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Vulnerability of the North-East Atlantic Shelf Marine Ecoregion – Scoping

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1 INTRODUCTION

1.1 Scope of work

The purpose of this report is to present the findings of a preliminary study to assist in shaping the approach to take for a vulnerability assessment of the North East Atlantic Marine Ecoregion (NEAME) with respect to the potential impacts of climate change.

The study has looked to achieve the following:

1. Collation of climate change reports relevant to the region and its ecology.

2. Carry out a limited review of these reports to:

   - Determine what climate change assessment scenarios to use in the vulnerability assessment. This includes both the number of scenarios (e.g. United Kingdom Climate Impacts Programme (UKCIP) emission scenario's), and the characteristics of the scenario's (e.g. sea level rise and sea surface temperature increases) and appropriate time horizons;
   - Summarise what parameters models and existing scenarios present that could be used to quantify the characteristics incorporated into the assessment scenarios;
   - Identify and list the threats posed to the NEAME by climate change that should be incorporated into the assessment scenarios;
   - Determine an appropriate spatial scale for parameter quantification;
   - Formulate quantification of some of these parameters for the assessment scenarios where information is readily available and consensus apparent;
   - Highlight potential key parameters for which there are little data or consensus; and
   - Consider whether a catastrophic scenario should be included in the assessment.

3. Compile a list of workshop invitees for a subsequent 2 day meeting to discuss the impacts (sourced from International Council for the Exploration of the Seas (ICES), climate change research centres and key govt/non-govt organisations).

1.2 Climate Change Models

Climate prediction models are powerful tools which enable prediction and enhance understanding of both global climate systems and change. However, due to the sheer complexity of the Earth’s climate, many scientific uncertainties exist regarding the ability of models to simulate scenarios involving ocean characteristics and also present a range in the predicted values of change. A principal reason for this lies in our incomplete knowledge of the key physiological, chemical and biological processes within the climate system itself.

In order to carry out this vulnerability assessment, we have, through a review of published predictions, identified a broad consensus of which characteristics of climate change would be appropriate to consider further. We have rationalised these characteristics and the time horizons to which they refer through consideration of their relevance to:

- Rate of climate change;
- Ability to measure these changes;
- Predictability; and
- Ecological relevance.

As such we have considered the following models and their predictions:

- Hadley Centre models (which UKCIP maintain provide superior ocean resolution to other models covering the same region);
- ECHAM (developed in Germany);
- CGCM2 (developed in Canada);
- NCAR1 (developed in USA);
- ESCAPE (for predicting sea level rise in the UK and Ireland);
- JERICHO (Joint Evaluation of Remote Sensing Information for Coastal and Harbour Organisations) that involves modelling of the coastal wave climate and inter-annual variability around the British coast
- WASA (Waves and Storms in the North Atlantic), a wave forecasting model coupled with an atmospheric circulation model encompassing the entire North Atlantic;
- STOWASUS-2100 (Regional STOrm, WAve and SUrge, Scenarios for the 2100 century) that is similar to WASA that is based on 30-year long global simulations also includes the North and Norwegian Sea, indicates a tendency towards extreme wave heights in the North Sea; and
- Other more recent models such as CICERO and TEF-ZOOM.

1.3 Ecological effects of climate change

In spite of substantial effort being expended in developing and improving climate change models, it is only relatively recently that the implications for marine ecology are now beginning to be considered in detail (Hiscock *et al*., 2001 and 2004; Beaugrand *et al.,* 2002 and 2004; Reid and Richardson, 2004; GLOBEC, 2003; Edwards and Richardson, 2004).

This study looks to bring together the climate change predictions and ecological consequences of assessment together with the specific objective of assessing the potential threats posed to the marine ecology of the NEAME and determining the key risks posed to the ecology. A separate study has been commissioned by WWF to consider the socio-economic implications of these threats.

2 SYNOPSES OF CURRENT CLIMATE CHANGE MODELS

2.1 Inter-governmental Panel on Climate Change (IPCC)

In 1992 IPCC published six emission scenarios for the next 100 years, referred to as IC92 scenarios, predicting emission trajectories for greenhouse gases (GHG), CO, CO_2, CH_4, N_2O, NO_X and SO_2 by 2100. The IPCC Special Report on emissions scenarios (SRES), the present updated version of IS92, uses a multi-model approach, incorporating six models from around the globe developing 40 SRES scenarios. To facilitate comparison baseline time periods across all models was standardized. Four sets of scenarios labelled “families” and incorporating all scenarios were developed. Grouped under the A1 family (rapid convergent growth) are:

- A1B (a balance between fossil fuels and alternative energy sources);
- A1F1 (fossil-fuel intensive); and
- A1T (predominantly non-fossil fuel).

The remaining three families are:

- A2 (fragmented world: technological change slower, more fragmented);
- B1 (convergence with global environmental emphasis: emphasis on global solutions); and
- B2 (local sustainability).

The HadCM3 model was used to make future climate predictions of atmospheric concentrations of greenhouse gases and sulphur for A2, B2 and A1F1 while separate models were used to calculate GHG concentrations. Key physical parameters include temperature, GHG and climate sensitivity.

Parameters also incorporated into the models included demography, social, economic and technological change.

2.2 Hadley Models and UKCIP

UKCIP present four alternative scenarios predicting a reasonable range of possible future climates based on varying GHG emissions: Low, Medium-Low, Medium-High and High. UKCIP follow IPCC SRES ranges and so the emissions scenarios match the IPCC scenarios as follows:

- A1T, A1B and A1F1 are characteristic of low/medium-low, medium-high and high emissions respectively; and
- A2, B1 and B2 are characteristic high/medium-high, medium-low/low and medium-high/medium-low emissions respectively.

In addition UKCIP, as advised by IPCC, has not attached probabilities to scenarios.

Emission scenarios for UKCIP02 are exclusively based on Hadley models. HadCM3 is a coupled ocean-atmosphere global circulation model with a 1.25deg. x 1.25 deg. ocean horizontal resolution which indirectly drives two other models namely HadAM3H and HadRM3H. Future regional climate results can be interpreted on a 50km scale, and can also be interpreted on a 5km scale when combined with a 5km observed climate data set. The baseline time period ranges from 1961-1990; three different time slices used for future climate predictions are 2020s, 2050s and 2080s.

Key physical parameter inputs incorporated by the models include GHG, precipitation, CO_2, sea level rise, sea surface temperature, sea ice melt, cloud cover and sulphate aerosols. Variables include temperature, precipitation, seasonality, variability, cloud cover, humidity, snowfall, soil moisture, storm tracks and the North Atlantic Oscillation.

2.3 Other models

The **CGCM2** (Coupled Global Climate Model) model developed by the Canadian Centre for Climate Modelling and Analysis (CCma) is an updated version of the CGCM1. Components, which are coupled together in the model, include an atmospheric and ocean general circulation model, thermodynamic sea ice model and land surface model. A grid scale of 340km is used over North West Europe.

The USA’s Climate Modelling Initiative (CMI) has developed **MITgcm**, a numerical model designed for the study of the atmosphere, ocean and climate possessing a non-hydrostatic capability and so can be used to study both small scale and large scale processes.

The **IPSL-CCM2** coupled global circulation model was developed by Laboratoire de Météorologie Dynamique du C.N.R.S. in France.

ESCAPE (the Evaluation of Strategies to address Climate change by Adapting to and Preventing Emissions) was developed by the Dutch Institute for Environment and Public Health, Climate Research Unit of East Anglia and Oxford University. The emissions component is interpolated from **IMAGE 1.0** (Integrated Model to Assess the Greenhouse Effect) and coupled to other models including an atmospheric chemistry module.

STOWASUS-2100 (Regional STOrm, WAve and SUrge Scenarios for the 2100 century), an EC funded, Europe-wide climate change project. The aim is to study wave and storm surges to model present activity as well as the effects of doubling of CO_2 levels and hence predict the potential future wave activity in North Atlantic and European waters. The model is a coupled oceanic-atmospheric numerical model. The model is a continuation and uses results from **WASA** (Waves and Storms in the North Atlantic), a project set up to model worsening storm and wave activity in the North East Atlantic, which had used the output from a high resolution, namely T1O6 spectral truncation, climate change scenario experiment. Atmospheric models are also coupled with regional models of very high resolution such as **HIRHAM** and **BOLAM**.

Two relatively new storm surge models have been set up by CCMS-POL, for the North East Atlantic and European Shelf (**NEAC**) with a 35km resolution and for the North and Irish Seas and English Channel with a 12km resolution (**NISE**). Models use 26 tidal harmonics while open boundary surge input for NISE is derived from NEAC results.

ECHAM4 (EC HAMburg version 4) of the Max Planck Institute for Meteorology is a coupled atmosphere-ocean-ice model. Parameters include sea-ice, sea level data, terrain heights, CO_2 levels. Of late ECHAM4 has also used T106 high resolution data with a 30 year time horizon, six times longer than time simulations used in WASA. This reduces sampling error and therefore increases the level of confidence attached to simulations for storm prediction which STOWASUS currently use.

2.4 Model intercomparison

Model inter-comparisons have been carried out by the World Climate Reseach Programme under the Atmospheric Model Intercomparison Project (AMIP) to determine systematic errors of atmospheric models. CMIP (Coupled Model Intercomparison Project) is the analogue of AMIP for global coupled ocean-atmosphere general circulation models developed by WMO (World Meteorological Organization). UKCIP02 carried out global climate model inter-comparisons involving CCCma, CSIRO Mk2 (Australia), CSM 1.0 (USA), DOE PCM (USA), MPI DMI (Germany), GFDL R30c (USA), HadCM3 (UK), MR12

(Japan) and NIES-CCSR v2 (Japan) to illustrate the varying model responses to UK climate.

Outcomse of intercomparison have not been rigorously assessed during this scoping study. Instead, we have taken the approach of accepting the majority view and favoured following the UKCIP models but have attempted to also make reference to data and predictions where available.

3 SCENARIOS AND THEIR CHARACTERISTICS

For the purpose of this vulnerability assessment, we endeavoured to simplify and rationalise the assessment process by focussing on published information that would inform selection of criteria assessment based on:

- Scenarios that are considered to be likely (i.e. a high probability that they will arise and the quantification is considered to be accurate);
- Scenario characteristics that drive the majority of the threats to either the NEAME as a whole or its various elements;
- Consideration of concentrating on a single pair of scenario predictions to provide a simplified range of changes and thus a means of facilitating assessment of effects with a particular threshold (that may fall on or between the two chosen scenarios);
- Taking published advice on building scenarios; and
- Considering the benefit of including a doomsday scenario of a single but fundamental physical process.

UKCIP (UKCIP 2002) advocate the use of either all four scenarios though accept that applying just low and high scenarios would be feasible. The report also goes further in suggesting that studies with major policy recommendations or specific design criteria in mind should investigate predictions from other models. As such Table 1 includes reference to margins of uncertainty for precipitation and air temperature. Further consideration will be required to apply these to the marine environment before the vulnerability assessment is progressed.

On the recommendations of the UKCIP report, and also as a consequence of limited available information in other reports, applying probabilities to each scenario has been avoided. This is a consequence of not knowing what future CO_2 emissions might be and determining the likelihood of which emissions scenario is the most probable.

Through a collation and review of the many climate change reports and model outputs, those scenario characteristics present in Table 1 have been concluded to be those that are the greatest threat to the NEAME. The first column marks those characteristics considered to represent positive feedback mechanisms.

The scenario characteristics have been quantified, where information is available (and with qualifications), in terms of their possible magnitude and the timescale to which they refer. In carrying out the vulnerability assessment it will be necessary to focus on a limited number of characteristics and these are shown in bold. The following rationale has been applied in their selection ahead of others:

- That they are first order changes (i.e. those that are not a consequence of other characteristics);
- That they will be key drivers of impact to the fauna and flora of the NEAME;
- That their effects are reasonably well understood;
- They impact the key components of the NEAME ecosystem; and
- They may trigger positive feedback mechanisms with severe consequences.

In reviewing papers on scenario characteristics it has proved appropriate to rationalise the available information under the principal headings of:

- Weather conditions; and
- Physical and oceanographic processes.

A summary of the key findings of the reviewed papers are provided below and provide explanatory notes for the threats listed in Table 1 and Table 2.

3.1.1 Weather conditions

Changes in weather conditions are anticipated, corresponding to a growing number of mild winters associated with an increasingly positive North Atlantic Oscillation (NAO) index. This increase in the NAO index will be accompanied by changes in ocean surface climate, horizontal ocean circulation and deep water formation (GLOBEC, 2003). In the North-East Atlantic a positive index is linked with intense mid-latitude westerly winds, increased incidence of Atlantic storms and increased wave height (OSPAR Commission, 2000).

A positive NAO index and an increase in **mean wave height** in the North Sea were recorded from approximately 1960 to 1979/80 and in the North Atlantic from between 1950 to 1979/80 (Bacon and Carter, 1991). Further, wave heights in the North Atlantic recorded during the 1980s were higher than at any time in the previous century (Bacon and Carter, 1993). Results from WASA (Alexandersson *et al*, 1998) support these observations, linking wave height increase to the NAO. However, it was also noted that waves reached similar heights at the beginning of the 20th century. Associated with increased wave activity is a rise in **suspended sediments** in the water column of coastal environments (OSPAR Commission, 2000).

Further changes in the wind field with further sizeable alterations to **wind speed and direction** might be a consequence of climate change, for example, sizeable variation has been observed in North Sea Wind (Furnes, 1992). Should an increase in the intensity of westerly winds occur, there are likely to be knock-on effects with respect to water transport and distribution, vertical mixing and surface heat flux (Frid *et al* 2003). For example, it has been observed that the wind field influences inflow and outflow from the North Sea (Skogen *et al,* 1995). Associated effects include changes to cloud cover and light penetration into surface waters. For example, it ihas been suggested that for the east England coastal strip, there will be an increase in **solar radiation** and decrease in **cloud cover** between 10% and 20% along the east coast of England (Yorkshire Futures, 2002). Understandably, it has been noted that in combination, all these factors have a very important influence on productivity, recruitment and distribution of, for example, fish stocks (Svendsen *et al,* 1995).

Increased occurrence of **westward tracking storms** and an increase in the frequency of **storm surges** will be exacerbated by depressions crossing the northern Irish Sea and enhance storm surges in the eastern Irish Sea (OSPAR Commission, 2000).

3.1.2 Physical processes

Changeability in climate could affect the hydrography of the NEAME region in a number of ways. Changes to **ocean circulation** processes have a potentially fundamental and far reaching effect on the NEAME. However, the processes are complex, our knowledge limited, the potential responses to climate change are not understood and differentiating natural variation from climate change effects have not as yet been achieved. It has been suggested that a reduction in the volume of the North Atlantic Drift Water would cause a slow down in ocean thermohaline circulation and that this would result in locally colder climates together with changing precipitation patterns (OSPAR Commission, 2000) and associated alterations to patterns of vertical mixing. Hulme *et al* (2002) have calculated a 25% decrease in Gulf Stream flow by 2100. Nutrient supply and dissolved oxygen concentrations may also be reduced as a consequence of changes to water circulation processes (IPCC, 2002).

The **thermohaline circulation** is driven by the cooling and sinking of water in the North Pole region. As well as cooling, increases in salinity power the sinking by increasing water density. As the water sinks, it “sucks” surface waters northward. However, it is believed that increases in temperature and precipitation are slowing this process in the Norway and Labrador Seas resulting in a destabilization of global ocean circulation (Jancovici, 2003). A number of major currents in the North Pole region are showing signs of change or believed to be vulnerable to changes, for example:

- A large inflow of freshwater from Greenland Sea in the 1960s known as the ‘Great Salinity Anomaly’ (GSA) with further saline anomalies reported from this region as well as from the Channel since (OSPAR

Commission, 2000). A third GSA, caused from outflows of freshwater from the Canadian Archipelago coupled with strong northerly winds, was reported circulating in the North-East Atlantic through the 1990s;

- Further decrease in Artic Water flowing southward could alter the flow of the North Atlantic Drift in the next 30 years, with major implications for regional climates in the NEAME (Hall-Spencer *et al*, 2004); and
- Further changes to the Iceland-Scotland Ridge Overflow Water (ISOW), which comprises a large part of the North Atlantic Deep Water.

It has even been suggested that disrupting the sinking of ocean water in the Arctic region may begin to reverse air and seawater warming in north-west Europe, initiating a mini-ice age (Eiss, 2004). Conversely, Hulme *et al*, (2002) propose that a diminished Gulf Stream may not result in a cooling down of the UK climate.

Outside of circulation changes, other process changes that might occur as a consequence of climate change include:

- The possibility of **increased volumes of Atlantic Water** entering the North Sea through the Shelf Edge Current resulting in alterations to ecosystem structure and dynamics, for example, through changes in seawater composition and the increased prospect of transport of alien species (GLOBEC, 2003);

- Increased concentrations of **atmospheric CO_2** will facilitate a related rise in seawater concentrations. This would lead to a lowering of seawater **pH**. As a consequence, **carbonate chemistry** processes could alter, affecting calcium carbonate deposition in microbial and other planktonic organisms. The implications for the planktonic fauna and flora as well as ocean-atmosphere interactions are not well understood but the suggestion is that the former may play a considerable and influential role in the latter (Kennedy *et al*, 2002);

- Other changes in seawater chemistry are likely to occur, particularly in relation to sea temperature rises. For example, higher temperatures reduce the **absorption capacity for oxygen, CO_2 and other gases** with the suggestion of a positive feedback mechanism with respect to the GHGs.

- Increased temperature or freshwater input results in increased density **stratification** reducing nutrient upwelling and hence productivity of the ocean. However, some high latitude areas may “benefit” from an increase in the growing season as a consequence of a rise in temperature (Kennedy *et al*, 2002);

- Further shifting of saline balance in the worlds oceans with reduction in **salinity** in northern latitudes and increase in salinity in the upper water column of low latitudes (Curry *et al*, 2003). Species abundance and distribution will be influenced by this just as they are by temperature changes. For example, the Japanese eel (*Anguilla japonica*) population has declined where changes to salinity fronts have occurred (GLOBEC, 2003);

- Release of **methane hydrates** (methane and water crystal) from marine sediments could be triggered by a 1°C increase in sea temperature as it dissociates with water and releases methane (Jancovici, 2003). Further information is provided below (Section 3.1.3);

- The combination of environmental stresses on the ecosystem would include changes in **pollutant toxicities** that would typically increase with rising temperatures; and

- Alterations to wind speed and direction which play a role in production of fish and invertebrates in particular in **areas of upwelling** (Kennedy *et al*, 2002).

3.1.3 Methane hydrates

The specific threat of substantial releases of methane from the dissociation of methane hydrates with a rise in temperature and resulting in a positive feedback of GHG emissions and global warming has warranted specific consideration in this scoping study.

Methane hydrates are retained under pressure in an ice-like lattice of water molecules but subject to constant flux, absorbing and releasing methane in response to ongoing natural alterations in the environment (NETL, 2004). Though our knowledge of their occurrence is incomplete, it is thought that they are primarily present along continental margins at intermediate water depths, from 250 m to several thousand metres. It is currently estimated that the present-day reservoir of carbon stored in methane hydrates is about 10,000 Gt (giga ton)[1] (Renssen *et al*, 2004).

The principal concern with respect to the potential for large scale release of methane from hydrate reservoirs focus on offshore Arctic where low temperatures presently allows their formation at sufficiently shallow depths and hence makes them vulnerable to sea temperature rise (Nisbet, 1990). It has been suggested by some researchers that an abrupt increase in atmospheric methane in the Pleistocene was caused by the sudden release from the ocean of frozen deposits of methane and correlated with warmer atmospheric

[1] Compared to 38,000 Gt carbon stored in the oceans, 2,000 Gt in soils and plants, and 730 Gt in the atmosphere (Rensson *et al.,* 2004)

conditions (Kennett *et al*., 2003). However, Maslin *et al* (2004) disagree that this is a potential climate change driver.

For the purpose of the vulnerability assessment of the NEAME it is therefore considered that dissociation of methane hydrates is not a significant threat, except with respect to a slow down in the thermohaline circulation which has indirect ramifications for the NEAME because of the potential warming of the Arctic region.

3.2 Data gaps

There is a consensus view that climate change will result in an increase in air temperature and a rise in sea level. With respect to other scenario characteristics, there is a wider range of views as to the potential outcomes of climate change. It is fully acknowledged that our overall understanding of climate process, atmospheric-ocean interactions and related areas is limited. However, the luxury of resolving these knowledge gaps before addressing the impacts of climate change does not exist. For the purpose of the NEAME vulnerability assessment, the key data gaps are considered to be as follows:

- Changes to storm surges;
- Wind strength and direction;
- Wind driven circulation and associated mixing;
- Changes to major circulation processes; and
- The North Atlantic Oscillation index.

Should it be deemed appropriate to include any of these scenario characteristics in the vulnerability assessment then it will be necessary to determine a “best guess” set of parameters.

The subjects of ocean circulation and the North Atlantic Oscillation are highly complex and subject to many uncertainties, as highlighted by the number of sea and ocean circulation permutations in Table 1. However, they are important factors, as is the North Atlantic Oscillation, to consider and as such one or more scenarios for change will require selection for the vulnerability analysis.

Table 1 List of scenario characteristics and potential changes for low and high scenarios

+ve f'back	Scenario/characteristic	Timescale	Scale/Parameter	Timescale	Scale/Parameter
		Scenario 1: low impact		**Scenario 2: high impact**	
	North Atlantic Oscillation index		Increase/oscillate		Increase/oscillate
	Sea surface temperature rise[2]	2080	2ºC increase	2080	4ºC increase
	Dissolved oxygen		Decrease		Decrease
	Growing season[3]	2080	Extended by 4 weeks (n. latitudes)	2080	Extended by 6 weeks (n. latitudes)
	Amplitude of air temp. range in littoral habitats		Increase (+/-0.5^{o}C[4])		Increase (+/- 2.0^{o}C[5])
	Amplitude of sea temp. change inshore/littoral		Increase		Increase
	Thermal stratification		New/Increase		New/Increase
	Near seabed deoxygenation		New/Increase		New/Increase
	Salinity		Decease (n. latitudes) /increase (s. latitudes)		Decease (n. latitudes) /increase (s. latitudes)
	Pollutant toxicities		Changes		Changes
	Occurrence/abundance of keystone (structural) species		Changes		Changes
	Timing of inter- and intra specific life cycle stages		Changes/asynchrony		Changes/asynchrony
	Sea level[6]	2100	15cm increase	2100	95cm increase (regional

[2] UKCIP02
[3] UKCIP02
[4] Uncertainty margin for variation in outputs from various models (low emissions)
[5] Uncertainty margin for variation in outputs from various models (high emissions)

			(regional variations)		variations)
	Coastal erosion		Increase		Increase
	Coastal squeeze		Increase		Increase
	Suspended solids in coastal environment		Increase		Increase
	Cloud cover/irradiation		Increase cover (decrease in east England coast)		Increase cover (decrease in east England coast)
	Storm surges		Increase frequency		Increase frequency
	Near surface atmospheric pressure[7]	2100	Increase by 5 kpa	2100	Increase by 15 kpa
	Flooding		Increase		Increase
	Wave action/storminess on coasts		Increase		Increase
	Wind speed and direction		Changes		Changes
	Precipitation/freshwater inputs		Increase (+/- 5 or +10%)[8]		Increase (+/- 20% or +40%)[9]
	Nutrient inputs (incl. run off)		Increase		Increase
	Ocean circulation		Changes		Changes
	Wind-driven water circulation/mixing		Variation		Variation
	Mixing/upwelling		Decrease		Decrease
	Density driven ocean circulation		Compromised		Compromised
	Northward movement of warm water		Reduced / cooling of NEAME	2100	Reduced (by 25%)/ cooling of NEAME
	Atlantic Water volume into North Sea		Increase		Increase

[6] UKCIP02
[7] STOWASUS-2100. An indicator of storm surges, wind etc.
[8] Uncertainty margin for average precipitation (winter or summer) for outputs from various models (low emissions)
[9] Uncertainty margin for average precipitation (winter or summer) for outputs from various models (high emissions)

	Deepwater formation/inflows		Decrease		Decrease
*	**CO_2 adsorption/emission**	2080	$[CO_2]_{atmos}$ increase to 525ppm. $[CO_2]_{sea}$ decrease	2080	$[CO_2]_{atmos}$ increase to 810ppm. $[CO_2]_{sea}$ decrease
	pH		Decrease		Decrease
*	Carbonate deposition		Decrease		Decrease

3.3 Catastrophic scenario

"An abrupt climate change occurs when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause" (Ocean Studies Board *et al*, 2002). It is now recognised that such an event is plausible (e.g. Schwartz and Randall, 2003).

Climate change authorities and scientific reports are increasingly referring to the possibility of a catastrophic scenario while scenario users consistently call for advice on possible abrupt climate change, particularly with respect to a major slowdown or "collapse" of the Gulf Stream. The occurrence of a major slowdown in the Gulf Stream termed a "climatic surprise" whereby the globe warms up but sea surface temperatures in the North Atlantic region decrease by 5 to 6°C within a couple of decades would result in extreme destabilisation of ecosystems (Jancovici, 2003). Unequivocal geological records illustrate a climate that can alter rapidly within decades occurring repeatedly over the last 100,000 years (National Research Council (U.S.), 1998). Hulme *et al*, (2002) propose that the Gulf Stream may weaken by 25% by 2100 suggesting that an increase in global warming will offset any cooling of the Gulf Stream though acknowledge the scientific community do not sufficiently understand about the factors that govern global ocean circulation.

As such it is considered appropriate to include a "doomsday" scenario in the NEAME vulnerability analysis.

Table 2 List of scenario characteristics and potential changes for a catastrophic scenario

Scenario/characteristic	Timescale	Scale/Parameter
Scenario 3: Climate Surprise: slowdown of the Gulf Stream		
Sea surface temperature	? 2080 - 2150	Decrease by 5 – 6°C
Sea level		?increase (from polar melt)
Coastal erosion		
Cloud cover/irradiation		Increase cover?
Storm surges		
Frequency of storm surges		?
Flooding		?
Wave action/storminess on coasts		Winter increase?
Precipitation		Decrease
Wind speed and direction		Increase (especially in winter)
Ocean circulation		Decrease
Wind-driven water circulation/mixing		Increase?
Mixing/upwelling (and nutrient resupply)		decrease
Density driven ocean circulation		decrease
Northward movement of warm water		decrease
Atlantic Water volume into North Sea		decrease
Methane hydrate release		In Arctic: causing positive feedback

3.4 Data gaps

Our understanding of a potential slowdown of the Gulf Stream is limited. In Jancovici's review of the subject (Jancovici 2003), the suggestion is that at current levels of climate change and CO_2 emissions, it is highly improbable that a slowdown of the Gulf Stream will occur this century. However, a rapid drop in temperature over only one or a few decades will have massive ramifications for the distribution, abundance and survivability of fauna and flora of the NEAME.

3.5 Conclusion

Consistent with the approach for the vulnerability assessment of low and high emission scenarios, the desire to keep the assessment as simple and focussed as practicable, it is felt that only a single catastrophic scenario characteristic should be included. This scenario should focus on the impact of a major slowdown in the Gulf Stream.

4 THREATS TO THE NEAME

This section describes the nature of the threats posed by the climate change scenarios described in the previous section. These are provided in Table 3 and list the potential ecological effects of climate change impacts presented in Table 1. Table 3 is organised in a manner that provides the overarching threat followed by more specific implications of these main threats. Thus changes in trophic status of waterbodies, as a consequence of increased nutrient input from freshwater run-off, may manifest as, for example, an increase in algal blooms; changes to macroalgal and benthic faunal species composition.

In many cases in Table 3, the threats apply equally across the full spectrum of fauna and flora, from unicellular algae to vertebrates, and as such these have not been listed exhaustively but explained with examples where available or appropriate.

In reviewing papers on threats to the NEAME ecology it has proved appropriate to rationalise the available information under the principal headings of:

- Coastal habitats;
- Marine ecosystem structure and function;
- Species distribution;
- Plankton and its productivity;
- Phenology; and
- Alien species.

A summary of the key findings of the reviewed papers are provided below and provide explanatory notes for the threats listed in Table 3.

4.1.1 Coastal habitats

There is an existing pressure on European and internationally important coastal habitats as they are subject to loss in extent through isostatic readjustment movement and **coastal squeeze**. Climate change driven **sea level rise** adds to this pressure (Richartz and

Sporrong, 2003; Yorkshire Futures, 2002). It has been suggested that as much as 20% of coastal wetlands worldwide may be lost by 2080 (IPCC, 2002).

Greater upstream penetration of seawater would impact habitats including saltmarshes by causing soils to waterlog and plants to die from salt stress while if marshes were to be flood protected sediment inputs would be restricted (Kennedy *et al*, 2002). The opposite scenario (of freshwater inundation) might be a consequence of increased precipitation and changes in wind speed and direction. Saltmarsh and other coastal wetlands response to climate change effects will be influenced by accretion rates, sediment supply and the backshore environment (IPCC, 2002). Additionally, artificial protective measures introduce another potential source of harm through the disruption of natural processes (OSPAR Commission, 2000; IPCC, 2002).

Coastal erosion is likely to be increased by climate change effects, notably storm surges and sea level rise. Additionally the patterns of coastal sediment processes could change as a consequence of changes to current patterns, such as those driven by wind (the direction and strength of which are predicted to change). Compensation for sea level rise through increase in the number and scale of flood defence schemes could have an effect on coastal erosion, which may be a lesser imperative (Yorkshire Futures, 2002). Coastal regions with lower profiles will be prone to erosion. For example, 176,000ha of land in Ireland is at risk of flooding and erosion (OSPAR Commission, 2000).

Associated consequences of increased erosion in coastal habitats include **increased organic and inorganic inputs** from terrestrial to coastal ecosystems (Frid *et al*, 2003). This will potentially impact on marine sediments as rivers will discharge enough carbon to maintain turnover of the marine dissolved organic pool, accounting for the complete organic carbon found in marine sediments (Waldron, 2004). Higher loads of sediment inputs could have a negative effect on **light penetration** in coastal ecosystems with adverse implications for residing organisms (Frid *et al*, 2003);

Air temperature increases, including both a raise in the mean annual value and increased short-term variations

It is estimated that inshore air temperatures could oscillate by as much as 2°C above or below average with future tendencies towards higher temperatures (Hiscock *et al*, 2004). Increase in summer high's and winter low's could markedly increase rates of mortality of many intertidal species (Yorkshire Futures, 2002; Crisp, 1964);

Species distributions are defined by the temperature range within which it can complete its life cycle (Van den Hoek, 1982) and as such will shift with changing air (and sea) temperatures;

With respect to **sea temperature increases**, a number of threats are immediately apparent in addition to shifts in species distribution and relative abundance patterns. It is predicted that the extent of this may be as much as an 80km movement northwards (NERC, 1999). Others include:

- Displacement of some species resulting in regional extinction due to the absence of suitable habitats as distributions are shifted northwards (Hiscock *et al,* 2004);
- The occurrence of thermal stratification in summer may result in deeper sheltered waters becoming periodically deoxygenated (Hiscock *et al*, 2004).
- Overheating of upper shore rock pools, in particular, causing species mortality e.g. *Patella vulgata* mortality on the north Scottish coast (Bowman, 1978); a number of

species survive at their northern limit in rock pools including the algae *Cystoseira tamariscifolia* and *Bifurcaria bifurcata* (Hiscock *et al*, 2004); and

- Higher sea temperatures are predicted to impact on species that require a lower temperature to initiate spawning (Hiscock *et al*, 2004) with possible separation of breeding and feeding habitats either spatially or temporally.

Intertidal species already occurring in Britain and Ireland will be at risk of **increased wave action and storminess** (Hiscock *et al*, 2004). Severe storm events will cause substantial physical damage to habitats and species (Kennedy *et al*, 2002).

There are numerous **in-combination effects** of climate change, for example:

- Adverse impacts to coastal habitats from human induced stresses will be exacerbated e.g. estuaries (Kennedy *et al*, 2002);
- Adverse effects on productivity and physiological functions of seagrass as sediment availability, temperature and sea level rise become affected (IPCC, 2002). Also expected additional adverse impact on fish (and other flora and fauna) populations that depend on seagrass (IPCC, 2002); and
- Additional sea level rise in regions exacerbated by historical vertical land movement with regional impacts in areas such as the south coast of England where land is sinking.

4.1.2 Marine ecosystem structure and function

Changes in marine ecosystem structure (plant and animal composition) and function (e.g. productivity, nutrient cycling) might occur as particular species become dominant and others become locally extinct (Kennedy *et al*, 2002). Such changes could manifest in a variety of ways, such as:

Biotope changes may occur most notably to keystone or characteristic species, unique seabed habitats such as maerl and key structural communities such as mussel beds resulting in the loss of associated species (Hiscock *et al*, 2004);

Relative and dramatic changes in **temperature mediated species distribution** including range and abundance for example:

Retreat of cold-water species distribution polewards and expansion of southern species. The likely outcome will be a decrease in abundance or loss of a number of northern marine species from the NEAME (Hiscock *et al*, 2001, 2004). The direction of change will also correspond to the time of year they spawn (GLOBEC, 2003). For example, species with similar ecological function may replace each other such as the northern sea urchin *Strongylocentrotus droebachiensis* may be replaced by the common sea urchin *Echinus esculentus* (Hiscock *et al*, 2004) ;

Increase in diversity of seabed marine life as air and seawater temperature increase, for example, predicted distribution extension of *Chthamalus montagui* onto the east coast of Scotland assuming a 1-2 °C rise in summer seawater temperature (Hiscock *et al,* 2001). Similarly, movements and changes in breeding patterns have been reported for Balanus perforatus (Herbert *et al*, 2003). Movements will be subject to the presence of other controlling factors such as favourable currents;

Expansion of warm-water species distribution in current location (i.e. increased abundance) and further northwards (Helmuth and Gilman, 2004; Hiscock *et al*, 2004), for example the rate of incidence of exotic and southern species (e.g. red mullet, anchovy and pilchard) migrating into the northern North Sea unparalleled in the last 79 years (Beare *et al*, 2003); and

Movements of species will depend, not least, on their mobility and life history strategies. In the case of pelagic or demersal species, they will possess an ability to move northwards quite rapidly and in tandem with rise in sea temperatures (Hiscock et al, 2004). Whereas benthic species are likely to redistribute slowly due unless they possess a highly dispersive larval distribution mechanism (Hiscock *et al*, 2004). Taking these factors into account, Hiscock *et al* (2001, 2004) list a series of benthic fauna whose distributions are likely to change as a consequence of rises in sea temperature.

Changing in food, for example plankton size and composition, would also be a factor in species distributions.

4.1.3 Plankton and its productivity

Plankton are of fundamental importance to the nutrient cycling and hence productivity of the NEAME. Changes to the distribution and species composition of plankton and changes to marine productivity as a result of alterations in temperature, nutrient supply, wind speed and sunlight are anticipated consequences of climate change (IPCC, 2002). In the NEAME, a decline of phytoplankton north of 59°N may be caused by unusually cold waters from the Arctic while the growing season is extending further south and leading to an increase in phytoplankton abundance (Reid *et al*, 1998). In the NEAME, the zooplankton copepod *Calanus finmarchicus* is a key species in energy transfer and productivity (GLOBEC, 2003). However, its life history is such that it is susceptible to changes in temperature and ocean circulation and evidence is already suggesting that the species is in decline, probably as a consequence of a reduction in Norwegian Sea Deep Water formation resulting in a reduction of overwintering habitat (GLOBEC, 2003). Changes in distribution of *C. helgolandicus* in the North-East Atlantic are also suggested to be a manifestation of sea temperature changes (Bonnet and Harris, 2004).

Changes in seawater composition, current patterns, nutrient status, light penetration and associated factors are considered likely to have substantial effects on phytoplankton community structure, abundance and productivity. Warm water plankton species are increasingly moving northwards while colder species are moving westwards (Reid and Richardson, 2004) as north-west Atlantic pelagic marine ecosystems shift towards a cooler climate as those in the north-east shift towards a warmer climate (Beaugrand, 2004). With these changes, there is an associated reduction in biomass and plankton size (Reid and Richardson, 2004). Long-term Continuous Plankton Recorder (CPR) data illustrate a 10° latitudinal shift northwards of planktonic copepods in the North-East Atlantic in approximately the last 40 years (Beaugrand *et al*, 2002).

However, should nutrient inputs increase, as suggested by predictions of increased freshwater runoff and highlighted by some authors (e.g. Frid *et al* 2003), then the possibility remains of an increase in phytoplankton biomass. This may, under certain circumstances be manifested in an increase in toxic algal blooms. Associated effects include poisoning events such as causes Diarrhetic Shellfish Poisoning, caused by *Dinophysis acuminata*, such as recorded in the southern North Sea in late summer/early autumn (Edwards and Richardson, 2003).

Undoubtedly, any shifts in the phytoplankton and zooplankton community structure and productivity will have knock on effects in all other parts of the NEAME. Potentially these impacts will be magnified at the top of the food web such that population crashes will occur amongst those species with specific ecological requirements, such as seabird species that are dependent on specific species of fish (IPCC, 2002), or subject to other pressures such as cod (Reid and Richardson, 2004).

4.1.4 Phenology

Changes in the timing of naturally recurring events such as the **earlier development** of decapod larvae (Edwards and Richardson, 2003) have the potential to have major implications on the NEAME. It is thought that the growing season has extended by 4 to 6 weeks (NERC 1999) with the potential for key production events occurring out of synchrony with others, such as prey items not being sufficiently abundant at a time of high demand during periods of larval growth for example planktivorous seabirds reproducing too early in the year (GLOBEC, 2003).

Similarly, alterations in **migration timings** could disrupt other predator-prey interactions at critical times. For example, the extent of migration in fish and cephalopods is strongly influenced by temperature changes associated with the North Atlantic Oscillation (Sims *et al,* 2004). Unless predator movements are controlled by the same cues then the potential to miss such key feeding opportunities exist.

4.1.5 Alien species

Introduction of **alien species** as a consequence of climate change could potentially bring about a significant alteration in ecosystem/community structure. Alien species pose a threat in a number of ways that include displacement of indigenous species, reduction in biodiversity, negative interactions such as biofouling and introduction of new and only weakly resistable diseases and parasites. Other threats and examples include:

- Occurrence of unusual species, for example the southern warm water dinoflagellate *Amphisolenia globifera* off the west coast of Ireland in November and of record numbers of parasites such as the isopod *Heterophryxus appendiculatus* (Edwards and Richardson, 2003);
- Increased risk of population “explosions” during summer months in Britain and Ireland for example of the non-native algae *Sargassum muticum* and the goldsinny wrasse *Ctenolabrus rupestris* (Hiscock *et al*, 2004);
- Introduction of alien species unrelated to climate change which may adversely impact on NEAME by interacting with the changing forces acting on ecosystem (GLOBEC, 2003); and
- New combinations of species may interact in an unpredictable manner, with those unable to readily relocate or compete facing possible risk of extinction (Ritchatz and Sporrong, 2003).

Table 3 Threats posed to the NEAME and their nature

Threat	Scenario characterisitc	Manifestations	
Changing trophic status of waterbodies	Increased nutrient inputs (run off and other freshwater inputs)	Algal blooms (and subsequent effects of mass die-off)	Changes to benthic species composition (nearshore)
	Variation in mixing patterns	Variation in phytoplankton spp abundance and composition	Increase occurrence of nuisance species
		Variation in macroalgae spp abundance and composition	Smothering of intertidal and shallow subtidal habitats
Changes to growing season/patterns (all fauna and flora) (2 - 3 weeks seasonal extensions, UKCIP02)	Nutrient cycles, temperature, changes in irradiation levels and variation in seasonality of intra/inter specific cycles resulting in greater/lesser/longer/shorter population sizes	Variation in distribution and abundances of *Calanus finmarchicus* and *C. helgolandicus*	Poopulation crashes, for example early seabird breeding clashing with late winter storms and wave surges flooding nests.
Changes to plankton/microbial community structure as carbonate deposition environment changes	pH lowers with increased atmospheric CO_2. Carbonate secretion becomes problematic.	Variation in phytoplankton spp abundance and composition	
Species redistribution as consequence of temperature increases (30 – 80 km N'wards, NERC 1999. 10^o latitude northwards, Beaugrand *et al*., 2002)	Distribution of northern spp recede/ southern spp expand (e.g. *Chthamalus montagui*)	Relative abundances will change as a consequence of differential in temperature tolerances	Some species become extinct (e.g. no appropriate habitat for spp receding north)
		New species arrive/displace. e.g. *Echinus esculentus* replace *Stronglyocentrotus*	New species reducing diversity by displacing more than 1 species.

		droebachiensis	
	Risk of alien species colonising increases in warm water/stressed ecosystems.		
Species/community composition changes	As well as temperature driven effects also secondary effects occur, such as those associated with salinity or amongst consumers as producers change in composition/size	Spp associated with keystone spp effected (e.g. loss of mussel beds, *Sabellaria, Serpula*, maerl, *Zostera* etc)	Alien spp arrive on currents that become more dominant
		Mean phytoplankton cell diameter/zooplankton size changes, limiting resource availability for species lacking feeding mechanisms to capture different prey.	
Species introductions	Changes in conditions and transport pathways	Allowing alien spp to arrive and become established. Subsequent displacement of indigenous populations	Diseases, parasites and toxic species included in introductions. Limited resistance in indigenous (stressed) populations
Decrease in biodiversity	Opportunistic spp become more prevalent	A shift toward simplified communities (lower diversity) more vulnerable to perturbations?	
Species recruitment	Reduced by various parameter changes (incl. temp, salinity etc.)		
Loss of intertidal habitat	Erosion, flooding, squeeze, salinity.	Decline in shorebird populations (possible population crashes)	
Character change to intertidal habitats	temperature extremes, storm events, wave action.	Rockpools overheating	Harsh winter/summer mediated mortalities
		Changes to degree of weather exposure	

Changes to enclosed water habitats	Salinity, temp, DO etc.	Stratification and associated deoxygenation changing spp composition	
Compound impacts of other environmental pressures	e.g. loss of habitat through coastal development and coastal squeeze	Population viability thresholds exceeded, resulting in crashes/local extinctions	
Toxic bloom species	Occurrence becomes more frequent	Blooms of e.g. *Dinophysis _cuminate* associated with trophic changes and also causing DSP	
Migratory patterns disrupted		Asynchrony of key interactions (breeding of predators not in synchrony with their prey)	
Disruption of other key life cycle stages		e.g. Reduction in Norwegian Sea Deep Water reduces overwintering habitat for *C. finmarchicus*.	
Mass reproduction failures	Changes in climate patterns cause loss of progeny, necessary quantities of resources to reproduce, or fatal climate conditions	Storm events during seabird brooding killing chicks	Failure in one species breeding season (e.g. sand eels) has knock on to predators (e.g. seabirds, seals etc)
Major changes in species compositions	Slowdown of Gulf Stream and rapid cooling	Major changes in species distributions, abundance and viability	

4.2 Data gaps

For many of the species, habitats and ecosystems in the NEAME, there is a limited understanding of their basic biology and life history strategies. A number of studies have recently sought to assess the practical ecological implications of climate change, with a particular emphasis on the effects of changes in temperature ((Hiscock *et al*., 2001, 2003 and 2004; Beaugrand *et al.,* 2002 and 2004; Reid and Richardson, 2004; GLOBEC, 2003; Edwards and Richardson, 2004).

However, in order to assess the vulnerability of the NEAME, it will be necessary to bring together existing knowledge (including that which is unpublished) on key (example) species and communities.

4.3 Conclusions

The key and representative threats to the NEAME have been highlighted in Table 3. These are considered to be those most appropriate to consider in a vulnerability analysis. The level of detail to which these are taken also needs consideration and should be representative, covering a wide spectrum of species and habitats that would respond to changes as described for the scenario characteristics and also cover all aspects of the NEAME, including pelagic, benthic, coastal, lower and higher plants and animals and economically significant aspects. These have been listed below (Section 6.2).

5 SPATIAL SCALE OF ASSESSMENT

For the purposes of this scoping study a number of spatial scales were considered for carrying out the vulnerability assessment. It was determined that this should be considered primarily from the ecosystem perspective rather than the scope and resolution of climate change models.

The NEAME (Figure 1) encompasses a wide range of latitudes with ecologically distinguishable regions being present. Further, existing data assessment, planning and reporting activities (e.g. OSPAR, ICES, English Nature's Natural Marine Areas) have already established a systematic rationalisation of the region. To take these two important aspects into account in determining the appropriate spatial scale for a simple framework for developing a vulnerability assessment we considered and ultimately discounted the following:

- The OSPAR region covers the area of interest and while they do take some account of biogeographic variations, within the NEAME there are only three regions defined. In particular they do not account for the major currents in the area, particularly in the North Sea (
Figure 2). This was deemed insufficient to consider the effects of climate change within the NEAME;

- English Nature's Natural Marine Areas (NMA's) are partially based on bioregional definitions. However, they are only defined within English Territorial Waters and clear parameters on how they were delineated were not available to expand the system to cover the complete area.
- The socio-political boundaries between countries (median lines) lack biological relevance and as such have been discounted.
- Continuous Plankton Recorder Regions (CPR regions) take some account of biogeograhic regionality in pelagic systems. However, organisational subdivision is also incorporated and this unnecessarily over-elaborates sub-division of the NEAME.
- Climate change models have resolved mean sea surface temperature data and predicted changes to a 5km x 5km grid. This was considered too detailed for the vulnerability assessment even though it is anticipated that some specific threats would be considered at a comparable resolution, for example the latitudinal redistributional movement of species.
- Biogeographical regions of the OPSAR Major Seabed Features (OSPAR 2000) differentiate regions in the NEAME such as Kattegut, Dogger Bank, German Bight, Faroe-Sheltand Basin and Skagerrak. The spatial arrangement of these, however, was not considered appropriate for the assessment being a mix of wide areas and localised nearshore features.

Figure 1 WWF NEAME Ecoregion.

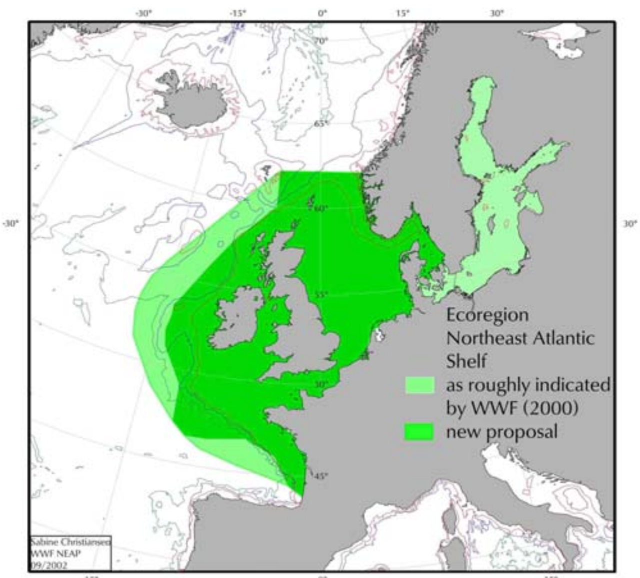
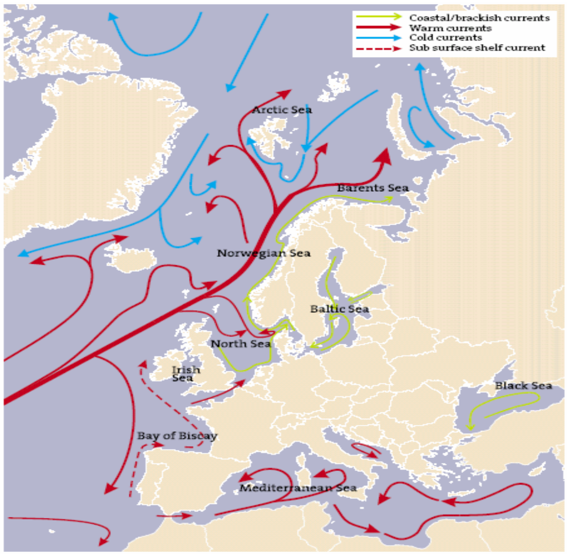


Figure 2 Major currents



within the area

Having discounted all of these possibilities, the ICES system has been adopted (Figure 3). Its primary focus is of pelagic and demersal fisheries interests and simultaneously captures a good fit with ecologically relevant divisions, for example Group 3 below for the greater part follow the divisions of Hardisty (1990) for the British Seas. As such, the following areas will be considered in the vulnerability assessment but grouped where applicable:

Group 1: North Sea and Kattegut

Region IIIa – Skagerrak and Kattegut

Region IV – southern, central and northern North Sea

Group 2: West Scotland and Rockall

Regions VIa and VIIb - West Scotland and West Ireland

Group 3: Irish Sea, Western Approaches and English Channel

Region VII (a to j) Irish Sea, English Channel, Bristol Channel, South-West Ireland and western approaches

Group 4: Brittany and Biscay

Region VIII (a and b) south Brittany and south Biscay.

I	Barents Sea
IIa	Norwegian Sea
IIb	Spitzbergen and Bear Island
IIIa	Skagerrak and Kattegat
IIIb	Sound
IIIc	Belt
IIId	Baltic Sea
IVa	Northern North Sea
IVb	Central North Sea
IVc	Southern North Sea
Va	Iceland
Vb	Faroes
VIa	West Scotland
VIa	West Scotland (Clyde stock)
VIb	Rockall
VIIa	Irish Sea
VIIb	West Ireland
VIIc	Porcupine Bank
VIId	Eastern English Channel
VIIe	Western English Channel
VIIf	Bristol Channel
VIIg	South-east Ireland
VIIh	Little Sole
VIIj	Great Sole
VIIk	West Great Sole
VIIIa	South Brittany
VIIIb	South Biscay
VIIIc	North and North-west Spain
VIIId	Central Biscay
VIIIe	West Biscay
IXa	Portuguese coast
IXb	West Portugal
X	Azores
XII	North Azores
XIVa	East Greenland
XIVb	South-East Greenland

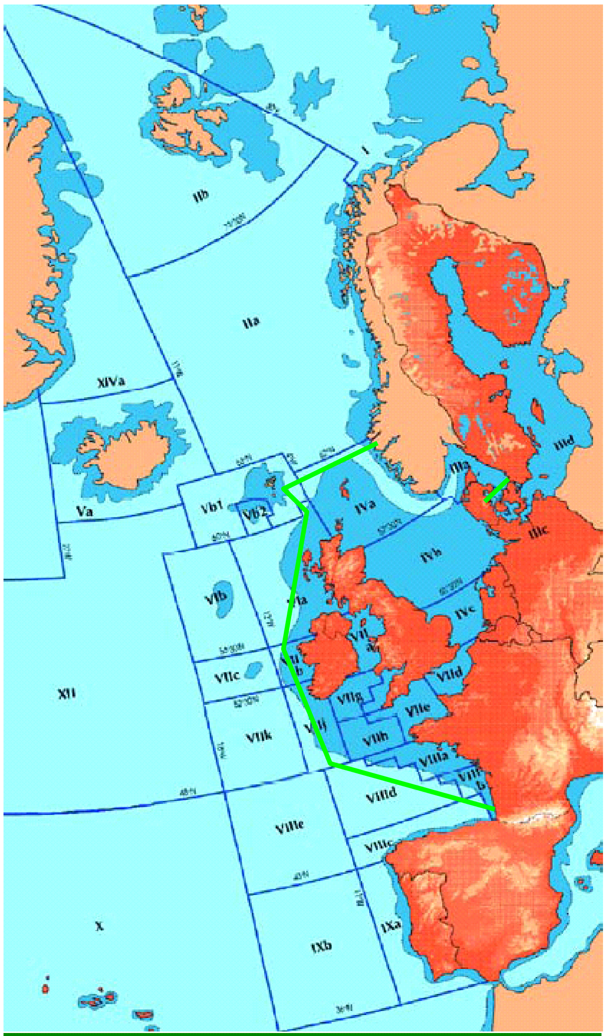


Figure 3 ICES regions and the NEAME (approximate seaward limits in green, highlighted on list).

6 APPROACH TO THE VULNERABILITY ASSESSMENT

6.1 Summary of the scoping study

The previous sections in this report describe the findings of a desk study on climate change and its potential impacts on the NEAME. It has been determined that the assessment should proceed following UKCIP – style scenarios but limit it to two: low emissions and high emissions.

Where information availability has allowed, the characteristics of these scenarios have been identified and then rationalised to include, for taking forward to the vulnerability assessment, the following:

- North Atlantic Oscillation Index
- Sea surface temperature rise
- Extension to growing season
- Amplitude of air temperature range in littoral habitats
- Sea level rise
- Storm surges
- Nutrient inputs
- Ocean circulation
- CO_2 adsorption/emission

Additionally, it is considered appropriate to consider the spectre of a catastrophic change to the climate. As such it is recommended that the vulnerability assessment includes consideration of a climate surprise event, namely:

- Slowdown of the Gulf Stream.

The potential threats posed to the NEAME by these scenario's and the chosen characteristics have also been reviewed and screened for inclusion in the vulnerability assessment. These are highlighted in Table 3 and summarised here:

- Changing trophic status with focus on the changes to phytoplankton abundance and composition (also effects of carbonate biochemistry);
- Changes to growing season, particularly with respect both to plankton (especially *Calanus*) and asynchrony of interactions;
- Species redistribution, particularly with respect to regional extinctions and decline of keystone and economically important species;
- Incursion of alien species with capacity to casue multiple-species impacts and/or have nuisance effect (to ecosystems and economic activity);

- Decline in biodiversity, as a consequence of the above (and others), with a focus on increased community vulnerability to perturbations; and
- In-combination pressures resulting in population crashes/local extinctions.

It will be necessary to focus the assessment of these effects on key or representative aspects of the NEAME and the following are suggested:

- Phytoplankton productivity and species composition;
- *Calanus finmarchicus* and *C. helgolandicus*;
- No more than four fish species, possibly cod, sand eel (all species), salmon and herring;
- Waders (collectively);
- Representative seabirds, possibly Northern gannet and fulmar;
- Representative marine mammals, possibly harbour porpoise and common seal;
- Seagrass beds; and
- Representative fauna or biotopes for rocky shore and sublittoral benthic habitats.

6.2 Vulnerability assessment

This scoping study has demonstrated that considerable data gaps exist – both in our knowledge of climate change effects and also basic environmental understanding. Further, what data that has been published would concerning the natural history of species, habitats and ecosystems within the NEAME would require substantial resources to compile, collate and analyse. To carry out a vulnerability assessment of the NEAME then, it is considered that the most appropriate and cost-effective way forward would be to convene a workshop of specialists who would bring together the necessary expertise and knowledge and be able to achieve the objectives of the assessment.

The salient features of the workshop would be as follows:

- Two day event with approximately 40 attendees;
- The first day would establish the context of the assessment and provide sufficient detail on the scenario characteristics, principal threats and featured ecoregion components (as detailed above) by selected invitees presenting review papers on their specialist areas.
- The close of the first day would refine the proposed assessment content;
- The second day would consist of a number of breakout groups who, using causal-chain analysis or other appropriate technique, identify the potential changes to the NEAME; and
- These changes would then be quantified in terms of the significance of the impact that such changes would have.

The workshop report would be the main body of the assessment which would be completed shortly thereafter.

6.3 Workshop delegates

There are numerous organizations and individuals studying climate change and its potential impacts in the NEAME. In order to carry out the vulnerability assessment it is recommended that a restricted number of these are brought together to discuss the environmental consequences of the selected scenarios described above and generate an expert consensus on the threats they pose. As such, the make up of the group, which we would aspire to restrict to around 40 individuals, would consist of:

- Experts with respect to the threats (the majority of attendees);
- Experts with respect to the scenario characteristics (a limited number); and
- Representatives of organisations that WWF would wish to bring the vulnerability assessment to the attention of.

The second group would, it is hoped, provide background information on the scenarios that will be presented and maintain accurate interpretation during discussions on the threats. As such the following Research organizations and scientists that are recommended for invitation to the workshop are highlighted amongst the full list of those considered. However, the list is short on expertise with respect to the first bullet point relating to the threats and hence requires further discussion.

6.3.1 Organisations

Department for Environment, Food and Rural Affairs (DEFRA)
Hadley Centre for Climate Prediction and Research
UK Climate Impacts Programme
Environment Agency
Centre for Ecology and Hydrology
Climate Research Unit
Tyndall Centre for Climate Change Research
Monarch Project
The Intergovernmental Panel on Climate Change (IPCC)
United National Framework Convention on Climate Change
The Pew Center on Global Climate Change
The World Conservation Monitoring Centre
SW Climate Change Impacts Partnership (SWCCIP)
Sea Mammal Research Unit
RSPB

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