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Climate Change and Fisheries

Fishing is dependent on marine food webs that are sensitive to stressors such as climate change and overfishing. This POSTnote focuses on marine fisheries, including wild capture and farming (aquaculture) of fin- and shellfish, and their processing. It summarises the impacts on oceans and fisheries of ocean warming, acidification, deoxygenation and storms, and explores how fisheries may adapt.

Overview

- Climate change drives modifications in marine ecosystems that affect fisheries' productivity and food security.
- The marine environment is experiencing increasing temperatures, acidification and deoxygenation.
- These changes are altering the distribution, abundance and health of commercial fish species, and the marine ecosystems on which they depend.
- Climate change and other stressors interact to affect ecosystems and fisheries.
- Fisheries' ability to adapt to climate change is hampered by a lack of targeted vulnerability assessments and uncertainty in the impacts on commercial fisheries.
- Improving fisheries' management and preventing overfishing will help maintain their long-term productivity.

Background

Fisheries depend on healthy, productive marine ecosystems (the biological communities of organisms, the environment, and their interactions). These marine ecosystems are exploited by marine fishing and aquaculture to provide approximately 11% of global average animal protein intake, but are vulnerable to climate change.[1,2]

Global population growth and increasing per capita consumption means that demand for fish products is expected to rise over coming decades.[1,3–5] However, growth in UK and global fish catches has stalled, with some regions experiencing declines of up to 35% between 1930–2010, primarily driven by overfishing.[1,6] Aquaculture has grown over recent years, with global fish production from this sector outstripping marine catches since 2016.[4,7] However, wild-capture and aquaculture are also vulnerable to climate change.[1] The extent to which increasing demand can be met will depend on the management of the entire industry, its environmental impact, and its ability to adapt to climate change, including ocean warming, acidification, deoxygenation and storms.[4,8]

Climate change directly affects the distribution, abundance and health of wild fish stocks, and the viability of aquaculture processes and stocks.[9] It also indirectly affects the survival and growth of fish by impacting on their prey (Box 1). Climate change compounds other pressures arising from human activities, such as overfishing, further affecting fisheries' environmental and economic sustainability.[1,6]

UK fisheries and the global market

The UK marine fishing industry (which includes wild capture, aquaculture and processing) is diverse (Box 2). In 2017, it added an estimated £1.53 billion to the UK economy and provided employment to 23,000 people in Great Britain.[10,11] Fisheries' economic contribution is unevenly distributed between sectors and around the UK (Box 2). It is mainly concentrated in a few large ports, though small inshore fisheries also support local livelihoods and culture.[11,12]

The value of UK catches in 2017 was £980.1 million.[13] However, UK fish consumption largely depends on imports, is mainly driven by demand for five key fish species (cod, haddock, tuna, salmon and prawns), and generated a £1.35 billion trade deficit in 2017.[13] Successful export markets exist for wild-caught species such as *Nephrops* (scampi/ langoustine), scallops and mackerel; as well as salmon from aquaculture.[13] Most fish species targeted by the UK industry in the Northeast Atlantic are managed in area-based stocks for Maximum Sustainable Yield (PN 572). This is the maximum level at which a stock can be exploited without

Box 1: The marine food web and climate change
Phytoplankton are microscopic organisms at the base of the marine food web. These primary producers capture energy from sunlight and are eaten by small marine animals, including young fin- and shellfish (zooplankton). The food web extends to predators of these organisms, including larger fish, seabirds, marine mammals and humans. Changes in food availability can affect survival and productivity of an organism, especially early in life.[14] Increased sea temperature has contributed to declines in North Sea phytoplankton productivity, partly by reducing mixing of surface and bottom water layers, which stops nutrients in bottom waters reaching phytoplankton at the surface, restricting their growth and productivity.[15,16] This is linked to declines in zooplankton and the fish species that predate on them, including cod, herring, haddock and sand eel, constraining fish availability.[16,17]

Increasing temperature also alters food availability for fish by changing prey distribution and abundance.[18] Changes to zooplankton in the Northeast Atlantic caused a decline in food quantity and quality for some fish, including cod.[18–20] However, the impacts on fisheries of zooplankton responses to factors other than temperature are unclear. Temperature is a cue for life cycle timing of many species; if temperature change affects the timing of interacting species differently, then this can create a detrimental mismatch that affects survival.[21] Fish metabolic rates increase with temperature, but their growth will be restricted by food limitation if productivity lower in the food web is altered or does not also increase with temperature.[22] Acidification also affects plankton physiology but projections based on a small number of species suggest that its impacts on phytoplankton may have negligible subsequent impacts on fish catches to 2100.[23]

long-term depletion. Stock yield is influenced by a species' biology, as well as by fishing pressure and environmental drivers.[24] Ongoing research aims to address the complexity and uncertainty in environmental drivers.[25]

Marine climate change

Emissions scenarios describe a range of realistic future greenhouse gas emissions, and allow simulation modelling of the resulting changes in the marine environment.[26] These have projected changes in sea temperature, acidity and oxygen content, as well as storm conditions and sea levels.

Temperature

Sea temperatures vary regionally but have risen over time and are projected to continue to increase, largely due to greenhouse gas emissions.[26,27] For example:

- Average sea surface temperatures in UK waters have increased by 0.8°C since 1870.[28]
- By 2100, sea surface temperature in the North Sea is projected to rise by 2.3–3.7°C, a larger projected increase than the global average of 0.6–2.0°C.[26,29]
- Marine heat-waves – extended periods in which sea water temperatures exceed a seasonal threshold – have become longer and more intense.[27,30] They are projected to increase, including in the large marine ecosystems that collectively produce 95% of the world's fish yields.[27,31]

Warming also affects both the layering (stratification) and circulation of sea water on a local to global scale.[15,32,33]

Stratification and circulation

Surface warming leads to density differences between surface and bottom water layers, increasing the stratification of sea water (reducing mixing of, for example, nutrients and oxygen between layers), which can be detrimental to organisms such as phytoplankton and fish (Box 1).[15] By

Box 2: UK fisheries
The main species in UK aquaculture are Atlantic salmon, blue mussels and Pacific oysters.[34,35] Marine capture fisheries target diverse species that can be grouped into three key categories:

- **Pelagic fish**, including herring and mackerel, are typically highly mobile and live in the water column. Large vessels of the UK fleet mainly target these species in the northern North Sea, west of Scotland, and the English Channel. Pelagic fish accounted for over 54% of the landed UK catch by weight, but only 26% by value.[13]
- **Demersal fish**, including cod, haddock and monkfish, live on or near the seabed. The UK fleet mainly targets these fish in the North Sea, west of Scotland, and in the western English Channel.[13]
- **Shellfish**, including *Nephrops*, scallops, crabs and lobsters are mainly caught in inshore waters around the UK. Shellfish are the most valuable UK wild-capture sector overall and per tonne.[13]

2100, climate change is also projected to reduce sea water circulation in the North Sea, causing it to become less saline and more vulnerable to eutrophication (excessive nutrient input), pollution and reduced oxygen content.[32]

Ocean acidification

Ocean acidification occurs as some of the excess carbon dioxide (CO_2) in the atmosphere dissolves in sea water, lowering the pH.[36] This is intensified in colder waters, in which CO_2 is more soluble – such as the Arctic Ocean.[37] Globally, acidification has increased since 1750.[38] Based on a medium emissions scenario, the change in global pH by 2100 is expected to be similar to changes that are thought to have caused widespread extinctions of marine animals 56 million years ago.[36] Locally, acidification has been occurring faster in UK seas than in the wider North Atlantic.[38] Local pH variability is driven by factors such as circulation and freshwater input, and is more pronounced in coastal areas.[36]

Reduced oxygen

Low oxygen conditions can be exacerbated by:

- Increased temperatures, because warmer waters hold less oxygen, and are more prone to excess phytoplankton growth and algal blooms.[39,40] As this growth decomposes, bacteria deplete the local oxygen in bottom waters.[41]
- Eutrophication, contributing to algal blooms, especially in coastal areas.[42] This may increase with climate change in some areas, and interacts with stratification.[32,41,43]
- Stratification, preventing mixing of low-oxygen bottom water with higher-oxygen surface water.[41] This is projected to increase, especially in northern latitudes.[40,41]
- Consumption of oxygen in stratified bottom waters by bottom-dwelling organisms.[44]

Climate change and eutrophication have contributed to oxygen deficiency in areas of the North Sea over the last five decades.[45,46] North Sea oxygen levels are expected to decline further over the next century, at rates faster than in other areas, such as the Atlantic and Pacific Oceans.[45,47–49]

Storminess and sea level

Attributing single storms events to climate change is difficult, and storminess projections are uncertain.[50] Individual projections suggest a strengthening in the most severe UK winter storms, but there are substantial differences between models, with low confidence overall in predicting the future behaviour of the North Atlantic storm track.[50,51] UK mean sea levels are projected to rise this century (PN 555).[51] For example, by 2100 sea levels near Edinburgh and London are expected to rise by 0.08–0.90 m and 0.29–1.15 m respectively, depending on the emissions scenario.[51] Future increases in extreme sea level should be expected due to rising mean sea level, and more extreme storm surges and waves may arise from natural variability.[52,53]

Impacts of climate change on fisheries

Warming, acidification and low oxygen can directly affect fish and the fisheries that depend on them, while storms and sea level rise may affect fishing activity and fish processing more directly, as outlined below. There are uncertainties surrounding who, what and where will be impacted by climate change, and to what extent.[2] This is partly because of uncertainty in future greenhouse gas emissions, and the scale of resulting climate change relative to what species or fishers can tolerate or adapt to.[54,55] Climate change impacts will also vary between fish species and life stages.[56,57] The future vulnerabilities of industry sectors and operators are not well-studied.[9,58] Localised changes may be significant for aquaculture and inshore fisheries, which operate in vulnerable coastal areas and are less able to relocate.[45,59–61]

Impacts of warming

Warming is altering the abundance and distribution of fish both spatially and over time, with implications for stock exploitability and patterns of fishing effort.[9,28,62] Distribution shifts are observed as species track suitable warmer or cooler conditions.[9,28,63] For example, warm water species, such as sea bass and anchovy, are moving into areas around the UK that were previously too cold for them or their prey.[9,64,65]Globally, and in UK seas, many cold water fish, such as cod, anglerfish and plaice, have tended to shift deeper and to higher latitudes to stay in cooler waters.[28,66,67] This response could compromise feeding by taking them away from shallower feeding areas.[68] Feeding may also be affected by climate change-induced changes in prey (Box 1). For example, a combination of rising temperatures and altered prey availability are thought to have caused the expansion of mackerel into Icelandic waters, leading to lengthy and ongoing international conflict over fish stocks.[9]

In wild fish, low mobility or factors such as habitat depth and oxygen availability may stop fish tracking thermally suitable waters.[69] This can cause declines in populations unable to shift from warming seas.[28,69] For example, between 1980–2002, some cold water demersal fish (such as cod) declined in warming European waters, but warm water fish (such as sole) became more abundant.[70] These barriers to movement are less likely to affect pelagic fish, which are highly mobile and less dependent on seabed habitat.[71]

Aquaculture pens stop fish tracking thermally suitable waters, and fish maintained at sub-optimal temperatures experience poor growth and reproduction, causing lower yields.[35] As a result, warming may make some sites unsuitable for the typical UK aquaculture species.[2]

Long-term exposure to warmer waters tends to cause faster maturation and smaller maximum body size in fish.[22,63,72] Temperature-driven reductions in body size were observed in some North Sea stocks between 1970–2008.[73] This caused an average 23% decline in potential yield across stocks including whiting, haddock and some herring.[73] Around the UK, warming can increase the abundance of some shellfish species, including scallops, and improve the development and catches of *Nephrops*.[74–77] Native species may experience competition or disease if invasive species, parasites and pathogens increase with warming.[28]

Little is known about the social and economic impacts on fishing communities.[9] Fishers may incur additional fuel or opportunity costs in tracking changing fish distributions, or may target alternative stocks within their vessel operating range.[62] Some fishers, particularly on inshore boats in the under 10m fleet, may be excluded from the fishery if stocks move outside their operating range and switching stocks is precluded by gear investments or quota allocations.[78]

Impacts of marine heat-waves

Heat-waves can drive distribution shifts and abundance change in fish and shellfish.[79–82] After a 2011 heat-wave, one Australian shellfishery experienced almost 100% mortality, with low growth, abundance and yield in others.[55] Heat-waves have also caused fishery closures, quota changes and shellfish disease outbreaks.[55,83,84]

Impacts of ocean acidification

Acidification can contribute to ecosystem degradation and affect an organism's physiology.[36,85] It can hinder the growth of shells and skeletons; this may affect some organisms (such as molluscs) more than others (such as finfish).[86] UK fisheries are vulnerable to acidification because of the high proportion of shellfish caught and because most of the fin- and shellfish catch occurs within UK waters. These are expected to experience increasing acidification, especially around the coast.[87,88] Aquaculture and inshore fisheries concentrated in coastal waters may be worst hit.[36] Recent assessments suggest high annual economic losses for UK shellfish production by 2100, with variation among regions based on catch composition.[23,87,89]

Impacts of deoxygenation

Sensitivity to low oxygen varies between species and life stages, and may depend on other stressors.[49] Acute exposure to very low oxygen can be detrimental to fish behaviour, growth and survival, but there are few long-term studies looking at the impacts of chronic low oxygen in wild species.[49] Impacts at local and regional scales are uncertain, partly because of the poor availability of detailed regional-scale oxygen projections.[40,45,49]

Impacts of storms and changing sea levels

Storms are a threat to life and can disrupt wild capture fisheries by forcing vessels to remain in port.[9,58] Storms can also reduce profits by affecting vessel and fishing gear performance, and by damaging aquaculture facilities.[9,35,58] For example, in 2005, over 800,000 fish escaped UK aquaculture during a single storm, threatening both wild populations and profits.[90,91] Excess nutrients, contaminants and pathogens associated with increased rainwater run-off are a concern for estuarine and coastal fisheries.[35] Storms and sea level rise may alter the quality and availability of coastal and estuarine habitat required for aquaculture, shellfish beds and fish nursery areas; they may also pose a flood risk to ports and fish processing infrastructure.[7,35,92]

Impacts of multiple stressors

Climate stressors are rarely experienced in isolation and may have interacting effects on marine organisms.[9,23,93–95] For example, some species only appear to be sensitive to acidification in the presence of thermal stress, low oxygen or food limitation, which act together to reduce growth and survival.[96–98] An assessment of observational, experimental and modelling research suggests that acidification and warming combined may cause 10–30% declines in UK fish and shellfish catches by 2020, relative to 1991–2000, with further declines by 2100 (based on current emissions).[23] These climate stressors can also interact with other factors that affect fisheries. For example:

- Overfishing and habitat loss have been identified as the biggest threats to marine ecosystems and the fisheries that depend on them.[60,99,100] This includes effects on non-target species, including seabirds and other fish, which are not yet included in fisheries assessments.[101]
- Overfishing and habitat loss decrease stock resilience: the ability to withstand and recover from stressors, including climate change.[6,102–104]
- Annual catch limits have repeatedly been set at unsustainable levels above scientific advice for over 30% of UK and EU commercial fish stocks.[105] Globally, over 31% of fish stocks are overfished.[7,106]
- Overfishing and climate change are also development issues; many developing countries rely on fisheries for nutrition and jobs but are at high risk of climate change.[60]
- Food security in these countries often relies on low-cost 'forage fish', which are also caught for international use in aquaculture feed.[107] This represents a conflict between use for direct and indirect human consumption.[107,108]
- Climate impacts on these forage fish, and other global fisheries, may challenge global trade in fish commodities, including fishmeal for aquaculture feed.[107,108]

Adapting to climate change

Improving fisheries management and preventing overfishing can build ecosystem and stock resilience to external stressors. This may help to offset negative climate change impacts, conserving marine ecosystems while increasing long-term yields, profits and benefits.[6,45,109–112] Ecosystem-based management (EBM) approaches account for more than just the target species and are more sustainable than managing stocks individually, but the complexities of EBM may necessitate long lead-times for implementation.[113,114]

EBM entails management across sectors and across regional and national borders. It can be supported by models to assess the projected impacts of climate change and proposed management actions.[82,113–118] Protected areas that are well-designed, evaluated and responsive to change may buffer against climate change and overfishing, and achieve fisheries goals within EBM (PN 437).[100,119–121] Box 3 details other industry-specific adaptation possibilities.

Barriers to adaptation

Adaptation is hampered by uncertainty in the commercial impacts of climate change and by a lack of targeted vulnerability analyses, which could identify specific risks to sectors and businesses.[2,58,61] Other challenges include:

- Existing policy.[78,82,122] For example, fisheries monitoring, regulation and access rights (e.g. quota) do not account for climate-induced changes in fish distribution or size.
- Poor communication and historic mistrust between industry, science and policy.[58]
- Cultural norms and gear investments cause fishers to target specific stocks or areas, hindering diversification.

Box 3: Potential adaptation approaches

Industry-focused approaches

- Enable industry to identify risks and adaptation options, which may be sector-, stock- or business-specific.[58,123,124] This requires improved communication and understanding of climate impacts.
- Follow the shifting stock distributions and fish in different areas.[58,78] However, if stocks decline, or shift beyond vessel operating ranges, managed exit from the fishery may prevent overfishing and improve sharing of remaining resources.[125]
- Target, and develop markets for, alternative or novel species.[78]
- New fisheries may emerge as species enter national waters, but overharvesting or conflict can occur if fisheries rapidly expand, as observed in unassessed seabass and shared mackerel stocks.[9]
- Gear and method innovations and information-sharing networks have been proposed to target new species and reduce bycatch, particularly in mixed stocks with changing composition.[126–129]
- Aquaculture may help to meet increased demand for fish; however, aquaculture food supplies rely on capture fisheries for fish oil.[60,130] Plant-based oils may be substituted but could alter fish nutrient content, and agriculture is also vulnerable to climate change (PN 600).[131,132]
- UK aquaculture may diversify into warm water species, such as seabass, or explore less vulnerable land-based systems.[35,132]
- New technology, including satellites, can assist placement of future aquaculture facilities in areas less vulnerable to climate change.[133]
- Resilient infrastructure and advanced early warning systems, alongside social adaptation, funding 'safety nets', and insurance, can mitigate some impacts of increased storminess.[2,134,135]

Fisheries' assessment and management

- Proactive assessment and management that accounts for climate change may prevent overfishing of shifting resources.[9,62] This will require international collaboration for the management of stocks that are shared with the EU and independent coastal states.
- Understanding and coordinating adaptation efforts across scales from fishers to government can prevent conflicting efforts; for example, changes to local fishing practices may mask changes in fishing conditions and so delay institutional spatial planning responses, or reduce the perceived need and incentive for transformational solutions.[136]
- Monitoring climate and fisheries at finer spatial and temporal scales can allow adaptive planning, especially within a collaborative network of industry, scientists and policy-makers.[60,78,137]
- Independent brokers can foster valuable co-management between the fishing industry, policymakers and scientists.[114,138–140]
- Adaptive harvest policies could account for and respond to climate-driven changes in stock productivity.[141] Failure to account for such changes led to collapse of the Gulf of Maine cod fishery.[80]
- Further research on multiple stressors and their implications for ecosystems and fisheries could inform future management.
- Seasonal and multi-annual climate and stock forecasts can help assessment and management but need further development.[142,143]
- Realign incentives to support sustainable fishing within EBM.[144,145]

Endnotes

POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of policy issues that have a basis in science and technology. POST is grateful to James Stewart for researching this briefing, to NERC for funding his parliamentary fellowship, and to all contributors and reviewers. For further information on this subject, please contact the co-author, Dr Jonathan Wentworth. Image Credit: US Fish and Wildlife Service, Carla Stanley

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