IMPACTS OF CLIMATE CHANGE ON FISHERIES

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Executive Summary

Distributions of both exploited and non-exploited North Sea fishes have responded markedly to recent increases in temperature, with nearly two-thirds of species shifting in mean latitude over the past 25 years. Seabass, red mullet, triggerfish, tuna, sting-rays, and seahorses are all becoming more commonplace, whereas cold-water species such as cod have declined markedly, with a strong negative relationship between the number of juveniles produced (termed 'recruitment') and observed sea temperatures, although intensive fishing also plays a key role.

Poor 'recruitment' success in cod may reflect a lack of available planktonic food items for larval fish, however knowledge of underlying mechanisms is rather limited. Climate change will also impact the transport of larval stages from spawning grounds to nursery areas. Model outputs suggest that cod stocks will continue to decline, and further temperature rises are likely to have a profound impact on commercial fisheries through continued shifts in distribution and alterations in community interactions.

Level of Confidence

Medium. There is quite a lot of information about, but understanding is still somewhat limited. However, there is certainly more information and understanding than is the case for mammals, birds or invasive species.

Key Sources of Information

See supporting evidence

Supporting Evidence

(1) What we currently know about fish and climate

Recent reviews for the North Atlantic clearly show that variability in ocean climate has far-reaching effects on the dynamics of fish populations and fisheries (Stenseth *et al.,* 2004; Drinkwater *et al.,* 2005). However, knowledge of the underlying mechanisms is rather limited. First, there is uncertainty about the future development of the ocean climate itself, as various aspects will be influenced such as circulation patterns, air and sea surface temperatures, frequency and intensity of storm surges, precipitation patterns and river run off. Second, fish and shellfish have complex life cycles comprising several life history stages, differing in habitat and their sensitivity to climate effects. Furthermore, these populations are part of an intricate network of ecosystem relationships and hence may be influenced by climate in an indirect manner through changes in predation or competitive processes. Added to this, the marine ecosystem is heavily influenced by fisheries and other human activities such as eutrophication and pollution that might interfere with or obscure the obvious effects of long-term climate change.

In several ocean basins, fluctuations in fish populations are known to correlate with decadal scale variability in ocean climate. Pelagic fisheries resources off the west coast of South America are known to change periodically in relation to an influx of warm water that reduces the upwelling of cool and nutrient rich waters (El Niño Southern Oscillation ENSO). Off the west coast of the USA and Canada, decadal scale changes in fish populations have been detected that are related to decadal scale variations in atmospheric forcing affecting ocean currents (Pacific Decadal Oscillation, PDO). In the North Atlantic, studies have reported decadal scale changes in ecosystems and fish populations that coincide with changes in the NAO index of the air pressure difference between Iceland and the Azores (North Atlantic Oscillation index, NAO: Hurrel, 1992).

Temperature is one of the primary factors, together with food availability and suitable spawning grounds, in determining the large-scale distribution pattern of fish. Because most fish species or stocks tend to prefer a specific temperature range (Coutant, 1977; Scott, 1982), an expansion or contraction of the distribution range of species often coincides with long-term changes in temperature. These changes are most evident near the northern or southern boundaries of the species range; warming results in a distributional shift northward, and cooling draws species southwards for both warm- and cold-water species (Rose, 2005). Statistical approaches such as correlation analysis have yielded important information on the pattern of change. For instance, the recent warming trend in the north-east Atlantic has coincided with a northward shift in the distribution of fish species from southerly waters (Quero *et al.,* 1998; Perry *et al.,* 2005, Beare *et al.,* 2004). Seabass and red mullet populations around British coasts have been growing in recent years. Similarly sightings of blue-fin tuna, triggerfish, thresher and blue sharks, sting-rays, turtles and seahorses are all becoming more commonplace (Stebbing *et al.,* 2002). A recent study by Perry *et al.,* (2005) demonstrated that distributions of both exploited and non-exploited North Sea fishes have responded markedly to recent increases in temperature, with nearly two-thirds of species shifting in mean latitude over 25 years. These authors suggest that further temperature rises are likely to have a profound impact on commercial fisheries through continued shifts in distribution and alterations in community interactions.

An important complication in assessing the impact of climate change on fish populations is to disentangle its effect from the effect of other drivers such as fishing. Daan *et al.,* (2005) indicated that fishing pressure was responsible for changes in the size structure of the fish community. Specifically, large, mainly predatory fish were reduced leading to an absolute increase in abundance of the smaller size classes and species. The effect of fishing may interact with the effect of climate and may have enhanced the apparent northward shift of the smaller sized fish species reported by Perry *et al.,* (2005).

Blanchard *et al.,* (2005) suggested a similar phenomenon for the Celtic Sea. Smaller, pelagic species have become more abundant in relative and absolute terms, presumably driven by changes in climate, whereas large commercial species such as cod have largely disappeared due to fishing. Many of the species which have expanded in recent years have been non-commercially exploited planktivorous species such as the boarfish *Capros aper,* which has become particularly abundant in French and UK survey catches (Pinnegar *et al.,* 2002). This phenomenon has been reported as occurring elsewhere in the North Atlantic including the Bay of Biscay (Farina *et al.,* 1997) and offshore seamounts (Fock *et al.,* 2002).

Heath (2005a, 2005b) studied changes in the food web of the North Sea, Baltic, Nordic Seas and Celtic Seas and showed that these were related to both climate effects and fishing. In the North Sea, variability in zooplankton production seems to have exerted a bottom-up effect on fish production, which in turn has exerted a top-down effect on the benthos. Conversely, in the Celtic and Irish Seas, Heath (2005a) argued that benthos production has been a bottom-up driver of fish production, which seems to have been independent of variability in plankton production, although this has subsequently been challenged (ICES 2006), on the basis that Heath (2005b) may have underestimated the role played by the planktivore *Micromesistius poutasso* (blue whiting).

Fishermen and scientists have known for over 50 years that the status of fish stocks can be greatly influenced by prevailing climatic conditions (Cushing 1982; Hjort 1914). In recent years scientists have focused their attention on the potential impact of climate change on North Sea cod populations. Cod is a cold-water species with a northerly distribution. A series of recent research papers has demonstrated that the number of juvenile fish entering the stock (termed ‘recruitment’) has declined markedly, and there is a strong negative correlation (O’Brien *et al.,* 2000) between cod ‘recruitment’ and ocean temperatures, which have generally been increasing.

The year-class size of marine fish is greatly influenced by the timing of spawning and the resulting match-mismatch with their prey and predators (Cushing, 1990). This was confirmed recently on the basis of satellite remote sensing and a long-term data set of haddock recruitment (Platt *et al.,* 2003). A clear seasonal shift to earlier appearance of fish larvae has been described for the southern North Sea (Greve *et al.,* 2001), in addition it has been demonstrated that rising temperatures have coincided with marked changes in plankton (Beugrand *et al.,* 2002). In particular there has been a decline in the abundance of the copepod *Calanus finmarchicus* but an increase in the closely related but smaller species *Calanus helgolandicus*. *C. finmarchicus* is a prey item for cod-larvae in the northern North Sea, and the loss of this species has been correlated with recent failures in cod ‘recruitment’ and an apparent increase in flatfish recruitment (Beugrand 2003, 2004; Reid *et al.,* 2001; 2003). *C. helgolandicus* occur at the wrong time of the year and are the wrong size to be of use to emerging cod-larvae. However *Calanus* (of either species) is not a major prey item for fish larvae in the southern North Sea (Last 1978a,b, 1980) and consequently several authors have argued that this ‘match/mis-match’ hypothesis does not provide a full explanation for recent failures in fish recruitment success.

Studies aimed at investigating the mechanisms or processes underlying the link between climate and fish stocks have followed three basic approaches:

The first approach, employing statistical analysis of long-term datasets to test *a priori* hypothesis, provided support for the climate effect on recruitment, e.g. through (i) the water volume suitable for egg survival (MacKenzie *et al.,* 2000), (ii) the timing and size/species composition of the plankton production and larval stages of fish (Beaugrand *et al.,* 2003; Edwards and Richardson, 2004); (iii) transport of larval stages from the spawning grounds to the nursery grounds (Corten, 1986).

The second approach has involved conducting both field and experimental studies describing the anticipated impact of climate on (i) zooplankton dynamics and fish growth (Buckley *et al.,* 2004, Möllmann *et al.,* 2005), (ii) impact of temperature on growth and survival (Keller and Klein-MacPhee, 2000), (iii) species interactions at different life stages (Köster and Möllmann, 2000).

Finally employing coupled bio-physical models to quantitatively integrate the proposed mechanisms and their interactions, has allowed some determination of the relative importance of various mechanisms (Hinrichsen *et al.,* 2002).

(2) What we might expect in the future

Drinkwater (2005) reviewed the possible impacts of future climate change on cod and used temperature-recruitment relationships found in Planque and Frédou (1999) together with outputs from Global Circulation Models (GCMs) to predict possible responses of cod stocks throughout the North Atlantic to future temperature and hydrodynamic changes. According to this study, stocks in the Celtic and Irish Sea are expected to disappear altogether by 2100, while those in the southern North Sea and Georges Bank will decline. Cod will likely spread northwards along the coasts of Greenland and Labrador, occupy larger areas of the Barents Sea, and may even extend onto some of the continental shelves of the Arctic Ocean. In addition, spawning sites will be established further north than currently, and it is likely that spring migrations will occur earlier and autumn returns will be later.

Clark *et al.,* (2003) used projections of future North Sea surface temperatures and estimated the likely impact of future climate change on the reproductive capacity of the North Sea cod stock, assuming that the current high level of mortality inflicted by the fishing industry continues. Output from the model suggested that the cod population will decline, even without a significant temperature increase. However, even a relatively modest level of climate change (+0.005 °C yr^{-1}) resulted in a more rapid decline in fish biomass and juvenile ‘recruitment’. Scenarios with higher rates of temperature increase resulted in greater predicted rates of decline in the cod population.

In the analyses of Clark *et al.,* (2003), fishing mortality was assumed to continue at the 1998-2000 average (F = 0.96). This is a relatively high value and does not take into account current efforts to cut fishing pressure. In a recent re-analysis by Kell *et al.,* (2005), the authors modelled the effect of introducing a ‘cod recovery plan’ (as being implemented by the European Commission), under which catches were set each year so that stock biomass increased by 30% annually until the cod stock had recovered to around 150,000 tonnes. The length of time taken for the cod stock to recover was not greatly affected by the choice of climate scenario (generally around 5-6 years). However, overall productivity was impacted, and stock biomass (SSB) was predicted to be considerably less than would have been the case assuming no temperature increase (251,035 tonnes compared to 286,689 tonnes in 2015).

(3) 'Other' climate impacts on fish?

Since the 1970s, the frequency and spatial distribution of phytoplankton blooms and associated fish kills have been increasing in coastal seas throughout the world. Why such events are becoming more frequent remains a matter of conjecture, but eutrophication of the coastal zone by human activity, together with increasing global temperatures are often suspected. The coastlines of northern France, Belgium, the Netherlands and Great Britain are regularly afflicted by *Phaeocystis* blooms, which form an unpleasant foam which is often mistaken for sewage pollution. Although not itself toxic, the adverse conditions caused by the degeneration of a *Phaeocystis* bloom results in an anoxic, mucilaginous layer over the seabed and hence mass suffocation of juvenile fish (Environment Agency 2004). A recent study (Peperzak, 2005) has attempted to evaluate whether harmful algal blooms are likely to occur more or less often over the next 100 years in the North Sea. Change in climate is expected to lead to an increase in extreme precipitation events (intense rainfall) in Britain, this will result in sudden pulses of freshwater being released at the coast and hence intermittent salinity stratification in an area imediately offshore. During such conditions, surface phytoplankton benefit from a decrease in salinity, greater availability of terrestrial nutrients, rapid increases in daily irradience and higher water temperature, all of which are conducive to bloom formation. Increasing global temperature may also lead to faster growth rates, particularly for highly toxic phytoplankton varieties such as *Prorocentrum* (producers of shellfish toxins), *Chattonella* and *Fibrocapsa* (toxic to fish). *Gyrodinium* is harmless to humans but can cause mass-mortalities among fish. This dinoflagellate produces a potent neurotoxin, which is known to bioaccumulate in the zooplankton food-chain (Environment Agency, 2004).

Most carbon dioxide released into the atmosphere as a result of burning fossil fuels will eventually be absorbed into the ocean. As the amount of CO_2 in the atmosphere rises, more of the gas reacts with seawater to produce bicarbonate and hydrogen ions, thereby increasing the acidity of the surface layer. Ocean pH was around 8.3 after the last ice age and 8.2 before CO_2 emissions took-off in the industrial era (CO_2 in the atmosphere amounted to around 280 parts-per-million). Ocean pH is now 8.1, with an atmospheric CO_2 concentration of around 380 parts-per-million (ppm). A report published by the Royal Society in June 2005 and focusing mainly on ocean acidification suggested that higher concentrations of carbon dioxide may make it harder for some marine animals to obtain oxygen from seawater. Fish and the larger invertebrates including cephalopods such as squid, take up oxygen and lose respired CO_2 through their gills. Increased CO_2 and decreased pH could have a major effect on this respiratory gas exchange system. Increased CO_2 concentration, known as hypercapnia, In addition to reducing the pH of body fluids, also changes the levels of bicarbonate and other ions. Small changes can be buffered within the cell, but larger changes require the active secretion of ions out of the body through specialized cells. In fish, the structure and activity of some of these secretion cells changes after 24 hours of hypercapnia. Some fish can change the density of these cells in a matter of hours or days, giving them greater tolerance to acidification (Ishimatsu et al 2004). However deep sea fish and cephalopods are known to be very sensitive to increases in external CO_2 (Ishimatsu *et a.,* 2004).

We have a limited understanding of the effect increased acidity might have on marine biota, but coral reefs, calcareous plankton and other organisms whose skeletons or shells contain calcium carbonate may be particularly affected. Many such organisms are a major food source for fish and higher consumers.

(4) What are the major knowledge gaps?

- ‘Real’ information about the linkages between larval fish (their survival and feeding), zooplankton and climate.
- Information for the west of Britain the North Sea has been considered in much greater detail in comparison with western Scotland, the Irish and Celtic Seas.
- Predictive studies, attempting to estimate changes in fish distributions, interactions between fish species as a result of changing distributions, the ecological role of incoming species, prospects for stock recovery and rebuilding.
- Experimental studies relating growth and reproductive output (in species other than cod) to temperature and/or other environmental variables

(5) What long-term data sets are available?

- Stock recruitment indices for all major commercial fish stocks. Available from ICES (2005) stock assessments. Also stock biomass and numbers.
- Fish stock abundance estimates from scientific surveys (both commercial and non-commercial species) from ICES and national laboratories (including FRS and Cefas). Available for all seas around the UK.
- Small-scale, long-term scientific surveys of fish populations (e.g. for the area around Plymouth). Available from the Marine Biological Association.
- Numbers of fish eggs and larvae – available (but not worked-up in recent years) as part of annual CPR (Continuous Plankton Recorder) programme. Supplemented with recent systematic surveys of fish eggs and larvae in the North Sea (Fox, pers. Comm.; Greve *et al.,* 2005), Celtic and Irish Seas (e.g. Fives, 2001).
- Studies/data-sets of fish larval diets (e.g. D. Righton pers. comm. – LIFECO project.; Last, 1978a,b;1980).

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