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Fisheries

JOHN K. PINNEGAR[1], WILLIAM W.L. CHEUNG[2], AND MIKE HEATH[3]

[1]Cefas, Pakefield Road, Lowestoft, Suffolk. NR33 0HT.

[2]School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ.

[3]University of Strathclyde, Department of Mathematics and Statistics, University of Strathclyde, 26 Richmond Street, Glasgow, G1 1XH

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EXECUTIVE SUMMARY

'What is already happening'

- There is evidence that location where high catches of cod, haddock, plaice and sole occur, as reported by UK commercial fishing vessels, seems to have shifted over the past 80-90 years. Climate change may be a factor but fishing and habitat modification have also had an important effect.
- Shifting distributions of fish, partly as a result of climate change are having an impact on the effectiveness of some fishery closure areas and on the apportionment of fishery resources between neighbouring countries (e.g. mackerel in the north-east Atlantic).
- New fisheries have developed for a number of warmer-water species including seabass, red mullet, anchovy and squid. The stock biomass of seabass in the Western Channel has quadrupled since 1985 from 500t, to over 2000t in 2004/5.

'What could happen in the future'.

- As a result of climate change, the UK as a whole is expected to benefit from slightly (i.e. +1-2% compared to present) higher fishery yields by 2050, although regions such as the Irish Sea and English Channel may see a reduction.
- Models suggest that cod stocks in the Celtic and Irish Seas may to disappear completely by 2100, while those in the North Sea are expected to decline. Climate change has been 'eroding' the maximum sustainable yield of cod in the North Sea by around 32,000t per decade.
- Very little work has been carried out on the social and economic implications of climate change for the UK fishing industry, however calculations suggest that consequences will be significant only for fishery-dependent communities in the North of Scotland and in the southwest England.
- Ocean acidification may pose a significant threat to the UK shellfish industry, but more research is required.

FULL REVIEW

Background

Even though there has been considerable research on the implications of climate change for 'fish' in recent years (see *MCCIP ARC Science Review 2010-11 Fish* [Pinnegar & Heath, 2010]) there has been surprisingly little attention given to the consequences of future climate change for fisheries and for coastal economies. Some progress has been made with regard to the prediction of global impacts on fisheries yields (e.g. Cheung *et al.* 2009b; Biswas *et al.* 2009), however likely implications at the local level, i.e. around the British Isles, are poorly understood.

Commercial fishing is an important socio-economic activity in coastal regions of the UK, particularly in Scotland. The UK catching sector employed almost 13,000 people in 2007 whilst the processing sector employed an additional 18,000 people. The dependency of jobs on fishing can be as high as 20% or more in some coastal communities. Catches of fish and shellfish by UK vessels achieved a first-sale value of £510 million in 2007. The fisheries sector (fishing boats and onshore processing) contributed £808 million Gross Value Added (GVA) to the UK economy.

Fishermen and scientists have known for over 100 years that the status of fish stocks can be greatly influenced by prevailing climatic conditions (Cushing 1982; Hjort 1914) and it is certainly the case that fishermen are interested in how their industry might have to adapt in the future as well as the risks and opportunities that they are likely to encounter in the years ahead. Fishermen often notice (and report) changes in the fish they are catching, or in the marine environment more generally, and in recent years they have played a key role in commissioning research and have tasked scientists with answering specific questions, many of which relate to the role played by a changing climate, versus the consequences of intensive fishing. It is often very difficult to differentiate the effects of fishing from those of climate change. Fishing can make stocks more vulnerable to climatic variability, i.e. occasional poor year classes (Ottersen *et al.* 2006), and at the same time climate change can reduce the capacity of stocks to withstand fishing mortality (Cook and Heath 2005).

In the following section we consider changes that have been observed in the distribution of fish catches, the ability of vessels to catch target animals, new and incoming fishery resources etc. We then consider how fisheries might be impacted in the future, including expectations of future fishery yield as well as losses and profits to the industry. Finally we consider possible socio-economic consequences, including necessary changes in fishery governance (McIlgorm *et al.* 2010) as well as future 'adaptation' costs in the industry (Sumaila and Cheung 2009).

1. What is already happening?

Changes in fish distribution – response of the fishery

Temperature is one of the primary factors, together with food availability and suitable spawning grounds that determine the large-scale distribution patterns of fish. Because most fish species tend to prefer a specific temperature range, an expansion or contraction of the distribution range often coincides with long-term changes in temperature and/or climate. Perry *et al.* (2005) demonstrated that distributions of both exploited and non-exploited North Sea fishes have changed markedly over the last 25 years. These authors concluded that further temperature rises are likely to have a profound impact on commercial fisheries through continued shifts in distribution and alterations in community interactions. However significant shifts were only observed for 15 out of the 36 species examined and it is unclear why 21 species studied in Perry's analysis (i.e. the majority) showed no apparent change. Dulvy *et al.* (2008) have subsequently demonstrated that the situation is actually much more complicated and that different species respond to climate change in different ways, with some fish moving into deeper waters, some species shifting northwards, and yet others changing their behaviour on a seasonal basis.

Distribution shifts may have 'knock on' impacts upon commercial fisheries catches because changes in migration or spawning location affect the 'catchability' of individuals to fishing gears. Populations may move away from (or towards) the area where fishing fleets operate and/or where spatial restrictions on fishing are in place.

Also species distributions may migrate across the boundaries where quotas belong to different nations. A notable example might arise as a result of quota allocations between Norway and the EU, or between Iceland and the EU. If, for example, species such as mackerel or herring move away from the EU sector, then EU fisheries may no longer be able to catch their full quota within indigenous waters, and hence there will be difficult political negotiations between nations with regard to future access to key fish stocks (e.g. Sissener and Bjorndal 2005). The converse happened in October 2009 when North Sea Mackerel appeared to have moved away from the Norwegian Sector, resulting in disagreements over permissible catches by Norwegian boats in EU waters. Norwegian vessels were forcibly evicted from Scottish waters by UK fishery patrol vessels once they had caught their allotted quota (see *Fishing News,* 9th October 2009). At the same time Iceland and the Faeroe Islands unilaterally claimed quota for mackerel, since the species had migrated westwards and had attained high abundance in their indigenous waters. International law provides that coastal States have sovereign rights to manage fisheries in waters under their jurisdiction. More than ninety percent of the global fish catch is estimated to be taken within waters under the jurisdiction of particular coastal states. With climate change in the future, we might anticipate more territorial disagreements of this type.

Theoretically, in the northern hemisphere, warming results in a distributional shift northward, and cooling draws species southwards. Heath (2007) looked at patterns in international fisheries landings for the whole northeast Atlantic region. Densities of landings of each species were summed by decade and expressed as a proportion of the total. Both northerly and southerly shifts were observed between decades for individual species, however more species shifted south than north between the 1970's and 1980's (a relatively cool period) and vice versa between the 1980's and 1990's (a relatively warm period). This seems to parallel observed interdecadal changes in sea and air temperatures.

Recent analyses of Scottish and English commercial catch data spanning the period 1913-2007, by Engelhard *et al.* (Cefas, Lowestoft) has revealed that the peak catches of target species such as cod, haddock, plaice and sole, have shifted but not in a consistent way. Cod distribution seems to have shifted steadily north-eastward, towards deeper water in the North Sea over the past 9 decades, whereas plaice distribution has moved north-westwards, and this confirms the findings of van Keeken *et al.*, (2007). Haddock catches have moved very little in terms of centre of distribution, but their southen boundary has shifted northwards by approximately 130 km over the past 80-90 years. Sole seem to have retreated away from the Dutch coast, southwards towards the eastern Channel, illustrating the fact that climate change in the North Sea is not a straightforward issue. In the North Sea the north tends to be colder than south in summer, but the south tends to be colder than the north in winter. Some southern North Sea species such as sole were previously excluded from large areas of shallow inshore habitat along the Dutch coast in winter because these waters cool down to <1 °C. Consequently sole tended to over-winter in deeper waters before returning to the shallows in spring, in order to avoid the lethally cold winter temperatures (Henderson and Seaby 2005). However, there is now anecdotal evidence that sole are arriving inshore earlier due to the rapidly warming seas in winter, and this is in contrast to the severe winters that were experienced in the 1960s, when mass mortality events were reported for several Lusitanian species, including sole but also conger eel *Conger conger* (Woodhead, 1964). Climate change may explain some of the changes that have been observed, however habitat degradation and different intensities of fishing pressure over the 95 year period, may also have played a role. Fishing mortality rates have been higher in the southern North Sea than in the north, and so apparent changes in distribution (as indicated by Perry *et al.* 2005) could simply be a consequence of local patterns of fishing pressure and different rates of depletion in spatially segregated sub-stocks. Distribution changes may have significant consequences for the distance that must be travelled by fishing boats to reach the target resources with implications for fuel usage and time at sea. In addition, increased or reduced storminess could impact the ability of fishing boats to access resources in the future, which may be further constrained if a 'days at sea' based management regime is in place.

'Non-stationarity' of natural ecosystems has been a confounding factor influencing the apparent success or failure of closure areas in the North Atlantic area, including the southern North Sea 'Plaice box' (see van Keeken *et al.*, 2007). In the North Sea, juvenile plaice are typically concentrated in shallow inshore waters and move gradually offshore as they become larger. Surveys in the Wadden Sea have shown that 1-group plaice are now almost absent from the area where they were once very abundant. This is probably linked to changes in the productivity of the region but also the changing temperature of the southern North Sea which has warmed considerably in recent years. The 'Plaice Box' is now considered to be much less effective as a management measure in comparison with the situation 10 or 15 years ago and this has been attributed to long-term climate change. Marine Protected Area (MPA) boundaries (and expectations) may need to be 'adaptive' in the future. For example, fisheries closures in the Bornholm Basin of the Baltic Sea do not account for year-to-year environmental variability and particularly the periodic inflow of water from the North Sea which greatly influences the spawning location and year class strength of species such as cod. In some years the Bornholm closure area is successful in protecting much of the cod stock, but in other years, most of the spawning population occurs outside of the boundaries of the Protected Area, and hence the MPA offers no protection at all (for a review of Baltic closure areas, see ICES 1999; 2004). The North Pacific Fishery Management Council has recently decided upon very risk-averse management actions in light of uncertainty about the effects of warming trends (and loss of sea ice) in the North Pacific region. The Council has assessed whether opportunities for unregulated fishing could result from changes in fish distribution, and has closed many areas in the Arctic Ocean to commercial fishing pending further research. Extensive area closures have been established (where fishing with bottom-trawl gear is prohibited) to protect vulnerable crab habitat and to control the northern expansion of the trawl fleet into newly ice-free waters (see Stram and Evans 2009). In UK waters there are a number of closed areas aimed at protecting particular fish stocks, and these include many estuarine sites which are predicted to experience marked changes in temperature and river flow in the next few decades. It is possible that estuaries where fishery closures are in place, for example to protect juvenile herring or seabass, may no longer be hospitable for these species in the near future, or that estuaries further north, that are currently unprotected, may need to be closed to fishing in the future to accommodate and protect the growing populations.

Are fish becoming more difficult to catch?

A further means by which climate change might impact commercial fisheries includes the potential that animals will behave differently in response to the oncoming gear, behaving in a more sluggish or skittish manner (sometimes a function of temperature or light levels) and thus making them more or less vulnerable to capture (see Winger 2005).

At a UK level, fishermen in the Thames estuary have suggested (J. Pinnegar- Pers. Comm.) that certain species are becoming increasingly difficult to catch, possibly due to improved clarity of the water column associated with changing climate. Fish populations in the Thames have however, changed in recent years (Attrill and Power, 2002) and this itself might be related to climate. Thus observed changes in catch rates of particular species may not necessarily reflect underlying differences in the 'catchability' of these species, compared to periods in the past.

A recently completed UK study by Dulvy *et al.* (2008) explored the year-by-year distributional response of the North Sea demersal fish assemblage to climate change and found that the whole North Sea fish assemblage had deepened by ~3.6 m per decade since 1981. This study concluded that the deepening response was far more dramatic in comparison with the latitudinal response that had previously been reported based on the same data (by Perry *et al.* 2005). This has important implications for fisheries since it is known that gear geometry and hence 'catchability' of certain fish species can be greatly influenced by water depth (Godø and Engås 1989).

A further, only recently appreciated consequence of anthropogenic greenhouse gas emissions could be a change in sound transmission in the ocean (Hester *et al.* 2008). The relative solubility of borate and boric acid in the ocean are known to be very dependent on pH, and it is the balance of these two solutes which is thought to influence noise attenuation. As atmospheric CO_2 concentrations increase, and more of this gas dissolves in the ocean, the pH of surface waters tend to decrease (become more acidic), and this could impact sound absorption in the audible range for most fishes. The decreased sound absorption will amplify ambient noise levels, and enhance long distance sound transmission. Consequently fish may be able to detect incoming fishing gear, much earlier in the future

Incoming species and new fisheries

UK fishermen have witnessed and responded to a number of new opportunities in recent years, as warm-water species have moved into UK seas and/or their exploitation has become commercially viable for the first time. Notable examples include new and/or expanding fisheries for seabass, red mullet, john dory, anchovy and squid.

Biomass estimates for seabass in the Western Channel have quadrupled from around 500 t in 1985, to in excess of 2100 t in 2004/2005, with populations also increasing rapidly in the Eastern Channel, North and Irish Seas (Pawson *et al.* 2007). This has resulted in an expansion of seabass fisheries (rising to >2500 vessels), both within the commercial fisheries sector, but also in the recreational fishing sector, for which seabass is a key target species. Bass are caught by angling on the Scottish east coast, but the northern limit of the commercial bass fishery is around Yorkshire, where trawl-caught fish are increasingly being landed into Scarborough and Whitby. In 2005 fisheries for seabass landed around 1600t in the UK, compared to only 460t in the mid 1980s.

Red mullet is a non-quota species of moderate, but increasing, importance to UK fisheries. From 1990 onwards, international landings from the English Channel increased strongly, and so have the landings from the North Sea. France is the main country targeting this species (with landings of 5392t in 2007) however UK commercial catches have also increased dramatically, from only 26t in 1980 to 355 t in 2007. Beare *et al.* (2004) demonstrated that red mullet are one of many species that have become significantly more prevalent in North Sea bottom trawl surveys in recent years, rising from near-absence during surveys between 1925 and 1990, to about 0.1 – 4 fish per hour of trawling between 1994 and 2004.

Commercial catches of anchovy increased considerably around UK coasts in 2007 rising to around 939t, with the result that several pelagic fishing boats switched to actively targeting this species for the first time. The apparent increase coincided with a gradual spread of anchovy (as indicated by research surveys) northward into the western Channel, southern North Sea and Irish Sea over the past decade and observations of large populations of juveniles in the Thames estuary and along the Dutch coast. In October 2009 two Devon trawlers hauled in a staggering 36 tons of anchovies worth £72,000 in just two days (Mail Online, 31st October), and a recent ICES report (ICES, 2008) confirmed that the species is now widely distributed over almost 80% of the North Sea, even though only occasional records of anchovy had been made off Britain and in the Skagerrak in the period between 1977 and 1989.

Squid numbers are highly uncertain around UK coasts, but there are strong indications that cephalopods (squid, octopus, cuttlefish) generally are becoming more abundant, possibly as a consequence of climate change (Hastie *et al.* 2009a). Growth in squid availability in the North Sea is generating considerable interest among policymakers and marine ecologists and has led to the establishment of a new fishery off the Aberdeen coast (see Hastie *et al.* 2009b). Off north-east Scotland, where most of the squid are found, more boats are now trawling squid than the region's traditional target species, such as haddock and cod. In 2007, UK squid landings exceeded 1800t (£5.9m) having risen from only 410t in 1980. Squid are highly sensitive to environmental conditions and populations are considered to be vulnerable to the effects of climate change. Sea surface temperature (SST) appears to influence recruitment strength and overall distribution (Hastie *et al.* 2009a).

Year-class strength and implications for fisheries

Recruitment variability, also referred to as the 'year-class strength', is a key measure of the productivity of a fish stock, and is defined as the number of juvenile fish of a given age surviving from the annual egg production to be exploited by the fishery. In the case of cod, there is a well established relationship between recruitment and sea temperature (O'Brien *et al.* 2000; Clarke *et al.* 2003; Beaugrand *et al.* 2003). At the northern extremes, warming leads to enhancement of recruitment, whilst in the North Sea, close to the southern limits of the range, warm conditions lead to weaker than average year classes, and vice-versa. During the late 1960's and early 1970's, cold conditions were correlated with a sequence of positive recruitment years in cod, haddock and whiting (Brander and Mohn, 2004) and subsequently high fisheries catches for a number of years to come (Heath and Brander, 2001). However, in more recent years, a warming climate has prevailed and year class strength has been weaker than average.

Extensive fishing may cause fish populations to be more vulnerable to short-term natural climate variability (O'Brien *et al.,* 2000; Walther *et al.,* 2002; Beaugrand *et al.,* 2003), by making such populations less able to 'buffer' against the effects of the occasional poor year classes. Conversely, long-term climate change may make stocks more vulnerable to fishing, by reducing the overall 'carrying capacity' of the stock, such that it might not be sustained at, or expected to recover to, levels observed in the past (Jennings and Blanchard 2004).

In the NE Arctic, during recent decades, there has been a clear, positive correlation between temperature and recruitment in cod, however this link was weak or non-existent in earlier periods (Ottersen and Stenseth 2001). As pointed out by Ottersen *et al.* (2006), it is likely that the higher dependency nowadays of recruitment on climate, relates to changes in stock structure, whereby spawners were on average 10–11 years old and >90 cm long in the past, compared to an average of 7–8 years old (or only 3 years old in the North Sea) and 80 cm long at present. The number of age classes has also decreased. This has been attributed to high fishing mortality especially from the 1960s onwards and to decreased age and size at maturation. A major implication is that fishery-induced impoverishment of stock structure (reduced and fewer ages, smaller sizes) can increase the sensitivity of a previously 'robust' stock to climate change. Worryingly, truncations in the age distributions of spawners have occurred in most cod stocks (see Planque *et al.*, 2009), including those around the United Kingdom.

Many authors have shown that the future prospects (and profits) of fisheries are highly dependent on year-class-strength, and strong relationships have been observed between recruitment success, fisheries catches and climatic variables in a number of key fish and shellfish stocks that are critical to the UK fisheries economy, most notably cod, whiting and haddock (Brander and Mohn, 2004), plaice (van der Veer and Witte 1999), herring (Nash and Dickey-Collas 2005) and more recently, scallops (Shephard *et al.* 2010). In the latter study, the authors focused on the scallop fishery based around the Isle of Man. Numbers of young scallops each year were on average, positively related to seawater temperature in the spring. The gonads of adult scallops were also larger, indicating higher egg production, in warmer years.

Ocean acidification – expectations and observations

In recent years ocean acidification (OA) has emerged as a high-profile and potentially very serious threat to marine ecosystem structure and function in the North Atlantic, with several authors predicting catastrophic consequences for commercial fisheries and aquaculture (e.g. Cooley and Doney 2009; Gazeau *et al.* 2007). The vast majority of the studies that have been published on the impacts of ocean acidification so far have tended to focus on benthic or planktonic species that are of limited importance for fisheries and aquaculture. However, it is clear that commercial species of shellfish may be impacted in the future. At high pCO_2 (low pH) the growth and shell formation of oysters and mussels seems to be impaired (Gazeau *et al.* 2007) and in the NW Pacific commercial oyster hatcheries are already reporting reduced survival of juveniles and hence reduced viability of aquaculture operations attributable to low pH in coastal waters.

Four of the ten most valuable marine fishery species in the UK are calcifying shellfish. These fisheries have grown substantially in the last decade and *Nephrops* (scampi), scallops, crabs and lobsters together contribute 44% of the UK total value (£234 million out of £535 million). Aquaculture of shellfish - predominantly oysters and mussels - is annually worth an additional £20 million in England and Wales (2006), £5 million in Scotland (2007) and more than £3.5 million in Northern Ireland. These statistics emphasise the importance of shellfish to the UK fishing fleet and highlight the potential for economic impacts as a result of ocean acidification.

Even though commercial fin-fishes may be less impacted by ocean acidification in terms of direct physiological effects, they may be impacted by changes in the marine food-web. Larvae and juveniles of most fish are reliant on planktonic crustaceans which may or may not be impacted by future ocean acidification. As adults, many commercial fish species (e.g. haddock and plaice) are also reliant on bivalve molluscs or echinoderms which are predicted to decline in the future as a result of ocean acidification (Fabry *et al* 2008). OA research programs have recently been instigated throughout the North Atlantic (e.g. FOARAM – USA, BIOACID-Germany, EPOCA-EU FP7) and it is anticipated that more information will soon emerge allowing better quantification of the financial risks associated with this problem.

Regional differences – where and when?

The impact of climate change on fisheries and fishing fleets will vary around the country depending on the make-up of the fleet in an individual fishing port, the species being targeted and distance/proximity to resources in the future. For example the UK pelagic fleet (mainly targeting herring and mackerel) primarily operates out of Peterhead and Fraserburgh in NE Scotland, in Lerwick (Shetland Islands), as well as Ardglass in Northern Ireland. By contrast, UK beam-trawlers are primarily concentrated in south-west England (Brixham, Plymouth and Newlyn), targeting sole, plaice and cuttlefish. The demersal 'otter-trawl' fleet which targets species such as haddock, cod and whiting, is more widely distributed but landings are highest in Peterhead, Aberdeen and Hull. Important shell fisheries occur all around the UK and include Nephrops (scampi) fisheries operating out of North Shields, Peterhead and Fraserburgh, Ardglass, Kilkeel and Portavogie; cockle fisheries operating out of Leigh-on-Sea, Morecambe, Bury Inlet and The Wash (Boston and Kings Lynn); scallop fisheries operating out of Brixham, Plymouth, Falmouth and Shoreham; and important whelk fisheries occur at Hastings, all of which could be impacted by future ocean acidification.

The fishing ports that have probably benefited most from incoming 'warm water' species are probably those in the Channel, where seabass, anchovy, red mullet and john dory populations have expanded the most (although French fisheries have exploited these resources more extensively). However the 'western approaches', Channel and southern North Sea are also the regions that have witnessed the greatest declines of 'traditional' (often cold-water) target species such as cod, and where future prospects for such species look the most bleak (Drinkwater 2005).

2. What could happen in the future?

Recent reviews provide strong circumstantial evidence to suggest that ocean climate will have far-reaching effects on the dynamics of fish populations. However, knowledge of the underlying mechanisms and likely future trajectories is rather limited (see Rijnsdorp *et al.* 2009). 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 events, precipitation patterns, pH and river run off. Second, fish have complex life cycles comprising several life history stages, differing in their sensitivity to climate effects (Graham and Harrod 2009). In June 2009 the UK Climate Impacts Programme (UKCIP) launched its UK Climate Projections (UKCP09), these provide some idea of what we might expect to happen in the marine waters around the UK in terms of physical parameters. Generally the shelf seas around the UK are projected to be 1.5–4ºC warmer by the end of the 21st century under a medium emissions scenario; areas that currently stratify on a seasonal basis, principally due to temperature, will not change their extent greatly but that stratification may last longer with earlier onset; it is thought possible that intensified seasonal stratification could lead to accumulation of organic matter in bottom layers causing oxygen depletion in some areas and that the frequency and size of extreme waves are generally expected to increase in the southwest of the UK, reduce to the north and experience little change in the North Sea.

Changes in fish distribution – expectations for future fisheries

Beyond an anticipated slow shift in fish distributions to more northerly and deeper waters (Perry *et al.* 2005; Dulvy *et al.*, 2008), information on the future prospects for fish communities as a result of climate change are somewhat limited, and often highly speculative. Modelling strategies for predicting the potential impacts of climate change on the natural distribution of species and consequently the response of fisheries have often focused on the characterization of a species' 'bioclimate envelope' (Pearson and Dawson 2003). In other words, by looking at the current range of temperatures tolerated by a species, it is possible to predict future distribution, if we know how the physical environment in an area will likely change in the future. This approach is being applied to fish communities by a number of research groups across Europe (especially under the EU 'RECLAIM' project). In addition a world-wide analysis has been carried out (Cheung *et al.* 2009a) using this technique, based on 1066 commercial fish and invertebrate species. This study suggested that climate change may lead to numerous local extinction events by the year 2050, especially in sub-polar regions, the tropics and semi-enclosed seas, with pelagic species (such as herring and anchovy) moving pole-ward by up to 600km and demersal species (such as cod and haddock) by an average of 223km.

The analysis of Cheung *et al.* included many species that exist in UK waters (including herring, cod, mackerel, sole, plaice, sprat, whiting and haddock) as well as species that are known to have increased around the British Isles in recent years (including John Dory, red mullet, anchovy and seabass).Building on this work Cheung *et al.* (2009b) attempted to predict changes in catch potential of exploited marine fish and invertebrates under various climate change scenarios. The study suggests that climate change may lead to large-scale redistribution of global catch potential, with an average 30–70% increase in yield of high-latitude regions, but a drop of up to 40% in the tropics. Around the UK it is suggested that fisheries will benefit from an increase in catch potential by around 1-2% (although not as much as in other northern European countries such as Norway), however there will be localised areas where overall fishery yields may be reduced (e.g. the Irish Sea and Channel). It should be noted that the very modest increases in yield predicted for the British Isles are largely indistinguishable from the noise in the data, and that there is currently no firm basis for predicting that yields around the British Isles will change either positively or negatively over the next 40 years due to climate (see below).

Scientists from IFREMER (the French marine and fisheries Agency) have used a delta GAM/GLM approach to model future plaice and red mullet distribution in the eastern English Channel and southern North Sea (see Vaz and Loots 2009). Abundance of each species was related to depth, seabed sediment type, bottom salinity and temperature, bottom shear stress, primary production and zooplankton biomass using outputs obtained from the hydrodynamic and ecosystem model ECOSMO. Results suggest that climate change may strongly impact the future distribution of plaice. For large plaice (>18cm), distribution will still be centered in the southern part of the North Sea, however for young individuals, the predicted distribution is anticipated to shift north-westwards and to the Dogger Bank area in particular. Small plaice (<18cm) are currently confined to the southern North Sea along the Dutch coast, a region that may become inhospitable in the near future. Red mullet abundance was again divided into small (<17.3cm) and large (>17.3cm) individuals, these were then modelled using a delta GLM approach. A small part of the red mullet population is known to overwinter in the North Sea along the Scottish and English coasts. Model outputs indicate that that the distribution of the red mullet will not change dramatically but that for small/young individuals, the offshore habitat situated on the Dogger Bank may become more favorable. Older individuals seem little impacted by the change in environment, but they may benefit from higher juvenile survival and expand their area of occupation as a result.

Biswas *et al.* (2009) provided estimates of total fisheries catches in the future, for large-scale oceanic regions (including the northeast Atlantic), using an analysis of how past catches have co-varied with trends in sea surface temperature (employing a statistical ‘moments’ based approach). The authors used outputs from a global climate model to predict water temperatures up to the year 2100 and suggested that for the NE Atlantic overall, fishery yields will decrease throughout the next century, whereas those in the NW Atlantic will increase.

Cod moves in mysterious ways – expectations for future fisheries

In terms of research into the future implications of climate change for commercial fisheries, probably the greatest amount of published work has focussed on cod and the fisheries that are dependent on this species. Drinkwater (2005) reviewed the possible impact of future climate change on cod and used temperature-recruitment relationships from 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, occupying 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 is the case, and it is likely that spring migrations will occur earlier and autumn returns will be later. However, the Celtic Sea and Irish Sea have warmed by large amounts since 1985, but for much of this period the Celtic Sea cod stock was the only one in the North Atlantic to increase in abundance. This may be because the Celtic Sea is essentially oceanic in character with little variation in bottom temperature between winter and summer. Prediction about the imminent demise of the Celtic Sea stock (at least due to climate change) should therefore be viewed with caution.

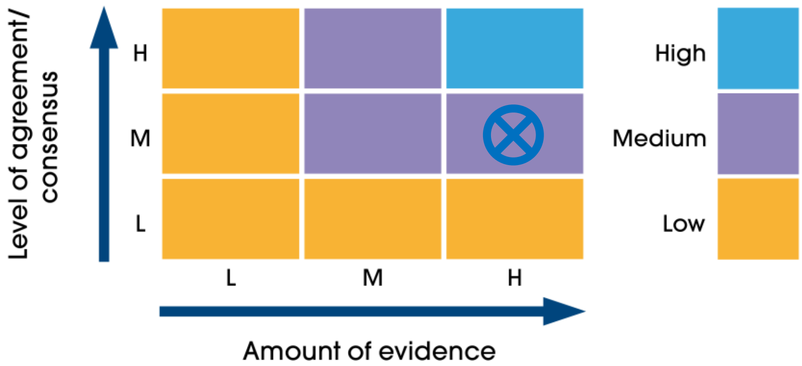
Clarke et al (2003) used projections of future North Sea surface temperatures and estimated the likely impact of climate change on the reproductive capacity of the cod stock, assuming that the high level of mortality inflicted by the fishing industry (in 2003) continued into the future. Output from the model suggested that the cod population would 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 faster rates of decline in the cod population. In the analyses of Clarke 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 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). The overall message from this study was that in the short term, climate change has little effect on stock recovery, which depends instead upon reducing fishing effort to allow existing year classes to survive to maturity. In the longer term, climate change may have a greater effects on stock status, but higher yields and biomass might equally be expected (perhaps more so) if fishing mortality is further reduced.

Cook and Heath (2005) examined the relationship between sea surface temperature and recruitment in a number of North Sea fish (cod, haddock, whiting, saithe, plaice, sole). These authors concluded that if the recent warming period were to continue, as suggested by climate models, stocks which express a negative relationship with temperature (including cod) might be expected to support much smaller fisheries in the future. In the case of cod, climate change has been estimated to have been eroding the maximum sustainable yield at a rate of 32,000 t per decade since 1980. Calculations show that the North Sea cod stock, could still support a sustainable fishery under a warmer climate but only at very much lower levels of fishing mortality, and that current 'precautionary reference' limits or targets (e.g. F_{MSY} – fishing mortality calculated for Maximum Sustainable Yield), calculated by ICES on the basis of historic time-series, may be unrealistically optimistic in the future.

Additional (although admittedly very preliminary) research has focussed on the potential impact of climate change on fishermen's livelihoods, adaptation costs, management and governance, economic impact on national and regional economies, and these studies are reviewed in the section on 'socio-economic impacts' (below).

3. Confidence in the science

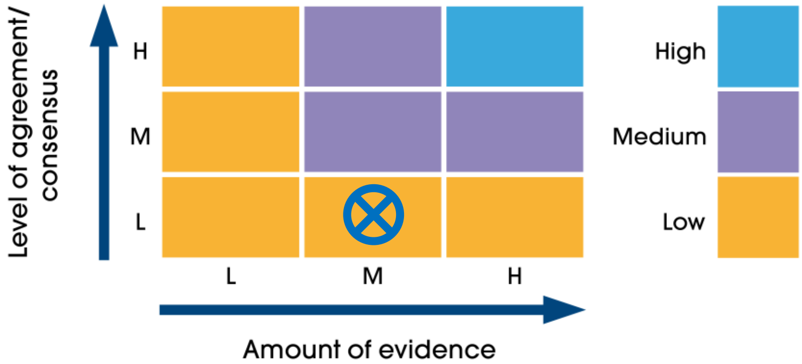
What is already happening: ***Medium***



In general there is probably more information available about fish and changes in the fishing industry than any other maritime sector or commodity. However there has been a surprising lack of studies which have attempted to communicate how changes in fish production or distribution might manifest themselves as impacts upon commercial fishing yields, profits or implications for society generally. Despite the large amount of data available, there is little consensus regarding whether or not climate change is having an impact on fisheries. Indeed recent crises in the European fishing industry have attracted considerable public interest and prompted a number of independent enquiries into the causes of the problems (Anon., 2004; RSE, 2004). While these enquiries have concluded that fishing is the main factor causing the decline of whitefish stocks such as cod and plaice, there remains a popular perception that environmental factors, such as climate change, are the main cause (see *Fishing News*, March 12th 2004; and Schiermeier, 2004).

Scientists currently disagree on the causes of an apparent northwards shift in fish distribution in the North Sea, and there are many competing but not mutually exclusive hypotheses to explain this phenomenon (see Rijnsdorp *et al.* 2009). However the most frequently voiced are: (1) warming causes species to expand northward, (2) fishing pressure has been consistently higher in the south compared to northern North Sea, causing higher mortality in the south and hence, an apparent overall distribution shift. It is possible that climate change is already having an effect, but this may be acting in combination with other important drivers, e.g. intensive fishing pressure and habitat degradation. Further work is needed to try to disentangle the various effects.

What could happen: ***Low***



With regard to understanding what might happen in the future, there are even fewer studies available (particularly at the UK level) and consequently there is even less consensus among researchers and policy makers concerning necessary adaptation strategies and policies. Again, there have been several studies which have attempted to predict future fish distribution, fishery yield or spawning stock biomass of particular species, but this has rarely (if ever) been translated into consequences for fisheries and/or society. The knowledge-base is particularly uncertain with regard to the possible future implications of ocean acidification. It should be noted that there are now more studies than were available at the time of the 2007/8 MCCIP assessment (see Brander 2009), however the vast majority of these are review and/or 'scoping' studies, with very little quantitative assessment or predictive modelling. Consequently **the level of confidence has not changed** from that stated in the 2007-2008 Annual Report Card.

4. Knowledge gaps

The top priority knowledge gaps that need to be addressed in the short term to provide better advice to be given to policy makers are:

1. An assessment of the social and economic implications of climate change on fishing fleets and dependent economies in the UK. So far there have been very few studies (if any) which have quantified implications specifically for the UK fisheries sector, even though this task is becoming increasingly urgent. The fishing industry itself has repeatedly questioned scientists about the challenges they are likely to face in the future, and in addition, the UK Climate Change Act (which became law on 26 November 2008) requires that a national adaptation programme be put in place and reviewed every five years which includes a thorough assessment to identify the most pressing climate change risks.
2. Improved understanding of the possible implications and level of threat posed by ocean acidification, particularly with reference to the UK shellfish industry.
3. Better wind and storm projections for the future, and improved understanding of how any changes in these variables might impact maritime safety, and/or access to fishery resources.

Hypoxia (low oxygen) is starting to become an issue of major concern for waters around the UK (Weston *et al.* 2008). However, little is understood with regard to the possible impact of low oxygen zones on fish and fisheries. In the central North Sea an area known as the ‘Oyster Grounds’ (part of the Dogger Bank) has witnessed decreasing oxygen levels in recent years (see Weston *et al.* 2008) and hypoxia has also been reported for coastal waters around the German Bight. Continued monitoring of this ecologically important region is essential if the causes and consequences of these potentially damaging low oxygen levels are to be fully understood. Low oxygen is predicted to occur more regularly in the future as a result of climate change. Waters will be warmer by 2–3ºC and therefore contain less dissolved oxygen by 0.4 mg l-1; the period of stratification will last for longer, and summer storms that normally dissipate areas of hypoxia will likely decrease in the future. In the Kattegat, the Baltic Sea, and the Gulf of St. Lawrence, cod completely avoid low oxygen waters (Chabot and Claireaux 2008). Furthermore, in the Baltic Sea cod eggs do not survive low oxygen conditions, and years with extensive hypoxia have been related to very poor stock recruitment for this species (Köster *et al.*, 2001).

5. Socio-economic impacts

So far, a surprisingly small amount of research has been directed towards understanding the future implications of climate change for fishing fleets, fishermen, coastal economies and society and this is certainly the case within the United Kingdom. There are a number of studies that investigate the vulnerability and adaptive capacity of the fisheries sector and dependent communities to climate change at a global scale (Allison *et al.* 2009; McClanahan *et al.* 2008). However, until recently there has been little directed analysis at the local scale of how climate variability and change is affecting the lives and livelihoods of those involved in the UK fishing and fish processing sectors.

A recent review paper by Badjeck *et al.* (2010) attempted identify the main pathways through which climate variability and change are impacting, or are likely to impact upon fishing-dependent communities in the future. The authors of this study point out that most research so far has looked at climate-driven changes in ocean productivity and its impact on fish distribution and have not considered indirect effects, such as the fact that extreme weather events may disrupt fishing operations and/or land-based infrastructure. Storms and severe weather events (which are anticipated to become more commonplace around the UK) can destroy landing sites, boats and fishing gear (Westlund *et al.* 2007). For instance, during Hurricane Gilbert in 1988, Jamaican fisherfolk lost 90% of their fish traps resulting in a huge loss of revenue and high cost of repairs, as well as resulting in the inability to resume fishing activities promptly after the disturbance (Aiken *et al.* 1992). Additionally, loss of revenues can be the result of closures or reduction of fisheries activities during weather anomalies, for example because of food safety concerns. In the UK, flash-floods are often accompanied by the release of untreated sewage from ‘combined sewer overflows’ (CSOs), and this can have serious consequences for shellfisheries or aquaculture facilities further downstream. Shellfisheries are monitored (for example by Cefas and Marine Scotland) to determine whether or not there are any signs of serious algal toxins, pathogenic bacteria or contaminants, and they are closed immediately if statutory levels have been exceeded. Peperzak (2003) attempted to evaluate whether harmful algal blooms are likely to occur more or less often over the next 100 years in the North Sea as a result of climate change, and concluded that we should expect more blooms, and hence fishery closures, largely as a consequence of an increase in extreme precipitation events (intense rainfall).

Fisheries managers and fisherfolk have historically had to adapt to the vagaries of weather and climate. Uncertainty is inherent in fisheries management, so there is an expectation of change and a stock of knowledge and experience of coping with it and adapting to it (Miller et al 1992). Badjeck *et al.* (2010) have argued that diversification is a primary means by which individuals can reduce risk and cope with future uncertainty. There is some evidence that the inability of fishing households to adapt to environmental change is not only linked to the level of poverty (or ability to raise capital), but also to the "specialization trap" where fisherfolk overly rely on one species or activity.

In the UK, fisheries contribute less than 0.05% to national GDP, however there are some regions where fisheries provide the mainstay of employment and are vitally important to the local economy. While fishermen account for a small percentage of the national workforce (0.2% in Scotland and 0.1% in England and Wales), national fishery statistics suggest that dependency is as high as 24% in the Western Isles, and 20% in Fraserburgh (NE Scotland), Brixham and Newlyn (SW England). Around 20% of UK fishermen are located in the south west of England and 13% in Aberdeenshire (see Anon. 2004), consequently, declines (or increases) in revenue as a result of climate change would be anticipated to affect these areas disproportionably more than any others. The fishing industry is also a significant component of Scotland's rural economy, for example in the North East and West Highland, Orkney and Shetland the value of landings accounts for approximately 6% of the area's GDP.

Arnason (2007) attempted to estimate the economic impact of climate change on fisheries and on the national economies of Iceland and Greenland. The author assumed that fisheries yields would increase by around 20% for the most important fish stocks (in particular cod and Atlanto-Scandian herring) in Iceland and up to 200% in Greenland over the next 50 years (based on projections from ACIA 2005). The analysis then used econometric techniques based on economic growth theory to estimate the role of the future fisheries sector in the wider economy of each country. Somewhat surprisingly the dramatic increase in fisheries yields assumed for Iceland resulted in only miniscule increases in national GDP, despite the fishing industry currently accounting around 10% of GDP and 40% of export earnings. The accumulative impact of climatic warming on Icelandic GDP was only 4% by 2054, and given economic volatility and measurement errors, this level of economic growth is considered hardly detectable at the 95% significance level. Benefits for the national economy of Greenland were greater (a 40% increase in GDP by 2054) but this assumed an enormous increase the fish stock (by 200%) and it should be remembered that the fishing industry in Greenland is the main source of non-government employment and local economic activity (over 90% of all exports). In the UK a slight increase in fisheries yield is also anticipated in the future, by around 1-2% (see Cheung *et al.* 2009b). Such change might be insignificant when uncertainties of the prediction are considered. Also, given the very small contribution that fisheries make towards national GDP it seems highly unlikely (based on the work of Arnason 2007) that such changes in fisheries profitability will have significant consequences for the national economy, although there could be minor benefits for highly dependent regions such as the Highlands and Islands.

The ACACIA report written by Des Clers (University College, London) and Brander (ICES) in 2000 provided the European impact assessment for the IPCC Third Assessment (2001) and includes a short chapter on Fisheries. Some of the economic and social implications of climate change for fisheries are set out in chapter 9 of the ACACIA report (ACACIA, 2000) from which Table 1, showing supply side and demand side adaptations of fisheries to climate change impacts, is taken. Many of the same adaptation options were also recently highlighted by McIlgorm *et al.* (2010) who reviewed how fishery governance may need to change in the light of future climate change.

In December 2009, Sumaila and Cheung (writing in a report for the World Bank) attempted to establish the costs of adaptation to climate change in the fisheries sector worldwide. The analysis began by detailing the likely impact of climate change on the productivity of marine fisheries (more than 1,000 species) and, through that, on landed catch values and household incomes. Adaptation costs were then estimated, based on the costs of restoring these revenue indicators to levels that would have prevailed in the absence of climate change. The impact of climate change on marine fisheries was assumed to primarily occur through changes in primary productivity, shifts in species distribution and through acidification of the oceans. The authors considered three scenarios that reflect these impacts. Climate change was predicted to lead to losses in gross fisheries revenues world-wide of $10–31 billion by 2050.

Governments have implemented various measures to manage fisheries, both to conserve fish stocks and to help communities that depend on fishery resources adapt to changes caused by overfishing and other factors. Measures include buybacks, transferable quotas, and investments in alternative sources of employment and income. Adaptation to climate change is likely to involve an extension of such policies, with a focus on providing alternative sources of income in fishing communities to lessen the dependence on fishery resources. In Europe (including the UK) the estimated annual cost of adaptation was between 0.03 and 0.15 $ billion. As compared to 1.05 - 1.70 $ billion of anticipated annual adaptation costs in East Asia and Pacific.

Impact	**Supply side**	**Demand side**
Fish distribution changes	• Revise fishing rights allocation • Allocate species combinations (MSC) and access at ecosystem level • Economic incentives to switch target species or use other gear	• Changes in consumer preferences driven by eco-labelling and certification (MSC accreditation) • Quality labelling (the last wild food…)
Decreased productivity	• Improve product quality and life • Reduce production inefficiencies and waste • Introduce ecosystem/portfolio management • Switch to new species • Increase imports	• Taxes on ecological costs of fish • Advertise unique nutritional value of fish, Inform customers

Table 1. *Adaptations of fisheries to climate change (from chapter 9 of ACACIA, 2000)*

Allison *et al.* (2009) provided an assessment of the 'vulnerability' of 132 national economies to potential climate change impacts on their capture fisheries using an indicator-based approach. Vulnerability to climate change depends upon three key elements: exposure (E) to physical effects of climate change, the degree of intrinsic sensitivity of the natural resource system or dependence of the national economy upon social and economic returns from that sector (S), and the extent to which adaptive capacity (AC) enables these potential impacts to be offset. In a further development of this work, Cefas scientists (as part of the recently completed NERC 'Quest-GSI' project) used a number of different Global Climate Models (GCMs) that provided outputs of sea surface temperature and improved formulation of fisheries catches. In terms of vulnerability, the authors ranked the UK as 215th out of 225, with good adaptive capacity and a relatively small anticipated impact. The Channel Islands were ranked 208 and the Isle of Man was ranked 218th.

To date it would seem that there have been few studies which have specifically looked at the socio-economics of the UK fishing fleet in relation to climate change. However a number of ongoing studies may provide useful insight in the near future, notably the NERC-funded 'Quest-Fish' project which aims to elucidate how climate change will affect global fish production and which may provide projections for industrial fisheries (e.g. those for sandeels) around the UK, as well as the Scottish aquaculture industry (which is reliant on international supplies of fish-meal). In addition, the Defra-funded ACME ('Adapting to Climate Change in the Marine Environment') project will build on the work of Cheung *et al.* (2009a,b) to predict the future re-distribution of fish stocks around the UK and how the UK fishing fleet will respond to these changes using a variety of different modelling approaches, including the 'Random Utility Model' developed by Hutton *et al.* (2004). Finally, the NERC-Defra joint call for research proposals on ocean acidification (published in July 2009) asked for submissions focussed on "Improved understanding of the potential population, community and ecosystem impacts for all life stages of commercially important species". This work is urgently needed to allay fears and to provide better information to the UK shellfish industry in particular.

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