investment, Ireland can benefit substantially from collaboration with overseas institutions that have well-established climate research programmes and predictive modelling capabilities and by engaging with GMES development and implementation.

Initially, the effects of marine climate change will be most apparent in low-lying coastal areas exposed to Atlantic storms, in the estuaries of major west-coast catchments and in sheltered, shallow coastal waters with restricted water exchange. Resource inventories for areas with these characteristics, spanning both terrestrial and aquatic parts of the coastal zone, should be prepared as an initial step in developing appropriate monitoring programmes and management strategies.

In the absence of long-term, noise-free marine biological data sets representing climatic effects alone, most predictions concerning biological changes are based on reasoned deductions. Studies are needed to improve knowledge of biodiversity in important marine habitats and to better understand natural cycles of production, recruitment and succession, especially of species that have a definitive role in community structure. Parameters investigated should be sensitive to environmental variations induced by changes in marine climate. Changing patterns of precipitation resulting in periods of rapid freshwater runoff will affect the marine environment; impacts may include high turbidity, changes in salinity and heat transfer. Accordingly, monitoring studies need to embrace both freshwater and marine systems so that changes within river catchments can be linked to changes in estuaries and coastal waters. These and other climate change impacts should be incorporated into river basin management plans being developed under the EU Water Framework Directive.

The information summarised in this report concerning potential climate-induced changes in Ireland's marine environment, and their effects, would firmly support an enhanced profile for climate research in Ireland's marine science programme. In view of the possibility that the rate of change could be more abrupt than envisaged by the current generation of global and regional climate models, possibly due to a weakened Gulf Stream *(see Introduction)*, the adequacy of the programme in terms of the collection of basic data on climate indicators should be reviewed as a matter of urgency. Programme elements that warrant particular attention are as follows:

Policy / Management

i. The predicted effects of climate change should be incorporated as a major consideration into County Development Plans, including coastal zone management plans *(see, for example, UKCIP, Annex I)*.

ii. The marine manifestations of climate change should be taken into account in implementing the Water Framework Directive (e.g. effect of inter-annual variation on reference values) and the design of the national marine monitoring programme, taking into account the aims of the EU Global Monitoring for Environment and Security (GMES) Programme.

iii. Establish ad hoc expert groups to advise the government of findings from marine climate research, as well as key issues arising from such research, related environmental and socio-economic implications and necessary management and policy responses.

iv. Strengthen and extend strategic partnerships with research institutions, particularly in other European and Atlantic-boundary countries, focusing on actions that will provide a) early warnings of marine climate anomalies indicative of regional change; and b) specialist training in order to improve national capabilities for predicting and managing change and response in marine ecosystems.

v. Develop and implement a national strategy and risk assessment procedure for combating marine species introductions likely to become established as a result of changes in climate; investigate the potential of non-native species for use in aquaculture; promote and facilitate the preservation and reporting of non-indigenous fish and invertebrates captured in nets and identified in surveys of coastal habitats and underwater structures.

Science

vi. Develop a comprehensive inventory of coastal features (e.g. morphology, habitats, coastal infrastructure, human settlements etc.) to assess vulnerabilities to climate-related pressures (increases in storminess, sea level, flooding erosion etc.) and thereby to identify associated coastal management priorities and policy issues.

vii. Recognizing that time-series data are the basis of climate models, give greater priority to time-series measurements that will allow the detection and quantification of seasonal trends in sea-surface temperatures, primary production, salinity, currents and wave climate in the sea areas surrounding Ireland; some key actions in this regard are given in paragraphs ix and x below.

viii. Extend the network of automated monitoring stations for sea temperature, salinity, wind strength, wave height and sea level and improve capacities for evaluating these data.

ix. Provide increased support to SAHFOS[90] to extend sampling of plankton in Irish waters and to identify abnormalities in primary and secondary production that may be indicative of changes in sea temperatures, frontal systems, circulation or other oceanographic features.

x. Establish a marine climate data archive, combining both historical and new information of relevance to the tracking of changes in marine ecosystems, under the auspices of an agency or institute that can ensure long-term storage, security and accessibility of the data. The archive should be continuously managed to optimise its utility for research, modelling and management purposes and be linked to other European marine data centres and climate change institutes.

xi. Intensify measurements of deep ocean currents to the west and north of Ireland as a contribution to scientific understanding of oceanic thermo-haline circulation.

[90] Sir Alister Hardy Foundation for Ocean Science

Acknowledgements

An early draft of this Report was presented to an invited Workshop held in Galway on 21st April 2004. The Workshop was attended by representatives of various State and Third Level Research and Development Institutions/Agencies and other interested parties. The authors would like to express their gratitude to the positive and helpful remarks and comments received at this Workshop.

A special thanks is due to those who submitted comments/clarifications in writing including Frank McGovern and Brendan Kelly (EPA), Rowan Fealy (NUI, Maynooth), Evelyn Murphy (Met Éireann), Liz Sides (NPWS), Bob Devoy (UCC), Fran Igoe (SRFB), David Jackson, Terry McMahon, Glenn Nolan, Brendan O'Hea, Russell Poole, Joe Silke and Jonathan White (Marine Institute). A special thanks to Jenny O'Leary and Deirdre Fitzhenry of the Marine Institute for their assistance in bringing this report to completion.

Annex I:

Selected Organisations involved in Climate Related Research

Met Éireann

Repeated long-term measurements of sea conditions are essential for assessing and predicting climate change and its significance for the marine environment. Met Éireann maintains records of marine observations made around Ireland over the past 100 years, mostly from ships. Observations consist of visual reports of sea height, sea direction and sea period, swell height, direction and period, wind speed and direction, cloud type, amount and height, visibility and general weather such as fog, rain, snow etc., and measured observations of pressure, air and sea temperature. Met Éireann also records climate parameters from its 5 coastal stations, some Commissioners of Irish Lights lighthouses (visibility), the AWS on Dun Laoghaire east pier (winds, temperature, pressure, humidity and rainfall) and from the Marathon Gas Platform (winds, waves, water levels, visibility, pressure and temperature).

Increasingly over the past 10 years, human observers are being supplemented by automatic systems that compile the information from sensors and send it to Met Éireann via satellite.

In 1999 an Automatic Weather Station was placed on board the Marine Institute's RV Celtic Voyager. This sends hourly observations of wind speed and direction (corrected for the motion of the ship), air pressure, characteristic and tendency (drift direction), air and dew point temperature and sea temperature to Met Éireann by satellite. In 2000, the first in the series of 5 data buoys was positioned ~60 miles west of the Aran Islands. Three other buoys have since been positioned in the Irish Sea, off the north-west and south-west coasts, and a 5th buoy installed off the south-east coast during 2004. The buoys report hourly measurements of wind speed (mean and gust), wind direction, pressure and pressure characteristic and tendency, temperature (air, sea) and dew point calculated from relative humidity, significant wave height and wave period. Eventually all buoys will have the added capability of measuring oceanographic parameters (current speed, temperature and salinity) at selected depths. Real-time hourly buoy observations are available from the Met Éireann[91] and Marine Institute[92] websites.

Met Éireann also participates in international marine data recording programmes including the European Group on Ocean Stations (EGOS), which deploys both drifting (expendable) and moored buoys in the North Atlantic, and the Data Buoy Co-operation Panel (DBCP) coordinated by WMO and IOC.

The Community Climate Change Consortium for Ireland (C4I) became operational in Met Éireann in April 2003. C4I uses a Regional Climate Model (RCM) to dynamically downscale the relatively coarse-grained information produced by global climate models. The RCM is validated by running simulations of the past climate and comparing the output against recorded observations. The process produces a description of the atmosphere on a three-dimensional grid covering Ireland and the Atlantic area with a typical horizontal resolution of 15km and includes detailed information on a wide range of surface parameters. Simulations of the future global climate, based on different scenarios of GHG emissions, will be similarly used by the RCM to provide regional detail on future climate change.

National University of Ireland, Maynooth (Dept. of Geography)

The Department of Geography at NUI Maynooth continues to play a leading role in assessing climate data and using output from Global and UK climate models to predict likely changes in Ireland's climate and the potential impacts on water resources, agriculture and industry. For purposes of the recent report[5] on climate change impacts, the researchers applied a technique for downscaling the coarse-scale climate simulations generated by global climate models (GCMs) to provide high spatial scale resolution scenarios that project likely changes in Irish climate based on 1961-90 averages.

At present the Department is not researching aspects of the offshore environment but is interested in climatic aspects such as storminess and sea surface temperatures. Some downscaling possibilities exist in these areas for which the university would have access to the relevant model output and other datasets.

[91] www.meteireann.ie
[92] www.marine.ie/databuoy

University College Cork (UCC)

UCC is currently engaged in a variety of mainly international projects to investigate physical aspects of climate change such as storminess, coastal sensitivity and sea-level changes. The projects include the collection of primary sedimentary and hydrodynamic datasets to aid in the study of coastal processes out to the 50-60m isobath. Other projects extend to the slope and shelf margins where significant progress has been made in understanding shelf stability, evolution, tsunami susceptibility etc. This shelf work is, in turn, linked to studies of climate-related studies such as the characterisation of wave-energy changes caused by increased storminess and production of the Hind-cast Wave Atlas of the Irish and Celtic Seas **(Hipocas)**. These projects are based essentially on General Circulation Models (GCMs) and downscaling modelling techniques.

National University of Ireland, Galway (NUIG)

There is increasing interest in climate change issues such as global warming, intense flooding occurrences, coastal erosion, melting icepacks, sea surface rises etc. Studies of climate change topics have had a long tradition at the National University of Ireland, Galway. These studies received added impetus in 2000 through successful funding for the establishment of the Environmental Change Institute through the Programme for Research in Third Level Institutions. One of its seven clusters is that of Climate Change whose goals include the enhancement of high quality basic research into climate change. The climate change projects include:

1) studies of sources and variability of atmospheric aerosol particles which predominately have a cooling influence on our climate;

2) radiative properties of aerosol particles;

3) methane isotopic studies and methane source emissions;

4) renewable biological energy generation (methane) from organic wastes and waste waters;

5) effect of climate on rainfall extremes; and

6) investigation of the greenhouse effect in the middle atmosphere

The first three projects are centred at the Mace Head Atmospheric Research Station, near Carna on the west coast of Ireland[93]. Observations from there of the 3 main greenhouse gases (carbon dioxide, methane and nitrous oxide) show a continuing upward increase in concentration (of order 0.4% per annum) since records began there from 1987. There is also evidence of reductions in the chlorofluorocarbons (CFC's) over the past several years, showing the impact of the enforcement of the Montreal Protocol, with a concomitant increase in concentrations of their substitutes, the halofluorocarbons (HFC's). Recent work has shown the importance of biogenic iodine emissions from marine algae on aerosol formation, and that such emissions have potentially a significant effect on global climate forcing.

The Environmental Change Institute (ECI) has a large complement of researchers and receives continuing financial support. A recent success has been the establishment of the Geographical Information Systems (GIS) centre, with its own satellite High Resolution Picture Transmission (HRPT) satellite receiver, acquiring several satellite images daily from the NOAA AVHRR sensors and from SEAWIFS. A Remote Sensing Research Group has been set up to analyse and validate satellite radiance imagery, from observations at Mace Head. A Climate Change Modelling Group has recently been set up within the ECI to implement aerosol and cloud modules, including chemical transport schemes, into a Regional Climate Model and to evaluate the effects of aerosols and clouds on regional climate change. This work is linked to the C4I Project (Community Climate Change Consortium for Ireland) and to the Regional Climate Analysis, Modelling and Prediction Centre located at Met Éireann.

[93] http://www.macehead.nuigalway.ie

UK Climate Impacts Programme (UKCIP)[94]

The UK's Climate Impacts Programme (UKCIP) was established in 1997 to help organisations identify how they will be affected by climate change and prepare adaptation strategies. The programme combines the capabilities of the Meteorological Office's Hadley Centre for Climate Prediction and Research with those of the Tyndall Centre for Climate Change Research based in Norwich (9 different institutions contribute to the work of the Tyndall Centre).

UKCIP operates a number of predictive models that, inter alia, yield predictions on aspects of marine climate such as sea level rise, storm surges, sea-surface temperatures and daily-average wind-speeds over ocean areas. It also produces technical papers on various aspects of climate change and publishes climate change scenarios for UK sea levels and marine climate[59]. In most cases the coverage includes Irish waters.

More recently UKCIP has produced a new tool for costing the impacts of climate change[95]. This tool provides a method to work out the costs of climate change impacts on an organisation, an event or an area. As well as introducing a method for valuing the impacts of climate change, it also shows how to compare these to the costs of adaptation, so that organisations can work out how much they will need to spend on adapting to climate change.

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[94] www.ukcip.org.uk
[95] http://www.ukcip.org.uk/news_dets.asp?news_id=8

Annex II:

Selected Climate Research Projects

MarClim

This 4-year project involves University College Cork, the Plymouth Marine Laboratory, the Scottish Association for Marine Science and the University of Plymouth and is led by the Marine Biological Association. It is designed to improve understanding of the impact of climate change on marine biodiversity[96]. It aims to make the best possible use of data held in Britain and Ireland on selected inter-tidal biota (indicator species), including some of the more temperature-sensitive species, in order to understand the climatically driven changes that may occur. Some relevant Irish datasets exist from Cork (Lough Hyne, Bantry Bay, Kinsale Harbour & Sherkin Island), Carnsore Point and Clare Island.

MONARCH

The implications of climate change were examined in the MONARCH project[97]. The purpose was to evaluate the direct impacts of climate change on natural resources of Britain and Ireland, from the land to the sea. Marine habitats of conservation value assessed as being vulnerable included those supporting the algae that produce maërl deposits and various worm reefs and horse mussel beds that are on the most southern fringe of their distribution in Ireland. Tidal flat areas for feeding birds were considered susceptible to change in the longer term.

JERICHO

The JERICHO[98] programme provides information to the UK Environment Agency on coastal wave climate and inter-annual variability essential to the planning of coastal defences. JERICHO is developing techniques, combining satellite data and models, to investigate the impact at the UK coast of a changing offshore wave climate. The programme has shown that satellite data can be used to monitor offshore wave climate but close to the coast (within 10-20 km) coastal wave models and *in situ* data are required. Presently, predictions of changes in weather patterns are not sufficiently reliable to enable confident projections of future coastal wave climate. Nevertheless, JERICHO has established techniques that will enable such projections once more reliable predictions are available. Meanwhile some "worst case scenarios" have been modelled. Coastal areas most likely to feel the greatest influence of future increases in wave climate are those exposed to the largest waves and areas with deep water close inshore.

CLIME: Climate and Lake Impacts in Europe

CLIME is an EU 5th framework project involving partners from ten countries. The primary aim of the Climate and Lake Impacts in Europe project is to develop a range of methods and models that can be used to assess the impact of present and future climatic conditions on lakes and catchments. The Marine Institute and Trinity College Dublin are the Irish partners. Long-term climatological data and water quality monitoring data are being collected as necessary inputs to Lake Catchment models.

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[96] http://www.mba.ac.uk/marclim/
[97] http://www.ukcip.org.uk/pdfs/monarch
[98] Institutes contributing to JERICHO include The Centre for Coastal and Marine Science - Proudman Laboratory and Halcrow Maritime (shallow water wave modelling); Southampton Oceanography Centre (analyses of large scale wave climate variability and computing support); Satellite Observing Systems (project managers, analyses of satellite and in situ data). JERICHO was supported by the British National Space Centre under the Earth Observation LINK programme.

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ISSN: 1649-590X