OSPAR COMMISSION

Impacts of climate change on the North-East Atlantic ecosystem

Monitoring and Assessment Series

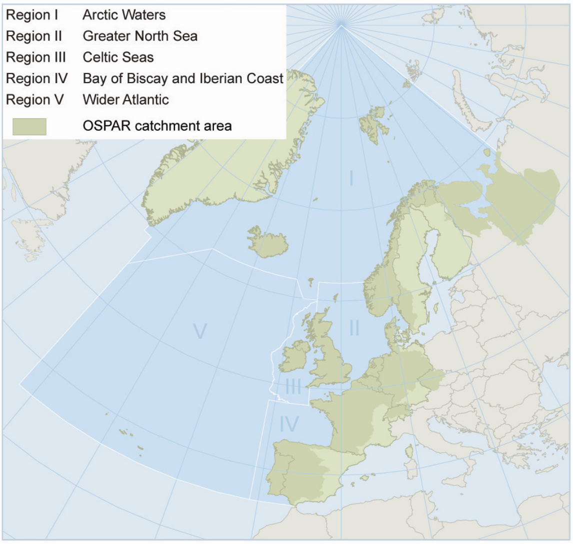
2009

OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. It has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Community and Spain.

Convention OSPAR

La Convention pour la protection du milieu marin de l'Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d'Oslo et de Paris,
à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998.
La Convention a été ratifiée par l'Allemagne, la Belgique, le Danemark, la Finlande, la France, l'Irlande, l'Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d'Irlande du Nord, la Suède et la Suisse et approuvée par la Communauté européenne et l'Espagne.



The OSPAR maritime area and its five Regions

Acknowledgement

This report has been prepared by Paul J Buckley and Stephen R Dye for the UK as lead country.

Photo cover page: Bear and melting ice©Sebastian Unger

Contents

Executive summary

Increased concentrations of anthropogenic greenhouse gases are recognised to have contributed to the rise in globally-averaged atmospheric temperatures since the mid-20th century. The UN Intergovernmental Panel on Climate Change (IPCC) has warned that continued emissions of greenhouse gases at or above current rates will cause further warming and will cause many changes in the global climate system during the 21st century. These are expected to be greater than those observed during the 20th century.

Atmospheric and ocean climate are closely coupled, with the ocean playing a significant role in regulating global and regional climate and weather patterns. The warming of the oceans accounts for more than 80% of the change in the energy content of the Earth's climate system over the last 50 years. Increased concentrations of atmospheric carbon dioxide (CO_2) are also making the oceans more acidic.

This assessment details the wide range of impacts on marine ecosystems that have been linked to changing climate. These include both the direct physical and chemical impacts on the marine environment (Table 1) and the subsequent impacts occurring in the ecosystems and their biodiversity (Table 2).

Many of the observed physical and chemical changes are consistent with increasing atmospheric CO_2 and a warming climate (e.g. rising sea temperature, reduced sea ice and acidification) but many of the causative links to climatic changes are still not well understood. It is difficult to predict the precise rate and magnitude of change (e.g. sea level rise, slowed Atlantic circulation, reduced sea ice extent, acidification, increased freshwater input) and direction of change (e.g. ocean uptake of CO_2, salinity; storminess, nutrient enrichment), and to map impacts at local level (e.g. coastal erosion, storminess, stratification, nutrient enrichment).

Physical and chemical changes have directly been linked to impacts on marine biota (e.g. range shifts in plankton, fish and intertidal species communities) and are suggested to have important secondary effects (e.g. prey availability for seabirds). Uncertainties about physical changes make it difficult to predict the effects of stratification on primary production, storminess on seabird nesting sites and nutrient enrichment on harmful algae blooms. Our understanding of the links between climate change and impacts on marine ecosystems also remains limited due to insufficient data (e.g. marine mammals; benthic ecology; intertidal communities) and the difficulties in establishing a link to local effects (e.g. occurrence of harmful algal blooms, establishment of non-indigenous species).

Regional summary of the relative strength of selected climate change 'drivers' (1 and 2) and impacts (3) in the OSPAR area:

🔴 *Strongest* 🟡 *less than strongest* 🟢 *weakest* ***?*** *relative strength not known*

	1. Sea temperature rise		**2. Acidification**		**3. Species distribution and abundance**	
	Observed	Projected	Observed	Projected	Observed	Projected
Confidence	High	High	High	High	High	Low
Region I	🟡	🔴 / 🟡	🟡	🔴	🔴	🔴
Region II	🔴	🟡	🟡	🟡	🔴	🔴
Region III	🟡	🟡	🟡	🟡	🟡	🟡
Region IV	🟡	🟡	🟡	🟡	🟡	🟡
Region V	🟡 / 🔴	🟡	🟡	🟡	**?**	**?**
Key factors	Increasing atmospheric greenhouse gas concentrations.		Uptake of CO2 by the oceans / pH change		Shifts of fish species Plankton/food web changes Non-indigenous species	

Table 0.1. *Projected climate change impacts on physical and chemical aspects of the marine environment and what has been observed*

IMPACT	What might happen	What has been observed
Increased sea temperatures	Warming in all OSPAR areas but with strongest warming in Region I (Xu *et al.* 2005, IPCC, 2007a)	Regions I–IV have warmed since 1994 at a greater rate than the global mean (ICES, 2008a) Warming most evident in Region II
Reducing sea ice	Region I: sea ice may disappear in the summer in coming decades (EEA, 2008)	Region I: extent of sea ice has decreased in recent decades (IPCC, 2007a).
Increased freshwater input	Region I: 10–30% increase in annual riverine input by 2100 (Walsh *et al*., 2005) with additional inputs from the melting of land-based ice (Gregory *et al.,* 2004, Dowdeswell, 2006) Regional precipitation is difficult to project but Region IV and the southern part of Region V may experience decreases in precipitation (IPCC, 2007a)	Region I: the supply of freshwater to the Arctic appears to have increased between the 1960s and the 1990s (Peterson *et al*., 2002, Wu *et al.,* 2005)
Changed salinity	Region I and V: The Atlantic ocean north of 60° might freshen during the 21st Century (Wu *et al.,* 2005)	Freshening in the deep waters of Regions I and V over the last 4 decades of the 20th century (Dickson *et al.,* 2002)
Slowed Atlantic overturning circulation	Slowdown of circulation in 21st Century is very likely (IPCC, 2007a)	Monitoring is now in place that will be able to observe long term change in the Atlantic Overturning Circulation (Cunningham *et al.,* 2007)
Shelf sea stratification	Regions II and III: Shelf seas may thermally stratify for longer, and more strongly but in the same locations (Lowe *et al*., 2009).	Regions II and III: some evidence for earlier stratification in recent years and onset of the associated bloom (Young and Holt, 2007, Sharples *et al.,* 2006).
Increased storms	Projections of storms in future climate are of very low confidence	Regions I–V: severe winds and mean wave heights increased over the past 50, but similar strength winds were also present in earlier decades (Gulev & Hasse, 1999, Gulev & Grigorieva, 2004)
Increased sea level	Between 0.18 and 0.59 m by 2100 mostly through thermal expansion and noting high uncertainty at the upper range due to ice sheet processes (IPCC, 2007a). A rise of 2 m in a century cannot be discounted as a possibility based upon past change (Rohling *et al*., 2008)	Global sea level rose on average at 1.7 mm/yr through the 20th Century. A faster rate of sea-level rise was evident in the 1990s (Nerem *et al*., 2006, Church and White, 2006, Rahmstorf, 2007)
Reduced uptake of CO_2	Dependent on water temperature, stratification and circulation	North Atlantic: reduced flux of CO_2 into surface waters in 2002-2005 compared with 1994-1995 (Schuster and Watson, 2007).
Acidification	During the 21st Century ocean acidity could reach levels unprecedented in the last few million years with potentially severe effects on calcareous organisms (Feely *et al.,* 2004, Turley, 2008)	Global: average decrease in pH of 0.1 units since the start of the industrial revolution (IPCC, 2007a)
Coastal erosion	Predictions are very uncertain and highly location specific (Cooper and Pilkey, 2004)	In many areas the combined effect of coastal erosion, infrastructure and sea defence development have lead to a narrow coastal zone (Doody *et al.,* 2004)
Nutrient enrichment	Predictions are linked to impacts of various factors, such as rainfall patterns on freshwater input and run-off, storminess on turbidity, sea temperature on stratification	Regions I–IV: Drier summers may already be contributing to a decrease in nutrient inputs (Hydes *et al*., 2008). Higher nutrients inputs in wet years have caused harmful algal blooms

Table 0.2. *Projected climate change impacts on biological aspects of the marine environment and what has been observed. In all case projections are limited by uncertainties in ocean climate projections and species and community responses*

IMPACT	**What might happen**	**What has been observed**
Plankton	Northwards shifts in species in shelf and open ocean (ICES, 2008a) Region I : Increased productivity with loss of sea ice (ACIA, 2005)	1000 km northward shift of many plankton species over the last 50 years (Beaugrand *et al.,* 2003) Changes in timing of seasonal plankton blooms (Edwards *et al.,* 2008)
Harmful algal blooms (HABs)	Potentially increasing incidence as a result of changes in sea temperature, salinity and stratification (Raine *et al.,* 2008)	Anomalous phytoplankton blooms (often harmful) in specific habitats affected by lower salinities (*e.g.* Norwegian trench) or higher temperatures (German Bight) (Hoepffner, 2006; Raine *et al.,* 2008)
Fish	Northward shifts in population but lack of knowledge of the underlying mechanisms make projections uncertain (Pinnegar *et al*., 2008) Increased temperature could increase the incidence of disease for farmed species of fish and shellfish (Pinnegar *et al.,* 2008)	Northwards shifts of both bottom dwelling and pelagic fish species most pronounced in Regions I and II (ICES 2008a)
Marine mammals	Loss of habitat for mammals dependent on sea ice (Evans *et al.,* 2008) Changes in availability of prey species are likely especially in RI due to mismatches in production (ACIA, 2005)	Data on distribution, abundance and condition of marine mammals is limited (ICES, 2007, 2008b) Ringed seals and polar bear may already be affected by loss of sea ice (IPCC 2007b, Evans *et al.,* 2008)
Seabirds	Impacts on seabirds are likely to be more important through changes in their food supply than through the losses of nests due to changed weather (Mitchell and Fredericksen, 2008)	Seabird breeding failure in the North Sea has been linked to variations in food availability as a result of increased sea temperatures (Frederiksen *et al.,* 2006)
Non-indigenous species	Increased invasions and establishment may be facilitated by climate change and pose a high risk to existing ecosystems (Elliott *et al.,* 2008)	Establishment of pacific oyster *Crassotrea gigas* and the barnacle *Elminius dodestus* has been linked to climate change (ICES, 2008a)
Intertidal communities	Continues extension and retraction of the ranges of different intertidal species (Mieszkowska, 2008)	Some warm water invertebrates and algae have increased in abundance and extend ranges around the UK over last 20 years (Herbert *et al*., 2003, Mieszkowska, 2008)
Benthic ecology	Benthic sessile organisms are largely tolerant to moderate environmental changes over reasonable adaptive time scales but are very vulnerable to abrupt and extreme events (Hoepffner, 2006)	Anomalous cold winter conditions have seen outbreaks of cold water species and die-offs of warm water species (ICES, 2008a) Species composition changes have occurred but not major shifts or changes in gross productivity (Frid and Moore, 2008, ICES, 2008a)

Récapitulatif

Il est maintenant reconnu que l'accroîssement des concentrations de gaz anthrophiques à effet de serre a contribué à augmenter les moyennes de températures atmosphériques dans le monde depuis le milieu du XXème siècle. Le Groupe d'experts intergouvernementaux sur l'évolution du climat (GIEC) des Nations Unies a prévenu que les émissions continues de gaz à effet de serre à un niveau égal ou supérieur au niveau actuel entraîneront un réchauffement supplémentaire et de nombreux changements dans le système climatique mondial au cours du XXIème siècle. Il est prévu que ces changements soient encore plus importants que ceux relevés au cours du XXème siècle.

Le climat atmosphérique et le climat océanique sont étroitement liés, l'océan jouant un rôle significatif dans la régulation du climat régional, du climat global et des tendances météorologiques. Le réchauffement des océans a été responsable de plus de 80% des changements de la puissance énergétique du système climatique de la planète au cours des cinquante dernières années. Des concentrations accrues de dioxyde de carbone atmosphérique (CO_2) contribuent également à augmenter l'acidité des océans.

La présente évaluation décrit en détail l'étendue des impacts sur les écosystèmes marins liés au changement climatique. Elle décrit les impacts physiques et chimiques sur le milieu marin (tableau 1) ainsi que les impacts qui en découlent pour les écosystèmes et leur biodiversité (tableau 2).

Un grand nombre des changements physiques et chimiques relevés correspondent à une augmentation du CO_2 atmosphérique et au réchauffement climatique (par exemple l'augmentation de la température des océans, la réduction de la calotte glaciaire et acidification) mais nombre des liens causatifs entraînant les changements climatiques ne sont pas encore expliqués. Il est difficile de prévoir avec précision le rythme et la magnitude du changement (par exemple la montée du niveau de la mer, la circulation océanique ralentie, la réduction de la calotte glaciaire, l'acidification, l'augmentation des apports d'eau douce) et la direction des changements (par exemple l'absorption du CO_2 par les océans, la salinité; la probabilité de tempêtes; l'enrichissement en nutriments). Il s'avère également difficile de cartographier les impacts au niveau local (par exemple l'érosion côtière, la probabilité de tempêtes, la stratification; l'enrichissement en nutriments).

Il a été établi qu'un lien direct existait entre les changements physiques et chimiques et les impacts sur le milieu vivant marin (par exemple la modification de la répartition des communautés de plancton, de poisson et d'espèces intertidales) et on suggère que ces changements ont d'importants effets secondaires (par exemple la disponibilité des proies pour les oiseaux de mer). Cependant les incertitudes au sujet de ces changements physiques rendent difficile de prévoir les effets de la stratification sur la production primaire, de la probabilité de tempêtes sur les sites de nidification des oiseaux de mer et de l'enrichissement en nutriments sur les efflorescences d'algues toxiques. Ne possédant que des données insuffisantes (par exemple sur les mammifères marins, l'écologie benthique et les communautés intertidales), il est encore difficile de comprendre les liens entre le changement climatique et les impacts sur les écosystèmes marins. Il est également difficile d'établir un lien avec les effets locaux (par exemple la présence d'efflorescences d'algues toxiques, l'établissement d'espèces non indigènes).

Synthèse régionale de la force relative des aspects motrices selectionnés (1 et 2) et de l'impact (3) du changement climatique dans la zone OSPAR:

● (rouge) *plus important* ● (jaune) *moins important* ● (vert) *peu important* ? *force relative inconnue*

	1. Augmentation de la température de la mer		**2. Acidification**		**3. Distribution et abondance des espèces**	
	Observée	Projetée	Observée	Projetée	Observée	Projetée
Confidence	Haute	Haute	Haute	Haute	Haute	Basse
Région I	● (jaune)	● (rouge) / ● (jaune)	● (jaune)	● (rouge)	● (rouge)	● (rouge)
Région II	● (rouge)	● (jaune)	● (jaune)	● (jaune)	● (rouge)	● (rouge)
Région III	● (jaune)	● (jaune)	● (jaune)	● (jaune)	● (jaune)	● (jaune)
Région IV	● (jaune)	● (jaune)	● (jaune)	● (jaune)	● (jaune)	● (jaune)
Région V	● (jaune) / ● (rouge)	● (jaune)	● (jaune)	● (jaune)	**?**	**?**
Facteurs clés	L'augmentation des teneurs atmosphériques en gaz à effet de serre		Absorption de CO_2 par les océans / modification du pH		Déplacement des espèces de poisson; modifications du plankton/de la chaîne alimentaire; espèces non indigènes	

***Tableau 0.1**. Impacts prévus du changement climatique sur les aspects physiques et chimiques du milieu marin et observations relevées*

IMPACT	Conséquences éventuelles	Observations relevées
Augmentation de la température des océans	Réchauffement dans toutes les zones OSPAR, surtout dans la Région I (Xu *et al.,* 2005, IPCC, 2007a)	Le réchauffement dans les Régions I–IV depuis 1994 est plus rapide que la moyenne globale (CIEM, 2008a) Le réchauffement le plus évident est dans la Région II
Réduction de la calotte glaciaire	Région I: la calotte glaciaire risque de disparaître en été au cours de décades à venir (AEE, 2008)	Région I: la calotte glaciaire a diminué au cours des dernières décades (GIEC, 2007a).
Augmentation des apports d'eau douce	Région I: augmentation de 10-30% des apports fluviaux annuels d'ici 2100 (Walsh *et al*., 2005) apports supplémentaires provenant de la fonte glaciaire à terre (Gregory *et al.,* 2004, Dowdeswell, 2006) Il est difficile de prévoir les précipitations régionales mais une diminution des précipitations risque de se produire dans la Région IV et la partie méridionale de la Région V (GIEC, 2007a)	Région I: Les apports d'eau douce dans l'Arctique semblent avoir augmenté entre les années 1960 et 1990 (Peterson *et al*., 2002, Wu *et al.,* 2005)
Modification de la salinité	Régions I et V: la partie de l'océan atlantique située au nord du 60ème parallèle pourrait se rafraîchir au cours du XXIème siècle (Wu *et al.,* 2005)	Rafraîchissement des eaux profondes des Régions I et V au cours des 4 dernières décades du XXème siècle (Dickson *et al.,* 2002)
Ralentissement de la circulation de renversement atlantique	Ralentissement de la circulation au cours du XXIème siècle très probable (GIEC, 2007a)	Une surveillance est maintenant en place permettant de relever les changements à long terme de la circulation de renversement atlantique (Cunningham *et al.,* 2008)
Stratification sur le plateau continental	Régions II et III: les mers épicontinentales risquent de subir une stratification thermique plus longue, et plus forte mais dans les mêmes zones (Lowe *et al*., 2009)	Régions II et III: quelques preuves d'une stratification précoce au cours de ces dernières années et début des efflorescences correspondantes (Young and Holt, 2007, Sharples *et al.,* 2006)
Augmentation des tempêtes	Les projections des tempêtes dans le climat futur ne sont pas très fiables	Régions I–V: les vents forts et la hauteur moyenne des vagues ont augmenté au cours des 50 dernières années, mais des vents de même force soufflaient également dans les décades antérieures (Gulev & Hasse, 1999, Gulev & Grigorieva, 2004)
Montée du niveau des océans	De 0,18 à 0,59 m d'ici 2100, essentiellement à cause de l'expansion thermale et en prenant note des grandes incertitudes que présente la couche supérieure du fait des processus de la plaque glaciaire (GIEC, 2007a). On ne peut pas éliminer la possibilité d'une montée de 2 m au cours d'un siècle basée sur des changements historiques (Rohling *et al*., 2008)	Le niveau global des océans est monté d'environ 1,7 mm/an durant le XXème siècle. Cette montée a été plus rapide dans les années 1990 (Nerem *et al*., 2006, Church and White, 2006, Rahmstorf, 2007)
Réduction de l'absorption de CO_2	Dépend de la température, de la stratification et de la circulation de l'eau	Atlantique du Nord: flux réduits de CO_2 dans les eaux de surface en 2002-2005 par rapport à 1994-1995 (Schuster and Watson, 2007)
Acidification	L'acidité des océans pourrait atteindre, au cours du XXIème siècle, des niveaux sans précédent par rapport à quelque millions d'années passées, en ayant des effets graves sur les organismes calcaires (Feely *et al.,* 2004, Turley, 2008)	Globalement: diminution moyenne en pH de 0,1 unités depuis le début de la révolution industrielle (GIEC, 2007a)
Erosion côtière	Les prédictions sont incertaines et très localisées (Cooper and Pilkey, 2004)	Dans de nombreuses zones, l'effet conjugué de l'érosion côtière et de la construction d'infrastructures et de défenses côtières entraîne un rétrécissement de la zone côtière (Doody *et al.,* 2004)
Enrichissement en nutriments	Les projections sont incertaines et liées aux impacts sur divers facteurs, tels que les effets du profil des précipitations sur les apports et le ruissellement d'eau douce, de la fréquence des tempêtes sur la turbidité, de la température de la mer sur la stratification	Régions I–IV: des étés plus secs pourraient déjà contribuer à une augmentation des apports de nutriments (Hydes *et al*., 2008;). Des apports plus élevés de nutriments les années à fortes précipitations ont entraîné des efflorescences d'algues toxiques

Tableau 0.2. *: Impacts prévus du changement climatique sur les aspects biologiques du milieu marin et observations relevées. Dans tous les cas les projections sont limitées par les incertitudes que présentent les projections sur le climat océanique et les réactions des espèces et des communautés*

IMPACT	**Conséquences éventuelles**	**Observations relevées**
Plancton	Déplacements des espèces vers le Nord dans les mers épicontinentales et en haute mer (CIEM, 2008a) Région I : productivité accrue avec perte de plaque glaciaire (ACIA, 2005)	Déplacement de 1000 km vers le Nord de nombreuses espèces planctoniques au cours des 50 dernières années (Beaugrand *et al.,* 2009) Modification de la période d'éclosion des efflorescences planctoniques (Edwards *et al.,* 2008)
Efflorescences d'algues toxiques (HAB)	Possibilité d'accroîssement résultant de la modification de la température, de la salinité et de la stratification des océans (Raine *et al.,* 2008)	Efflorescences planctoniques anormales (souvent toxiques) dans des habitats spécifiques affectés par des salinités plus faibles (par exemple fosse norvégienne) ou températures plus élevées (German Bight). (Hoepffner, 2006; Raine *et al.,* 2008)
Poisson	Déplacement des populations vers le Nord mais le manque de connaissances sur les mécanismes sous-jacents rend les projections incertaines (Pinnegar *et al*., 2008). Des températures plus élevées pourraient augmenter la présence de maladies affectant les espèces de poisson, mollusques et crustacés de culture (Pinnegar *et al.,* 2008)	Déplacement vers le Nord des espèces halieutiques benthiques et pélagiques plus prononcé dans les Régions I et II (CIEM, 2008a)
Mammifères marins	Perte d'habitat pour les mammifères dépendant de la calotte glaciaire (Evens *et al.,* 2008) Modifications de la disponibilité des espèces proies en particulier dans la Région I du fait de décalages dans la production (ACIA, 2005)	Les données sur la distribution, l'abondance et la condition des mammifères marins sont limitées (CIEM, 2007, 2008b) Le phoque marbré et l'ours polaire risquent déjà d'être affectés par la réduction de la calotte glaciaire (GIEC 2007b, Evens *et al.,* 2008)
Oiseaux de mer	Les impacts sur les oiseaux de mer risquent d'être plus importants lorsqu'ils sont causés par la modification de la disponibilité alimentaire plutôt que par la perte de nids due au changement climatique (Mitchell and Fredericksen, 2008)	L'échec de la reproduction des oiseaux de mer dans la mer du Nord a été lié aux variations de la disponibilité alimentaire entraînées par l'augmentation de la température des océans (Frederiksen *et al.,* 2006)
Espèces non indigènes	Leur invasion et établissement risquent d'être facilités par le changement climatique et présenter de grands risques pour les écosystèmes existants (Elliott *et al.,* 2008)	L'établissement de l'huître creuse *Crassotrea gigas* et de la balanne *Elminius dodestus* a été lié au changement climatique (CIEM, 2008a)
Communautés intertidales	Extension et contraction continues de la gamme des diverses espèces intertidales (Meiszkowska, 2008)	L'abondance et l'ampleur de la gamme de certains invertébrés et algues d'eaux chaudes ont augmenté à proximité du Royaume-Uni au cours des 20 dernières années (Herbert *et al*., 2003, Meiszkowska, 2008)
Ecologie benthique	Les organismes benthiques sessiles tolèrent dans l'ensemble des modifications modérées de l'environnement s'étendant sur des périodes d'adaptation raisonnables mais ils sont très vulnérables lorsqu'il s'agit d'évènements soudains et extrêmes (Hoepffner, 2006)	Des conditions hivernales anormalement froides ont entraîné la prolifération d'espèces d'eaux froides et la disparition d'espèces d'eaux chaudes. (CIEM, 2008a) Des modifications de la composition des espèces se sont produites mais l'on n'a observé aucun déplacement ou aucune modification importants de la productivité brute (Frid and Moore, 2008, ICES, 2008a)

1. Introduction

Why is OSPAR concerned with climate change issues?

The OSPAR maritime area covers the north-eastern North Atlantic (east of Cape Farewell and north of Gibraltar) and its extended system into the shelf seas, the high latitudes and the Arctic. This region is one of key importance to the global climate system and the same processes that help to govern the climate globally impact upon local marine systems within the region.

The growing realisation that human action is affecting the climate has developed at the same time as growing recognition of the importance of naturally occurring variations in the climate. This report focuses on **climate change** as the human induced warming trend and also on the observed changes associated with **climate variability** (cycles of change in climate, here principally at a decadal scale) that may be the best indication of how ecosystems might be affected by climate change. In the marine environment time-series measurements are mostly short, very few allow observations to be linked to climate change with a high certainty, but all have been collected through periods of climate variability that allow some assessment of the changes that will occur in a warmer world.

In its future work, OSPAR needs to take changes due to climate change into account and, where necessary, adapt current policies and objectives to support work on reducing emissions and to account for increased vulnerability of marine ecosystems.

2. Climate Change

The Greenhouse and Carbon Cycle

The Earth's climate system sets the conditions in which we live and ecological systems evolve. Greenhouse gasses (GHG) in the atmosphere regulate the re-radiation of heat out into space balancing the incoming heating from the sun maintaining the Earths climate through the natural greenhouse effect. Over the scale of millions of years conditions change very strongly and major epochs of the earth's history are associated with shifts in the climate. Since the ice sheets last retreated from northern Europe (10-15 000 years ago), the Earth has been in a warm period during which modern society and current ecosystems have developed.

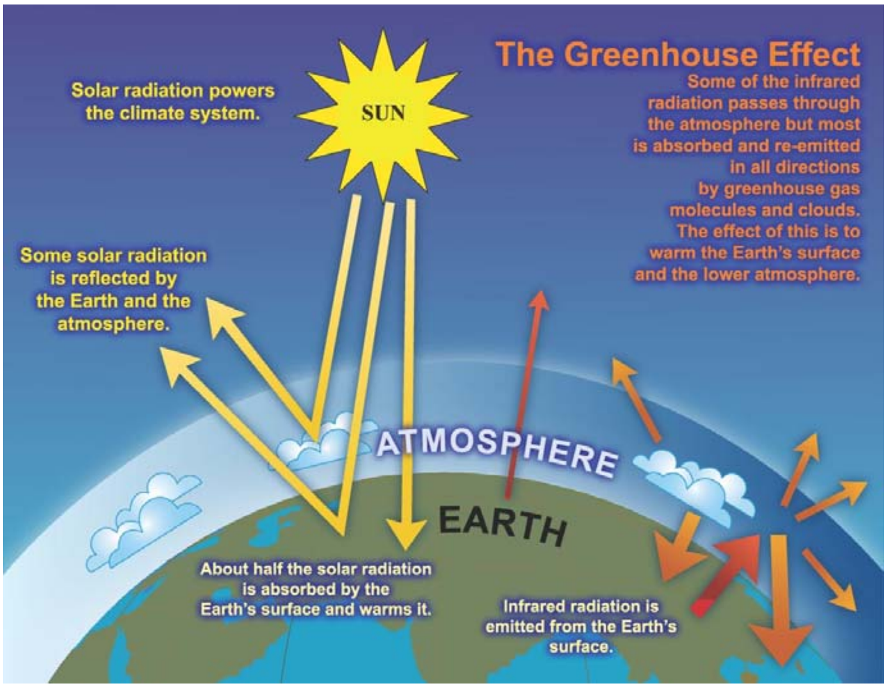


Figure 2.1 *Schematic of the Greenhouse effect reproduced from IPCC-AR4 WG1 FAQ1.3 (IPCC, 2007a)*

Since the start of the industrial revolution mankind has been using some of the geologically-stored carbon in fossil fuels, shortcutting the geologically slow cycling of carbon. The anthropogenic input of carbon dioxide and other greenhouse gases to the atmosphere is recognised to pose a threat to the stability and natural cycles of the climate and the social and ecological systems that rely on it.

How is climate change being addressed?

Facing up to the challenges and opportunities presented by climate change requires both sound scientific evidence and an effective framework for developing international social and regulatory mechanisms (i.e. good evidence and sound decision-making).

Global

The United Nations Framework Convention on Climate Change (UNFCCC) has been in place since 1994. Its key objective is 'to achieve stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. Member nations meet annually at the Conference of Parties (COP), and it was at the third of these meetings in Japan where the Kyoto treaty was negotiated, with most industrialized nations and some central European economies agreeing to legally binding reductions in greenhouse gas emissions of around 6 to 8% below 1990 levels between 2008 and 2012. A timetable to agree a post-2012 framework was agreed at the 2007 COP in Bali, which aims to be completed by the Copenhagen COP meeting in December 2009.

Europe – target to avoid dangerous climate change

The EU has proposed a target aimed at limiting global temperature increase to less than 2 °C above the pre-industrial level. Contributing to this objective, prior to the Copenhagen COP, the EU has aimed to cut GHG emissions by at least 20% relative to 1990 baseline levels by 2020 (EC Climate Action - http://ec.europa.eu/climateaction/index_en.htm downloaded 31st July 2009). Also prior to the December 2009 COP, some member states have stated further commitments (for example the UK and Germany aim to cut emissions by 34% and 40% respectively by 2020 relative to 1990). Even if the EU target is achieved, the global warming we are already committed to will lead to climate change impacts for which countries worldwide will need to adapt.

Evidence base

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007a/b/c hereon IPCC-AR4) states that "most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* (over 90% likelihood) due to the observed increase in anthropogenic greenhouse gas concentrations". This use of 'very likely' in the IPCC-AR4 statement represents a greater degree of certainty than in previous IPCC assessments with regards to the direct impact of human activity on global climate.

Observed temperature changes over the 20th century agree much better with model simulations that include anthropogenic forcing than those that do not (see Figure 2.2). Over the last 50 years, the warming of the oceans accounts for more than 80% of the change in the energy content of the Earth's climate system. (IPCC, 2007a). Many of these changes are observed in the OSPAR maritime area and some of the large-scale processes within this area involving its oceans and seas play key roles in climate regulation. The evidence base is also growing to support the suggestion that these marine climate changes are having an impact upon the marine ecosystem and the services that it provides.

The IPCC-AR4 warns that "continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century"(IPCC, 2007c).

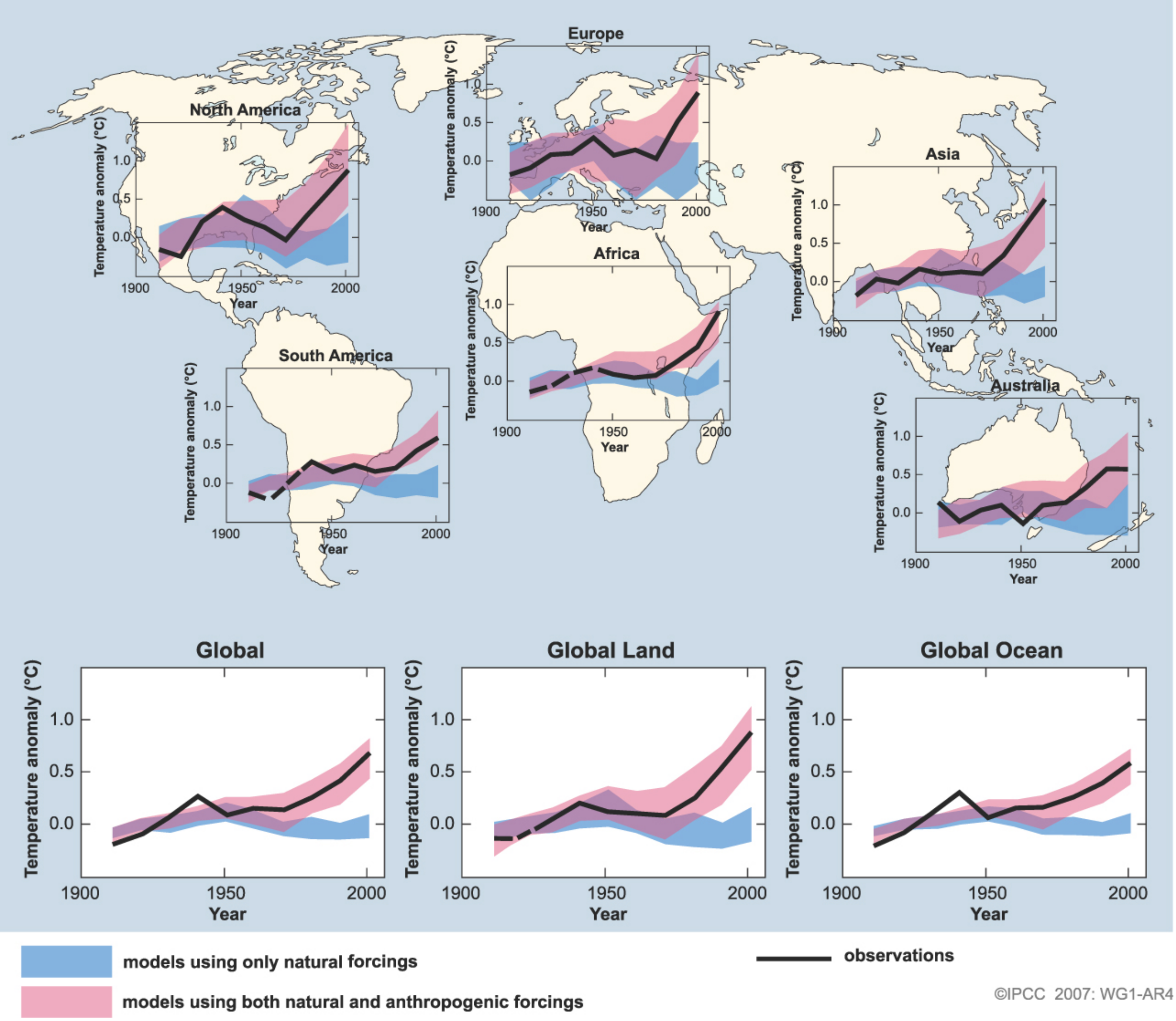


Figure 2.2 *IPCC figure of time series showing observed 20th century climate (black) versus climate models with (pink) and without (blue) anthropogenic GHG. [Reproduced from IPCC AR4 WG1 Chp 9 FAQ 9.2] (IPCC, 2007a)*

Climate Change Scenarios

In order to assess the development of climate over the next 100 years a forecast has been made of emissions of GHG. The actual future profile of GHG emissions is currently impossible to predict as it will depend on a number of complex interacting processes (e.g. population growth, economic, social and regulatory development as well as technological advances). The IPCC use scenarios that follow six storylines of the future developed in the IPCC Special Report on Emissions Scenarios (IPCC-SRES, 2000). For a full description of the six scenarios please see www.ipcc.ch/ipccreports/sres/emission/003.htm . Briefly and, for example, B2 is a scenario with more local solutions to economic, social, and environmental sustainability; the scenario A1B has rapid economic development with a balanced emphasis on all energy sources; and A2 is a scenario with a divided world, self reliant nations, and a continuously increasing population. It is not possible to assess which of the scenarios is the most likely or closest to the actual future. Until the scientific understanding of likelihood of future emissions is better developed, or new scenarios are developed, the IPCC-SRES scenarios remain the main tool for considering future possible climates.

The long residence time-scales associated with GHGs in the atmosphere means that we are already locked into a certain amount of climate change and this is reflected in the outcomes of models that show little difference in global temperature rise until the middle of the 21st century. Later in the 21st Century the

The long residence time-scales associated with GHGs in the atmosphere means that we are already locked into a certain amount of climate change and this is reflected in the outcomes of models that show little difference in global temperature rise until the middle of the 21st century. Later in the 21st Century the scenarios diverge and give a range of temperature changes, for instance by the last three decades of the century under SRES A2 and B2 Europe undergoes a warming in all seasons in the higher A2 scenario this is estimated to be 2.5 to 5.5°C, while under emissions scenario B2 the range is lower (1 to 4°C).

Current indications are that CO_2 levels are actually higher than the six emission scenarios used by IPCC to project climate this century (Raupach *et al.*, 2007).

Climate modelling of regions, oceans and seas

The ocean has long time-scales and short space-scales that make the modelling of ocean climate variability and change demanding compared to the atmosphere. Yet in order to model the Earth's climate as a whole the ocean and cryosphere have to be included in Global Climate Models GCMs.

Since the third IPCC report in 2000 the development of the oceanic component of GCMs has continued. "Resolution has increased and models have generally abandoned the 'rigid lid' treatment of the ocean surface. New physical parametrizations and numerics include true freshwater fluxes, improved river and estuary mixing schemes and the use of positive definite advection schemes. Adiabatic isopycnal mixing schemes are now widely used. Some of these improvements have led to a reduction in the uncertainty associated with the use of less sophisticated parametrizations (e.g. virtual salt flux). Progress in developing Atmosphere-Ocean GCM (AOGCM) cryospheric components has been clearest for sea ice. Almost all state-of-the-art AOGCMs now include more elaborate sea ice dynamics and some now include several sea ice thickness categories and relatively advanced thermodynamics" (IPCC, 2007a).

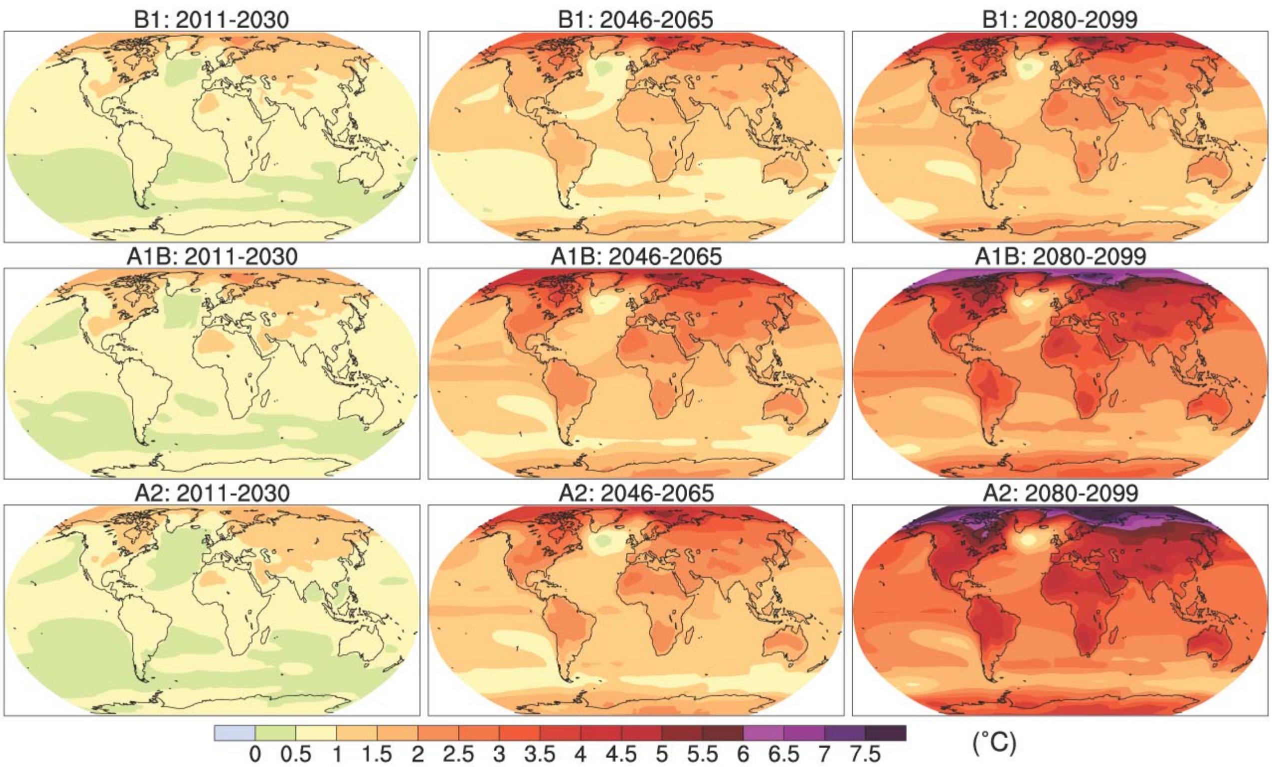


Figure 2.3 *IPCC-AR4 WG1 (Figure 10.8) Multi-model mean of annual mean surface warming (surface air temp) for 3 scenarios (B1: more integrated, and more ecologically friendly growth aimed at global environmental sustainability, A1B: rapid economic development with a balanced emphasis on all energy sources, A2: a divided world, self reliant nations, continuously increasing population) and 3 time periods, change is relative to 1980-1999. (IPCC, 2007a)*

The Arctic ocean and subpolar seas present a particular challenge for climate models. Coarse resolution in global models prevents the proper representation of local processes that are of global importance (such as the formation of waters in the Nordic Seas that supply the deep water overflows).

Water cycle responses to climate change are particularly uncertain on the boundaries between areas of increasing and decreasing precipitation. There are important climate processes for regional climate that are uncertain in terms of climate change response. These include the NAO (the North Atlantic Oscillation is a region wide pattern of atmospheric pressure), blocking (persistence of high pressure systems that can have a strong effect on weather for a season), and the thermohaline circulation. (IPCC, 2007a)

Most models continue to have difficulty controlling climate drift, particularly in the deep ocean this drift must be accounted for when assessing change in many oceanic variables (IPCC, 2007a).

3. Climate Change Impacts on the marine environment

This section examines the evidence available for climate change impacts on the marine environment and ecosystem. Firstly we consider changes to the environment itself, in essence the changes in the marine climate that are part of, and result from, changes in the whole climate system. This is followed by the impacts of the changing climate on the biological part of the marine ecosystem.

Direct evidence of biological impacts of anthropogenic climate change is difficult to demonstrate with high certainty due to natural variation on wide spatial and temporal scales (Hoepffner, 2006). However, a wide range of observed impacts on marine biological systems have been linked to changing climate, either directly (through impacts of sea temperature) or indirectly through impacts on the timing, distribution and abundance of species.

3.1 Changes to the marine environment

Sea Temperature

What is the issue?

The IPCC AR4 concluded that it is ‘likely’ that anthropogenic forcing has contributed to the observed warming of the upper several hundred metres of the global ocean during the latter part of the 20th century. Both sea and land surface temperatures in, and bordering, the OSPAR Maritime Area have increased from 1995 to 2004 at a rate which is well above the global mean (ICES, 2008a).

What has happened and how confident?

In the OSPAR Region II (North Sea) the rate of warming is about 1–2°C over the past 25 years whereas in the western OSPAR Regions the warming is less (0.4–0.8°C) and evidence suggest that summer periods in the North Sea surface waters have become longer and warmer and winters have become shorter and less cold. The increase in temperature in OSPAR Region IV (Biscay and western Iberia) is lower in the south and is also strongly influenced by upwelling (ICES, 2008a – see their Figure 3.1.3)

The strong influence of regional weather patterns (NAO, NAM- the Northern Annular Mode is a hemispheric scale pattern of climate variability) and ocean circulation (North Atlantic Current) means that the global warming signal is only partly reflected in the temperatures of European Seas (ICES, 2008a) and it is apparent that natural variability is still the dominant forcing factor on temperature change in the European Seas (IPCC, 2007a).

Over a longer timescale, sea surface temperature (SST; Rayner *et al*., 2003) for the area 45°-60°N, 3°-20°W (the eastern part of Region V and border with Region III) exhibits a linear warming trend of 0.38°C over the

1900 to 2007 period but very strong warming since the early 1990s, with the warmest years in the record being 2007, 2006 and 2005 (Cannaby and Hüsrevoğlu, 2009).

What might happen?

The IPCC projects future ocean warming to be relatively large in the Arctic, with less warming over the North Atlantic (e.g. Xu *et al*., 2005). However, changes in SST for the different geographic regions across Europe are difficult to predict as the resolution of the coupled-ocean atmosphere models used is not high enough (EEA, 2008).

Are there any OSPAR regional differences

The surface waters in all OSPAR regions warmed in 1999 – 2008 relative to the period 1971 – 2000 (Figure 3.1.1). In the North Sea the monthly mean sea surface temperatures (SST) has exceeded the long-term mean since the late eighties. This warm period peaked in 2002, which was the warmest year since the beginning of [area-averaged] SST recordings in 1968

In Region III, work by Cannaby and Hüsrevoğlu (2009) an analysis of a nearshore time-series (Malin Head) exhibits a linear warming trend of 0.85°C over 1958-2006 with the warmest years in the record occurring since 1995. They carefully attribute about half of this warming to anthropogenic climate change.

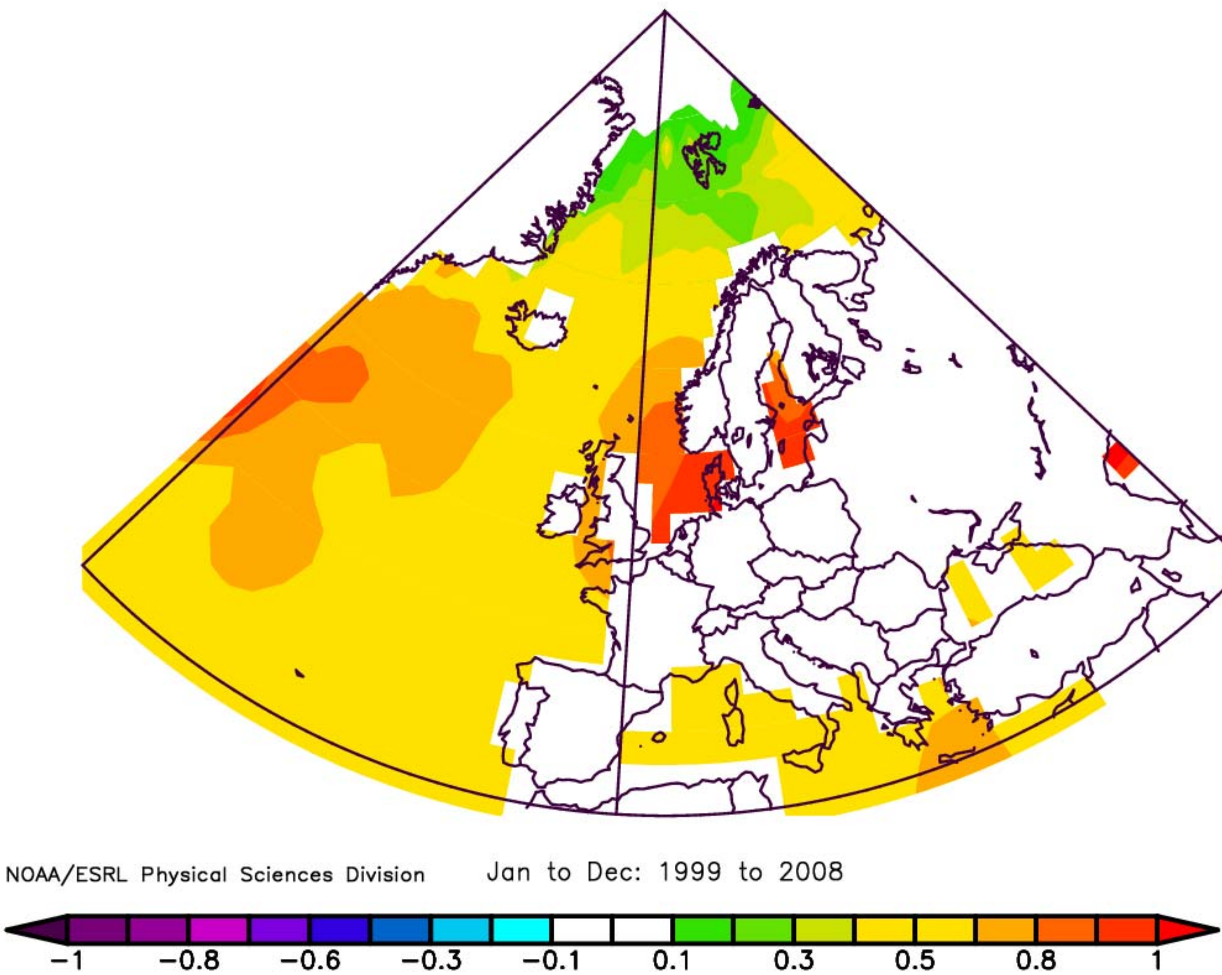


Figure 3.1.1 *Annual mean sea surface temperature (SST) anomaly for the OSPAR region, showing the mean of the period 1999–2008 minus the 1971–2000 mean. The plot uses an extended reconstruction of global SST data (NOAA_ERSST_V3 data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA* http://www.cdc.noaa.gov/)

Sea ice

What is the issue?

Sea ice is formed at the surface of the ocean and can persist through the summer to become multi-year ice. The high albedo of ice means that much of the incoming shortwave solar radiation to the Arctic region is reflected back to space without being able to warm the atmosphere, land or sea. Sea ice also helps directly to regulate the air-sea exchange of freshwater, heat and gasses. Its effect on light and plankton in the upper ocean leads to strong coupling with Arctic trophic structures. Changes in sea-ice also have an impact on the uses of the sea through improved access whether for transpolar shipping routes, fishing, oil and gas exploration or eco-tourism.

What has happened and how confident?

Satellite observations show that annual average sea ice extent has decreased by 2.7 ± 0.6% per decade since 1978 with declines being particularly marked in summer. The summer minimum has been declining at a rate of about 7.4 ± 2.4% (IPCC, 2007a) per decade. In September 2007 the lowest extent ever recorded of about half the normal minimum of the 1950s (EEA, 2008) was caused to some degree by regional warming combined with an anomalous Sea Level Pressure pattern. It is not known what long term impact an extreme event like 2007 can have, but the nature of the positive feedback to heating through lost albedo mean that it could be long-lasting and strong. The minimum ice extent in the following summer (2008) had greater coverage than 2007 but remained low compared to previous years, and consisted of relatively young and thin ice.

Reductions in sea-ice extent have had significant impacts on the North East Atlantic ecosystem. The IPCC AR4 (IPCC, 2007a) reported with high confidence that “the reduction of Arctic sea ice has led to improved marine access, increased coastal wave action, changes in coastal ecology/biological production and adverse effects on ice-dependent marine wildlife, and continued loss of Arctic sea ice will have human costs and benefits”.

What might happen?

Rising temperatures would be expected to continue the downward trend. A recent study, based on IPCC AR4 model simulations, projected mean reductions of annually averaged sea ice area in the Arctic by 2080-2100 of 31%, 33% and 22% under the A2, A1B and B1 SRES scenarios (Zhang and Walsh, 2006).

The observed trend for much greater sea ice loss in summer compared to winter is a feature of future models (see Figure 3.1.2) and it is possible that Arctic sea ice may disappear at the height of the melting season in the coming decades (EEA, 2008). In contrast, the area of seasonal (winter-only) sea-ice coverage actually increases in many models (IPCC, 2007b).

Are there any OSPAR regional differences?

Sea ice is regularly evident in OSPAR Region I. In particularly hard winters, limited areas of sea ice can also occur in Region II.

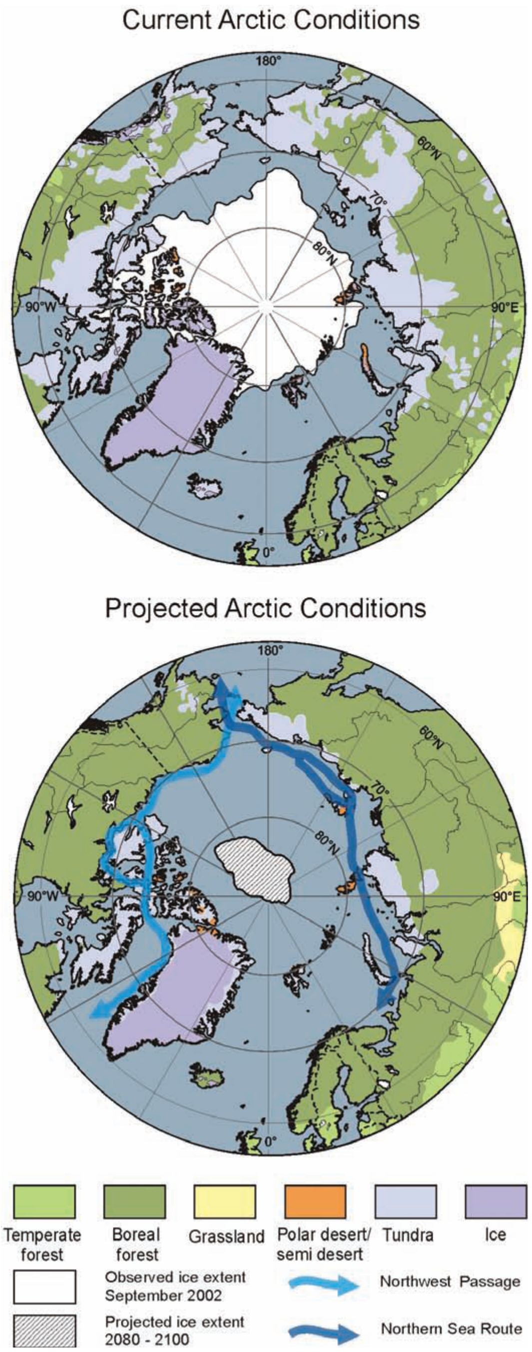


Figure 3.1.2. *Observed minimum sea-ice extent for September 2002, and projected (2080 - 2100) sea-ice minimum extent, together with potential new/improved sea routes (redrawn from Instanes et al., 2005; Walsh et al., 2005). From IPCC (p.659) WG II (IPCC, 2007b)*

Freshwater input

What is the issue?

The large scale balance of freshwater is important through its impact on the thermohaline circulation but also for riverine inputs from coasts that can strongly affect productivity (through nutrient supply) as well as local currents and pathways (through freshwater effects on buoyancy). On an annual time-scale the whole of the North Atlantic and its extended system into the shelf seas, high latitudes and Arctic, north of about 50° N benefits from an excess of precipitation over evaporation (P – E > 0 mm/year). P – E is particularly high to the south and west of Norway and over Iceland and south-east Greenland (Serreze *et al*., 2008). This atmospheric flux of freshwater into the region is balanced, with river-runoff as an intermediate step, by the oceanic transport of ice and freshened seawater southward into regions where evaporation predominates.

What has happened and how confident?

Winter rainfall has substantially increased over Northern Europe, increasing flooding along river basins and increasing runoff into the North Sea (Struyf *et al*., 2004).

(Peterson *et al*., 2002) concluded that the average annual discharge from six Arctic rivers increased by 7% from 1936 to 1999. The increase is linked both to Arctic warming and to the amplifying NAO/AO (NAO/Arctic Oscillation system) from the 1960s to the 1990s. (Wu *et al*., 2005) reproduced the trend in Arctic riverflow using an 'all forcings simulation' of a global coupled climate model (HadCM3 – the UK Met Office Hadley Centre coupled model) in which the model was forced with both anthropogenic (greenhouse gases, sulphate aerosols and ozone) and natural (solar and volcanic) external factors. The simulated change in Arctic river flow shows a consistent upward trend from the 1960s, 'in very good agreement' both in timing and amplitude with the trend reported by Peterson *et al*. (2002) from river monitoring data. The trend is not evident in the set of experiments using only natural forcings. They therefore describe it as likely that the upward trend in circumarctic riverflow is real, part of an anthropogenic intensification of the global hydrological cycle. (Curry *et al*., 2003) describe evidence of the accelerated water cycle through freshening of the Nordic Seas and upper North Atlantic while sub-tropical seas appear more saline over 4 decades.

What might happen?

Future projections give an estimated increase of 10-30% in annual river flow to the Arctic Ocean by the end of the 21st century (Walsh *et al*., 2005 in IPCC, 2007b) with additional inputs from the melting of land based ice, most notably Greenland (Gregory *et al*., 2001; Dowdeswell, 2006).

Confidence in model projections of future precipitation is low, downscaling studies demonstrate that local precipitation changes can vary significantly from those expected from the large-scale hydrological response pattern. (IPCC, 2007a)

Are there any OSPAR regional differences?

The IPCC (2007a, see FAQ 11.1) suggests that, while regional prediction of precipitation remains uncertain, Region IV and southern area of Regions III and V are more likely to experience decreases in precipitation, and reduction in supply of freshwater in summer months, either directly or through changes in local catchments. They also suggest that precipitation is more likely to increase over Region I in summer and over Regions I and II in winter.

Ocean salinity

What is the issue?

The salinity of the surface layer of the ocean (the top 100 m) is most heavily influenced by changes in precipitation and evaporation (Josey and Marsh, 2005) and is more variable than deep-sea salinity. Ocean salinity is important through its effect on the density of the water and resultant impacts on ocean circulation. Reduction of sea ice, acceleration of the global water cycle and thawing of ice on land will all modify the oceans salinity. In shelf seas, changes in salinity at the surface would have an impact on the presence or absence of stratification of the water column and on the local circulation.

What has happened and how confident?

In the deep northern North Atlantic and Nordic seas, salinity evolved from a maximum in the 1960s to a minimum in the mid-1990's and in conjunction with observations of increasing salinity in the tropics these changes have been suggested to be evidence of a global scale acceleration of the water cycle. (Dickson *et al*., 2002, Curry *et al*., 2003). The freshening in northern regions is thought to be consistent with these regions having greater precipitation, although higher runoff, ice melting, advection and changes in the meridional overturning circulation may also contribute (IPCC, 2007a).

(Hatun *et al,* 2005) suggests that the salinity of the waters in Regions III and V that feed Region I (the North Atlantic inflow to the Nordic Seas) is influenced by the relative importance of the subtropical and sub-polar gyres(Figure 3.1.3). The salinity of the inflow is strongly correlated to the Sub-polar gyre index of (Hakkinen and Rhines, 2004). Direct measurements of the waters of the North Atlantic Current that feed the Nordic Seas and Arctic through Fram Strait have undergone a strong increase in salinity since the mid 1990s. Increasing to a maximum in the observed record in 2005 (Hughes and Holliday, 2007, Holliday *et al*., 2008).

The measurements and trends observed are of high confidence, however it is not possible to attribute them to climate change, though they are consistent with changes that might be expected given an acceleration of the hydrological cycle.

What might happen?

Changes in precipitation patterns, ocean circulation and ice melt would cause changes in the salinity of the upper ocean. In the OSPAR region these could be passed onto deep water through the modification of overflow water and the water that it entrains.

The IPCC suite of models project, with low confidence, that the Atlantic Ocean north of 60°N will freshen during the 21st century (Wu *et al*., 2005).

Are there any OSPAR regional differences?

Changes in salinity will be strongly dependent upon location. Salinity in all the regions is strongly associated with ocean circulation, the shelves will be more sensitive to local river runoff and catchment precipitation while the northern and western areas of Regions I and V are sensitive to changes in the polar ice and freshwater cycle.

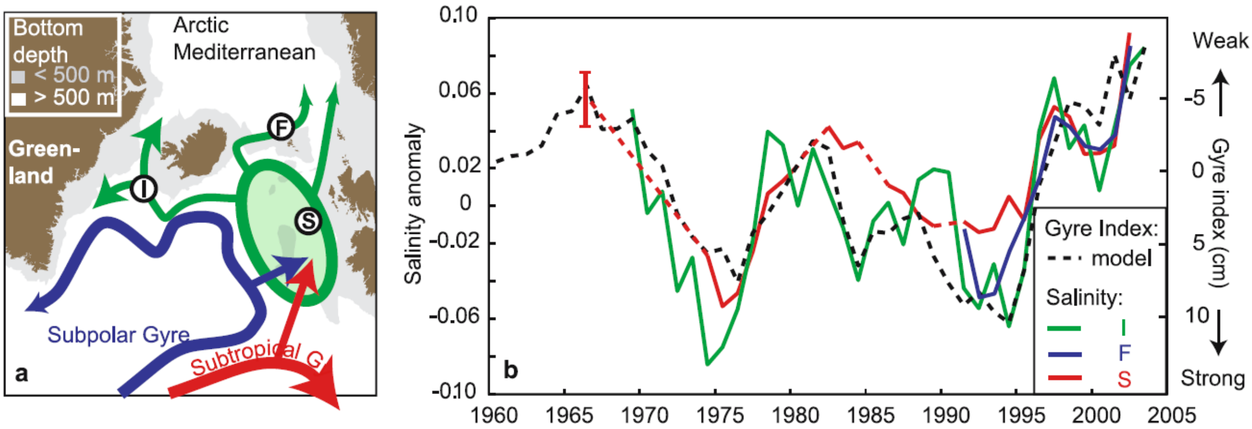


Figure 3.1.3. *(Hatun et al., 2005). Salinity of the inflows to the Nordic Seas the relative contributions of waters from the Subpolar and Subtropical gyres due to the 'strength' of the subpolar gyre (Hakkinen and Rhines, 2004)*

Atlantic Meridional Overturning Circulation

What is the issue?

The Atlantic Meridional Overturning Circulation (MOC) is driven by changes in the temperature and salinity of surface water as it moves north in the Atlantic. The cooling of warm Atlantic waters as they move towards the North Pole leads to the sinking of dense waters, which then pass south eventually supplying all the oceans of the world with deep water. North-western Europe benefits from the regional warming provided by this current. As the circulation requires water to be made dense in northern latitudes, freshwater input has the potential to slow or stop it in its current form if the water becomes too fresh and therefore too light to sink.

What has happened and how confident?

Continuous direct measurements of the MOC have only become possible recently and these show that day to day variability is high (Cunningham *et al.,* 2007). This variability is high compared to the previous discrete hydrographic observations, which had been suggested as evidence of a slowing of 30% in the Meridional Overturning Circulation (MOC) since the early 1990s (Bryden *et al*., 2005).

What might happen?

Whilst the IPCC AR4 considered it 'very likely' (greater than 90% chance) that the MOC will slow down during the next century (with models predicting an average 25% decrease under SRES scenario A1B), temperatures are still expected to increase in the region as the signal from greenhouse warming will overcome any associated cooling effect. This weakening of the MOC has been suggested to be a result of an increase in high latitude temperatures and precipitation (reducing surface water density).

Are there any OSPAR regional differences?

The local temperature response to change in the MOC is strongest in Region I.

Shelf sea stratification

What is the issue?

In the shelf seas some areas stratify seasonally where surface waters are made buoyant enough through heating and addition of freshwater to overcome the mixing associated with tides. These areas of stratification have an impact on the seas circulation and on many components of the ecosystem through nutrient supply.

What has happened and how confident?

There is some evidence of a recent trend to earlier stratification and onset of the spring bloom in European Shelf Seas (Regions II and III), largely in response to warming air temperatures (Young and Holt, 2007, Sharples *et al*., 2006).

What might happen?

Our understanding of how shallow seas respond to meteorology suggest that stratification and the associated spring bloom will, on average, occur earlier in a warmer climate (Sharples and Dye, 2008). UK Climate Projections (Lowe *et al*., 2009) suggest that, under a medium future emissions scenario (A1B – IPCC-SRES, 2000), most areas of shelf sea stratification in Regions II and III will not change their extent greatly but that stratification may be stronger and last longer with earlier onset. Conversely areas of Regions II and III that are stratified by salinity along the European continental coast appear to be stratified for a shorter period under the same future projection (Lowe *et al.,* 2009). Intensified seasonal thermohaline stratification could lead to accumulation of organic matter in bottom layers, causing oxygen depletion in some areas. Increased stratification will also enhance the development of flagellates, utilising nutrients from deep layers.

Increasing temperature and its impacts on stratification on algal blooms have been investigated by (Peperzak, 2003) who showed the importance of increasing temperature and stratification in doubling the growth rate of harmful algae, concluding that the risk of HABs due to climate change will increase rather than decrease in the future.

Are there any OSPAR regional differences?

Shelf sea stratification is most important in OSPAR Regions II and III. In Regions I, IV and V areas of stratification that are controlled by bottom mixing are less evident primarily due to the restricted shelves.

Storms and waves

What is the issue?

Wind-driven waves and storms are seen as the primary drivers of short-term coastal processes on many European coasts (Smith *et al*., 2000). Higher waves and increased storm-surge elevations would have important potential consequences such as enhanced erosion and flooding in estuaries, deltas and embayments (Flather and Williams, 2000; Lionello *et al*., 2002; Tsimplis *et al*., 2005; Woth *et al*., 2005).

What has happened and how confident?

Recent analyses of a more extensive data set confirm a significant upward trend in wave heights in the North Atlantic, but only for the last 50 years and embedded within a pattern of multi-decadal variability over more than a century (Gulev and Hasse, 1999; Gulev and Grigorieva, 2004).

Many of the changes in storms and waves over the last 50 years in the North East Atlantic can be understood in terms of the behaviour of the NAO. A recent strong trend in the NAO (towards stormier conditions) is apparently unique in its history, but it is controversial whether this is a response to greenhouse gas forcing (Osborn, 2004).

What might happen?

At present confidence in Global Climate Models (GCMs) and Regional Climate Models (RCMs) modelled wind field changes is very low (Hulme *et al*., 2002).

In light of the overall low confidence, a large number of analyses have been conducted and many GCMs suggest a general trend towards the stormier tendency of NAO in the 21st century (e.g. Terray *et al*., 2004; Miller *et al*., 2006). However, some Regional Climate Models suggest different and mostly weaker changes in winds and storminess (e.g. Hulme *et al*., 2002; Barnett *et al*., 2006). Overall climate models typically predict a decrease in the total number of extra-tropical cyclones but an increase in the number of the most intense storms (Lambert and Fyfe, 2006).

Either a strengthening of the storm track or an increase in intense cyclones will result in a deterioration of wave conditions (Wolf and Woolf, 2006).

Are there any OSPAR regional differences?

The size of storm systems means that variations in the path of storms across the North Atlantic would directly affect the OSPAR regions differently. It may be that a decrease in storms over one area might directly mean an increase in another.

Sea level (including effects on coastal habitats).

What is the issue?

Sea-level rise (SLR) can cause flooding, coastal erosion and the loss of coastal regions. It reduces the return period for extreme water levels and threatens existing coastal ecosystems. Future impacts from SLR will be felt most keenly on low-lying coastlines with high population densities and relatively small tidal ranges (Kundzewicz *et al*., 2001). Decisions on adaptation measures (e.g. coastal defence or re-alignment) will affect coastal communities and ecosystems.

What has happened and how confident?

Over the 20th Century global average sea level rose at an average of 1.7mm/yr. The rate of SLR varied from -0.3mm/yr to 2.8mm/yr along European coasts depending on the region.

Tide-gauge and satellite data-sets indicate an accelerated trend in SLR since about 1990 (Nerem *et al*., 2006; Church and White, 2006; Rahmstorf, 2007). In 2008, the EEA reported this increased rate in the satellite data as 3.1 mm/year during the previous 15 years. At present it is unclear whether this higher rate is part of a continual long-term acceleration in the rate of rise or is associated with shorter timescale variability of the climate and sea level system.

What might happen?

The IPCC AR4 projects an overall level of rise during the 21st century of 0.18-0.59m above the 1980-2000 level but with large uncertainties attached to the upper limit associated with ice sheet dynamics. Thermal expansion is the largest component in the IPCC projection, contributing 70–75 % for all scenarios. Glaciers, ice caps and the Greenland ice sheet are also projected to contribute to sea-level rise but with high uncertainty (IPCC, 2007a).

Average rates of 1.6±0.8 m per century of sea-level rise during the last inter-glacial (Rohling *et al*., 2008) may give an insight to rises that cannot be discounted in the coming century, but there is no evidence to suggest this is currently happening.

SLR projections for Arctic coasts based on SRES scenarios indicate an increased risk of flooding and coastal erosion after 2050 but always lower than the risk in the North Sea (Johansson *et al*., 2004, Meier *et al*., 2004, 2006; Nicholls, 2004; EEA, 2008).

An additional 1.6 million people living in Europe's coastal zones could experience coastal flooding by 2080 (EEA, 2008).

Are there any OSPAR regional differences?

Change in absolute sea level is seen locally through changes in the sea level relative to the land. Land-level is responding to the millennial time-scale change of glaciation where land that was covered by ice is now rising. Relative sea-level rise is lesser in those areas experiencing isostatic uplift. The rate of uplift is not constant and some areas traditionally thought to be at low risk of significant changes in relative sea-level may be within range of SLR (Smith *et al*., 2000).

In Northern Europe, the removal of the great Eurasian ice sheets at the end of the last glacial period has led to a post-glacial ‘rebound’ of the land. Fennoscandia and Denmark were at the centre of the former ice mass, here the isostatic post-glacial rebound mean that Sweden and Finland are subject to uplift at a rate that is leading to relative falls of sea level (Doody *et al*., 2004).

By contrast, beyond the edge of the former Eurasian ice masses, in the North Sea between Norway and Great Britain and extending through the north-western Netherlands and northern Germany, the collapse of the glacial ‘forebulge’, and re-filling of the ocean basins when the ice sheets melted mean that subsidence is apparent (Lowe *et al*., 2009).

In Iceland, melting of the four major ice caps since 1890 is leading to glacio-isostatic uplift of land in the centre and south-east of the country (Lund and Arnadottir, 2009). In Greenland, the response of the Greenland ice sheet to glacio-isostatic adjustment (both since the last glacial and through present-day wastage) largely leads to falling sea levels, particularly in the south-east where present day ice-loss is greatest and sea level could be falling at rates as high as a few mm per year (Fleming *et al*., 2009).

Air-Sea exchange of gases (inc CO_2)

What is the issue?

Uptake of CO_2 by the ocean is a primary control on the level of GHGs in the atmosphere, and hence a control on the climate.

What has happened and how confident?

The North Atlantic is the major store of dissolved CO_2 in the global ocean (Sabine *et al.*, 2004) which has taken up about one quarter of the anthropogenic emissions of CO_2 in the last 200 years.

Recent evidence suggests that the flux of atmospheric CO_2 into the surface of the North Atlantic reduced in 2002-05 compared with that measured in 1994-95 (Schuster and Watson, 2007).

What might happen?

Uptake of CO_2 in the future will be strongly affected by changes in water temperature and significant changes in circulation and stratification of the upper ocean.

Are there any OSPAR regional differences?

The exchange of CO_2 is differs between the open ocean and the shelf seas and between cold and warm waters. Where sea ice exists this will also have an impact on the exchange.

Acidification

What is the issue?

When atmospheric CO_2 dissolves in the ocean, a weak acid is formed. Increasing atmospheric CO_2 leads to increasing acidity of the ocean (reflected by a lowering in pH). A potential feedback from increased acidity is that it may decrease the oceans ability to take up more CO_2 (Turley, 2008).

The effects of increased CO_2 in the ocean have only recently been seriously debated and the underlying knowledge base is presently small. As recently as the 1990s awareness of the effects that acidification could be having was limited and the QSR 2000 did not mention CO_2 effects directly (OSPAR 2000).

What has happened and how confident?

The ocean is becoming more acidic as it has taken up anthropogenic carbon since the start of the industrial revolution, with an average decrease in pH of 0.1 units (IPCC, 2007a). Current changes in ocean carbon chemistry are at least 100 times more rapid than any experienced over the past 100 000 years. During the 21st century this change could reach levels unprecedented in the past few million years (Feely *et al*., 2004). The basic chemistry of atmospheric CO_2 leading to decreased pH is well understood and there is high scientific confidence in the change in pH resulting from anthropogenic CO_2 increases (Key *et al.*, 2004).

Whilst there is some basic physiological understanding of processes, there is little in the way of field observations supporting impacts of the changed pH on organisms (ICES, 2008a).

What might happen?

Depending on the future trajectory of CO_2 emissions, scenario projections suggest a further reduction of about 0.2 to 0.5 pH units (Orr *et al*., 2005; Caldeira and Wickett, 2003).

Changed pH will have consequences for the carbonate saturation state of the seawater and increased difficulty for marine organisms to build carbonate shells. This would be likely to impact negatively upon some pelagic organisms, including potential key species of phytoplankton and zooplankton (ICES, 2008a) with potential consequences for the entire ecosystem structure (Hoepffner, 2006). Impacts of pH on other organisms than aragonitic and calcitic organisms are theoretically serious, notably through impacts on nutrient speciation and therefore primary production and biodiversity but there has been little research on this (Turley 2008).

Are there any OSPAR regional differences?

Since the last QSR, work by Bellerby *et al*. (2005, Fig 3.1.4 below) on an area relevant to OSPAR concluded that future change would not be uniform, with regional gradients associated with the transition between Atlantic and Arctic waters.

Ocean acidification may have the greatest impact in the Arctic (OSPAR Region I) where an analysis of the effect of doubling atmospheric CO_2 concentration suggested the possibility of a complete undersaturation of aragonite by 2100 (EEA, 2008). A recent study warns that the impact of acidification may be imminent in the Arctic suggesting that periods of undersaturation of aragonite could occur in some locations of the Arctic before 2020 (Steinacher *et al*., 2009).

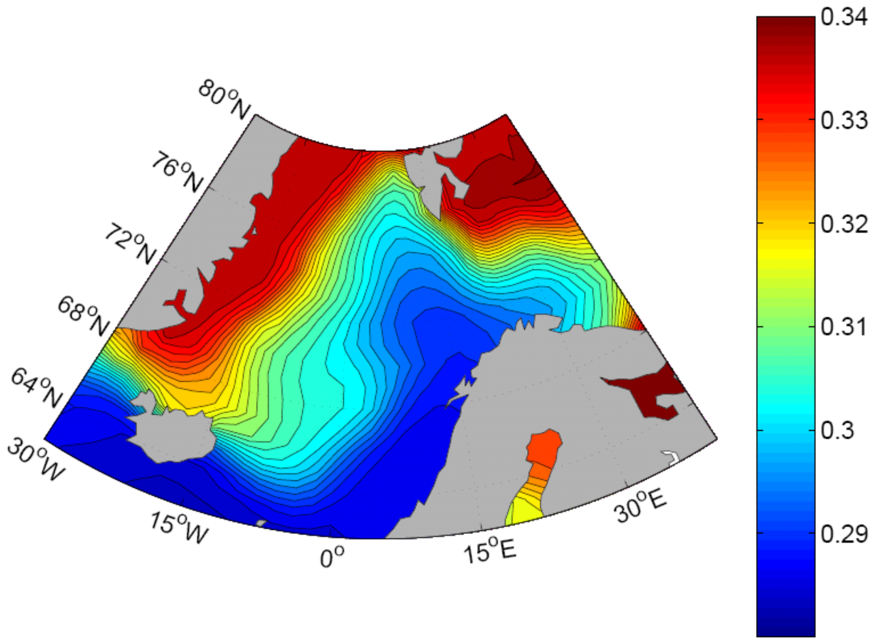


Figure 3.1.4. *From (Bellerby et al., 2005) shows the projected reduction in surface pH from 1997 to 2067 in a scenario where atmospheric CO_2 doubles during that time.*

Coastal Erosion

What is the issue?

Sea-level rise and changes to storms caused by climate change have the potential to change coastal erosion and accretion. This may cause changes in the remobilisation of sediments or lead to loss of habitat at the coast. A plausible extreme scenario for some places is the complete loss of coastal margin.

"Living with coastal erosion in Europe: Sediment and Space for Sustainability" (Doody *et al.*, 2004) was published by the EU EUROSION research programme in 2004 which considered impacts of climate change, and is the primary source of information.

What has happened and how confident?

EUROSION (Doody *et al.*, 2004) reported that the combined effect of coastal erosion, infrastructure development and the building of defences to protect them has led to, in many areas, a narrow coastal zone. Constructing barriers such as roads, dykes, and other coastal developments leads to 'Coastal Squeeze' through reduced scope for low-lying and inter-tidal areas to naturally adjust to changes in sea level, storms and tides. This causes a direct loss of natural habitats. In areas where relative sea level is rising or where sediment availability is reduced, there is a further coastal squeeze evident as a steepened beach profile.

What might happen?

The degree of coastal erosion that may result from sea-level rise is very uncertain (Cooper and Pilkey, 2004). Models of coastal sediment flux under climate warming scenarios shows some 'soft' coasts retreating by more than 40 m per century whilst others show accretion of about 10 m per century (Walkden and Hall, 2005; Dickson *et al.*, 2007).

Some current areas of salt-marsh, coastal dunes and wetlands will decrease and possibly disappear and with them natural vegetation and species, affecting the ecosystem services that these areas supply. The natural ability of wetlands to absorb nitrogen and metals discharged by rivers could be changed with the risk of accelerating eutrophication of coastal waters.

Are there any OSPAR regional differences?

Although a large proportion of the coastline of the OSPAR area is robust to SLR (Stone and Orford, 2004), there are extensive subsiding, geologically 'soft', low-lying coasts, such as in the southern North Sea.

The (IPCC, 2007b) reported that, SLR projections under some SRES scenarios indicate an increased risk of flooding and coastal erosion on Arctic and Baltic coasts after 2050 (Johansson *et al.*, 2004; Meier *et al.*, 2004, 2006; Kont *et al.*, 2008).

Nutrient enrichment.

What is the issue?

OSPAR assessments of the waterborne and atmospheric inputs of nutrients highlight a number of key variables affecting eutrophication that are associated with climate (OSPAR Commission, 2009a and 2009b). Rainfall patterns affect the level nutrients entering rivers and subsequently discharged to the sea. Sea temperature directly impacts upon phytoplankton and seasonal stratification with consequential changes to the availability of nutrients in the summer, extent of growth and types of phytoplankton expected. Increasing storminess would affect turbidity and mixing of the sea, which also influences the light climate to which phytoplankton are exposed, and may decrease overall growth in shallow areas. These factors may also affect the growth of macrophytes and toxic algae. It is important to be able to distinguish between changes due to climate and changes induced by anthropogenic nutrient inputs to the sea (OSPAR Commission, 2009a and 2009b).

What has happened and how confident?

Drier summers may already be contributing to a decrease in nutrient inputs in European seas although it is difficult to distinguish between changes due to the effects of human inputs (e.g. agricultural run-off) and those that may be due to climate change through rainfall and ocean transport.

In the 1990's, OSPAR Contracting Parties were reporting climate-related effects on eutrophication. The Netherlands noted a large increase in the toxic species Dinophysis following an unusually wet year, and Denmark noted a significant decrease in nutrient inputs and chlorophyll levels caused by a number of uncharacteristically dry years.

What might happen?

Overall impacts of climate warming upon coastal and marine ecosystems are likely to intensify the problems of eutrophication (IPCC, 2007b)

In the future, drier summers may decrease nutrient inputs, although sudden storms may deliver pulses with consequences that are difficult to predict. More intense winter storms would raise concentrations of nutrients at the ocean surface and may increase transfer of nutrients into shelf seas. If summer stratification (reduced mixing) becomes stronger, nutrient supply from deeper to surface waters will reduce during the productive season (Hydes *et al.,* 2008).

Are there any OSPAR regional differences?

The main impacts appear to add a further pressure to those areas susceptible to eutrophication as such this is of primary importance to particular areas within OSPAR regions. Suggestions of potential regional climate impacts are discussed in (OSPAR Commission, 2008).

Winter rainfall has substantially increased over Northern Europe, increasing flooding along river basins and increasing runoff into the North Sea (Struyf *et al.*, 2004). Nutrients in Region II may now be transferred to the coastal environment more quickly.

3.2 Impacts on biology

Changes in biogeography and the distribution and extent of habitats

What is the issue?

Recent changes in ocean climate, most notably rising sea temperatures, have been linked to changes in the distribution, abundance and phenology of marine species across the OSPAR maritime area.

What has happened and how confident?

Rising temperatures over the last decade have played a primary role in influencing the ecology of European seas (Hoepffner, 2006). This conclusion is supported by an ICES meta-analysis of long-term datasets for almost 300 species of plankton, benthic species, fish and seabirds. This recent study identifies climate change as a recognisably important factor in driving changes in distribution, abundance and seasonality of marine biota across the OSPAR maritime area (ICES, 2008a, see case study A for more details).

Evidence from the MarClim project suggests that species range expansions in response to climatic warming is occurring quicker in marine systems (plankton, fish as well as intertidal species) than terrestrial systems.

What might happen?

Rising sea temperatures will continue to impact upon the distribution, abundance and timing of marine species with important consequences for predator-prey relationships, and could facilitate the spread of invasive species and stress locally restricted species. The Arctic ocean may become seasonally ice free in the next few decades, with important consequences for ice-dependant species in the Arctic. Sea level rise, storms and erosion will affect coastal habitats. These changes will take place against the backdrop of increased acidification of our seas adding further stress to marine ecosystems.

Are there any OSPAR regional differences?

Some regions within the OSPAR maritime area have been more intensively studied than others, such as OSPAR region II. Recent global studies suggest that climate change may lead to numerous local extinction in the sub-polar regions, the tropics and semi-enclosed seas by 2050 (Cheung *et al*, 2009a).

Plankton

What is the issue?

Increased regional sea temperatures in the North East Atlantic have triggered a major re-organisation of zooplankton species composition and biodiversity. Future warming will lead to further changes in the regional distribution of primary and secondary production and as the base of the marine food web lead to impacts at higher trophic levels.

What has happened and how confident?

Beaugrand *et al.,* (2002) and Edwards *et al.,* (2008) highlight observed changes in zooplankton distribution and abundance, specifically biogeographical shifts of calanoid copepod communities in recent decades, with the warm-water species shifting northwards and the cold-water species retreating northwards.

The changes that have taken place in these Northern European waters are sufficiently abrupt and persistent to be termed as ‘regime shifts’ (Beaugrand, 2004) with a northward shift in the distribution of many plankton and fish species by over 10 degrees of latitude (or over 1000km) being observed over the past fifty years (Figure 3.2.1). This has been particularly associated with the shelf edge current running north along the European continental margin (Beaugrand *et al.,* 2002; Brander *et al.,* 2003; Genner *et al.,* 2004).

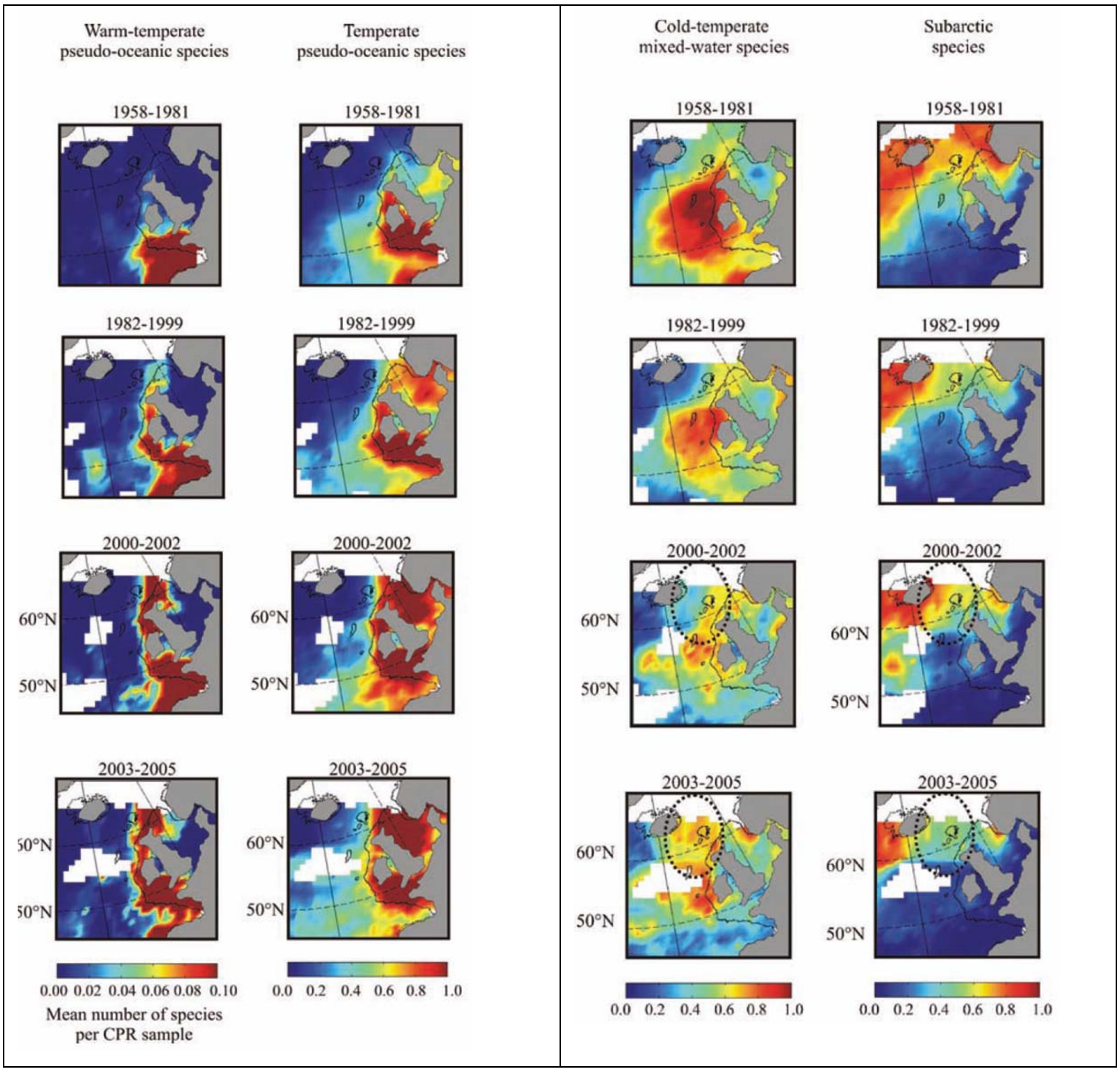


Figure 3.2.1. *Maps showing biogeographical shifts of calanoid copepod communities in recent decades, with the warm-water species shifting northwards and the cold-water species likewise retracting north, by over 10° of latitude (Edwards et al., 2008a).*

In the North Sea, the regime shift is well demonstrated by the ratio of the cold-temperate *Calanus finmarchicus* to the warm-temperate *Calanus helgolandicus* (see Figure 3.2.2). The dominance of *C. helgolandicus* over the last decade is clear and it should be noted that the overall abundance of *Calanus* in the North Sea has considerably declined with important implications for other trophic levels.

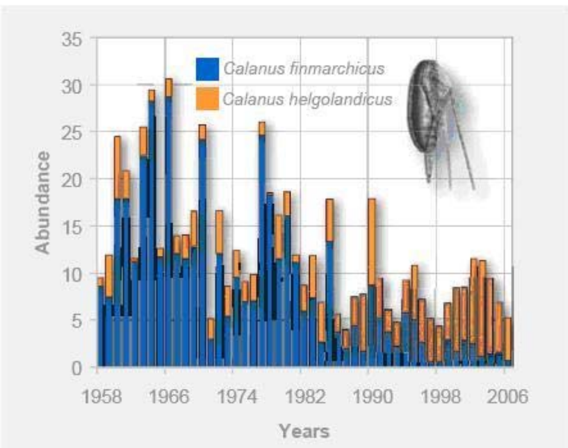


Figure 3.2.2 *A simple percentage ratio between a warm-water species (Calanus helgolandicus) and a cold-water species (Calanus finmarchicus) annually from 1958-2006 and total annual Calanus abundance. Note: while the warm species is replacing the cold water species the actual total Calanus abundance is decreasing (Edwards et al., 2008a)*

Over the past 30 years, rising sea temperatures have been accompanied by a rise in the NAO index. This has led to significant changes in plankton production, biodiversity and species distribution with impacts on fisheries production and other higher predators (e.g. seabirds) (Reid and Edwards, 2001; Edwards *et al.*, 2002; Beaugrand *et al.,* 2003; Richardson and Schoeman, 2004; Southward *et al.*, 2004; Alheit *et al.*, 2005; Heath, 2005).

The seasonal timing of plankton production has also altered in response to recent climate changes with some species occurring between four to six weeks earlier than 20 years ago. This has effects upon their availability to predators, including fish (MCCIP, 2008). As responses to climate warming have varied between different functional groups and trophic levels, there has been a mismatch in predator-prey relationship (Hoepffner, 2006).

What might happen?

With increasing temperature in the future there is an expectation that there will be a demonstrable shift/expansion of distribution northward related to species' biological associations and ecological characteristics (ICES, 2008a). In the northern seas of Europe, and the Arctic, the open ocean plankton production is predicted to significantly increase in the large areas that will become ice-free in summer as the result of higher temperatures (ACIA, 2005). Such changes in productivity will affect the biodiversity and carrying capacity of these natural systems, as well as the potential for the use of the sea by society (Hoeppfner, 2006).

Future warming is likely to alter the geographical distribution of primary and secondary pelagic production, affecting ecosystem services such as oxygen production, carbon sequestration and biogeochemical cycling. These changes may place additional stress on already-depleted fish stocks as well as have consequences for mammal and seabird populations (Edwards *et al.,* 2008b).

Are there any OSPAR regional differences?

As described above, changes across all European Seas have been observed associated with the 'regime shift' in species composition, abundance and timing over the past 50 years.

Algal blooms

What is the issue?

Changes in ocean climate (sea temperature, salinity and stratification) could lead to changes in the incidence of harmful algal blooms (blooms with harmful consequences due to the release of toxins or by depletion of oxygen). For example, higher temperatures in the future could lead to better growth conditions.

What has happened and how confident?

Over the last few decades, changes in phytoplankton species in the European Seas have created a situation of anomalous phytoplankton blooms, often associated with harmful consequences (i.e., HABs) on humans and the surrounding ecosystem (Hoepffner, 2006). This has been especially the case since the major hydroclimatic change (regime shift) that occurred in the mid 1980s, although increases are primarily restricted to specific habitats affected by lower salinities, such as the Norwegian Trench, and much higher temperatures, such as the German Bight (Raine *et al.,* 2008).

The increasing frequency of blooms and the potential harmful consequences have seen the development of regional and national programmes such as EUROHAB (Granéli *et al.*, 1999). The EU-US scientific initiative on harmful algal blooms (EC-NSF 2003) is an example of a thematic programme promoting new research in this area. The development of a common approach may lead to better understanding and management of local HAB events (Hoeppfner, 2006).

What might happen?

In the future, higher temperatures may lead to better growth conditions, and increased stability (leading to increased water clarity), with the potential to favour the growth of some toxic and other HAB species (Raine *et al.,* 2008).

The major environmental variables associated with climate change that will affect HABs are:

- Increase in temperature.
- Increase in the frequency of storms.
- An increase in amount of flooding, particularly during the summer months.
- Alterations in the coastline due to sea-level rise.

It is, at present, difficult to assess the timescale over which such changes will occur through lack of knowledge of the exact dependence of each species on any climatic variable (Raine *et al.,* 2008).

Are there any OSPAR regional differences?

See what has happened and what might happen sections above.

Fish

What is the issue?

Demersal and pelagic species in all OSPAR regions have experienced range shifts and changes in abundance over broad spatial areas and on multi-decadal timescales. Sine the QSR 2000, it has become apparent that these changes appear to agree more often with the expected climate effect as fishing may have masked this effect over longer timescales (ICES, 2008a).

What has happened and how confident?

ICES 2008a states that there is ‘ample evidence for changes in fish distribution and abundance that are consistent with the expected (i) northward shift or towards deeper regions of the distribution and (ii) increase in abundance in the northern part and decrease in the southern part of the range’.

These changes are most pronounced in OSPAR Regions I and II (northern seas) and have been observed in both bottom-dwelling and pelagic species as well as in exploited and unexploited species. Whilst other factors such as fishing prevent us from unequivocally attributing these responses to climate it is ‘highly likely’ that climate effects are contributing to this change. For example, it is reported that stocks of cod in the North Sea are decreasing at a rate that cannot be explained by overfishing alone (Schubert *et al.*, 2006) and also that North Sea cod stock could still support a sustainable fishery under a warmer climate but only at very much lower levels of fishing mortality (Cook and Heath, 2005).

In 2008 the MCCIP report card stated, with high confidence, that since 1980, the distribution of many warm water northeast Atlantic fish species has shifted northwards to occupy latitudes at which they were once non-existent or rare.

The rate of northward movement of a particular species, the silvery john dory, has been estimated at about 50 km/year (EEA, 2008). Other species have become more common further north, (Brander *et al.,* 2003) suggest that fish such as sea bass (*Dicentrarchus labrax*) and red mullet (*Mullus surmuletus*) have extended their ranges to include western Norway in recent years.

What might happen?

Looking ahead, although we can expect that climate change will have far-reaching impacts on the dynamics of fish populations, knowledge of underlying mechanisms is rather limited, especially in non-commercial species (Pinnegar *et al.,* 2008). Such uncertainties in making projections of fish distribution changes over the next 20–50 years arise from both the uncertainties in projections of ocean climate and uncertainties of fish community responses to those changes (EEA, 2008). Additionally, the overall interactions and cumulative impacts on marine biota of sea-level rise (coastal squeeze with losses of nursery and spawning habitats), increased storminess, changes in the NAO, changing salinity, acidification of coastal waters, and other stressors such as pollutants, are likely but little known (IPCC, 2007b). In spite of these uncertainties, an assessment of the vulnerability of the North-East Atlantic marine ecoregion concluded that climate change is 'very likely' to produce significant impacts on selected marine fish and shellfish (Baker, 2005).

Farmed fish and shellfish species may become more susceptible to a wider variety of diseases as temperatures increase (Gubbins and Bricknell, 2008). Increasing harmful algal and jellyfish blooms may lead to additional fish kills and closure of some shellfish harvesting area. There will be some opportunities for new farmed species but storms and waves could damage aquaculture sites (Pinnegar *et al.,* 2008).

Are there any OSPAR regional differences?

A regional warming in the marine Arctic of 1–3°C would be expected to lead to northward displacements of fish populations (Figure 3.2.3.), along with the establishment of discrete populations (e.g., cod near Greenland) and the immigration of southern species (ACIA, 2005). Recent global studies project a large-scale redistribution of global catch potential, with an average of 30–70% increase in high-latitude regions and a drop of up to 40% in the tropics; EEZ regions with the highest expected increase in catch potential by 2055 include Norway and Greenland (Region I), and the United States (Alaska) and Russia (Asia) (Cheung *et al.*, 2009b).

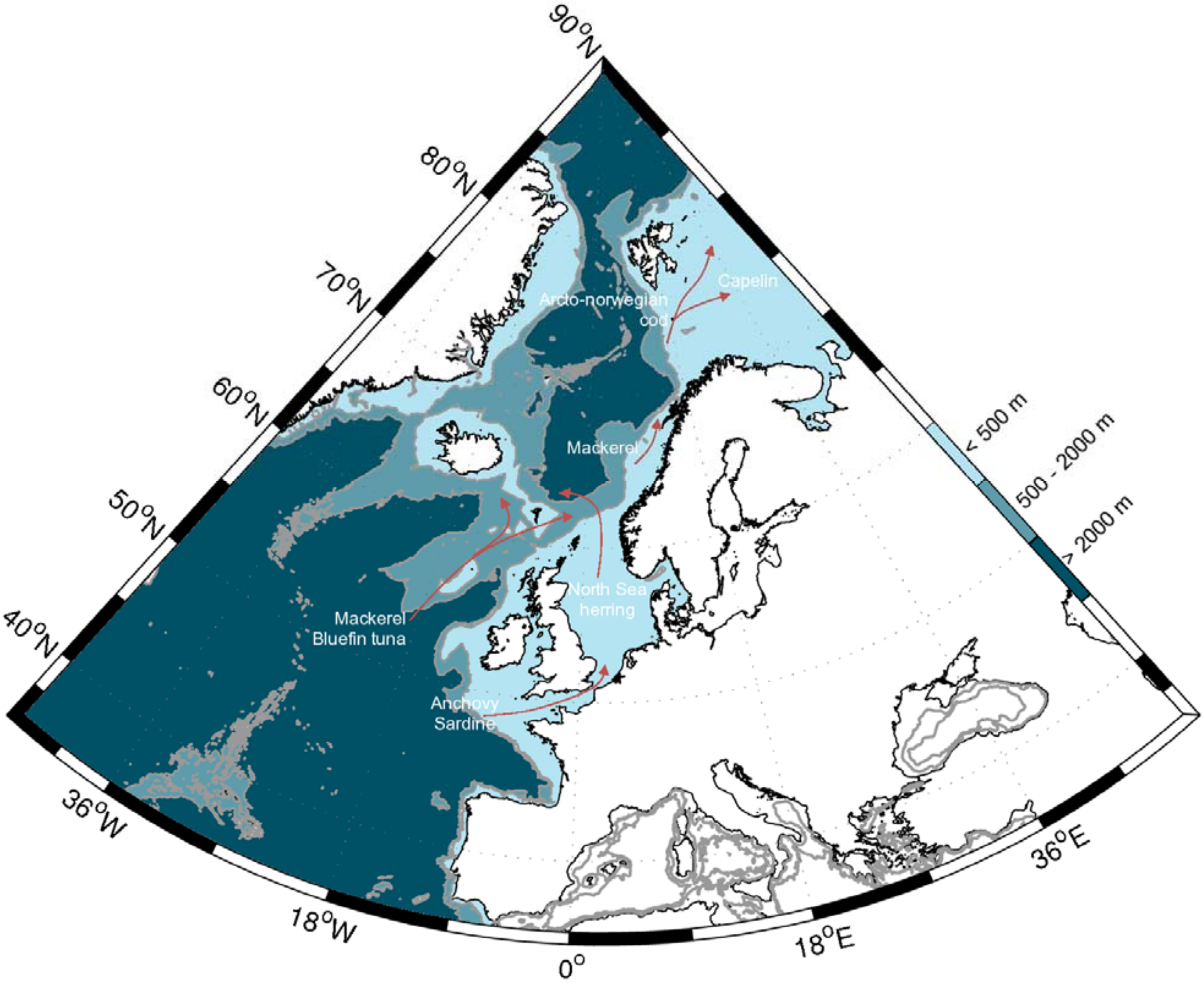


Figure 3.2.3. *Likely extensions of the feeding areas for some of the main commercial fish populations in the north-eastern Atlantic under climate change. The extent of the movements is for illustrative purposes and not a quantitative estimate of distance moved (modified after (Blindheim et al., 2001) in (ACIA, 2005)).*

Marine mammals.

What is the issue?

Climate change might be expected to directly impact upon Marine Mammals as continued decline in Arctic sea ice leads to a loss of habitat for ice-dependant species (polar bears, seals, pinnepeds) (ACIA, 2005; IPCC, 2007b; Evans *et al.,* 2008). As higher predators, marine mammals might also be expected to be indirectly impacted by climate change through shifts in prey availability.

What has happened and how confident?

Most species of marine mammals would be expected to exhibit a degree of resilience to climate change, being warm blooded vertebrates that can cope with large changes to their external environment. The impacts of climate change on marine mammals remain poorly understood and as a result, there has been a great deal of speculation but without very much substantive evidence (Evans *et al.,* 2008). (ICES, 2007 and 2008b) concluded that analyses of climate change impacts on marine mammals in the OSPAR maritime area are hampered by a lack of data on distribution, abundance and condition of marine mammals. Studying small populations of marine mammals is difficult and many published reports on trends in abundance and distribution are inconclusive with regard to the causal role of climate change. Apparent range shifts observed in a number of toothed cetacean species could be linked to changing water temperature but may simply reflect changes of regional food resources (ICES, 2008a).

Some marine mammal scientists are more confident than others that we are witnessing ecological effects of climate change as opposed to responses of individuals and local populations to local environmental variability. However, the statistical power to discriminate between the two remains low (Evans *et al.,* 2008).

Loss of habitat for mammals dependent on sea-ice is already thought to be affecting ringed seals (which need sea ice to support breeding, moulting and resting, and feed on ice amphipods and cod) (IPCC, 2007b) and their main predator, the polar bear, in the Arctic (Evans *et al.,* 2008).

What might happen?

The greatest impacts from climate change are expected to result from loss of habitat for mammals dependant on sea ice, especially ice breeding pinnepeds (Evans *et al.,* 2008). The early melting of sea ice may lead to an increasing mismatch in timing between sea-ice organisms and secondary production that could severely affect populations of marine mammals (ACIA, 2005).

Other potential impacts of climate change are mainly associated with changes in the abundance and distribution of marine mammal prey (zooplankton, fish and cephalopods) although the relative importance of these and their likelihood of occurrence remains unknown (Evans *et al.,* 2008).

Are there any OSPAR regional differences?

As stated in the *what might happen section*, the greatest impacts are expected at the ice edge of the Arctic in OSPAR Region I through loss of habitat. Away from the ice edge sea temperature changes could impact on the availability of prey species.

Seabirds.

What is the issue?

Climate change has the potential to impact upon seabirds through changes in prey availability and through severe weather affecting nesting sites.

What has happened and how confident?

Whilst quantitative evidence is lacking, the ICES 2008 advice book makes some general inferences about how seabirds react to climate change:

- In some circumstances, a warming trend advances the timing of breeding and in others breeding is retarded. Seabirds show some flexibility in dealing with climate change in this regard but are ultimately constrained because of the finite (and often lengthy) time required to complete the breeding cycle;

- Because they are long-lived, seabirds are often able to ‘buffer’ short-term (< 10 years) environmental variability, especially at the population level;
- Seabirds are vulnerable to both spatial and temporal mismatches in prey availability, especially when breeding at fixed colony sites with the foraging constraints that these entail.

Many factors affect range shifts and it is not clear how changes in ocean climate (e.g. circulation and sea temperature) are involved but they are presumed to be a contributing factor (Mitchell *et al.*, 2004; Wernham *et al.*, 2002).

Variations in food quality are likely to be an important link between climate and seabirds. In the North Sea, changes in plankton caused by climate variability have affected sandeel populations. This has had consequences for the breeding success of many seabirds, in particular black-legged kittiwakes. (Frederiksen *et al.*, 2006). However, it is rarely possible to identify exact causal mechanisms (Mitchell and Frederiksen, 2008)

Evidence for changes in seabird demography and population dynamics is building and are summarised below (Table 3.2.1.).

What might happen?

Because seabirds are very long-lived, it is only possible to document and understand the causes of changes in population size and distribution by continuous monitoring over many years.

Future climate change is likely to affect seabirds in two major ways, either directly through an increased frequency of severe weather causing e.g. nest flooding, or indirectly through changes in their food supply. The consensus is that the latter is likely to be more important for most species (Mitchell and Frederiksen, 2008).

There is a link between wildlife diseases and climate that suggests the possibility of a future threat to seabirds through climate change. This hypothesis remains difficult to test due to lack of baseline data, background understanding and coincident pressures (Harvell *et al*., 2002, Newman *et al*., 2007).

Modelling studies predicting how seabirds will respond to climate change in the long term are still at an early stage.

Are there any OSPAR regional differences?

Monitoring of seabird populations is highly variable across the OSPAR maritime area. OSPAR Region II (North Sea) is much better studied than other OSPAR regions.

Table 3.2.1. *Links between climate change and aspects of seabird condition and behaviour (ICES, 2008a)*

Seabird parameter	Species	Region	Climate variable	Sign of correlation with warming	Sources
Breeding range	Lesser black-backed gull	U.K.	Sea temperature	Positive	Mitchell *et al*. (2004)
	Northern gannet	U.K.	Sea temperature	Positive	Mitchell *et al*. (2004)
Non-breeding range	Lesser black-backed gull	U.K.		Positive	Wernham *et al*. (2002), Mitchell *et al*. (2004)
	Common guillemot	Shetland	Sea temperature, sandeels		Heubeck *et al*. (1991)
Reproductive success	Northern fulmar	Orkney (North Sea)	NAO index	Negative (hatching); positive (fledging)	Thompson and Ollason (2001)
	Atlantic puffin	Røst Norwegian Sea	Sea temperature	Positive	Durant *et al*. (2003)
	Atlantic puffin	Røst Norwegian Sea	Salinity	Negative	Durant *et al*. (2006)
	Greater black-backed gull	Newfoundland	Sea temperature	Positive	Regehr and Rodway (1999)
	Herring gull	Newfoundland	Sea temperature	Positive	Regehr and Rodway (1999)
	Black-legged kittiwake	Newfoundland	Sea temperature	Positive	Regehr and Rodway (1999)
	Leach's storm-petrel	Newfoundland	Sea temperature	Positive	Regehr and Rodway (1999)
	Black-legged kittiwake	Isle of May (North Sea)	Sea temperature	Negative	Frederiksen *et al*. (2004a)
	Black-legged kittiwake	Six coastal sections of OSPAR Regions II and III	Sea temperature	Negative within 2 sections. Negative in across-section comparison	Frederiksen *et al*. (2007)
Annual survival	Northern fulmar	Orkney (North Sea)	NAO index	Negative	Grosbois and Thompson (2005)
	Black-legged kittiwake	Isle of May (North Sea)	Sea temperature	Negative	Frederiksen *et al*. (2004a, 2006)
	Atlantic puffin	North Sea, Irish Sea	Sea temperature	Negative	Harris *et al*. (2005)
	Atlantic puffin	Røst Norwegian Sea	Sea temperature	Positive	Harris *et al*. (2005)
	Atlantic puffin	Norway (Barents Sea)	Sea temperature	Negative	Sandvik *et al*.(2005)
	Common guillemot	Norway (Barents Sea)	Sea temperature	Negative	Sandvik *et al*. (2005)
	Black-legged kittiwake	Norway (Barents Sea)	Sea temperature	Positive	Sandvik *et al*. (2005)

Seabird parameter	Species	Region	Climate variable	Sign of correlation with warming	Sources
Population change	Common guillemot	Circumpolar	Sea temperature	Increase with moderate cooling of SST	Irons *et al*. (in press)
	Brünnich's guillemot	Circumpolar	Sea temperature	Increase with moderate warming of SST	Irons *et al*. (in press)
	Black-legged kittiwake	Isle of May (North Sea)	Sea temperature	Negative	Frederiksen *et al*. (2004a)
Nesting (laying or hatching) date	Black-legged kittiwake	Isle of May	NAO index	Positive	Frederiksen *et al*. (2004b)
	Common guillemot	Isle of May	NAO index	Positive	Frederiksen *et al*. (2004b)
	Atlantic puffin	St. Kilda	Sea temperature	Positive	Harris *et al*. (1998)
	Atlantic puffin	Røst (Norwegian Sea)	NAO winter Index	Negative	Durant *et al*. (2004)
	Common guillemot	Isle of May (North Sea)	Sea temperature	Negative	Harris and Wanless (1988)
	Razorbill	Isle of May (North Sea)	Sea temperature	Negative	Harris and Wanless (1989)
	European shag	Isle of May (North Sea)	Wind	Negative	Aebischer and Wanless (1992)
Fledging date	Common guillemot	Baltic Sea	Air temperature	Negative	Hedgren (1979)
Foraging cost	Common guillemot	Isle of May (North Sea)	Stormy weather	Positive	Finney *et al*. (1999)
	Northern fulmar	Shetland (North Sea)	Wind speed	Negative	Furness and Bryant (1996)

Non-native species.

What is the issue?

Changes to ocean climate, particular sea temperature could allow some species to expand their ranges to become established in new regions, whilst some already introduced species could take advantage of warmer conditions to become more abundant.

Some of these non-native species can be considered to be invasive if they spread rapidly and cause economic or environmental harm, or harm to human health. Most introductions arrive via human intervention, intentional or otherwise (e.g. aquaculture, ballast water).

What has happened and how confident?

ICES 2008a highlights the following non-indigenous species that have become established (i.e. reproducing in the new location) in the OSPAR Maritime Area:

Algae (*Codium fragile* (a green alga), *Sargassum muticum* (a brown alga); molluscs (slipper limpet *Crepidula fornicata*, Pacific oyster *Crassostrea gigas*); barnacles (*Megabalanus tintinnalulum*, *Balanus amphitrite*, *Solidobalanus fallax*, *Elminius modestus*);and a bryozoan (*Bugula neritina*).

The establishment of two non-indigenous species have been directly related to warming temperatures in the OSPAR maritime region, the pacific oyster *Crassostrea gigas* (an escaped aquaculture species) and the barnacle species *Elminius modestus*, which has extended reproductive periods due to warmer sea temperatures.

Crassostrea gigas is similarly enjoying longer reproductive periods, most notably in OSPAR Region II along Belgium and British coasts, in Dutch and German waters and along the Swedish West Coast (Spencer *et al*., 1994; Gollasch *et al.*, 2007; Kerckhof *et al.*, 2007). In the Wadden sea increases have been particularly pronounced since 2000 to the detriment of the blue mussel *Mytilus edulis*. This increase appears to be highly correlated to increased summer temperatures (Nehls and Büttger, 2007).

Pacific oysters have also been found in OSPAR Region III on southern and western Irish coasts in recent decades (Boelens *et al.*, 2005).

As sea ice continues to decrease, we could see a potential inundation of new organisms to the North Atlantic from the Pacific. The Pacific diatom *Neodenticula seminae* arrived in the North Atlantic in 1999; after becoming locally extinct 800,000 years ago and could be the first evidence of a trans-Arctic migration in modern times (Reid *et al.,* 2007). Global studies project that species invasion to be most intense in the Arctic and the Southern Ocean (Cheung *et al.*, 2009a).

What might happen?

The 2008 MCCIP report card assigned a high level of confidence that climate change would impact on non-natives (MCCIP, 2008). There is a growing body of evidence from around the world that climate change can facilitate marine invasions, and the potential risks from new introductions in the future are high and these introduced species can have severe impacts on the existing ecosystems (Elliott *et al.*, 2008).

Are there any OSPAR regional differences?

See *what has happened* section.

Intertidal species

What is the issue?

Climate change may be facilitating the rapid migration of many intertidal species such as *Bifurcaria bifurcate* (a brown seaweed) and acorn barnacle (*Semibalanus balanoides)*. Evidence suggests that species range expansion in response to climatic warming is occurring quicker in inter-tidal areas than in terrestrial systems.

What has happened and how confident?

The MarClim project provided strong evidence that recent climate change has resulted in changes in the abundance, population structure and biogeographic ranges of a number of intertidal indicator species around the UK and Ireland.

Compared with terrestrial systems, the extension of southern intertidal species northwards and eastwards towards the colder North Sea is occurring much more rapidly, at rates of up to 50km per decade. This rate far exceeds the global average of 6.1 km per decade observed in terrestrial systems.

Some warm water invertebrates and algae show continued increases in abundance and have extended their ranges around northern Scotland (e.g. *Gibbula umbilicalis* and *Chthamalus montagui*) and eastwards along the English Channel (e.g. *Bifurcaria bifurcate* and *Osilinus lineatus*) over the last 20 years (Meiszkowska *et al,.* 2008).

In the United Kingdom, it is likely that northern range extensions have occurred in response to climatic warming increasing reproductive effort and juvenile survival success allowing these species to establish on suitable habitats. Eastwards range extensions have occurred due to a combination of the proliferation of artificial sea defences along this coast providing suitable habitat where none was previously present and greater recruitment success of southern species in response to climatic warming.

Cold-water species such as the acorn barnacle (*Semibalanus balanoides*) and dabberlocks alga (*Alaria esculenta*) have continued to decrease through the period 2001-2007 (Meiszkowska *et al*., 2008) but the rate of recession is not as fast as the rate of advancement in southern species.

What might happen?

In the short term, different rates of extensions and retreats will increase diversity close to biogeographical boundaries but in the long term will return to previous levels as northern retractions lead to different species compositions becoming established.

Continued extension and retraction of ranges would be expected in the future with rising temperatures. Projected changes in sea level and storms may have important indirect impacts as the building of more sea defences would allow intertidal species to unnaturally extend their range by acting as artificial rocky shores (Meiszkowska *et al*., 2008)

Are there any OSPAR regional differences?

Long-term time series around UK and Republic of Ireland show extensions of ranges of intertidal species (e.g. figure 3.2.4. from (Herbert *et al.*, 2003)) over the last five decades in OSPAR Regions II and III.

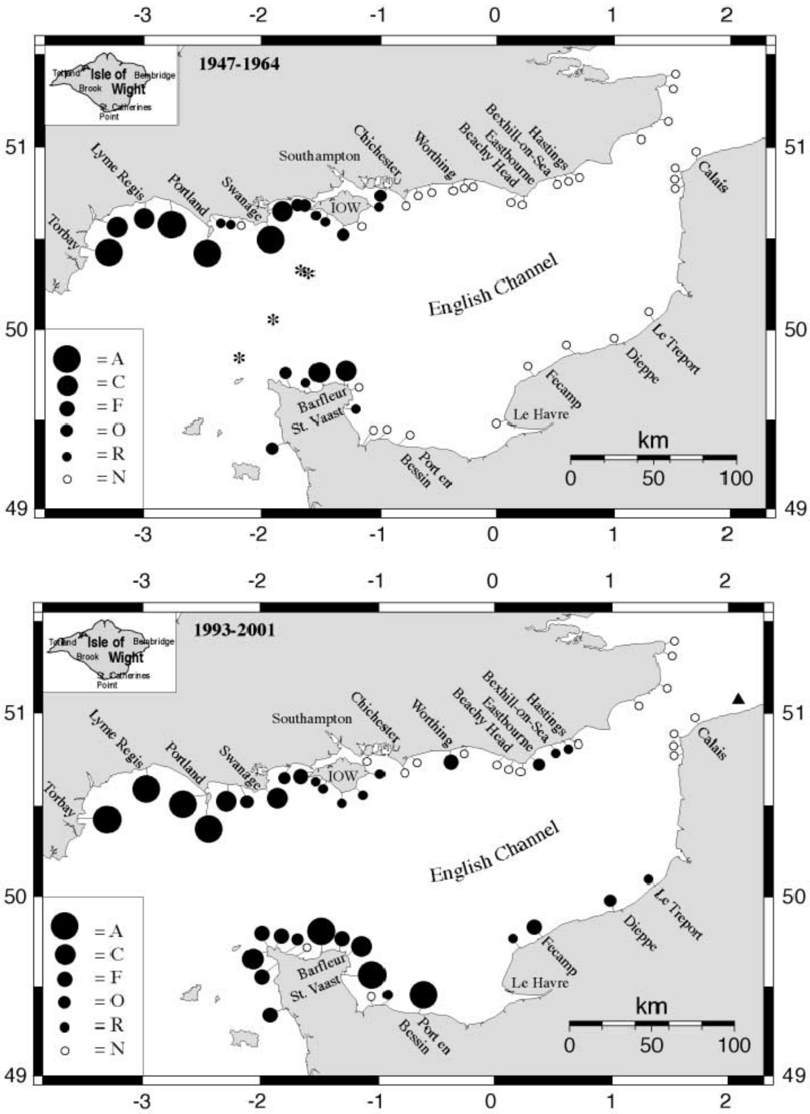


Figure 3.2.4. *Demonstration of the shifting range of intertidal species along the English Channel coast. Reproduced from (Herbert et al., (2003)). Original caption: Distribution of Balanus perforatus in the eastern English Channel, excluding Channel Islands. Above maximum abundance measured between 1947-1964 (Crisp and Southward, 1958; A.J.S., personal observation). For abundance scale see Table 1. *, denotes records from the SV 'Manihine' (BMNH collection). Below, intertidal distribution between 1993-2001. black triangle indicates sublittoral record from Dunkirk in 1982 (Davoult et al., 1993).*

Benthic ecology and environment

What is the issue?

Climatic processes influence the abundance and species composition of seabed communities, directly affect the availability of food for bottom-feeding fish.

There is little information available on how benthic environments may be affected by climate change particularly as variability is more associated with very long-term geological responses over 1000s of years.

Any alteration in the seabed communities linked to climate change could alter rates and timing of processes such as nutrient cycling, larval supply to plankton and organic waste assimilation (Frid and Moore, 2008).

What has happened and how confident?

Benthic sessile organisms have been demonstrated to tolerate, in most cases, moderate changes over reasonable adaptive time scales. However, they are very vulnerable to abrupt and extreme events and after such events, the re-colonization of the benthos can take several tens of years, or even centuries, particularly for species having less successful sexual reproduction (Hoepffner, 2006)

(ICES, 2008a) reports that the strongest evidence of responses in benthic taxa that would be expected as a result of climate change was:

a) cases (in relatively shallow waters as seen in the Wadden Sea and nearshore German Bight) where anomalously cold winter conditions led to die-offs of species commonly associated with relatively warmer waters, or outbreaks of species commonly associated with relatively colder water (Beukema, 1990; Reiss *et al.*, 2006).

b) cases of benthic species being reported as expanding in areas outside their historical ranges that are characteristic of areas to the south or more coastal than the areas into which they are spreading.

Both of these observations are consistent with climate sensitivity in the benthos, but with possibly a non-linear response. This situation could make the benthic biota a particularly high risk community for impacts of climate change, as changes are likely to be abrupt rather than incremental over time.

For the benthic environment itself, the basic knowledge of natural sedimentary changes on timescales of decades is generally insufficient to allow changes to be confidently identified and their significance assessed. Away from the coast there are few conclusive observations of changes in sediments of any kind, and none which can be definitively attributed to climate change.

What might happen?

To date, changes have been manifest through species composition but not major shifts or changes in gross productivity, which is likely to remain the case in the short to medium term. As benthic communities are broadly similar around the world, the system is not likely to become vastly different i.e. polychaetes, molluscs and echinoderms will still dominate the macrofauna but there remains the possibility that ecological processes will be severely altered (Frid and Moore, 2008).

The understanding that cold-water corals, such as *Lophelia pertusa* are more widespread and diverse than expected is relatively recent. They are present over a wide bathymetric and hydrographical of Atlantic European continental margin (Dullo *et al*., 2008). Roberts *et al.* (2006) suggested that these cold-water corals could be particularly vulnerable to future ocean acidification.

The natural drivers of potential future change in the benthic environment itself include: relative sea-level rise; wave climate; water salinity and temperature; air temperature; changes in tidal range. Identification of possible future benthic environment impacts with attribution to climatic drivers will remain difficult.

Are there any OSPAR regional differences?

See *what might happen* above

Changes to benthic environments are difficult to assess but are more likely to occur at a broader scale in the shallower OSPAR regions II and III with impacts in Regions I, IV and V limited to the shelf areas.

4. References

ACIA, 2005. Arctic Climate Impact Assessment. Cambridge University Press, 1042p.

Alheit, J., Mollmann, C., Dutz, J., Kornilovs, G., Loewe, P., Mohrholz, V., Wasmund, N., 2005. Synchronous ecological regime shifts in the central Baltic and the North Sea in the late 1980s. ICES J Mar Sci 62:1205-1215

Baker, T., 2005. Vulnerability Assessment of the North-East Atlantic Shelf Marine Ecoregion to Climate Change, Workshop Project Report, WWF, Godalming, Surrey, 79 pp.

Barnett, C., J. Hossell,C., Perry, M., Procter, C. and Hughes, G., 2006. Patterns of climate change across Scotland: Technical Report. SNIFFER Project CC03, Scotland & Northern Island Forum for Environmental Research, 102pp.

Beaugrand, G., Reid, P.C., Ibañez, F., Lindley, J.A., and Edwards, M., 2002. Reorganization of North Atlantic marine copepod biodiversity and climate. Science, 296: 1692–1694.

Beaugrand, G., Brander, K.M., Lindley, J.A., Souissi, S., Reid, P.C., 2003. Plankton effect on cod recruitment in the North Sea. Nature 426:661-664

Beaugrand, G., 2004. The North Sea regime shift: evidence, causes, mechanisms and consequences. Prog Oceanogr 60:245-262

Bellerby, R.G.J., Olsen, A., Furevik, T., and Anderson, L.G., 2005. Response of the surface ocean CO_2 system in the Nordic seas and northern North Atlantic to climate change, in The Nordic seas, an integrated perspective, Geophys. Monogr. Ser., vol. 158, edited by Drange, H., Dokken, T., Furevik, T., Gerdes, R. and. Berger, W., pp. 189-197, AGU, Washington D.C., USA, 2005

Beukema, J.J., 1990. Expected effects on changes in winter temperatures on benthic animals living in soft sediments in coastal North Sea areas, in Beukema, J.J. *et al*. (Ed.) . Expected effects of climatic change on marine coastal ecosystems. Developments in Hydrobiology, 57: pp. 83-92

Blindheim, J., Toresen, R. and Loeng, H., 2001. Fremtidige klimatiske endringer og betydningen for fiskeressursene. Havets miljo 2001.Fisken og Havet, 2:73–78.

Boelens, R., Minchin, D., and O'Sullivan, G., 2005. Climate change: implications for Ireland's marine environment and resources. Marine Foresight Series No 2, Marine Institute, Oranmore, Co. Galway. 40pp.

Brander, K., Blom, G., M.F.B, Erzini, K., Henderson, G., Mackenzie, B.R., Mendes, H., Ribeiro, J., Santos, A.M.P, Toresen, R., 2003. Changes In Fish Distribution In The Eastern North Atlantic: Are We Seeing A Coherent Response To Changing Temperature? ICES Marine Science Symposia 219:261-270

Bryden, H. L., Longworth, H. R., and Cunningham, S. A., 2005. Slowing of the Atlantic meridional overturning circulation at 25ºN. Nature, 438, 655-657

Caldeira, K. and Wickett, M. E., 2003. Anthropogenic carbon and ocean pH. Nature 425, 365.

Cannaby & Hüsrevoğlu, 2009 The influence of low-frequency variability and long-term trends in North Atlantic sea surface temperature on Irish waters, ICES Journal of Marine Science: Journal du Conseil, doi:10.1093/icesjms/fsp062

Cheung, W.W.L., Lam, V.W.Y, Sarmiento, J.L., Kearney, K., Watson, R., Pauly, D., 2009a. Projecting global marine biodiversity impacts under climate change scenarios. Fish and Fisheries, 10: 235–251

Cheung, W., Lam, V., Sarmiento, J., Kearney, K., Watson, R., Zeller, D. and Pauly, D., 2009b. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Global Change Biology In press.

Church, J.A. and White, N.J., 2006. A 20th century acceleration in global sea-level rise. Geophysical Research Letters 33, L01602, doi:10.1029/2005GL024826

Cook, R.M. & Heath, M.R., 2005. The implications of warming climate for the management of North Sea demersal fisheries. ICES Journal of Marine Science, 62: 1322-1326.

Cooper, J.A.G and Pilkey, O.H., 2004. Sea-level rise and shoreline retreat: time to abandon the Bruun Rule. Global and Planetary Change 43: 157-171.

Cunningham, S.A., Kanzow, T., Rayner, D ., Baringer, M.O., Johns, W.E., Marotzke, J., Longworth, H.R., Grant, E.M., Hirschi, J.J-M., Beal, L.M., Meinen, C.S. and Bryden, H.L., 2007. Temporal Variability of the Atlantic Meridional Overturning Circulation at 26.5°N. Science 317 (5840), 935. doi:10.1126/science.1141304

Curry, R., Dickson, B., Yashayaev, I., 2003. A change in the freshwater balance of the Atlantic Ocean over the past four decades, Nature , 426, 826-829.

Davoult, D.; Dewarumez, J.-M. et al. (1993). Long-term changes (1979-1990) in three benthic communities (eastern English Channel): use of factor analysis and rank-frequency diagrams for studying structural developments. Neth. J. Aquat. Ecol. 27: 415-425

Dickson, R. R., Yashayaev, I., Meincke, J., Turrell, W., Dye, S. and Holfort, J., 2002. Rapid freshening of the deep North Atlantic Ocean over the past four decades. Nature, 416, 832-837.

Dickson, M., Walkden, M. and Hall, J., 2007. Systemic Impacts of Climate Change on an Eroding Coastal Region over the 21st Century. Climatic Change, 84, 141-166.

Doody, P., Ferreira, M., Lombardo, S., Lucius, I., Misdorp, R., Niesing, H., Salman, A., Smallegange, M., 2004. Living with coastal erosion in Europe: sediment and space for sustainability: Results from the EUROSION study. European Commission: Luxembourg. ISBN 92-894-7496-3. 38 pp.

Dowdeswell, J.A., 2006. A changing Greenland Ice Sheet and global sea-level rise. Science, 311, p. 963-964

Dullo, W-C, Flögel, S., Rüggeberg, A., 2008. Cold-water coral growth in relation to the hydrography of the Celtic and Nordic European continental margin. Marine Ecology Progress Series, 371, 165-176. doi:10.3354/meps07623

EC-NSF, 2003. The EU-US Scientific initiative on Harmful Algal Blooms. Report from a Workshop jointly funded by the European Commission – Environment and Sustainable Development programme – and the US National Science Foundation (Trieste, Italy, Sept. 5-8, 2002).

Edwards, M., Beaugrand, G., Reid, P.C., Rowden, A.A., Jones, M.B., 2002. Ocean climate anomalies and the ecology of the North Sea. Marine Ecology-Progress Series 239:1-10

Edwards, M., Johns, D.G., Beaugrand, G., Licandro, P., John, A.W.G. & Stevens, D. P., 2008a. Ecological Status Report: results from the CPR survey 2006/2007. SAHFOS Technical Report, 5: 1-8. Plymouth, U.K. ISSN 1744-0750

Edwards, M., Reid, P.C. and Heath, M., 2008b. Plankton in Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J. and Wallace, C.J.), Scientific review, 8pp, www.mccip.org.uk/arc/2007/PDF/Plankton.pdf

EEA (European Environment Agency), 2008. Impacts of Europe's Changing Climate: 2008 Indicator-based Assessment (EEA Report, no. 4/2008) (JRC Reference Report, no. JRC47756) ISBN: 978-92-9167-372-8

Elliott, P., Reid, P.C., Edwards, M. and McCollin, T., 2008. Non-native species in Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J. and Wallace, C.J.), Scientific review, 9pp. www.mccip.org.uk/arc/2007/PDF/Non-native.pdf

Evans, P.G.H., Boyd, I.L. and MacLeod, C.D., 2008. Marine Mammals in Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J. and Wallace, C.J.), Scientific review, 12pp. http://www.mccip.org.uk/arc/2007/PDF/Marine-Mammals.pdf

Feely, R.A., Sabine, C.L., Lee, K., Berelson, W., Kleypas, J., Fabry, V. J., & Millero, F. J., 2004. Impact of anthropogenic CO_2 on the $CaCO_2$ system in the ocean. Science 305, 362–366.

Flather, R.A. and Williams, J.A., 2000. "Climate change effects on storm surges: methodologies and results". 66-78 in, Climate scenarios for water-related and coastal impact. Beersma, J., Agnew, M., Viner, D. and Hulme, M. (Eds. Norwich:CRU, ECLAT-2 Workshop Report, No 3).

Frederiksen, M., Edwards, M., Richardson, A.J., Halliday, N.C. & Wanless, S., 2006. From plankton to top predators: bottom-up control of a marine food web across four trophic levels. Journal of Animal Ecology , 75: 1259-1268.

Fleming, K., Wünsch, J., Lambeck, K., 2009. Glacial-isostatic contributions to present-day sea-level change around Greenland. Scientific Technical Report STR05/09, GeoForschungsZentrum, Potsdam ,ISSN 1610-0956 30pp.

Frid, C.L.J. and Moore, D., 2008. Seabed Ecology in Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J. and Wallace, C.J.), Scientific review, 7pp. www.mccip.org.uk/arc/2007/PDF/Seabed-Ecology.pdf

Genner, M.J., Sims, D.W., Wearmouth, V.J., Southall, E.J., Southward, A.J., Henderson, P.A., Hawkins, S.J., 2004. Regional climatic warming drives long-term community changes of British marine fish. Proc R Soc Lond, Ser B: Biol Sci 271:655-661

Gollasch, S., Kieser, D., Minchin, D. and Wallentinus, I., 2007. Status of introductions of non indigenous marine species to the North Atlantic and adjacent waters 1992–2002: Ten-year summary of national reports considered at meetings of the Working Group on Introductions and Transfers of Marine Organisms. ICES Cooperative Research Report 284. 156 pp.

Gregory, J.M., Church, J.A., Boer G.J., Dixon, K.W., Flato, G.M., Jackett, D.R., Lowe, J.A., O'Farrell, S.P., Roeckner, E., Russell, G.L., Stouffer, R.J., Winton, M., 2001. Comparison of results from several AOGCMs for global and regional sea-level change 1900-2100. Climate Dynamics 18 (3-4): 225-240.

Granéli, E., Codd, G.A., Dale, B., Lipiatou, E.,.Maestrini, S.Y. and Rosenthal, H., 1999. EUROHAB.Science initiative. Harmful algal blooms in European marine and brackish waters. Energy,Environment and sustainable development. EUR 18592.

Gubbins, M.J. and Bricknell, I., 2008. Aquaculture in Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J. and Wallace, C.J.), Scientific review, 15pp. www.mccip.org.uk/arc/2007/PDF/Aquaculture.pdf

Gulev, S.K. and L. Hasse., 1999. Changes of wind waves in the North Atlantic over the last 30 years. International Journal of Climatology. 19, 1091-1117

Gulev, S.K. and Grigorieva, V., 2004. Last century changes in ocean wind wave height from global visual wave data. Geophysical Research Letters, 31, L24302, doi:10.1029/2004GL021040

Häkkinen, S. and Rhines, P.B., 2004. Decline of Subpolar North Atlantic Circulation During the 1990s. Science, 304, 555 – 559 doi:10.1126/science.1094917

Harvell, C.D., Mitchell, C.E., Ward, J.R., Altizer, S., Dobson, A.P., Ostfeld, R.S., Samuel, M.D., 2002. Climate Warming and Disease Risks for Terrestrial and Marine Biota. Science, 296, 2158-2162

Hátún, H., Sando, A.B., Drange, H., Hansen, B., and Valdimarsson, H., 2005. Influence of the Atlantic subpolar gyre on the thermohaline circulation, Science, 309, 1841-1844.

Heath, M.R., 2005. Changes in the structure and function of the North Sea fish foodweb, 1973-2000, and the impacts of fishing and climate. ICES J Mar Sci 62:847-868

Herbert, R.J.H., Hawkins, S.J., Sheader, M. & Southward, A.J., 2003. Range extension and reproduction of the barnacle Balanus perforatus in the eastern English Channel. Journal of the Marine Biological Association of the UK. 83: 73-82.

Hoepffner, N. (Ed.), 2006. Marine and coastal dimensions of climate change in Europe. European Commission- Joint Research Centre, report EUR 22554 EN, Ispra, pp 107 (http://ies.jrc.ec.europa.eu/fileadmin/Documentation/Reports/Varie/cc_marine_report_optimized2.pdf)

Holliday, N.P., Hughes, S.L., Bacon, S., Beszczynska-Möller, A., Hansen, B., Lavin, A., Loeng, H., Mork, K.A., Østerhus, S., Sherwin, T. and Walczowski, W., 2008. Reversal of the 1960s - 1990s freshening trend in the northeast North Atlantic and Nordic Seas. Geophysical Research Letters, 35, L03614. (doi:10.1029/2007GL032675)

Hughes, S.L. and Holliday, N.P. (Eds.), 2007. ICES Report on Ocean Climate 2006, ICES Cooperative Research Report No. 289, 59pp

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, UEA, Norwich, April 2002.

Hydes, D., Mills, D. and Heath, M., 2008. Nutrient Enrichment in Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J. and Wallace, C.J.), Scientific review, 8pp. www.mccip.org.uk/arc/2007/PDF/Nutrient-enrichment.pdf

ICES, 2007. Report of the Working Group on Marine Mammal Ecology (WGMME), 27–30 March 2007, Vilm,Germany. ICES CM 2007/ACE:03. 61 pp.

ICES, 2008a. Advice on the changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature. ICES advice 2008 book 1, section 1.5.5.1 32 pp.

ICES, 2008b. Report of the Working Group on Marine Mammal Ecology (WGMME). ICES CM 2008/ACOM:44.

IPCC-SRES, 2000. IPCC Special Report on Emissions Scenarios, (eds. Nebojsa Nakicenovic and Rob Swart) Cambridge University Press, UK. pp 570

IPCC, 2007a. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC, 2007b. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (eds.)], Cambridge University Press, Cambridge, UK, 976pp

IPCC, 2007c. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Johansson, M.M., Kahma, K.K. and Bowman, H., 2004. Scenarios for sea level on the Finnish coast. Boreal Environment Research 9: 153–166.

Josey, S.A. and Marsh, R., 2005. Surface freshwater flux variability and recent freshening of the North Atlantic in the Eastern Subpolar Gyre, J. Geophys. Res., 110, C05008, doi:10.1029/2004JC002521.

Kerckhof, F., Haelters, J., and Gollasch, S., 2007. Alien species in the marine and brackish ecosystem: the situation in Belgian waters. Aquatic Invasions, 2: 243–257.

Key, R.M., Kozyr, A., Sabine, C.L., Lee, K., Wanninkhof, R., Bullister, J.L., Feely, R.A., Millero, F.J., Mordy, C., Peng, T.-H., 2004. A global ocean carbon climatology: Results from Global Data Analysis Project (GLODAP), Global Biogeochem. Cycles, 18, GB4031, doi:10.1029/2004GB002247

Kont, A., Jaagus, J., Aunap, R., Ratas, U,. Rivis, R., 2008, Implications of Sea-Level Rise for Estonia, J. Coastal Res. 24, 423-431

Kundzewicz, Z. W., Parry, M., Cramer, W., Holten, J. I., Kaczmarek, Z., Martens, P., Nicholls, R.J., Oquist, M., Rounsevell, M.D.A. and Szolgay, J., 2001. Europe. Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, 641–692.

Lambert, S.J. and Fyfe, J.C., 2006. Changes in winter cyclone frequencies and strengths simulated in enhanced greenhouse warming experiments: results from the models participating in the IPCC diagnostic exercise. Climate Dynamics, 26, 713-728.

Lionello, P., Dalan, F., Elvini, E., 2002 Cyclones in the Mediterranean Region: the present and the doubled CO_2 climate scenarios. Clim. Res., 22, 147-159.

Lowe, J.A., Howard, T., Pardaens, A., Tinker, J., Holt, J., Wakelin, S., Milne, G., Leake, J., Wolf, J., Horsburgh, K., Reeder, T., Jenkins, G., Ridley, J., Dye, S., Bradley, S., 2009. UK Climate Projections science report: Marine and coastal projections. Met Office Hadley Centre, Exeter, UK. ISBN 978-1-906360-03-0

Lund, B. and Arnadottir, Th., 2009. Current glacial isostatic adjustment in Iceland. Geophysical Research Abstracts, Vol. 11, EGU2009-7803, EGU General Assembly 2009

MARCLIM Marine biodiversity and climate change – MARCLIM project - http://www.mba.ac.uk/marclim

MCCIP, 2008. Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J. and Wallace, C.J.) - Annual Report Card 2007

Meier, H.E.M., Broman, B. and Kjellström, E. (2004). Simulated sea level in past and future climates of the Baltic Sea. Climate Research 27: 59–75.

Meier, H.E.M., Broman, B., Kallio, H. and Kjellström, E., 2006. Projections of future surface winds, sea levels, and wind waves in the late 21st Century and their application for impact studies of flood prone areas in the Baltic Sea region. In: Schmidt-Thomé, P. (ed): Sea level change affecting the spatial development of the Baltic Sea region, Geological Survey of Finland, Special Paper 41: 23–43.

Mieszkowska, N., Moore, P., Hawkins, S., Burrows, M., 2008. Intertidal Species in Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J. and Wallace, C.J.). Scientific review, 9pp. www.mccip.org.uk/arc/2007/PDF/Intertidal-species.pdf

Miller, R.L., Schmidt, G.A. and Shindell, D.T., 2006. Forced annular variations in the 20th century Intergovernmental Panel on Climate Change Fourth Assessment Report models. Journal of Geophysical Research, 111, D18101, doi:10.1029/2005JD006323

Mitchell, P. I., Newton, S. F., Ratcliffe, N., and Dunn, T. E., 2004. Seabird populations of Britain and Ireland. T. and A.D. Poyser; London.

Mitchell, I and Frederiksen, M, 2008. Seabirds in Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter JM, Buckley PJ and Wallace CJ), Scientific review, 8pp, www.mccip.org.uk/arc/2007/PDF/Seabirds.pdf

Nehls, G., and Büttger, H., 2007. Spread of the Pacific oyster Crassostrea gigas in the Wadden Sea. Causes and consequences of a successful invasion, BioConsult SH, Husum, 54 pp

Nerem, R. S.; Leuliette, E. and Cazenave, A., 2006. Present-day sea-level change: A review. Comptes Rendus Geoscience 338: 1077–1083.

Newman, S.H., Chmura, A., Converse, K., Kilpatrick, A.M., Patel, N., Lammers, E., Daszak, P., 2007 Aquatic bird disease and mortality as an indicator of changing ecosystem health Marine Ecology Progress Series, 352: 299–309. doi:10.3354/meps07076

Nicholls, R.J., 2004. Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios. Global Environmental Change 14: 69–86.

Osborn, T.J., 2004. Simulating the winter North Atlantic Oscillation: the roles of internal variability and greenhouse gas forcing. Climate Dynamics, 22, 605-623. doi:10.1007/s00382-004-0405-1

Orr, J.C., Fabry, V.J., Aumont, O., Bopp, L., Doney, S.C., Feely, R.A., Gnanadesikan, A., Gruber, N., Ishida, A., Joos, F., Key, R. M., Lindsay, K., Maier-Reimer, E., Matear, R., Monfray, P., Mouchet, A., Najjar, R.G., Plattner, G.-K., Rodgers, K. B., Sabine, C. L., Sarmiento, J. L., Schlitzer, R., Slater, R. D., Totterdell, I. J. , Weirig, M.-F., Yamanaka, Y. and Yool, A., 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms, Nature, 437, 681-686.

OSPAR Commission, 2008. Second integrated report on the eutrophication status of the OSPAR maritime area. OSPAR Commission, London, 2008. Publication 372/2008.

OSPAR Commission, 2009a. Trends in waterborne inputs – Assessment of riverine inputs and direct discharges of nutrients and selected hazardous substances to OSPAR maritime area in 1990-2006. OSPAR Commission, London, 2009. Publication 448/2009.

OSPAR Commission, 2009b.Trends in atmospheric concentrations and deposition of nitrogen and selected hazardous substances to the OSPAR maritime area. OSPAR Commission, London, 2009. Publication 447/2009. In press

Peperzak, L., 2003. Climate change and harmful algal blooms in the North Sea. Acta Oecologica, 24, Supplement 1: 139-144.

Peterson, B.J., Holmes, R.M., McClelland, J.W., Vorosmarty, C.J., Lammers, R.B., Shiklomanov, A., Shiklomanov, I., Rahmstorf, S., 2002 Increasing River Discharge to the Arctic Ocean, Science, 298, 2171 – 2173, doi:10.1126/science.1077445

Pinnegar, J.K., Sims, D.W. and Heath, M., 2008. Fish and Fisheries in Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J. and Wallace, C.J.), Scientific review, 32pp. www.mccip.org.uk/arc/2007/PDF/Fish-and-Fisheries.pdf

Rahmstorf, S., 2007. A semi-empirical approach to projecting future sea-level rise. Science 315: 367–370.

Raine, R., Edwards, M., Reid, P.C., Bresnan, E. and Fernand, L., 2008. Harmful Algal Blooms in Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J. and Wallace, C.J.), Scientific review, 8 pp. www.mccip.org.uk/arc/2007/PDF/HABs.pdf

Raupach, M.R., Marland, G., Ciais, P., Le Quere, C., Canadell, J. G., Klepper, G., Field, C.B., 2007. Global and regional drivers of accelerating CO_2 emissions. Proceedings of the National Academy Science , 104: 24, 10288-10293 doi: 10.1073/pnas.0700609104

Rayner, N.A., Parker, D.E., Horton, E. B., Folland, C.K., Alexander, L. V., Rowell, D.P., Kent, E. C. and Kaplan, A., 2003. Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late Nineteenth Century. Journal of Geophysical Research, 108, (D14), 4407. doi:10.1029/2002JD002670

Reid, P.C., Edwards, M., 2001. Long-term changes in the pelagos, benthos and fisheries of the North Sea. Senckenbergiana Maritima 31:107-115

Reid, P.C., Johns, D.G., Edwards, M., Chelstarr, M., Poulins, M. and Snoeijs, P., 2007. A biological consequence of reducing Arctic ice cover: arrival of the Pacific diatom Neodenticula seminae in the North Atlantic for the first time in 800 000 years, Glob. Change Bio. 13, 1910-1921

Richardson, A.J., Schoeman, D.S., 2004. Climate Impact on Plankton Ecosystems in the Northeast Atlantic. Science, 305:1609-1612

Reiss, H., Meybohm, K. and Kröncke, I., 2006. Cold winter effects on benthic macrofauna communities in near- and offshore regions of the North Sea. Helgoland Marine Research, 60, 224-238 doi:10.1007/s10152-006-0038-3

Roberts, J.M., Wheeler, A.J., Freiwald, A., 2006. Reefs of the Deep: The Biology and Geology of Cold-Water Coral Ecosystems. Science, 312, 543 - 547, doi:10.1126/science.1119861

Rohling, E.J., Grant, K., Hemleben, C., Siddall, M., Hoogakker, B.A,. Bolshaw, M., Kucera, M., 2008. High rates of sea-level rise during the last interglacial period, Nature Geoscience, 1, 38-42

Sabine, C L., Feely, R.A., Gruber, N., Key, R.M., Lee, K., Bullister, J.L., Wanninkhof, R., Wong, C.S., Wallace, D.W.R., Tilbrook, B., Millero, F.J., Peng, T.H., Kozyr, A., Ono, T. & Rios, A.F., 2004. The oceanic sink for anthropogenic CO_2. Science 305, 367–371.

Schubert, R. *et al*., 2006. The Future Oceans Warming up, Rising High, Turning Sour. German Advisory Council on Global Change, (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen, WBGU), Special report, Berlin, pp. 123 http://www.wbgu.de/wbgu_sn2006_en.pdf)

Schuster, U., and Watson, A.J., 2007. A variable and decreasing sink for atmospheric CO_2 in the North Atlantic, Geophys, J. Res., 112, C11006, doi:10.1029/2006JC003941

Serreze, M.C., Barrett,. A.P. & Slater, A.G., 2008. Variability and Change in the Atmospheric Branch of the Arctic Hydrologic Cycle. *in* Arctic- Subarctic Ocean Fluxes (Eds. Dickson, R.R., Meincke, J., & Rhines, P.), 343-362, Springer, Netherlands, doi:10.1007/978-1-4020-6774-7_15

Sharples, J., Ross, O.N., Scott B.E., Greenstreet, S.P.R., Fraser, H., 2006. Inter-annual variability in the timing of stratification and the spring bloom in the North-western North Sea, Continental Shelf Research, 26, 733–751 doi:10.1016/j.csr.2006.01.011

Sharples, J. and Dye, S., 2008. Shelf Sea Stratification and the Spring Bloom in Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J. and Wallace, C.J.), Scientific review, 5pp. www.mccip.org.uk/arc/2007/PDF/Stratification.pdf

Smith, D.E, Raper, S.B., Zerbini, S. and Sánchez-Arcilla, A., Eds., 2000. Sea Level Change and Coastal Processes: Implications for Europe. Office for Official Publications of the European Communities, Luxembourg, 247pp

Steinacher, M., Joos, F., Frölicher, T.L., Plattner, G-K. & Doney, S.C., 2009. Imminent ocean acidification in the Arctic projected with the NCAR global coupled carbon cycle-climate model. Biogeosciences, 6, 515-533.

Stone, G.W. and Orford, J.D., 2004. Storms and their significance in coastal morpho-sedimentary dynamics. Marine Geology, 210, 1-5. doi:10.1016/j.margeo.2004.05.003

Southward, A.J., Langmead, O., Hardman-Mountford, N.J., Aiken, J., Boalch, G.T., Dando, P.R., Genner, M.J., Joint, I., Kendall, M.A., Halliday, N.C., Harris, R.P., Leaper, R., Mieszkowska, N., Pingree, R.D., Richardson, A.J., Sims, D.W., Smith, T., Walne, A.W., Hawkins, S.J., 2004. Long-Term Oceanographic and Ecological Research in the Western English Channel. Adv Mar Biol 47:1-105

Spencer, B.E., Edwards, D.B., Kaiser, M.J., and Richardson, C. A., 1994. Spatfalls of the non-native Pacific oyster, Crassostrea gigas in British waters. Aquatic Conservation and Freshwater Ecosystems, 4: 203–217.

Struyf, E., van Damme, S. and Meire, P., 2004. Possible effects of climate change on estuarine nutrient fluxes: a case study in the highly nutrified Schelde estuary (Belgium. The Netherlands). Estuarine, Coastal and Shelf Sci., doi:10.1016/j.ecss.2004.03.004.

Terray, L., Demory, M.-E., Déqué, M., de Coetlogon, G. and Maisonnave, E., 2004. Simulation of late-21st-century changes in wintertime atmospheric circulation over Europe due to anthropogenic causes. Journal of Climate, 17, 4630-4635

Tsimplis, M.N.,. Woolf, D.K., Osborn, T., Wakelin, S., Woodworth, P., Wolf, J., Flather, R., Blackman, D., Shaw, A.G.P., Pert, F., Challenor, P. and Yan, Z., 2005. Towards a vulnerability assessment of the UK and northern European coasts: the role of regional climate variability. Philosophical Transactions: Mathematical, Physical & Engineering Sciences. doi:10.1098/rsta.2005.1571.

Turley, C., 2008. Ocean Acidification in Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J. and Wallace C.J.), Scientific review, 7pp. www.mccip.org.uk/arc/2007/PDF/Ocean-Acidification.pdf

Walkden, M.J.A. and Hall, J.W., 2005. A predictive meso-scale model of the erosion and profile development of soft rock shores. Coastal Engineering 52:535-563.

Walsh, J.E., Anisimov, O.,. Hagen, J.O.M., Jakobsson, T., Oerlemans, J., Prowse, T.D., Romanovsky, V., Savelieva, N., Serreze, M., Shiklomanov, I. and Solomon, S., 2005. Cryosphere and hydrology. Arctic Climate Impacts Assessment, ACIA, Symon, C., Arris, L. and Heal, B. Eds., Cambridge University Press, Cambridge, 183-242.

Wernham, C.V., Toms, P.M., Marchant, J.H., Clark, J A., Siriwardena, G.M., and Baillie, S.R. (Eds.), 2002. The migration atlas: movements of the birds of Britain and Ireland. Poyser, T and A.D., London

Wolf, J. and Woolf, D.K., 2006. Waves and climate change in the North-East Atlantic. Geophysical Research Letters, 33, L06604, doi:10.1029/2005GL025113

Woth, K., 2005. North Sea storm surge statistics based on projections in a warmer climate: How important are the driving GCM and the chosen emission scenario? Geophysical Research Letters 32 (22), L22708.

Wu, P., Wood, R., Stott, P., 2005. Human influence on increasing Arctic river discharges. Geophys. Res. Lttr. 32, L02707, doi:10.1029/2005GL021570

Xu, Y., Zhao, Z.-C., Luo, Y. and Gao, X., 2005. Climate change projections for the 21st century by the NCC/IAPT63 with SRES scenarios. Acta Meteorologica Sinica 19: 407–417.

Young, E.F. and Holt, J.T., 2007. Prediction and analysis of long-term variability of temperature and salinity in the Irish Sea, J. of Geophys. Res., 112, C01008, doi:10.1029/2005JC003386

Zhang, X. and Walsh, J.E., 2006. Toward a seasonally ice-covered Arctic Ocean: scenarios from the IPCCAR4 model simulations. J. Climate, 19, 1730-1747.

Case Study A - Changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in ocean climate

Source: ICES advice 2008, book 1: Chapter 1.5.5.1, An assessment of the changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature.

Background: The overall aim of this study was to use a range of long-term datasets to examine evidence for climate change impacts on the distribution and abundance of marine species in the OSPAR maritime area. The study focussed primarily on effects that may be linked to changes in sea surface temperature. A meta-analysis of almost 300 species was conducted to see if observations match expected changes in response to the effects of climate.

Summary: Changes in distribution, abundance, and other characteristics (particularly seasonality) of marine biota in the OSPAR maritime area are consistent with expected climate effects (see table 1). Whilst this does not mean that all changes are consistent with a climate change effect or that climate is the only cause, it is undoubtedly a recognisably important factor in around ¾ of the 288 cases examined here. These species included zooplankton (83 cases), benthos (85 cases), fish (100 cases), and seabirds (20 cases). Seabirds showed the weakest relationship but for other species, particularly zooplankton and fish species, the relationship was much stronger.

The majority of the cases examined here were from OSPAR Region II and there were none from OSPAR Region V.

***Table CSA1**: Numbers are cases of change in distribution, abundance, or other characteristics (e.g. phennology, seasonality). Colour coding represents the percentages that were in the direction expected as a result of effects of climate (Red > 75%; Yellow 50-75%; Blue<50%). Note that for plankton, OSPAR Region I includes some species occurring also in Regions I to IV (Beaugrand et al., 2002)*

OSPAR Region	Zooplankton			Benthos		Fish		Seabirds	Total	% change in expected direction
	Distribution	Abundance	Other	Distribution	Abundance	Distribution	Abundance	Distribution and abundance		
I	4	1				2	13	7	27	74%
II	3	9	61	40	32	42	15	10	212	77%
III						9	12	3	24	83%
IV	1	4		13		2	5		25	76%
Total	8	14	61	53	32	55	45	20	288	
% change in expected direction	100%	64%	100%	66%	66%	82%	71%	60%	77%	

Why use this methodology? Meta-analyses are essentially ways of synthesising studies across systems and regions, such as the broad aggregated area covered by OSPAR. The Meta-analysis used here was based upon one adopted by the IPCC (2007) to detect the effects of climate change and has the following advantages.

1. It uses a recognized methodology to address the question "how strong is the evidence that changes in distribution, abundance and condition go beyond normal?"

2. It provides a means of summarizing and adding value to the material provided by the examples available

3. It provides a direct comparison with the IPCC meta-analysis (and greatly increases the amount of marine information beyond what was available to the IPCC);

4. It is straightforward and involves little additional computation or statistics.

References:

IPCC, 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E., Cambridge University Press, Cambridge, UK, 976pp

Case Study B - Arctic Sea-Ice

Sources: This case study is largely based on findings from the National Sea Ice Data Centre (NSIDC), Arctic Climate Impact Assessment (ACIA), IPCC 4th Assessment Report and the 2007 Arctic Report Card (Richter-Menge *et al.*, 2008).

Background: Using recent evidence from a range of sources, we report on the rapid reduction of Arctic sea ice extent in the past few decades and discuss implications for Arctic ecosystems, particularly in OSPAR region I.

Summary: The continued significant reduction in the extent of summer sea ice cover illustrates the dramatic impact increased global temperatures are having on Arctic regions. The IPCC 4th assessment reported with high confidence that continued changes in sea ice extent, along with warming (Figure CSB1)and acidification of the polar oceans are likely to further impact the biomass and community composition of marine biota and Arctic human activities.

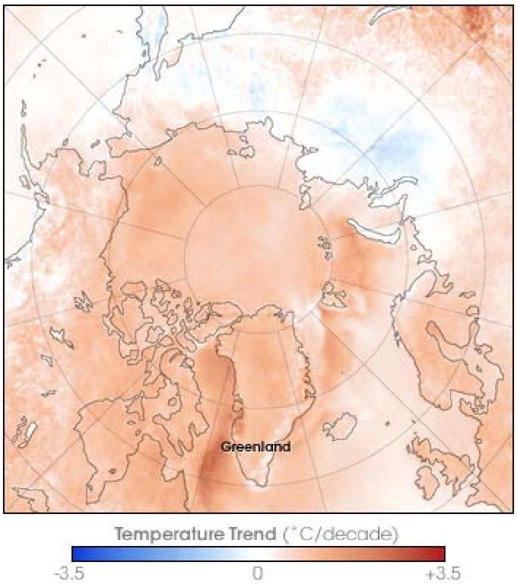


Figure CSB1
Rise in Arctic temperatures per decade since 1981 (NASA map by Robert Simmons; data supplied by J. Comiso Goddard Space Flight Center).

Observations: The loss of the sea-ice extent at its minimum has become evident since the early part of this decade where the period 2000-2005 clearly showed a reduction in the coverage of ice at its late summer minimum (Figure CSB2). In the latest available two years (2007 and 2008) the decrease has been even more rapid and extreme (through a number of factors). It is predicted that the Arctic will be ice-free in summer within the next few decades.

The science here is developing rapidly with a number of papers explaining the causes of change working their way to publication.

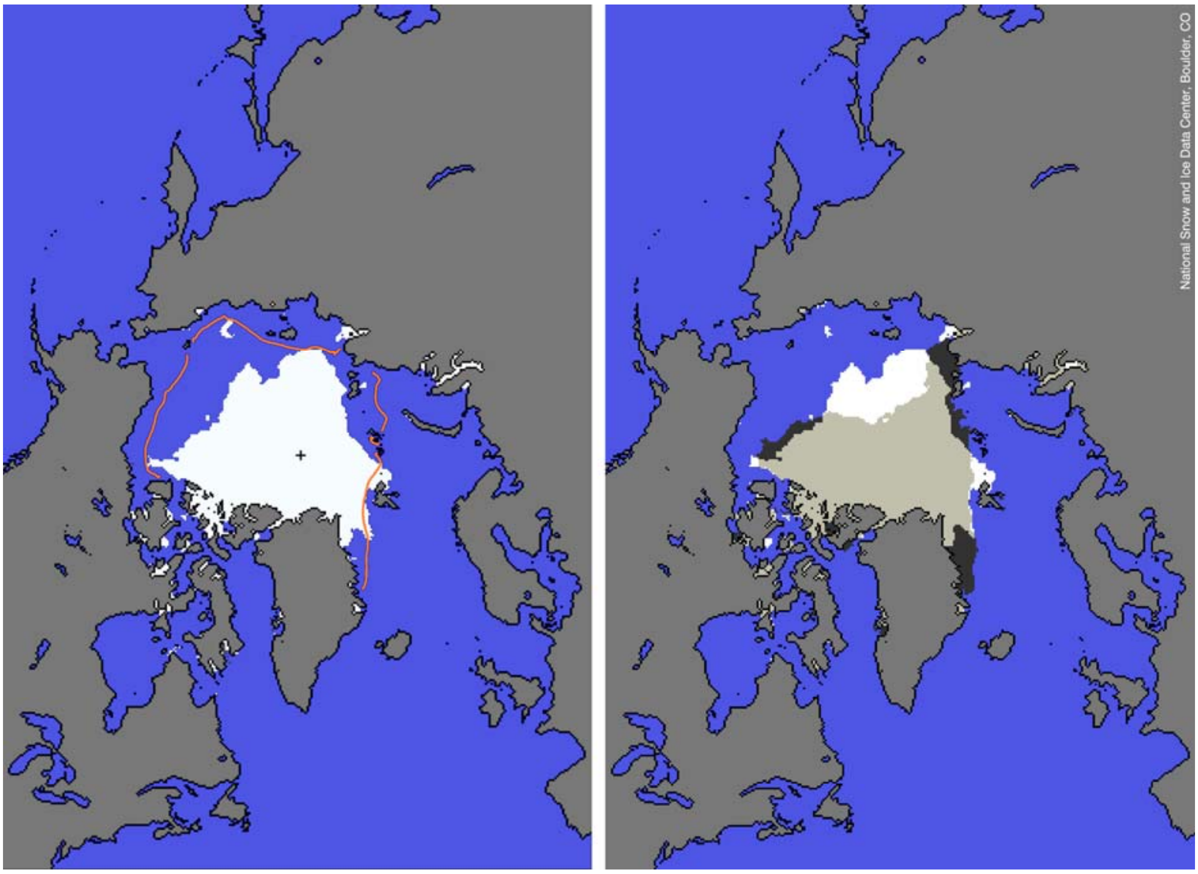


Figure CSB2 *from the NSIDC: Left panel: minimum sea ice extent observed in 2008 compared to long term (since late 70s). Note that both an eastern and a western sea-route passage appear to be open. Right panel – difference between the 2008 minimum and the 2007 minimum which was the lowest ever recorded. Here white areas denote ice in 2008 but not in 2007, dark-grey areas were ice in 2007 but not 2008 and pale-grey were ice in both years*

Biological and human impacts: Thinning and reduced cover of Arctic Sea Ice are likely to substantially alter ecosystems (Figure CSB3) in close proximity to the sea ice. With an increase in open water, primary and secondary production will increase south of the ice edge with benefits to important commercial fish species in the North Atlantic such as cod and herring (IPCC, 2007, p. 669). Marine mammals such as ringed seals and polar bears, which are dependent on sea ice for feeding and breeding, will be affected by diminished ice extent, as will some seabirds. This could be exacerbated by mismatch of timing of marine mammals with prey availability due to early summer ice melt (ACIA, 2005).

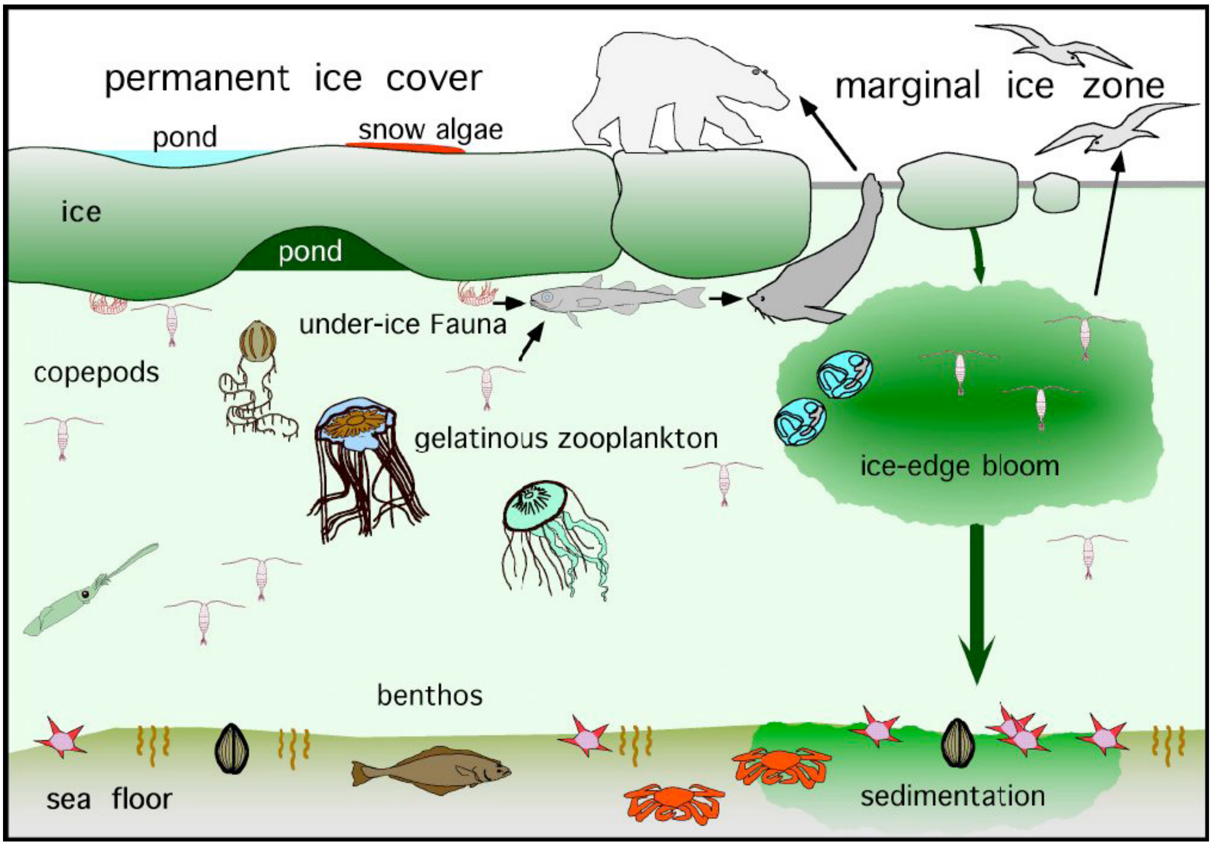


Figure CSB3 *Arctic marine food web - Schematic representation of the Arctic coastal marine ecosystem illustrating the reliance on sea ice. Reproduced in ICARP II (2005) from Arctic Ocean Diversity, a project of the Census of Marine Life www.arcodiv.org.*

Rising water temperatures south of the ice edge are likely lead to an increased risk of Harmful Algal Blooms and occurrences of marine pests and pollution, which will be exacerbated by increased shipping (ACIA 2005).

As sea ice continues to decrease, we could see a potential inundation of new organisms to the North Atlantic from the Pacific. The Pacific diatom *Neodenticula seminae* arrived in the North Atlantic in 1999; after becoming locally extinct 800,000 years ago and could be the first evidence of a trans-Arctic migration in modern times (Reid *et al*., 2007).

Coastal vulnerability to storms in Arctic regions is increasing with reduced sea ice (IPCC 2007). Severe coastal erosion will be an increasing hazard as rising seas, combined with reduced sea ice, allow higher waves and storm surges to reach the shore. The risk of flooding in coastal wetlands is likely to increase affecting coastal ecosystems and people, who may be forced to relocate. Reduced sea ice is likely to lengthen the navigation season and increase marine access to the Arctic's natural resources (ACIA 2005). Increases in commercial activities in Arctic seas and along Arctic coasts will inevitably lead to an increase in pollution hazards and a greater risk of alien species introductions through ship ballast water.

References:

ACIA, 2005. Arctic Climate Impact Assessment. Cambridge University Press, 1042p.

IPCC, 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson, Cambridge University Press, Cambridge, UK, 976pp

ICARP II – Science Plan 3, Arctic Coastal Processes, 2005. Second International Conference on Arctic Research Planning, Copenhagen, Denmark, 10–12 November 2005, www.icarp.dk.

Richter-Menge, J., Overland, J., Svoboda, M., Box, J. , Loonen, M.J.J.E., Proshutinsky, A., Romanovsky, V., Russell, D., Sawatzky, C.D., Simpkins, M., Armstrong, R., Ashik, I., Bai, L.-S., Bromwich, D., Cappelen, J., Carmack, E.,. Comiso, J., Ebbinge, B., Frolov, I., Gascard, J.C., Itoh, M., Jia, G.J., Krishfield, R.,. McLaughlin, F., Meier, W., Mikkelsen, N., Morison, J., Mote, T., Nghiem, S., Perovich, D., Polyakov, I., Reist, J.D., Rudels, B., Schauer, U., Shiklomanov, A., Shimada , K., Sokolov, V., Steele, M., Timmermans, M.-L., Toole, J., Veenhuis, B., Walker, D., Walsh, J., Wang, M., Weidick, A., Zöckler, C., 2008. Arctic Report Card 2008, http://www.arctic.noaa.gov/reportcard

National Snow and Ice Data Centre (NSIDC) www.nsidc.org

Reid, P.C., Johns, D.G., Edwards, M., Chelstarr, M., Poulins, M. and Snoeijs, P., 2007. A biological consequence of reducing Arctic ice cover: arrival of the Pacific diatom Neodenticula seminae in the North Atlantic for the first time in 800 000 years, Glob. Change Bio. 13, 1910-1921

Case Study C - Marine acidification: effects and monitoring of marine acidification in the seas surrounding Sweden

Source: P. Andersson *et al.* (2008) Marine Acidification: On effects and monitoring of marine acidification in the seas surrounding Sweden. SMHI Oceanografi, 92, pp62.

Background: This study was commissioned by the Swedish Environmental Protection Agency to assess:

- The need for monitoring acidification in the seas surrounding Sweden.
- How monitoring should be conducted.
- Where monitoring should take place.

The sites covered include two that fall within OSPAR region II.

Summary: The trend towards decreased pH in the world's oceans is largely reflected in waters surrounding Sweden. Even over the short timescales measurements have been taken, around 15 years, reductions are shown to be statistically significant. Little is known of the biological, ecological and economical effects of the current and near future marine acidification but it is predicted that these will be catastrophic.

Observations: Rates of pH change from 1993 to 2007 at 6 stations surrounding Sweden were analysed to see if any trends could be detected. Future projections to 2050 and 2100 are estimated at 5 of the 6 sites (see table CSC1).

Table CSC1 *Overview of the rate of pH change per year, pH values, significance and forecast scenarios (based on calculated values) in different sea areas and depths. The last column indicates the total pH decline between 1993 and 2007.*

Sea Area	Depth m	pH/yr	pH 2007	p	pH 2050	pH 2100	Change pH 1993-2007
Skagerack	0 – 50	-0.0028	8.15	0.136			
	> 75	-0.0026	8.09	0.156			
Kattegat	0 – 25	-0.0044	8.15	< 0.0001	7.96	7.74	0.06
	> 30	-0.0079	8.00	< 0.0001	7.66	7.27	0.11
S Baltic Proper	0 – 20	-0.0041	8.19	0.0941	8.01	7.81	
	30 – 60	-0.0142	7.86	< 0.0001	7.25	6.54	0.2
	> 70	-0.0156	7.36	< 0.0001	6.69	5.91	0.2
C & N Baltic Proper	0 – 20	+0.0024	8.19	0.347			
	30 – 60	-0.0102	7.79	< 0.0001	7.35	6.84	0.14
	> 70	-0.0063	7.22	< 0.0001	6.95	6.63	0.09
Bothnian Sea	0 – 30	-0.0316	7.69	< 0.0001	6.33	4.75	0.44
	> 40	-0.0192	7.62	0.0006	6.79	5.84	0.27
Bothnian Bay	0 - 30	-0.0143	7.61	0.0133	7.00	6.28	0.20
	> 40	-0.0130	7.60	0.0002	7.05	6.40	0.18

Decreases in pH over the time period covered are shown to be statistically significant at a number of locations (based on linear regression of monthly mean values ($p<0.05$, see table 1)). This applies to both surface and deeper waters. This is true for one of the two stations located in OSPAR region II, Kattegat. Here, projections suggest a decrease in surface pH of 0.2 units by 2050 and 0.4 units by 2100. Based on current trends, rates of decline are projected to be double this at depths of over 30m. For the second OSPAR site at Skagerrak, measurements do not exist from 2001-2007 so similar comparisons cannot be made. However, a downward trend in pH is also indicated for this site.

Limitations to monitoring and recommended improvements: Few time series of acidification measurements exist and those that do are short, especially for the OSPAR region II site at Skagerrak. Geographical coverage in waters surrounding Sweden is poor. It is recommended that acidification parameters should be measured at more stations as part of the national monitoring programme, that measurements should be taken throughout the water column at specified depths and that specific measurements of PCO_2 be taken, including the use of ferryboxes. For completeness, primary production should also be monitored.

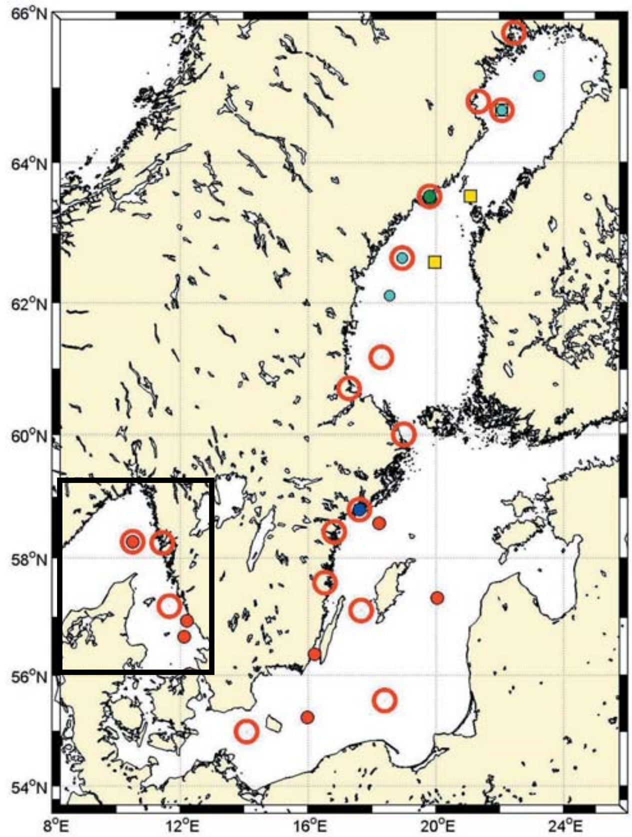


***Figure CSC1**. Overview of stations that currently measure pH and suggestion of additional stations. Those in OSPAR region II are highlighted in the small black box. Red dot: Monthly measurements, SMHI. Yellow square: Winter survey, once a year, SMHI. Green dot: Monthly measurements, UMF. Cyan dot: Measurements 3 times per year, UMF Blue dot: Measurements 24 times per year, SMF. Red circles: Suggestion of additional stations.*

Biological impacts: There is very little work on existing, or future, effects of acidification on marine ecosystems. Results of experiments are only just becoming available and all of this data shows negative impacts of near–future levels of acidification on calcifying species, which is consistent with earlier reports.

With specific reference to Swedish coastal waters, calcifying species such as the coccolithophorid *Emiliania huxleyi*, the blue mussel *Mytilus edulis*, the barnacle *Balanus improvisus*, the cold-water coral *Lophelia pertusa*, and a number of crustaceans and echinoderms (e.g. *Amphiura filiformis*), play major roles as ecosystem engineers in the Skagerrak. Given the experimental results obtained to date and the observed trends of declining pH in Swedish coastal waters, it is likely that significant ecosystem-wide effects will be observed within 50 – 100 years, and possibly sooner.

Research needs: Investigations of the effects of acidification on early life-history of key ecosystem-structuring species, and commercially important fish and shellfish; ecosystem-level impacts studies; regional-scale modelling of acidification mechanisms and testable ecosystem-scale food-web models to compare these regional models with.

OSPAR COMMISSION

New Court
48 Carey Street
London WC2A 2JQ
United Kingdom

t: +44 (0)20 7430 5200
f: +44 (0)20 7430 5225
e: secretariat@ospar.org
www.ospar.org

OSPAR's vision is of a clean, healthy and biologically diverse North-East Atlantic used sustainably

ISBN 978-1-907390-04-3
Publication Number: 463/2009