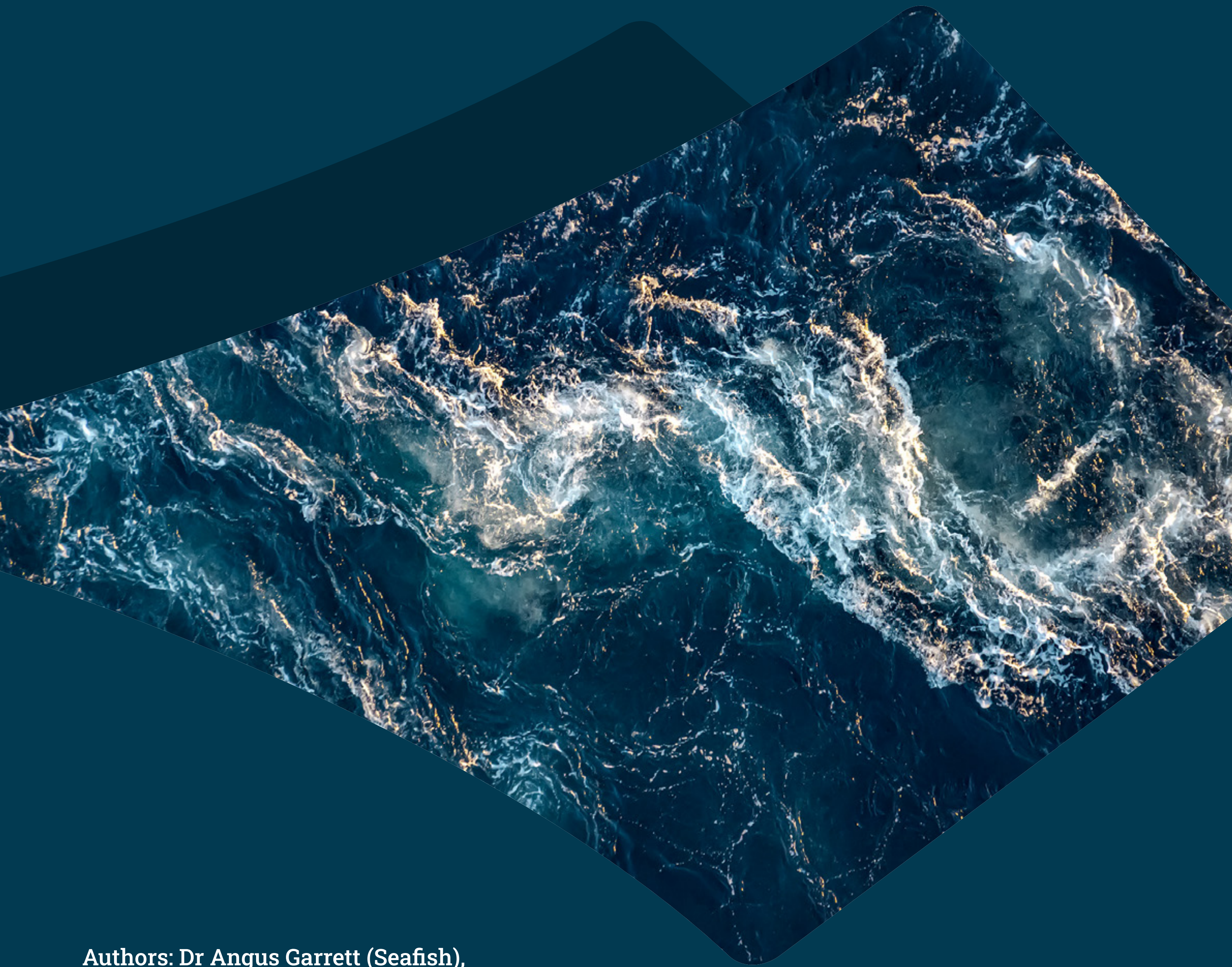
Climate change adaptation in the UK (wild capture) seafood industry 2020-21

A Seafish/MCCIP Watching brief report. Spring 2022.



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Contents

1

Introduction

Climate change is a strategic challenge across all UK sectors (including UK seafood). In late 2015, Seafish together with the Marine Climate Change Impacts Partnership (MCCIP) published a review of climate change adaptation for UK domestic and international (wild capture) seafood[1]. This contributed to the UK Government, 'Adaptation Reporting Powers' commitment on climate change, requiring that certain industries or organisations report to parliament every five years.

The Seafish review concluded, at that time, that climate change was an important challenge for UK seafood, but that industry considers it a 'low priority' relative to other risks. As such a watching brief is to be maintained on climate change developments and their impacts on UK industry. Specifically, seeking regular feedback from industry stakeholders on climate change, impacts and adaptation actions. The findings to be incorporated into Seafish annual horizon reporting.

This watching brief report considers recent advances in understanding and industry experience of climate change drivers and impacts across 2020 and 2021. Advances in understanding draws on new scientific evidence collated through the MCCIP initiative[2], experience of these drivers is captured through semi-structured interviews with 11 UK industry stakeholders. Findings are provided for domestic and international seafood, and, where appropriate, by major fish species grouping concerned. This report provides a 'light touch' overview and is indicative only.

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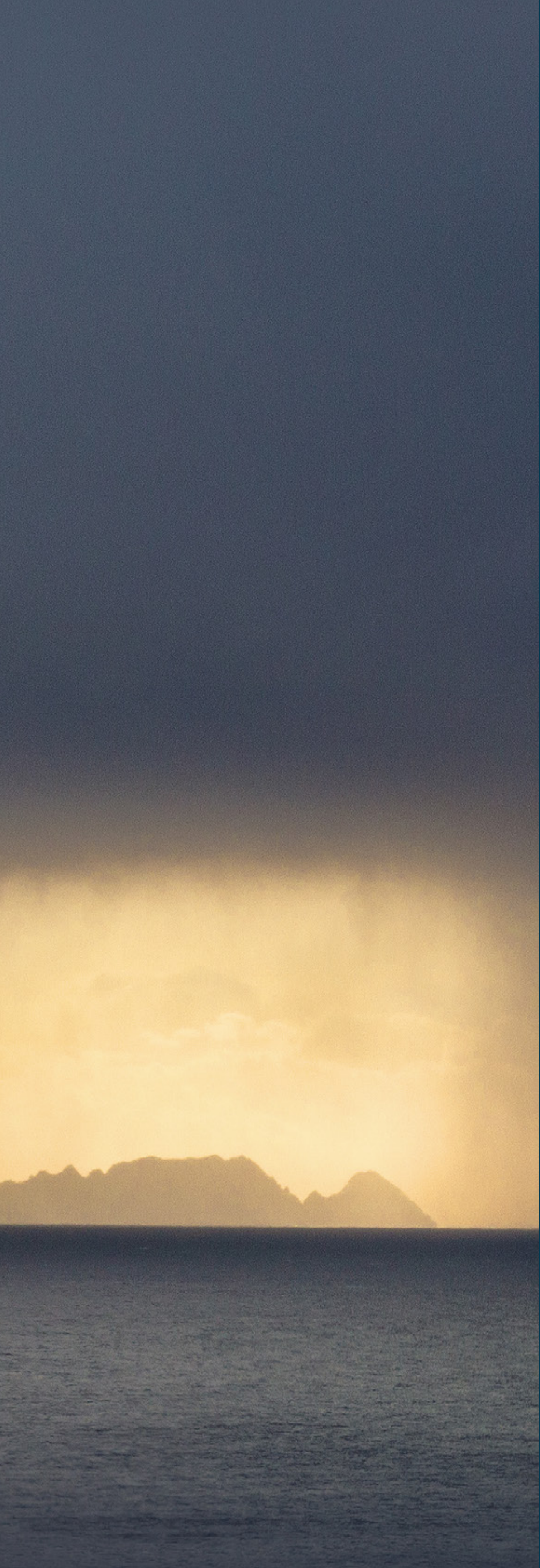
1 http://www.seafish.org/media/1476673/climate_change_report_-_lr.pdf

2 See MCCIP (2017). Marine Climate Change Impacts: 10 years' experience of science to policy reporting. (Eds. Frost M, Baxter J, Buckley P, Dye S and Stoker B) Summary Report, MCCIP, Lowestoft, 12pp.

2

Scientific evidence

Advances in understanding climate change drivers and impacts



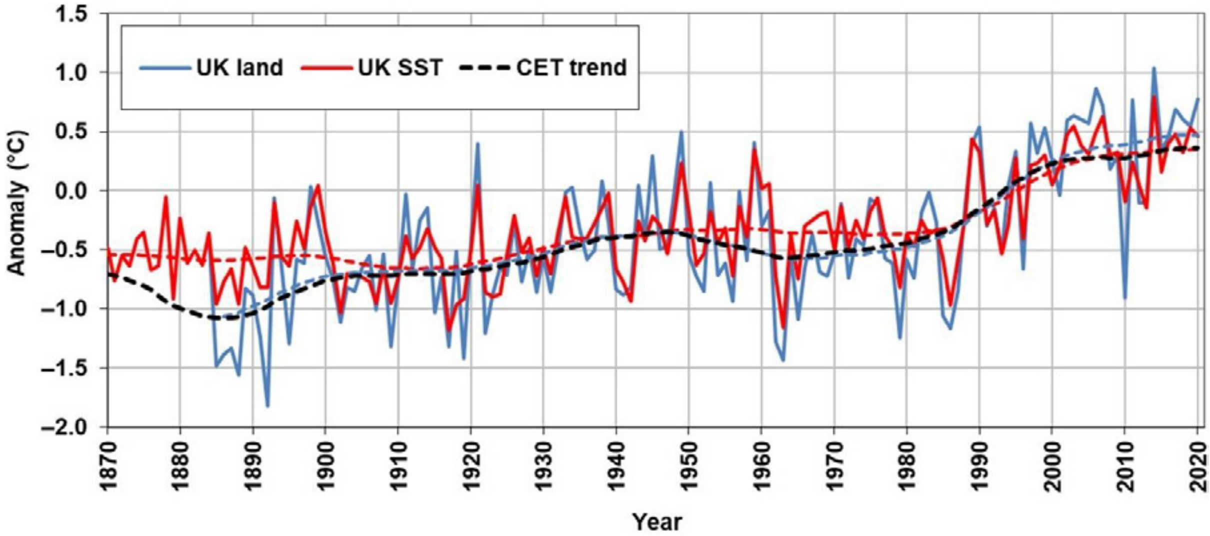
2.1 Physical climate change drivers (sea level rise, temperature, storms and waves, ocean acidification and de-oxygenation, changes in terrestrial rainfall).

General observations on UK climate[3]: According to Kendon et al. (2021) 2020 was the third warmest year for the UK since 1884, and the chances of extreme high temperatures in parts of the UK are increasing (Met Office). Winter 2019/20 was the 5th wettest on record (data back to 1862) for the UK whilst summer 2020 was warmer, wetter and duller than average. The period included five named storms: Ciara, Dennis, Jorge, Ellen and Francis (Kendon et al. 2021).

UK sea temperatures in 2020 (near-coastal sea-surface temperature) were the eighth warmest since 1870. Over the last 30 years, warming has been most pronounced in the north of Scotland and the southern North Sea, with sea-surface temperatures increasing by up to 0.24°C per decade. Note that shorter-term variations are superimposed on this longer-term trend. For example, a period of cooler sea-surface temperatures was observed from 2010 to 2013 whilst recent years have seen warmer conditions return (Kendon et al. 2021; Tinker and Howes, 2020). From the start of the 20th century, mean sea level around the UK has risen by an overall 16.5 cm (approximately 1.5 mm·year−1 on average) with the rate of sea level rise increasing recently (Kendon et al. 2021).

By contrast, 2021 was fairly 'average' for the UK, with temperature and sunshine levels fairly close to the long-term average and rainfall slightly below. Broadly speaking, colder than average conditions dominated through the early part of the year, but most months were warmer than average from June to December. The period included four named storms: Christoph in January, Darcy in early February, Evert in July, and Arwen in November. The latter, one of the most powerful and damaging storms of the latest decade, brought weather warning for wind along the north east coast. (Met Office: https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2021/2021-a-year-in-weather-a-review)

3 Met Office and 2020 State of the UK Climate Report



Area	1961–1990 average	1981–2010 average	2011–2020 average	2020
UK land	8.3	8.8	9.3	9.6
UK near-coast SST	11.1	11.5	11.8	11.9

Figure 1. UK annual mean temperature over land 1884–2020, Central England temperature trend and UK annual mean sea surface temperature across near-coastal waters around the UK 1870–2020 (°C), expressed as anomalies relative to the 1981–2010 long-term average. Hatched blue and red lines are the UK land and sea-surface temperature (SST) trends. The table provides average annual values (°C) (from Kendon et al. 2021).

General observations on North Atlantic climate: The North Atlantic Oscillation (NAO) is a large-scale atmospheric pressure gradient in the North Atlantic region (as measured by the difference in Portugal and Iceland). Changes in local weather patterns such as temperature, rainfall and wind strength/ direction (see above) are all strongly influenced by phasing of the NAO:

- A positive phase represents a stronger than usual difference in pressure between the two regions. Winds from the west dominate, bringing with them warm air, while the position of the jet stream enables stronger and more frequent storms to travel across the Atlantic.
- A negative phase represents the reverse with a weaker than usual difference in pressure. Winds from the east and north-east are more frequent, bringing with them cold air, while the adjusted position of the jet stream leads to weaker and less frequent storms.

The NAO index for December-February 2019-2020 was positive (+2.85) bringing a mild and wet winter for 2019-2020. The reported NAO for December-February 2020-2021 was slightly negative (-0.62) suggesting a colder period. The forecast for winter 2021-2022 again neutral or slightly negative (Met Office Winter Weather Outlook 2021).

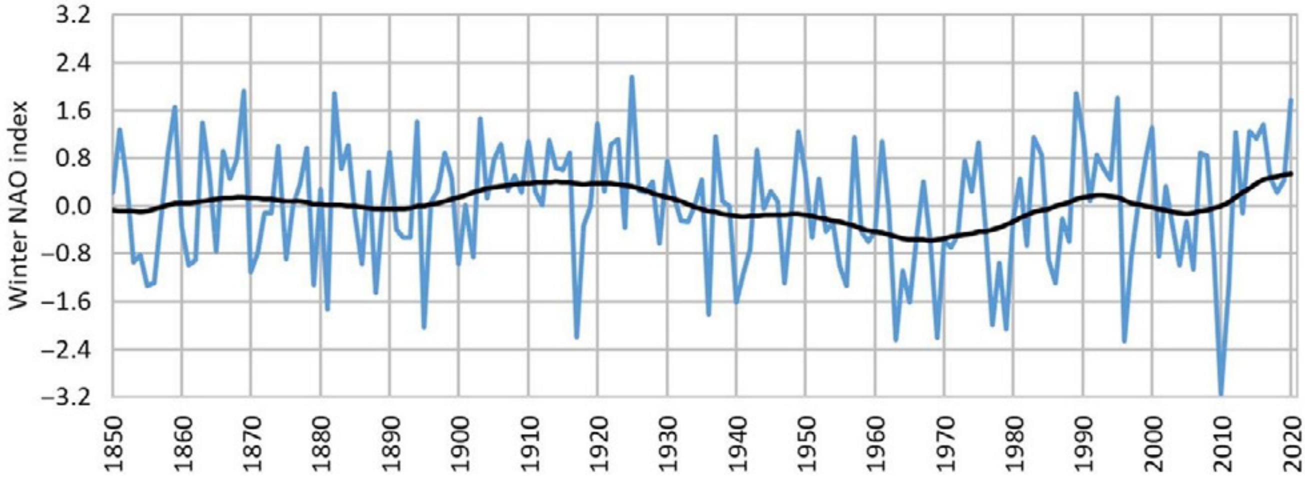


Figure 2. Winter NAO index based on standardized monthly mean pressure difference between stations in Gibraltar and south-west Iceland (see Annex 1 for details). Winter 2020 refers to the period December 2019–February 2020 (from Kendon et al. 2021). Note that winter 2021 (December 2020–February 2021) will appear in State of the UK Climate 2021.

The status of sea temperature, salinity, and atmospheric conditions in the North Atlantic region, as well as observed trends and recent variability, is reported each year in the ICES Report on Ocean Climate (IROC). The report combines decades of ocean observations across the region. Trends to 2019 are shown in figure 3.

Insights relating to 2020 from the (currently unpublished) 2021 IROC report suggest.

- Barents Sea temperatures were well above the 1981-2010 average, but lower than 2019.
- Temperature around Iceland was close to the long-term average.
- Warmer than average conditions in the southern North Sea (especially Q1 and Q4).
- Elevated temperatures in the western English Channel for the first half of the year.
- Mean sea-surface temperature values were near or below average for SW Ireland.

Further commentary on ocean observations relating to North Atlantic ICES regions (specifically Barents Sea, Norwegian Sea, Iceland, Rockall Trough, Southwest approaches, Celtic Sea, and North Sea) can be found in Annex 2.

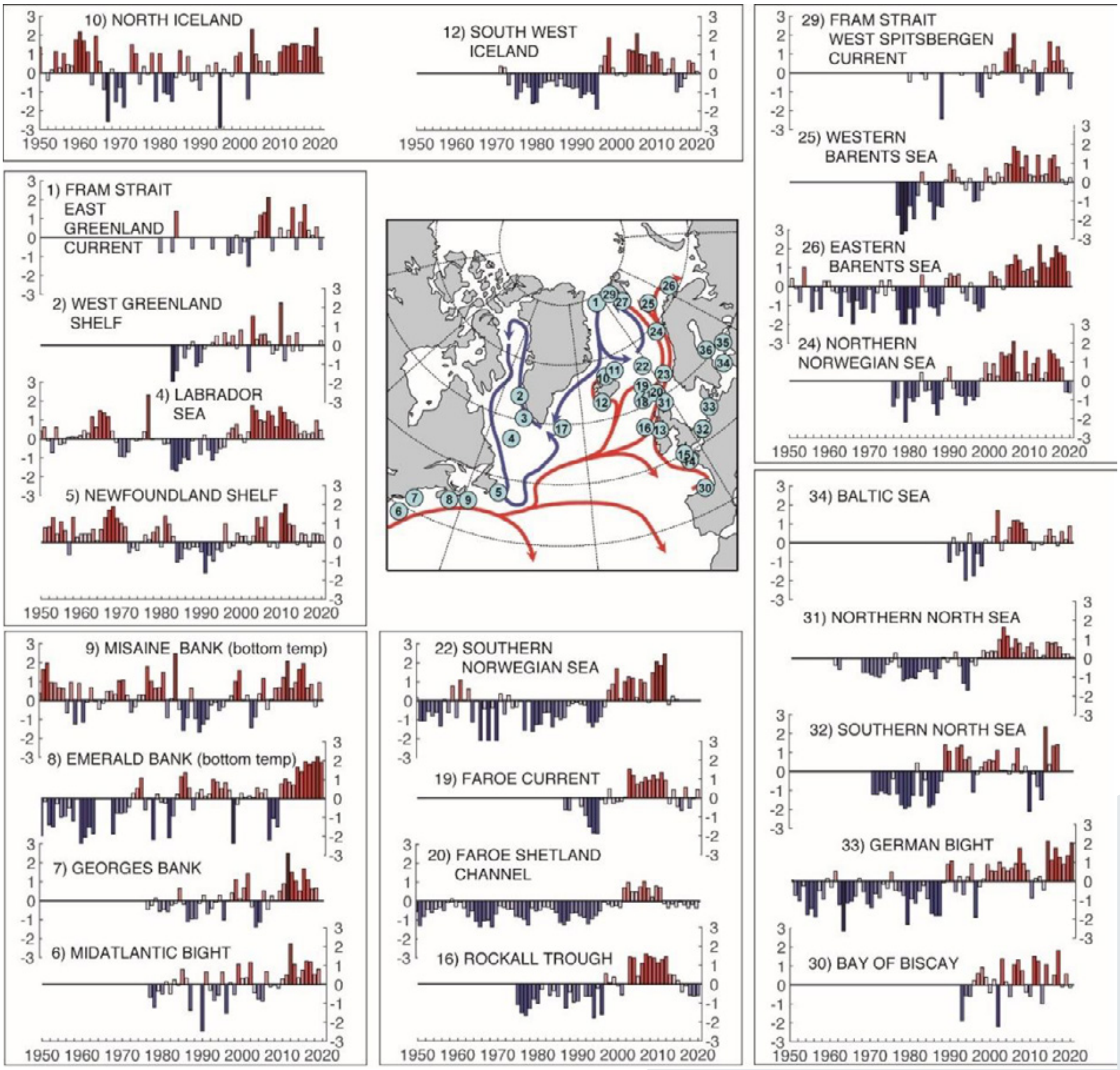


Figure 3. Upper ocean temperature anomalies at selected locations across the North Atlantic. Time-series of normalized anomalies at each of the selected stations. Colour intervals 0.5 s.d.; reds = positive/warm; blues = negative/cool (from IROC 2020).

2.2 Implications (changing catch potential, impacts on offshore operations and assets, impacts on onshore operations and assets).

2.2.1 Domestic system

Fishery resources

Recruitment and temperature: Many hundreds of scientific papers in recent decades have linked the 'recruitment' of fish to prevailing climatic conditions, and in particular, sea surface temperature (SST), the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO).

Some fish species recruit into the fishery within the first year of life (e.g. **sprat**), whereas others (for example **North Sea saithe**) only enter the fishery as recruits after 3 or 4 years, due to a quirk of behaviour and migration patterns. According to up-to-date recruitment estimates for commercial fish of interest to UK fisheries, as derived from ICES stock assessments carried out in 2021 (see Annex 3):

- For many (if not most) stocks and species, recruitment in 2020 and in 2021 was suggested to be poor, when compared to the long-term average (1980-2010).
- The exceptions to this include **Barents Sea cod and haddock** (in 2020) as well as several pelagic species (**North Atlantic mackerel, North Sea sprat, Irish Sea herring, North Atlantic blue whiting**) that have benefited from strong year-classes entering the population in recent years.
- Several warm-water species (e.g. **North Sea Turbot, Western English Channel sole**) witnessed strong recruitment in both 2020 and 2021, and several stocks exhibited strong recruitment in 2020 but not in 2021 (**North Sea Norway pout, whiting and sandeel, Bristol Channel/Celtic Sea sole, Celtic Seas, Bay of Biscay monkfish**).

Over the past two years several scientific publications have explored UK commercial species and the relationship between historical 'recruitment' and climatic indices. These include:

- Báez et al. (2021) provided a general review of how the North Atlantic Oscillation (NAO), and the underlying climatic conditions that this reflects, can impact fisheries throughout the north Atlantic and Mediterranean. There is a significant relationship between NAO and fishery yields, in terms of target species abundance, recruitment, catchability, and body condition, with cumulative and synergistic effects. Possible effects of climate change on these fisheries, through a change in NAO pattern, were also explored.
- Bentley et al. (2020) identified correlations between large-scale climatic indicators, temperature, primary and secondary productivity, and fish recruitment in the Irish Sea and incorporated them into a food web model co-created by scientists and fishers. Model *simulations* suggested that historic environmental change suppressed the overall production of commercial finfish. This limited opportunities for the fishing industry, whilst also dampening the rate of stock recovery, despite marked reductions in fishing effort.
- Romagnoni et al. (2020) examined the influence of larval transport and temperature on recruitment dynamics of **North Sea cod**. Although larval drift appears to play a minor role in the recruitment dynamics of North Sea cod, the effect is comparable in magnitude to the well-established effect of sea surface temperature on cod recruitment.
- Van de Wolfshaar et al. (2021) examined the effect of climate change on the growth and survival of early life history stages of **common sole** in different nursery areas of the North Sea. Under climate change scenarios where wind changes and water temperature increases, the early arrival of fish larvae in their nurseries results in larger young of the year at the end of summer. However, early arrival leads to higher mortality on average, due to initially slow growth in spring.

- Régnier et al. (2019), studied temperature effects on the recruitment of North Sea **sandeel**, within the context of trophic mismatch. Examining temperature, fish larval and copepod abundance at a Scottish coastal monitoring site, the study explored how temperature affects the life-cycle match between sandeel hatching and egg production of its copepod prey and explained variation in sandeel recruitment. Projected warming scenarios indicated an increasing probability of life-cycle 'decoupling' with an associated decline in sandeel recruitment.
- MacDonald et al. (2019) examined the timing of **sandeel** spawning and hatching off the East coast of Scotland. By analyzing the abundance, length, and age distributions of sandeel larvae the authors were able to determine the temporal distribution of hatching rates each year and back-track to the likely spawning dates of the sandeels. Estimated spawning dates showed no evidence of correlation with environmental cues such as tidal or lunar phases. However, hatch end dates varied by 20 days over the 10-year period and were correlated with the date of the seasonal minimum of sea bottom temperature.

Fisheries yield and temperature: Several scientific publications have explored future pathways, modelling projections of fisheries yield in the face of various anticipated climate scenarios. In Europe, marine fish stocks are mostly managed through assessment of their exploitation and ecological status compared to reference points such as the level of fishing pressure that corresponds with Maximum Sustainable Yield (FMSY). However, MSY and its associated fishing mortality rate FMSY are sensitive to both stock characteristics and climatic conditions.

- Travers-Trolet et al. (2020) explored the variability of MSY reference points under climate change by using a multi-species model applied to the Eastern English Channel. The model was first run to fit the historical situation (2000–2009) and then used to assess the ecosystem state for the 2050–2059 period, using two contrasting climate change scenarios (medium emissions (RCP 4.5) and high emissions (RCP 8.5). For 80% of cases F_{MSY} projections showed consistent decreasing pattern as climate conditions changed from historical to RCP scenarios in the Eastern English Channel. This result constitutes a risk for fisheries management, and anticipation of climate change impacts on fish community would require targeting a smaller fishing mortality than F_{MSY} to ensure sustainable exploitation of marine stocks.
- Fernandes et al. (2020) explored the potential impact of different climate change scenarios on the four main commercial pelagic species in the North-East Atlantic (NEA): A**tlantic mackerel, European sprat, Atlantic herring** and **blue whiting**. Modelling all target species as being exploited at their maximum sustainable yield (MSY), **herring, mackerel** and **blue whiting** were projected to increase under the low emissions scenario (RCP2.6), but future projections under the high emissions scenario (RCP8.5) show mixed responses with decreases or no changes forecasted for herring, sprat and blue whiting. Only for Atlantic mackerel were persistent increases suggested under both the high and low emission scenarios.
- Modelling an age structured population of **Atlantic cod** Winter et al. (2020) suggested that stressors such as fishing and climate change, can worsen the impact of an 'Allee effect' (where a decline in abundance reduces population productivity). Findings suggest that, where there is an Allee effect, a fishing moratorium is only sufficient for recovery when sea surface temperature rise remains within 2°C and fishing is restricted within 10 years. If sea surface temperature rises beyond 2°C, even immediate banning of fishing is not sufficient to guarantee recovery.

Fish distribution and temperature: Several scientific publications have explored the relationship between temperature and the distribution of fish. These include:

- Mclean et al. (2021) examined fish distribution changes in both the North Pacific and North Atlantic (including seas around the British Isles) in relation to the average 'thermal affinity' of a fish community. 'Thermal affinity' closely tracked changes in sea surface temperature and increased in 72% of locations. Increased 'thermal affinity' occurred primarily along the northeast coast of the United States, in the Scottish Seas, the North Sea, the Baltic Sea, the Barents Sea, and around the Aleutian Islands. Decreases were more prominent along the west and southeast coasts of the United States and in the Bering Sea. Where 'thermal affinity' increased, in 31% of cases it was primarily due to decreases in cold-affinity species (i.e. deborealization), but this was less pronounced in the Scottish Seas and the North Sea where there were stronger increases in warm-affinity species (i.e. tropicalization).
- Bluemel et al. (2022) examined long-term changes in the distribution and abundance of **Atlantic wolffish** in the North Sea: a once common species across much of the central and northern North Sea. Since the 1980s, wolffish have seen a decline in abundance, demographic characteristics (reduced size) and geographical range, with the shallower and more southerly parts of its range most impacted. Bycatch through fishing remains a potential threat and, with the likely impacts of predicted climate change, risks of further regional depletion and/or localised extinction.
- Mclean et al. (2019) used a 33-year database of fish monitoring to compare North Sea fish communities in terms of species and traits (including length and age, offspring size, water column position, and thermal preference). Most of the variation was explained by a pronounced spatial gradient, with distinct communities in the southern and northern North Sea related to depth, sea surface temperature, salinity and bed shear stress. Both species and traits changed significantly over time; in particular, communities shifted towards smaller, faster growing species with higher thermal preferences. Similarly, Beukhof et al. (2019) examined abundance of demersal fish species in the North Sea, using 30 years of data, combined with trait information (body size, life history, growth rate, reproduction, trophic level etc). Results revealed strong spatial structuring and long-term changes in fish traits, with temporal changes being irregularly distributed across the North Sea.
- Mérillet et al. (2020) explored interactions between an entire demersal ecosystem with the environment in the Celtic Sea, using bottom trawl data over a 17-year period. The results showed that over the past two decades, biotic communities in the Celtic Sea were likely controlled more by environmental variables than fisheries. At a local scale, in the centre of the Celtic Sea, dynamics were probably driven by interannual variation in temperature. Fishing was an important influence early in the time series (2000) but decreased in importance after 2009.
- Núñez-Riboni et al. (2019) examined past and projected changes of the suitable thermal habitat of **North Sea cod** under climate change. Modelling the spatial distribution of different life stages of cod from 1967 to 2015 showed that suitability has decreased south of 56°N (>12% in the Southern Bight) and increased north of it (with maximum of roughly 10% in southern Skagerrak). Future changes to suitability were estimated throughout the century using temperature projections from a regional climate model under a high emissions scenario (RCP8.5). The results show that southern Skagerrak, the central and northern North Sea and the edge of the Norwegian trench will remain thermally suitable for **North Sea cod** throughout the century.

Large-scale and long-term changes in fish abundance and distribution in response to climate change have been simulated through modelling. However, national and regional fisheries management also requires shorter-term projections on smaller spatial scales, and these need to be validated against locally relevant fisheries data.

- Using 26-year fish survey data, Fernandes et al. (2020) assessed the ability of models to correctly simulate the changes in fish distribution and abundance that occurred in response to climate variability and change. Comparing model simulations with annual fish survey data, model results can be used to guide fisheries management at larger spatial scales, but more caution is needed at smaller scales. Differences between fishery model results decrease dramatically when results are aggregated to larger scales (e.g. the whole North Sea), to total catches rather than individual species, or when using the average of several - rather than individual - simulations.

A persistent feature of reports over the past 10 years has been the suggestion of increasing cephalopod (squid, cuttlefish and octopus) populations and resulting fisheries. Most notably, Doubleday et al. (2016) demonstrated that cephalopod populations have increased worldwide over the last six decades. This is based on global time–series data of **cephalopod** catch rates (catch per unit of fishing or sampling effort).

- A recent study by Oesterwind et al. (2020) highlighted increased abundance of **shortfin squid** in the southern North Sea and provided evidence of a new spawning area. Barrett et al. (2021) examined occurrences of **lesser flying squid** and the **shortfin squid** and compared these with oceanographic data from international surveys to gain insight into environmental predictors of their presence throughout the North Sea. Spawning of **lesser flying squid** was found in relatively cooler and more saline waters (6–8°C, 34.2–35.1 psu) in the northern North Sea linked to the Fair Isle Current and East Shetland Atlantic Inflow, whilst spawning of **shortfin squid** occurred across the entire North Sea (mostly at 9–10.5°C, 34.1–34.8 psu).
- Schickele et al. (2021) provided future distribution projections for three commercially important **cephalopods** (*Octopus vulgaris, Sepia officinalis and Loligo vulgaris*) in Europe. The authors suggest a future decrease in the suitability of environmental conditions in the Mediterranean Sea and the Bay of Biscay. Conversely, the study projected a rapidly increasing environmental suitability in the North, Norwegian and Baltic Seas for all species.

In recent years, both commercial and recreational fishers have reported seeing large numbers of **Atlantic bluefin tuna**, especially off Devon and Cornwall, but also in the North Sea. Historically this species had been present throughout much of the North-East Atlantic, including around the British Isles where it had previously been the target of a UK sport fishery based in Yorkshire (Bennema, 2018).

Throughout 2020 and 2021, scientific investigations into **bluefin tuna** migrations and movements have been conducted (in particular, tagging experiments) under the auspices of the Defra-funded THUNNUS UK and CHART programmes. 2021 was the first year in which the UK held its own **bluefin tuna** quota. Under this quota, allocations have been made to account for incidental mortality arising from the ‘catch-and-release tagging’ programme (CHART) and for unavoidable by-catch in commercial fisheries.

Fish distribution and ocean acidification: Over the past decade, hundreds of papers have been published focussing on the impact of Ocean Acidification (OA), but fewer studies relevant to UK fisheries and aquaculture have been published since funding programmes ended in 2016.

Responses in fin-fish to ocean acidification are particularly uncertain. However, several recent studies (e.g. Stiasny et al. 2019) have noted that early life stages (eggs and young larvae) of fish may be more sensitive to the direct effect of OA than adults.

Stewart-Sinclair et al. (2020) modelled the vulnerability of global **bivalve** mariculture to impacts of climate change and ocean acidification over the period 2020–2100, under a high emissions scenario (RCP8.5). The vulnerability of all coastal nations was assessed in terms of exposure to climate change and ocean acidification, species sensitivity and adaptive capacity in the sector. Sensitivity was predicted to be high in developing countries - mainly due to the cultivation of species that have a narrow habitat tolerance, and in some European nations (France, Ireland, Italy, Portugal, and Spain) - due to the relatively high economic value of the shellfish production sector. Adaptive capacity was predicted to be low in developing countries – mainly due to governance issues, and in some developed countries (Denmark, Germany, Iceland, Netherlands, Sweden, and the UK) - linked to limited species diversity in the sector. The bivalve mariculture industry of the UK (mainly oysters and mussels) was scored as being 'moderately' vulnerable overall to the combined impacts of climate change and ocean acidification.

Offshore operations, ports and communities

Fleet, gear and crew and storminess: Changing storminess poses a direct risk to fisheries, disrupting fishing effort and posing a physical danger to fishers, vessels and gear, fishing communities and infrastructure. Although changing storminess has the potential to cause immediate and catastrophic impacts (Sainsbury et al., 2018), uncertainty in projections of past and future storminess from global and regional climate models remains high (see Watching brief, 2019).

With the caveat that confidence in wind and storm projections are relatively low, some models suggest that north-west Europe will experience fewer, though more intense, storms in the future (Mölter et al. 2016).

Sainsbury et al. (2021) explored the sensitivity of individual fishers to changing storminess. Working with skippers from southwest England, the study examined the trade-off between physical risk at sea and the anticipated economic rewards of continued fishing under adverse weather conditions. Fishers preferred increased wind speed and wave height up to a threshold, after which they became increasingly averse to worsening conditions. Fishing gear, vessel length, presence of crew, vessel ownership, skipper age, recent fishing success and reliance on fishing income all influenced the skippers' decisions on whether to go to sea. Pfeiffer (2020) offered further insights from a similar study conducted in the United States.

Fleet, fishing communities and climate risk: Payne et al. (2021) assessed the relative climate risk to 380 fishing fleets and 105 coastal regions in Europe. Risk was based on anticipated hazard (catch composition and stock sensitivity to climate change, using projections out to 2050), present-day exposure (catch diversity or dominance) and vulnerability (net profit margin of fleet, or GDP per capita of the region).

The analysis revealed wide variation in climate risk within the European continent and even within a single country (Figure 4). Countries in southeast Europe (Bulgaria, Cyprus, Romania, Malta, Croatia) as well as the UK were identified as having the highest risks to both fishing fleets and coastal regions overall, but often for very contrasting reasons.

Systematic differences in climate risk were seen among gear types, for example:

- Dredgers had the highest climate risk. These fleets generally targeted populations with high-climate hazards and had low-species diversity in their catches (giving high exposure); good profitability, on the other hand, lowered their vulnerability and somewhat reduced overall risk.
- Fleets using pelagic and demersal trawls together with purse seine fleets had the lowest-climate risks, primarily due to the low hazard associated with the species on which they fish.

The findings highlight the wide variety of challenges facing European countries in adapting their fisheries sectors to a changing climate. For example:

- In some cases, such as in the southern Baltic states, a focus on building adaptive capacity in coastal regions would be of most benefit (e.g., by creating alternative employment opportunities or providing an economic "safety net" through wider social measures).
- In other regions, fleet risks dominate, and therefore, increasing the efficiency, adaptive capacity, and catch diversity of the fleets would appear to be a priority.

Some areas, such as the UK and southeast Europe, appear to require both types of response and therefore present the greatest adaptation challenges.

The UK was highlighted primarily because of high hazard scores (stock sensitivity) combined with high exposure scores (low catch diversity) compared to other countries. In the UK, for example, climate risk was greatest in the north of England, while fisheries in northern Scotland and the south of England exhibited much lower risk. Indeed, 6 of the 10 regions with the highest climate risk in Europe, including the overall top region (Tees Valley and Durham), were in the UK. These results were strongly influenced by high-hazard scores for the species landed in these regions combined with high exposure (low catch diversity) and high vulnerability due to relatively low GDP per capita in some of these regions.

UK regions where the climate risk score for fisheries was:

- **highest** were Tees Valley and Durham, Cumbria, West Central Scotland, Northumberland/ Tyne and Wear, East Yorkshire and Northern Lincolnshire, and Southern Scotland.
- **lowest** were: North Eastern Scotland; East Wales; Highlands and Islands; and Hampshire and Isle of Wight.

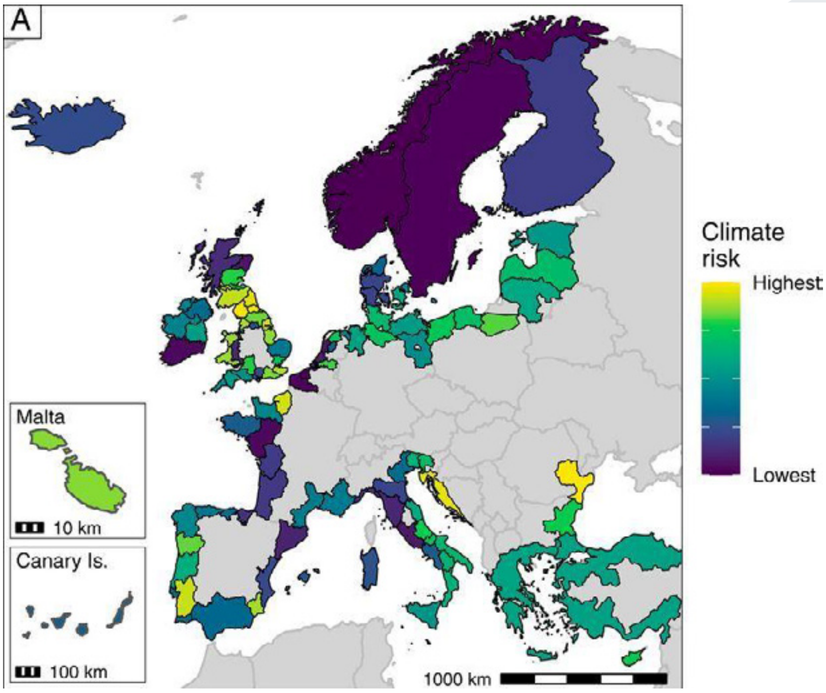


Figure 4. The combined climate risk ranking to fisheries for each coastal region of Europe (Payne et al. 2021)

2.2.2. International system

Fishery resources

Fish distribution and temperature: Several scientific papers have focussed on **Alaska pollock** and climatic influences in the North Pacific, following unusual oceanographic conditions between 2013 and 2015 – a marine heat wave that has come to be known as the "Blob"[4].

According to Rogers et al. (2020) this warm Blob affected ecosystems from the California Current in the South to the Gulf of Alaska and the Bering Sea in the North. In the Gulf of Alaska during the spring of 2015, pollock larvae were caught at record low levels relative to a 30-year time series. Survival rates were low during the summer, and by late summer, numbers were further reduced, with very low abundances of juvenile (age-0) pollock.

Mechanisms that have been proposed to explain this phenomenon, include:

- Low-saline conditions may have impacted egg buoyancy and survival.
- Population densities of zooplankton nauplii may have been too low to support first-feeding of larvae.
- Body condition of age-0 pollock was poor and a bioenergetics model indicated that reduced quality of zooplankton prey, coupled with warmer temperatures, increased the ration required for positive growth by up to 19%, at a time when prey abundance was likely reduced.

Thus, **walleye pollock** experienced a cascade of poor conditions for growth and survival through early life stages, resulting in the near disappearance of the 2015-year class in the population by the end of their first year.

Eisner et al. (2020) explored **walleye pollock** abundance using temperature profiles and NOAA trawl sample data for adult and juvenile (age-1) fish in 2010 and 2017-2019 in the northeastern and southeastern Bering Sea. Results showed increased adult pollock abundance in northern regions of the Bering Sea shelf in both the US and Russian sectors in recent years in the 2017-2019. In contrast, lower abundances, compared to historic means, were observed in southern regions of the shelf, suggesting the pollock moved directionally from the south to the north. Pollock distributions relate to reductions in sea-ice, cold pool extent and currents. Adult pollock prefer temperatures of 0–6 °C; whereas age-1 pollock tolerate a broader range.

According to NOAA (2019) a new marine heat wave emerged in the North Pacific towards the end of 2019. This raised concerns that a similar warm "Blob" to that observed in 2013–2015, might reappear in the near future.

Several scientific papers have also focussed on climate and **tuna fisheries**. Tuna are globally distributed species, mainly in the equatorial regions (mid Atlantic, Indian Ocean and Eastern/Western Pacific), and are a major source of government revenue in some countries. Tuna are characterized by dynamic distribution patterns that respond to climate variability and long-term change.

Erauskin-Extramiana et al. (2019) investigated the effect of climatic conditions on the worldwide distribution and relative abundance of six tuna species between 1958 and 2004 and estimated the expected end-of-the-century changes based on a high emissions scenario (RCP8.5). Over the historical period, suitable habitats shifted poleward for 20 out of 22 tuna stocks: on average, tuna habitat distribution limits have shifted poleward

4 A marine climate event that has come to be known as the "Blob" refers to a period of especially unusual oceanographic conditions, whereby a major marine heat wave occurred throughout the northwest Pacific between 2013 and 2015. This was the largest marine heat wave globally since 1982 with sea surface temperature anomalies of +6 °C compared to normal climatic conditions in the region.

6.5 km per decade in the northern hemisphere and 5.5 km per decade in the southern hemisphere. Specifically, throughout the 20th Century, habitat suitability for:

- **skipjack, yellowfin** and **bigeye tuna** declined in the Indian Ocean and eastern-Pacific but increased in the tropical Atlantic.
- **albacore tuna** declined in the southern hemisphere, but seems to have improved in both the North Pacific and North Atlantic.

Larger tuna distribution shifts and changes in abundance are expected in the future, especially by the end-of-the-century (2080–2099):

- Temperate tunas (**albacore, Atlantic bluefin**, and **southern bluefin**) and the tropical bigeye tuna are expected to decline in the tropics and shift poleward.
- In contrast, **skipjack** and **yellowfin tunas** are projected to become more abundant in tropical areas as well as in most coastal countries' exclusive economic zones (EEZ).

Notably, catch-per-unit-effort for **skipjack tuna** is projected to increase in many Caribbean EEZs, however no change is anticipated for countries in the eastern Indian Ocean (e.g. Cook Islands, Maldives and Indonesia). Populations may decline in the Papua New Guinea and the Philippines by end of Century.

Bell et al. (2021) examined climate-driven redistribution of tuna and the potential disruption to the economies of Pacific Small Island Developing States (SIDS), given that some island nations derive more than 70% of government revenues from tuna fishing licences. By 2050, under a high emissions scenario (RCP 8.5), the total biomass of three tuna species (**skipjack, yellowfin** and **bigeye**) in the waters of ten Pacific SIDS could decline by an average of 13%, with Papua New Guinea and Solomon Islands being particularly adversely impacted. Some island nations, e.g. Gilbert Islands and Kiribati, are projected to witness increased tuna catches if the world follows a medium emissions scenario (RCP4.5), but would suffer serious declines under a high emissions scenario (RCP 8.5).

Townhill et al. (2021) explored how the distribution of commercially important tuna could change in the waters around the UK's Overseas Territories in the South Atlantic under two climate change scenarios. The future suitable habitat of **southern bluefin, albacore, bigeye, yellowfin** and **skipjack tunas** were modelled. The waters of Tristan da Cunha are the most suitable for **southern bluefin tuna**, and overall, the environmental conditions will remain so in the future but unlikely to become more suitable for the other tuna species. Ascension Island and Saint Helena will become more suitable in the future for the other tuna species, particularly **skipjack tuna** around Ascension Island.

Food security and supply chain impacts

Few scientific papers have focussed on how climate change impacts across global supply chains. Davis et al (2021) reviewed the literature on environmental variability and shocks (including extreme rainfall and temperatures) and how various factors can drive these through food supply chains (including cereals and meat proteins such as beef, seafood etc). Most research focusses on environmental variability and the production stage. Research on how shocks ripple through food supply chains and subsequently effect consumption is limited. As food systems are interconnected, a shock at one stage impacts subsequent stages, a shock in one country or region can have serious implications for another. Further research should focus on understanding shock events beyond production impacts, to minimize systemic risks and enhance the capacity to cope with disruptions.

3

Industry experience of climate change impacts and relevant responses

Industry experience of climate change within domestic and international systems over the course of 2020 and 2021 is described by major fish species grouping. The following anecdotal points describe industry experience of climate related impacts and adaptation responses. ***Note:*** *Stakeholders urged* ***caution*** *in attributing the impacts experienced by industry directly to climate drivers. There are other relevant drivers at play - including social (e.g. fisheries management) and environmental (biological and oceanic cycles) drivers - so the link between climate drivers and the impacts experienced should be considered indicative only. Additional caution is urged given the unique disruption to seafood capture and supply from Covid-19, the effects of which cannot be underestimated.*

3.1 Domestic (see tables A1.1 and A1.2 in Annex 1)

Notable impacts experienced by industry relate to 'temperature' and 'storminess and waves'. Changing weather patterns are considered very important to industry: notable patterns include temperature variation and unusual periods that "seem to be coming in lumps". More generally, the seasons seem to be gradually extending; summer is stretching into September, autumn is edging into November, with winter moving into January.

Whitefish

- *Impacts relating to 'temperature':*
  - Whitefish species are following the same trend as in recent years with temperature potentially playing a role in **fish distribution**. This impacts on fishing patterns and catch potential of target species in terms of location but also timing and seasons.
  - Temperature variation has been noticeable. Spring 2020 was very hot and affected fishing and availability of fish e.g. there was an abundance of fish in the springtime perhaps because of warming waters. Spring 2021 was notably cold, with warming waters coming later: as sea temperatures took time to recover it remained cool until early summer (as opposed to normal warming by April).
  - **Cod** continue to gradually move north; the search for food is believed to be a factor in this. There are therefore mixed prospects for cod in the North Sea and elsewhere: cod is doing better in northern North sea, and less well in southern North Sea and Celtic Sea. Although there have been fewer vessels at sea, this is due to other factors e.g. loss of quota.
  - **Hake**, and the timing of fishing north of Shetland, may have been affected by the colder spring in 2021.
  - **Sea bass** recovery and its recent appearance in the Humber estuary may have been helped by changes in temperature. If so, this would be a beneficial impact of climate change: although, at this stage, the industry has no access to catch this.
- *Impacts relating to 'storminess and waves':*
  - In contrast to previous periods, there has been a general absence of extreme **weather conditions** (storms, freezing weather etc) over the last two years. With fewer dramatic incidents, disruption of fishing activity and damage to onshore/offshore assets due to weather events has been limited. However, weather patterns are considered unusual with periods that *"seem to be coming in lumps"*: the 2020/21 winter saw a month of absolute calm followed by heavy weather, whilst there appear to be more 'freak' storms outside winter periods.

Pelagic

- *Impacts relating to 'temperature':*
  - Recent **mackerel** and **herring** trends appear to be following the longer-term patterns relating to the large and changing pelagic **fish distribution** in the North East Atlantic. The search for food by these species appears to be a factor, and temperature may be playing a role. These changes, transcending international boundaries, present challenges to managing the fisheries and has consequences for catch potential of target species.
  - North Sea **herring**: There have been some year-to-year changes in the June-September maatjes herring fishery: in 2020 the fishery was ~100 miles north east of Peterhead but in 2021 it was ~15 miles east of Shetland. The spawning area for the September roe fishery remained unchanged in both 2020 and 2021. It is not clear what is driving this shift, but food is likely to be a part of it.

- **Mackerel:** In the 2010-2014 period there was a westward drift of the fishery towards Iceland/Greenland. The shift coincided with a stock reaching its largest ever size and was potentially driven by the fish reaching out in search of food (particularly larger fish on the edge of that stock). More recently, in the 2017-2020 period, that westward shift was over: in the summer of 2021, the stock had shifted further east rather than north (on the eastern side of the Norwegian sea). Drivers for this shift remain unclear although food may be a factor.

Shellfish

- *Impacts relating to 'temperature':*
    - Temperature of waters appears to play a role in the **accessibility and distribution of shellfish** (if too cold, shellfish 'just shut down'). This impacts on fishing patterns and catch potential of target species in terms of location and timing. The relatively low water temperature in 2021 was notable and caused some difficulties for some shellfish fisheries which remained sluggish for much of the year.
    - Although not explicitly linked with temperature, the 2021 **brown crab** fishery has been poor in northern Scotland and has seen poor availability off Norfolk and the East of England.
    - The **squid** fishery in northern Scotland, once a summer fishery, has been poor in the summer months and is now extending into November. These shifts are particularly notable inshore, e.g. in the Moray Firth, where temperature changes are perhaps more noticeable. However other factors, like offshore wind, may also be playing a role displacing inshore squid.
    - In contrast, a notable species change was in the 2020-21 **Nephrops** fishery. In 2020, as lockdown eased from mid-summer to the end of the year, fishing was good and carried on - proving remarkably good - in the relatively cold 2021 spring. This might suggest Nephrops prefer a colder temperature. This resulted in good steady fishing comparable to some of the better years fishing for this species.

Progress against adaptation responses

Notable responses in:

- <u>Fisheries management</u> include advancing a **'more robust strategic fisheries knowledge base'** by developing **closer science-industry collaboration and engaged research**. Examples include:
    - A concerted industry approach in Scotland which is building the foundation for a more robust strategic fisheries knowledge base, that can incorporate climate factors. Industry now employs a growing community of applied researchers and scientists, embedded in Scottish Fishermen's Federation (SFF), Scottish Pelagic Fishermen's Association (SPFA), Scottish Fishermen's Organisation (SFO), and Scottish White Fish Producers Association (SWFPA) and Inshore Fisheries Groups (IFGs). This Scottish science/industry network meets regularly throughout year. The approach is oriented towards practical use, for example ensuring research data is quality assured so that it can be fed into ICES assessments rather than producing articles for research journals. From an initial approach that 'attended meetings and reported back', industry research is now much more proactive. *Once this foundation is achieved, the data collected can be expanded to look at other factors such as temperature.*

- Expanding science-industry collaboration in Scotland, with more extensive initiatives in the pelagic sector but also in others such as whitefish. Examples include:
    - Whitefish: a prize-winning programme on cod avoidance and real time reporting on the West coast of Scotland. Focussed on stock distribution, and how that is changing, this is a collaborative programme with Aberdeen University.
    - Pelagic: All large pelagic vessels are now self-sampling every haul - tracking length, weight, and age of mackerel and herring. Data on the mackerel fishery is going directly into ICES. A practical output has been to improve, and resolve differences between, national data: Scottish data is no longer out of kilter with the likes of Norwegian, Icelandic data etc (as it had been previously). Other collaborations include an initiative with the University of Aberdeen and researchers in the Netherlands to explore seasonal fat content of mackerel, collaboration with pelagic factories, and - over the last two years - vessels providing additional data, covering areas missed by the acoustic grid surveys of the Government, to estimate the West of Scotland herring population during the spawning season.
- Elsewhere in the UK, fisheries science partnerships have been operating on reduced funding over the last decade. There is uncertainty at present as arrangements for supporting fisheries science evolve to reflect the requirements of the new UK Fisheries Act.
- <u>Fisheries governance</u> includes potential maladaptation such as impediments to **quota swaps / transfers** operating efficiently and the maintenance of historical management arrangement for species with Total Allowable Catch. Consequently, previous arrangements have been replaced by a wider agreement which may prove more rigid.
    - Efficient operation of quota swaps/transfers has been impacted by the process of the UK leaving the EU. Swaps/transfers are problematic until a new mechanism, an international state-to-state arrangement, is put in place. The temporary system currently in operation *"looks 'clunkier' than the previous system, but the jury is still out until a new system 'beds down'"*. Although quota swaps are underway, this is not at the previous level – this may be due to a reticence to allow international swaps.
    - Review of domestic quota allocation and a review of management arrangements ('relative stability' and 'zonal attachment') will be subject to the UK-EU Trade and Cooperation Agreement until 2026, with fisheries now part of that agreement. In the face of shifting fish distributions, retaining 'relative stability' as an underpinning offers advantages to EU fleets and this may hinder alternative options e.g. Some 15-20 years ago, hake was targeted by EU fleets in SW Ireland and Bay of Biscay. Since that time there have been changes – involving temperature change - to undermine hake catch in that region; these include hake moving northwards into UK waters.

- Fishing operations includes **enhancing operational safety** through:
  - The continuing trend in new build whitefish vessels in Scotland. It is estimated that around 80% of the Scottish whitefish fleet can now work in the worst of weathers: new vessels over the last 10-20 years have been 'future proofed' against extreme weather e.g. seine netters have crew enclosures and covered areas. This longer term 'technological creep' reduces the time the fleet is tied up, due to foul weather.
  - The continuing trend in new build pelagic vessels in Scotland. New pelagic vessels have higher decks and pump from the stern rather than the side. The vessels have also become larger, safer and more comfortable for the crew e.g. a 70m vessel has replaced its 65m predecessor, a 75m with 70m etc.
  - In shellfish, there is a trend for greater investment in catamarans with safety believed to be an important factor in that. These vessels are steadier in the water, have larger carrying capacity, and can work a lot more gear.
- Port and transportation resilience includes **improved port risk management** and assessing the **freight ferry vulnerabilities**:
  - As previously reported, Peterhead port has deepened the harbour, moved the fish market to its previous site and heightened the north wall break water. Building on earlier wall refurbishment, an additional £1.5m investment has been made in further physical infrastructure to protect against flooding. Until this investment has been completed, temporary protective measures are in place: 30-40 containers loaded with stones placed in front of the market to prevent flooding from winter weather, and concrete structures placed shoreside to dissipate incoming water. In addition, the new Peterhead market has solar panels across its roofs to help provide energy for refrigerated facilities.
  - Completing repairs to Fraserburgh port to address historical port damage is underway but taking a prolonged period to complete.
  - Vulnerability of freight ferries to climate change has not been assessed, but logistical problems in Scotland are occurring for other reasons with impacts on the fresh supply chain. Examples include lack of space on Shetland ferries making it difficult to get fish off the island, whilst Caledonian MacBrayne (CalMac) ferries on the West coast have had numerous breakdowns.
- Processing and markets to develop **markets for available domestic seafood** have been strengthened considerably over the last two years with a greater focus on the UK domestic market. This has been driven by wider factors rather than climate change; for example EU markets are becoming more expensive to access (due to Brexit) and freight costs are increasing (due to Covid). The Covid-19 crisis has meant operators focussing on marketing and finding new domestic customers for the available fish. The crisis has accelerated this adaptation: securing new markets and customers in a matter of months rather than years. For example, shellfish operators changed their approach to marketing to secure UK sales when export markets were cut off. In some cases, producers have sold product directly (opening local shops etc).

3.2 International (see tables A1.3 and A1.4 in Annex 1)

Notable impacts experienced by industry relate to 'temperature' and 'storminess and waves'.

Whitefish

- *Impacts relating to 'temperature' and 'storminess':*
  - Norwegian **cod** and **haddock**: Temperature is implicated as a factor, amongst others - like fish recruitment and fishing pressure, contributing to the changes seen in the Norwegian inshore cod and haddock fishery. Stocks in the 200 nautical mile zone are still declining, this is linked to the northerly **shift in distribution** of cod and haddock in the Svalbard area. Storminess in the Svalbard area has also been notable. Vessels are having to sail further afield to find the volumes needed to ensure businesses remain viable. Anecdotally, suppliers in northern Norway are finding it more difficult to fish in the season, not getting all their target catch. With vessels having to be out longer, this affects catch quality, and the by-catch of other species. A new development, in the UK fish and chip shop sector, relates to maintaining supply of whitefish in a market of rapidly rising prices. Supply is challenged by dissatisfaction around fish sizes (sizes being too small) combined with constraints posed by seasonality (cod sizes are a seasonal effect) and uncertainty over longer term supplies (the suggestion of a year-on-year quota cut in the Barents sea based on recent ICES forecasts, and restrictions on Russian supplies).
  - **Alaska pollock**: Anecdotal reports of shortages in **availability**, although difficult to disentangle from other important factors like Covid-19 supply disruptions.

Pelagic

- *Impacts relating to 'temperature':*
  - **North East Atlantic mackerel and herring**: Temperature may be playing a role in the large and **changing distribution** of mackerel and herring fisheries in the NE Atlantic. The changing distribution follows a 6-8 year cycle of movement; this has recently seen a shift from East to West, but could reverse direction in due course. A recent mackerel stock survey suggested a 58% decline in biomass. Such changes, which transcend international boundaries, make stock management and the setting of total allowable catch particularly challenging. This is also having a downstream impact on business reputation.
- *Impacts relating to 'storminess':*
  - **Tuna:** Recent shortages in the availability of tuna from the Indian ocean during summer months were attributed to bad monsoon conditions and **reduced catchability**. However, this is difficult to separate from supply chain and port disruption associated with Covid-19; particularly disruptions driven by periods of fluctuating demand coupled with limited supply stock (as vessels weren't fishing due to lockdowns).

Shellfish

No notable impacts identified.

Progress against adaptation responses

Notable responses in:

- Fisheries management: In Norwegian cod and haddock, the Norway/Russia agreement concerning international access and governance rights in the Svalbard area of the Arctic remains in place: research on the closed areas, and the moratorium on fishing, is ongoing. In mackerel, herring and blue whiting, industry stakeholders (including retailers and processors from across the UK) established the North Atlantic Pelagic Advocacy Group (NAPA) to consider how the supply chain could drive improvements to the management of these North East Atlantic fisheries. Amongst others, NAPA is focussed on the movement of mackerel and how it could affect zonal attachment, the impact of international caps, and long-term sustainable harvest strategies. Note, these actions do not explicitly cover climate change but do contribute to adaptation responses, such as **‘monitoring and assessing the impact of changes in specific regional supplies**’, and **‘ensuring international fisheries management regimes provide early resolution on ‘rights to fish**’’.
- Processing and markets: Being unable to meet the requirements limiting by-catch, the Norwegian inshore cod and haddock fishery recently lost MSC certification (see NSC, 2021). Efforts in the UK include engaging with Norwegian suppliers to drive an improvement project in this fishery. Such efforts contribute to **‘engagement with overseas stakeholders to support climate change adaptation’** in that supply chain. However, non-MSC markets, that compete for Norwegian product, are challenging those efforts.

4

Conclusion

In general, business and investment decisions are driven by expected returns based on anticipated changes. Where changes are highly uncertain, there is reticence to invest in activities where the expected impacts and consequences are vague. Being concerned with a natural resource, the wild capture seafood industry is *inherently* uncertain: it is very often – and by necessity – a reactive industry, able to react and adapt to rapidly changing circumstances. It is therefore to be expected that industry operators will tend to be more reactive, with response to climate related changes delayed until such changes are much closer or impacts much clearer.

In the last two years there has been limited direct movement on adaptation actions. The significant industry adaptations are in response to Brexit, Covid-19 or to challenges in specific fisheries. The recognition and discussion of climate related changes by industry remains limited and broad in its scope; partly a result of having to 'firefight' immediate and known challenges e.g. Brexit or freight problems. Although some of the industry adaptations reported here are driven primarily by these other factors, they can nevertheless be relevant to the industry having to adapt to a changing climate. Indeed, these other factors can accelerate climate related adaptations.

Important themes arise from industry experience in this watching brief. In the domestic arena, certain developments over the last few years could undermine the ability of the industry to adapt to climate change. Two examples are pertinent:

- Shared understanding of climate change is impeded by limited science-industry collaboration. Collaboration is necessary because Government sponsored research is not sufficiently responsive (does not keep up with changes as quick as it should) or regular enough (leaving gaps in data) – this makes for poor science as researchers rely more on proxies or extrapolations. Collaboration is difficult due to lack of trust, partly because science and industry are working to different purposes and quality agendas. For example, academic scientists are often motivated to produce peer reviewed journal articles, industry researchers to support decision-making. Collaboration is easier with resources, but more difficult where resources are constrained. Resources are constrained to varying extents in different parts of the industry, and by a legacy of reduced funding and the changes afoot whilst new arrangements under the UK Fisheries Act are implemented.

- Developing flexible institutional arrangements that support adaptive climate change response is being frustrated by introducing systems that are inflexible. Examples include:
    - the UK-EU Trade and Cooperation Agreement where the opportunities for the fleet (e.g. to target new species) as an independent UK coastal state have not yet materialised;
    - public policy development where priorities seem to be shaped by biological/ environmental rather than socio/economic considerations (fisheries appear secondary in policies on climate change adaptation e.g. emphasis on Marine Protected Areas, in marine planning e.g. local management measures and spatial access for competing marine sectors, and in the attention given to 'blue carbon' habitats when evidence is limited).

In the international arena, several industry and individual supply chain adaptations have been advanced. These are improvement actions prompted by market/reputation imperatives (e.g. sourcing from responsibly managed fisheries) rather than by climate change. Nonetheless, whether adaptations relate to 'climate change' or 'sustainable management of the ocean' it is recognised that these actions are interlinked, difficult to attribute, but are *"all good things to be doing, and improvements we would want to see anyway."*

Market led initiatives could potentially play a critical role in adaptation in the international arena, particularly where policy agreements remain elusive. Active engagement with overseas stakeholders has been recognised as a means of enhancing adaptation (Garrett et al, 2015). One emerging question is whether co-operation, and adaptation, within international supply chains can gain traction. Industry experience, highlighted in this exercise, suggests engagement is a particular challenge when overseas suppliers have an opportunity to switch to markets that don't have the same level of scrutiny or policy.

5

Annex 1-3

Consultees
References

Annex 1
Anticipated climate change impacts and adaptation responses in UK seafood

OFFSHORE	Sea level rise, extreme water levels	Increased storminess and waves	Air or sea temperature change	Ocean acidification and deoxygenation	Changes in rainfall / run off
WHITEFISH					
a) Fishery resources					
i. Alterations in species phenology			🔴		
ii. Impacts on choke species (linked to landing obligations)			🔴 🟢		
iii. Changes to growth rate of target species			🔴 🟢		
iv. Changes to the distribution of target species			🔴 🟢		
v. Changes to year-class strength (including larval survival)			🔴 🟢		
vi. Migration patterns of target species (timing and routes)			🔴 🟢		
b) Offshore operations					
i. Staff physical working conditions		🔴			
ii. Gear deployment / performance		🔴			
iii. Damage to fleet		🔴			
PELAGIC					
a) Fishery resources					
i. Migration patterns of target species (timing and routes)			🔴		
ii. Alterations in species phenology			🔴		
iii. Changes to the catchability of target species		🔴	🔴		
iv. Changes to growth rate of target species			🔴 🟢		
v. Changes to the distribution of target species			🔴 🟢		
vi. Changes to year-class strength (including larval survival)			🔴 🟢		
b) Offshore operations					
i. Staff physical working conditions		🔴			
ii. Gear deployment / performance		🔴			
SHELLFISH					
a) Fishery resources					
i. Presence of HABs		🔴	🔴		🔴
ii. Presence of pests and diseases					🔴
iii. Changes to year-class strength (including spatfall)			🔴 🟢		
iv. Presence of non-natives / jellyfish			🔴 🟢		
v. Changes to the distribution of target species (including squid)			🟢		
vi. Changes to growth rates of target species			🔴 🟢		
b) Offshore operations					
i. Staff physical working conditions		🔴			
ii. Gear deployment / performance		🔴			
iii. Damage to fleet		🔴			
ONSHORE					
a) Ports and harbours					
i. Damage to site infrastructure	🔴	🔴			🔴
ii. Boat damage in ports / harbours		🔴			
iii. Integrity of electricity supply					🔴
b) Employment and fishing communities					
i. Integrity of housing and local amenities	🔴	🔴			
ii. Days at sea		🔴			
c) Transportation of catch					
i. Disruption to ferry service		🔴			
d) Processing of catch					
i. Damage to site infrastructure	🔴	🔴			🔴
ii. Integrity of electricity supply					🔴

Table A1.1 Summary of key domestic offshore and onshore threats (red dots) and opportunities (green dots)

Speed of response (inertia)		System	Adaptation response	Owner	Scale of resource			
					Minor	Moderate	Significant	Major
	Underway	Fishery	Scientific advice and data collection through partnership working	Fisheries Science Partnerships				
	Underway	Fishery	Development of training and education modules for fishermen	Fishing into the Future (with Seafish)				
	Underway	Operations	Enhance operational safety (raised decks)	Industry				
	Underway	Operations	Enhance operational safety (Personal Flotation Devices)	The Fishing Industry Safety Group				
	Underway	Operations	Enhance operational safety (Safety at Sea training)	Seafish-approved training providers				
	Underway	Ports	Build port resilience	Port / harbour authorities / Department of Transport				
	Underway	Processing	Develop markets for available domestic seafood	Seafood Scotland				
	Immediate (<2 years)	Ports	Ensure berth allocations for vulnerable vessels	Port / harbour authorities		■		
	Immediate (<2 years)	Processing	Develop marketing strategies for seafood in rest of UK	Industry trade organisations		■		
	Short term (2-5 years)	Fishery	Develop close science-industry collaboration and engaged research	Industry trade associations / scientists		■	■	
	Short term (2-5 years)	Fishery	Ensure quota swaps / transfers	Industry		■		
	Short term (2-5 years)	Operations	Keep a watching brief on climate change and potential responses	Industry trade associations	■			
	Short term (2-5 years)	Ports	Improving port risk management	Port / harbour authorities	■	■		
	Short term (2-5 years)	Transport	Assess vulnerability of freight ferries	Government			■	
	Short term (2-5 years)	Processing	Establish specific seafood marketing organisations for rest of UK	Industry trade organisations (e.g. Fishmongers Hall)			■	
	Medium term (5-15 years)	Fishery	Developing a more robust, strategic fisheries knowledge base.	Scientists / industry / Govt			■	
	Medium term (5-15 years)	Fishery	Review of domestic quota allocation	EU / UK Govt / Fisheries scientists / industry			■	■
	Medium term (5-15 years)	Operations	Review of fishing seasons in response to disruptions	Industry / Government			■	
	Long term (>15 years)	Fishery	Review 'Relative stability' (Governance) arrangements	EU / UK Govt / Fisheries scientists / industry				■
	Long term (>15 years)	Operations	Assess vulnerability of fleets across the EU	EU research				■
	Long term (>15 years)	Processing	Re-locate processing sites inland	Processors and planning inspectorate				■

Table A1.2 Adaptation responses for the domestic system

OFFSHORE	Sea level rise, extreme water levels	Increased storminess and waves	Air or sea temperature change	Ocean acidification and deoxygenation	Changes in rainfall / run off
Wild capture (general)					
i. Changes in species distribution and fisheries productivity (+ve and -ve effects)			🔴 🟢		
ii. Loss of fisheries production at lower latitudes			🔴		
iii. Enhanced fisheries production at high latitudes			🟢		
iv. Impact on international fisheries governance and access rights			🔴		
WHITEFISH					
a) Fishery resources					
i. Changes in distribution or catch potential of target of species (general)			🔴 🟢		
- Arctic fisheries			🔴 🟢		
- North Atlantic Fisheries			🔴 🟢		
- North Pacific (Alaska and Bering Sea) fisheries			🔴 🟢		
- Mid Atlantic – offshore Senegal, The Gambia, Sierra Leone, Ghana			🔴		
b) Offshore operations					
i. Gear deployment / performance		🔴			
PELAGIC					
a) Fishery resources					
i. Changes in distribution or catch potential of target species (general)			🔴		
- Tuna fisheries			🔴		
- Pacific Ocean anchoveta and sardine fisheries			🔴		
SHELLFISH					
a) Fishery resources					
i. Changes in distribution or catch potential of target species				🔴	
ii. Introduction of non-native species			🔴		
b) Offshore operations					
i. Staff physical working conditions		🔴			
ONSHORE					
a) Ports and harbours					
i. Damage to site infrastructure	🔴	🔴			🔴
ii. Vessels / gear damage in ports / harbours		🔴			
c) Onshore processing					
i. Disruption or damage to coastal processing facilities	🔴	🔴			🔴
SOCIO-ECONOMIC CONDITIONS					
i. Impact on national economies of changes in fisheries			🔴 🟢	🔴	
ii. Impact on food security of changes in fisheries			🔴	🔴	

Table A1.3 Summary of key international offshore and onshore threats (red dots) and opportunities (green dots)

Speed of response (inertia)		System	Adaptation response	Owner	Scale of resource: Minor	Moderate	Significant	Major
	Underway	**Offshore**	IMO convention on standards of training and certification of 'watchkeepers' (fishing sector)	IMO				
	Immediate (<2 years)	**Fishery**	Review of key sources of existing supply and available options	UK Industry - especially integrated supply chains / UK Govt / scientists		■	■	
	Short term (2-5 years)	**Fishery**	Monitoring and assessing the impact of changes in specific regional supplies	UK industry bodies / Support organisations / Govts / scientists		■	■	
		Fishery	Promoting an awareness of climate change in the North Atlantic pelagic fishery	UK Industry / UK Govt / scientists		■		
		Fishery	Ensure management regimes embrace the concept of climate change adaptation	International industry bodies / Govts / scientists		■	■	
		Fishery	Ensuring international fisheries management regimes provide early resolution on 'rights to fish'	Industry bodies / RFMOs / scientists / Govts.		■	■	
		Offshore	Maintain ability to catch	UK and international industry / marine engineers and designers		■	■	
		Offshore	Ensure capacity for enhanced productivity of whitefish fisheries at higher latitude	UK and international industry / scientists		■		
		Processing	Improve resilience and capacity of overseas facilities	UK and international industry / Govt / RFMOs / scientists		■	■	
	Medium term (5-15 years)	**Fishery**	Assessing the viability of enhanced regional productivity	UK industry / Govt / scientists		■		
		Fishery	Developing much closer science-industry links to understand climate driven regional changes	UK industry / Govt / scientists		■	■	
		Offshore	Engagement with overseas stakeholders to support climate change adaptation	UK industry / industry bodies / investors / RFMOs / scientists / Govts		■	■	■
		Processing	Maintain a watching brief on climate change and potential responses overseas	UK industry / Govt / scientists		■	■	
	Long term (>15 years)		-					

Table A1.4 Adaptation responses for the international system

Annex 2
Commentary on ocean observations relating to North Atlantic ICES regions in 2020

Barents Sea
In the central Barents Sea (Kola Section), air and water temperatures in 2020 were still above the 1981-2010 average. The 2020 annual mean temperature in the central Kola Section (0-200 m) was typical of warm years and exceeded the 1981-2010 average by 0.3°C, but it was 0.1°C lower than in 2019 and reached the second lowest value, after 2011. According to data from the Barents Sea Ecosystem Survey carried out in August-October 2020, surface, deeper, and bottom waters were still warmer than the 1981-2010 average (by 1.4, 0.5 and 0.7°C on average, respectively) in most of the Barents Sea.

Barents Sea ice extent was still below the 1981-2010 average. There was almost no ice in the sea from July to November. Due to much warmer-than-normal air temperatures in summer and autumn 2020, ice formation started later than usual. The 2020 annual mean ice coverage of the Barents Sea was 11% below average and 2% less than in the previous year.

Norwegian Sea
Annual temperature averages in 2020 were close to the long-term means at both the Svinøy-NW and Sørkapp-W while it was 0:3°C below the long-term mean at the Gimsøy-NW section.

Iceland
Mean annual air temperature in 2020 was slightly above average in southern Iceland (Reykjavik), and continued to be above average in northern Iceland (Akureyri). The temperature in the Atlantic water south of Iceland in spring was close to the long-term average but 0.3°C lower than the year before. In North Icelandic waters the temperature decreased by 1.5°C in spring and the salinity of decreased by 0.09 psu but both temperature and salinity continued to be above the long-term average.

Rockall Trough
Temperature of the upper 800 m remained close to the 1981-2010 mean in 2020. The upper ocean had been cooling relative to a peak of 9.8°C in 2007 though this cooling appears to have halted or slightly reversed in 2019 and 2020.

Southwest Approaches
Station E1 (50.03°N; 4.37°W) is situated on the southern UK coast in the western English Channel. Measurements have been taken at station E1 since the end of the 19th century, with data currently available since 1903. The spring and early summer of 2020 posted temperatures around the long-term mean (at the surface) but some heat during the late summer manifested as temperatures in excess of 19°C during August. At 50 m, temperatures were above the series mean for the first half of the year; around average for the summer months until the breakdown in stratification vented warmer temperatures throughout the water column. The autumn and early winter were slightly above the long-term mean.

Celtic Sea
For the M3 buoy (off SW Ireland) sea surface temperature time series, cool conditions continued and the mean in 2020 was 0.36°C below the 2003-2010 mean. Monthly mean sea surface temperature values were near or below normal throughout the year.

North Sea

The 2020 IROC report includes two time-series for the North Sea; one based on an average of sea surface temperature across the whole region, but also observations from a specific monitoring station at Helgoland Roads in the southern North Sea. Based on both time series, 2020 was warmer than the long-term average. The annual mean of area-averaged North Sea SST was 11.0°C (+0.7°C compared to the long-term average). The annual local average at Helgoland Roads in the southern North Sea was 11.8°C (+1.5°C). Temperatures in January to March and in November to December were particularly elevated (were ≥+1°C) as were temperatures in June (+1.1°C). The area-averaged summer SST (July-September) of 14.2°C was about 0.3°C below the 1981-2010 mean. In the summer, distinct differences occurred in the bottom layer, which showed negative anomalies up to -1°C in the western North Sea, but positive anomalies in the central and eastern part of up to +3°C above the Dogger Bank and +2:5°C south of Norway and west of Jutland. The differences between surface and bottom temperature in the central North Sea was about 6°C and up to 8°C south of Norway.

Annex 3
Fish Stock Recruitment in 2020 and 2021

ICES defines 'recruitment' as *"The amount of fish added to the exploitable stock each year. For example, the number of fish that grow to become vulnerable to the fishing gear in one year would be the recruitment to the fishable stock that year. This term mostly used in referring to the number of fish from a year class reaching a certain age. For example, all fish reaching their first year are age 1 recruits"*.

There have been many hundreds of scientific papers in recent decades that have linked the 'recruitment' of fish to prevailing climatic conditions, and in particular, sea surface temperature (SST), the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO).

Some fish species recruit into the fishery within the first year of life (e.g. sprat), whereas others (for example North Sea saithe) only enter the fishery as recruits after 3 or 4 years, due to a quirk of behaviour and migration patterns. Table 1 provides up-to-date recruitment estimates for commercial fish of interest to UK fisheries, as derived from ICES stock assessments carried out in 2021.

- For many (if not most) stocks and species, recruitment in 2020 and in 2021 was suggested to be poor, when compared to the long-term average (1980-2010).
- The exceptions to this include Barents Sea cod and haddock (in 2020) as well as several pelagic species (North Atlantic mackerel, North Sea sprat, Irish Sea herring, North Atlantic blue whiting) that have benefited from strong year-classes entering the population in recent years.
- Several warm-water species (e.g. North Sea Turbot, Western English Channel sole) witnessed strong recruitment in both 2020 and 2021, and several stocks exhibited strong recruitment in 2020 but not in 2021 (North Sea Norway pout, whiting and sandeel, Bristol Channel/Celtic Sea sole, Celtic Seas, Bay of Biscay monkfish).

For stocks experiencing continued poor recruitment (those indicated in red), it may be necessary for managers to lower fishing pressure going forward (see projection studies reported below), in order to ensure long-term resilience and persistence of these populations.

Species	Stock	Average recruitment 1980-2010 (thousands)	2020 recruitment (thousands)	2021 recruitment (thousands)
Cod	North Sea	864,928	271,264	186,075
Cod	Western English Channel & southern Celtic Seas	10,613	1,488	1,526
Cod	Northeast Arctic (Barents Sea)	551,559	561,552	557,000
Cod	Iceland Grounds	145,130	143,159	130,766
Cod	West of Scotland	11,293	3,928	5,005
Haddock	North Sea, West of Scotland	10,985,199	13,682,503	6,640,480
Haddock	Irish Sea	414,825	6,914	371,740
Haddock	Western English Channel & southern Celtic Seas	455,435	136,259	312,600
Haddock	Rockall	76,542	14,947	50,739
Haddock	Iceland Grounds	80,266	15,733	167,484
Haddock	Northeast Arctic (Barents Sea)	264,892	440,809	158,028
Mackerel	Northeast Atlantic	4,014,246	5,743,130	4,367,513
Horse Mackerel	Northeast Atlantic - west (8, 2.a, 4.a, 5.b, 6.a, 7.a–c and 7.e–k)	4,750,315	1,083,960	2,345,380
Blue Whiting	Northeast Atlantic & adjacent waters	18,348,232	29,805,438	20,982,149
Norway Pout	North Sea	45,160	56,504	24,117
Sandeel	Central & southern North Sea, Dogger Bank (4.b–c, Sandeel Area 1r)	162,338,312	52,640,692	110,640,139
Sandeel	Eastern Scotland (divisions 4.a–b, Sandeel Area 4)	122,981,438	303,836,413	73,785,221
Herring	North Sea, Skagerrak & Kattegat, eastern English Channel	37,371,419	24,676,200	30,422,300
Herring	Irish Sea	189,136	470,241	284,959
Herring	Celtic Sea, & southwest of Ireland	563,632	320,017	164,568
Sprat	Skagerrak, Kattegat & North Sea	87,298,883	94,106,900	127,373,950
Plaice	Irish Sea	20,128	6,098	12,994
Plaice	North Sea	1,294,363	1,390,640	1,263,949
Plaice	Eastern English Channel	67,732	34,881	742,35
Turbot	North Sea	4,434	6,374	4,566
Sole	North Sea	161,682	48,146	113,711
Sole	Irish Sea	5,689	2,931	
Sole	Bristol Channel, Celtic Sea	5,649	6,434	5,055
Sole	Eastern English Channel	25,819	17,791	23,489
Sole	Western English Channel	4,492	11,728	4,967
Saithe	North Sea, Rockall & West of Scotland, Skagerrak and Kattegat	147,634	31,492	71,483
Whiting	North Sea & eastern English Channel	17,091,372	21,546,571	14,140,017
Whiting	Irish Sea	315,815	129,971	119,971
Whiting	West of Scotland	570,436	202,293	202,757
Whiting	Southern Celtic Seas & western English Channel	1,192,448	395,701	533,781
Megrim	West & southwest of Ireland, Bay of Biscay	233,347	221,690	
Monkfish (white)	Celtic Seas, Bay of Biscay	34,340	48,519	32,708

Table A3.1. Average stock recruitment for species of interest to commercial fisheries in the United Kingdom, compared to the reference period 1980-2010. Lower=red, Higher=blue.

Consultees

1. David Anderson, Aberdeen Fish Producers Organisation
2. Lucy Blow, New England Seafood International
3. Will Clark, Wilsea Ltd
4. Ian Gatt, Scottish Pelagic Fishermen's Association
5. Cameron Moffat, Young's Seafood Ltd
6. Jennie Montell, Espersen
7. Malcolm Morrison, Scottish Fishermen's Federation
8. Dale Rodmell, National Federation of Fishermen's Organisations
9. Robert Stevenson, Lunar Fish Producers Organisation Ltd
10. Julie Waites, Frozen At Sea Fillets Association
11. Laky Zervudachi, Direct Seafoods Ltd

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