Marine Fisheries

Summary

Key policy messages

Overall, it is considered that climate change could have a material impact on the feasibility of achieving the 25 Year Environment Plan (25YEP) fisheries goal of '*ensuring that all marine fish stocks (in UK waters) are recovered to and maintained at levels that can produce their maximum sustainable yield (MSY), while protecting the wider marine environment'***.** Climate change has the potential to reduce the maximum sustainable yield, as well as impacting on the marine environment. The studies available suggest a decline in catch potential for England, for example, with up to 60% in a 4°C world by the end of the century. Climate change is therefore likely to make it harder to achieve the outcome, and could constrain the ambitions in the 25YEP. These impacts are likely to be much greater (disproportionately so) under a 4°C pathway. Climate change may also alter the suitability of different marine areas for different species, and thus affect Marine Protected Areas (especially when these have been designated for specific species). However, climate change does not feature heavily in the Fisheries White Paper, indeed, there is only one mention of climate change in the entire document, and there is no mention of climate change in the draft Fisheries Bill. Given the importance of these documents for driving future policy, this omission represents a major policy gap.

This study has identified that there are additional adaptation options that can address these impacts, although further research is needed (especially on the implications of climate change on the achievability of the 25YEP target and the costs and benefits of adaptation to meet this). An initial analysis here identifies that the key early adaptation priority is to enhance existing activities that use adaptive management, improving information (from monitoring, research etc.) to iteratively and flexibly adapt fisheries policy. Initial analysis indicates there could be an increase in fishery value (through the value of information) of approximately 10% from such an approach, with a high positive benefit to cost ratio. This would involve the use of information to inform policy, e.g. in setting maximum catch potential, including new species, combined with information of threats and opportunities to fisherman. We also note that increasing the proportion of 'no-take' Marine Protected Areas around the UK to 8.5% of total area (fully protected MPAs are currently about 3% while all MPAs are 24%) and would have potentially large economic benefits.

What is the objective and outcome?

The 25 Year Environment Plan (25YEP) (HMG, 2018) has a key theme of ensuring clean, productive and biologically diverse seas and oceans. The plan includes a target for 'ensuring that all fish stocks are recovered to and maintained at levels that can produce their maximum sustainable yield'. The plan also refers to the need to restore and protect the marine ecosystem. Following the 25YEP, Defra has also produced a White Paper (Defra, 2018), the consultation document on *Sustainable Fisheries for Future Generations*. This sets out the aim to build a sustainable UK fishing industry by taking responsibility for managing fisheries resources within UK waters, while continuing to protect and improve the marine environment. We have therefore considered a fisheries outcome of *ensuring that all marine fish stocks (in UK waters) are recovered to and maintained at levels that can produce their maximum sustainable yield (MSY), while protecting the wider marine environment.*

This outcome is still quite broad, and neither the 25YEP nor White Paper set specific targets or deadlines (for achieving MSY). For this reason, this study has developed a broad Theory of Change / logic model to better articulate the outcome.

It is stressed that the impact of Brexit will have large consequences for the sector, but as these are extremely difficult to predict currently, we have focused the analysis on the 25YEP and Fisheries White Paper goals as they are presented.

How does climate change affect the outcome, in a 2 vs 4°C pathway?

The study has looked at the impacts of climate change on the sustainability of fisheries, to investigate how climate change (considering 2 and 4°C scenarios) might affect the outcome of maintaining maximum sustainable yield of fish stocks (in UK waters). It is stressed that these effects need to be seen against the background of existing fishing activities that dominate many fish stocks, i.e. climate change is an additional threat multiplier, and further, that the analysis of these changes is uncertain.

There are a large number of pathways by which climate change could affect the outcome (Barange et al., 2014; Barange et al., 2018). While most of the focus in the literature has been on sea temperatures and species shifts (e.g. Cheung et al., 2010: Cheung et al., 2013), extreme temperature events are also important (Smale et al., 2019). The potential effects of climate change on fisheries may be direct (on landed species) or indirect, through the ecosystem, for example affecting species lower down in the food chain or changing marine habitats. Ocean acidification also poses a major threat to shellfish species (Mangi et al., 2018) and climate change could also have impacts on fishing activities (distance travelled) and safety at sea (marine storms) (Woolf et al, 2013). Climate change is likely to impact on the marine environment and ecosystems services these provide, thus affecting the secondary goal of protecting the wider marine environment.

These changes are projected to lead to alterations in fish populations: sizes, juvenile recruitment, and geographical distribution, affecting maximum sustainable yield and catch potential (Brown et al., 2016: Barange et al., 2018). There are also likely to be impacts on fishing fleets: distance travelled, catch type, and values of catch (Frontier, 2013). The overall net impact could be positive or negative, and will vary by marine zone.

Studies on climate change impacts on fisheries in the UK indicate that on average, changes in catch potential for species could range from -15% to -18% on a 2°C degree pathway by mid- and end- of century respectively (RCP 2.6); and -18% and -35% by mid- and the end of century under 4°C pathway (RCP 8.5) compared to current levels (Barange et al., 2018). In England, it has been estimated that impacts on potential catch relative to present (1991-2000 baseline) level will be around -20% in both climate scenarios up to 2050s, but diverge significantly after then, with more significant reductions under a 4°C degree scenario by the end of the century (-60%), mostly due to a decline in shellfish stock and landings (Fernandes et al., 2017).

The analysis of risks has also considered thresholds and the potential for lock-in. There are clearly many thresholds associated with the marine environment, and the suitability for species. These also include extreme temperature thresholds. The study has also identified an interesting issue of lock-in (i.e. the potential for large increases in future risk from a lack of early policy action that are difficult or costly to reverse later) with marine protected areas (MPAs), where these are set up on the basis of biogenic habitats. This is because they are chosen based on their historic marine climate suitability. With climate change, the potential suitability of these areas for some species is likely to change. Many features for which MPAs have been designated are potentially vulnerable to climate change, meaning the ongoing utility of MPAs as they are currently designated could be affected. This highlights the need to consider climate change when looking at future MPA siting and reasons for the designation.

What are the economic costs of climate change, i.e. the effect on the outcome?

Given that the information on future impacts on fisheries from climate change is uncertain, it is difficult to estimate the economic costs of these effects. There are some studies that provide partial estimates, and these indicate the losses in revenue from productivity and catch changes could be as much as 20% of current levels by 2050, for England (Barange et al., 2018). The evidence suggests these losses could be driven largely by the negative impacts on shellfish catches (Fernandes et al., 2017). Much larger losses are projected to occur after 2050, i.e. under high emission scenarios, there is a rapid increase in economic costs to the fisheries sector.

What are the potential adaptation options to address these impacts?

Climate change does not feature heavily in the Fisheries White Paper, indeed, there is only one mention of climate change in the entire document, and there is no mention of climate change in the draft Fisheries Bill. The Second National Adaptation Programme (NAP2) (Defra, 2018) does identify some activities in place, for example, the Sea Fish Industry Authority (Seafish) annual climate change updates for the capture fishing industry, and there are plans for climate to be included in forthcoming Marine Plans. However, given the scale of potential impact, there is a clear potential adaptation gap in the policy framework for fisheries.

This study has then considered the potential adaptation options that could be introduced to help deliver the 25YEP/White Paper target, i.e. to close the adaptation deficit. There are a large number of fisheries adaptation options, addressing different risks, but most of these are extensions of existing policy and comprise (Poulain et al., 2018) institutional adaptation (policy, legal, fisheries management and planning [including conservation and protection]), diversification (within and between the sector), risk preparedness and reduction.

These potential options have been considered using a high-level adaptation pathways approach focused on three areas. The first is early low and no regret options that address current risks and build resilience, including information and awareness raising for capture fisheries, ensuring improved fisheries management (taking account of climate change), and maintaining healthy and productive stocks and systems. The second is focused on 'climate-smart' decision making, notably for marine protection areas (noting these could be considered to be low-regret), as these need to be sited / considered with the future climate in mind. These would address the second part of the outcome on protecting the marine environment. The third is on early planning / iterative adaptive management, focusing on monitoring (marine climate, acidification, species abundance and distribution), etc. with a feed back into fisheries policy (e.g. to set maximum catch potential for current species, but also to include new species in policy) and to raise awareness of changes to fisherman, to provide information to help them adapt.

We highlight that there would be large benefits from fisheries policies taking a more adaptive management-based approach, given the uncertainty in the future risks and opportunities from climate change. This is likely to be a key priority for delivering the 25YEP under climate change, i.e. to iteratively monitor and adjust fisheries policy responses, and to pass this information back to fishermen, to support climate smart investment decisions.

What are the benefits and potential costs of adaptation?

The final step has been to consider the costs and benefits of additional adaptation actions, to get the outcome back on track. This is challenging, as it is compounded by the lack of information on the economics of adaptation for fisheries. For this case study, we focus on the costs of a number of key adaptation options that could help address the impact of climate change on the 25 YEP / Fisheries White Paper goal and target in England.

The first option is to develop an <u>adaptive management approach for the fisheries</u> sector in England. This involves a scale up in monitoring, scientific information and awareness raising. Indicative costs have been assessed, based on the scale-up of current research and monitoring activities, and their potential benefits (based on Costello et al. 2009). This analysis indicates there could be an increase in fishery value (through the value of information) by approximately 10%, which has a positive benefit to cost ratio.

The second option is to further increase Marine Protected Areas to improve the marine environment in the face of climate change, and also enhance fisheries. More marine areas – with full protection – could be required to deliver the same level of ecosystem service function/benefit as now, due to the marginal impact of climate change. The literature indicates MPAs deliver significant benefits (Heal and Rising, 2014; Moran et al., 2008; Kenter et al., 2013; eftec, 2014; European Commission, 2017), both environmental and economic: when used as a fishery management approach alongside quota and effort-based approaches, they can contribute to increasing yields (if they are designed well). The literature indicates that the average break-even point for economic benefits (expressed as landed catch values) of MPAs where fishing is restricted is 8.5% of marine area. This would mean that in the UK an additional 195,000 Km^2 should be protected for economic benefits to be realised, at an estimated annual average cost of approximately £73.5 million. It is stressed, however, that additional MPAs need to be designed and sited with future climate change in mind, i.e. to be climate smart.

Finally, there is a question of whether other options might be introduced to ensure maximum sustainable yields are maintained under climate change (option 3). This involves some complex issues because of trade-offs. There are many options that could enhance the efficiency and effectiveness of the fishing industry, and thus help address climate risks, but if the fishing industry is more efficient, it would also then be in a position to increase catch (i.e. this would put greater pressure on maximum sustainable yields). An alternative is to introduce stricter policies to reduce maximum sustainable yields, or to reduce fishing pressure in the short-term to allow stock enhancement and larger MSY later, in effect to build in contingency for climate change. However, this would involve important downsides (catch potential) for the fishing industry. Other than MPAs, the review has not found any obvious answers. The analysis of additional options, and trade-offs, is highlighted as a key question for future analysis.

Step 1. What is the objective and the outcome?

The Defra 25 Year Environment Plan (25YEP) (HMG, 2018) has a theme on ensuring clean, productive and biologically diverse seas and oceans. The plan includes a specific target for 'ensuring that all fish stocks are recovered to and maintained at levels that can produce their maximum sustainable yield'. The plan also refers to the need to restore and protect the marine ecosystem. Following the 25YEP, Defra has also produced a White Paper on *Sustainable fisheries for future generations*. This sets out the aim to build a sustainable UK fishing industry by taking responsibility for managing fisheries resources within UK waters, while continuing to protect and improve the marine environment (Defra, 2018). It recommends an ecosystem approach to fisheries management, which aims for more sustainable management and accounts for, and seeks to minimise, impacts on non-commercial species and the marine environment generally. This involves '*restoring and maintaining the healthy fish stocks and marine environment which underpin a prosperous fishing industry'*. There is also a Fisheries Bill that is currently passing through Parliament, which is a framework bill that will provide the Government with powers to set annual total allowable catches for UK waters post EU-Exit, and powers to the amend the fisheries regulations that will be transposed from EU legislation.

Against this background, we have therefore considered for this study an outcome related to the 25 YEP and White Paper of *ensuring that all marine fish stocks (in UK waters) are recovered to and maintained at levels that can produce their maximum sustainable yield, while protecting the wider marine environment.*

It is noted that the explicit mention of fisheries in the 25 YEP relates to marine fisheries and not inland and migratory species, including inland (freshwater) fisheries. We take the same approach in this paper and exclude non-marine fisheries.

This case study has started with an analysis of the outcome. The approach proposed by Defra is an ecosystem-based approach that applies the principle of Maximum Sustainable Yield (MSY), when setting or agreeing total allowable catches. Success in achieving this Outcome is defined in Defra's White Paper in general terms as 'the ability to rebuild and maintain stocks, while improving the health of our marine ecosystems and adapting to changes including the impacts of climate change'. However, a clear, quantifiable target (e.g. in terms of current levels of stock that need to be maintained, or ecosystems services that should be preserved to current levels) is not set in the 25YEP, and there is no fixed deadline, including in the White Paper (unlike the current target for the Common Fisheries Policy). Therefore, we have developed an outline Theory Of Change (ToC) and logic model that would meet the broad outcomes set out in the 25 YEP and Fisheries White Paper, and achieving this by the end of the 25YEP period, i.e. 2043.

The main responsibility for delivering this Outcome is with Defra, as the lead policy maker on fisheries for England; and secondly with the implementing agencies. The Sea Fish Industry Authority (Seafish) supports the industry to work for a sustainable, profitable future and offers regulatory guidance and services to all parts of the seafood industry.

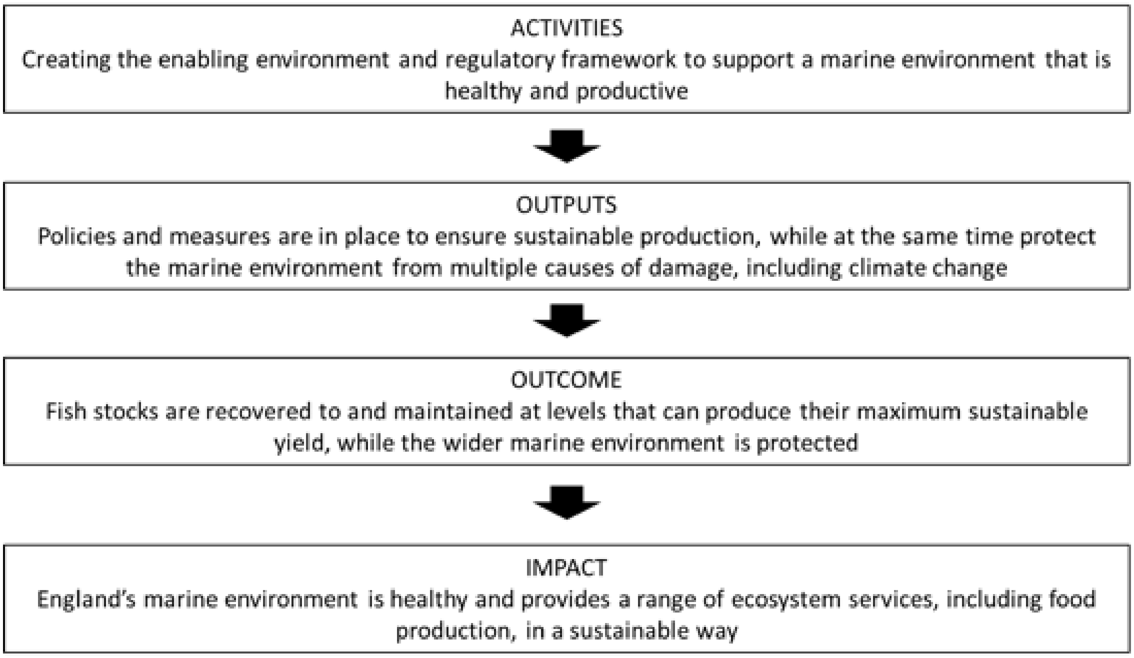

Figure 1. Illustrative Logic Model for Fisheries

EU and international fisheries policies, and translation into UK regulation

Currently, the fishing industry operates within a complex regulatory framework, largely determined at the EU level. The main source of laws governing fisheries in English waters is the EU Common Fisheries Policy (CFP). The CFP's objective is to be 'environmentally, economically and socially sustainable' and to contribute to the availability of food supplies. There is no explicit mention of climate change in the original text or subsequent amendments, although there is discussion of environmental conditions and sustainable use[1].

However, as reported by Defra (2018), if/when the UK leaves the EU, it will become an independent coastal state under international law (UN Convention on the Law of the Sea (UNCLOS)) and will have the right to control and manage access to fish in UK waters out to 200 nautical miles or the median line. It is stressed that the impact of Brexit will have large consequences for the sector, but exact changes are difficult to predict currently, thus this analysis does not take different possible EU-Exit scenarios into account.

Alongside the CFP, the EU Marine Strategy Framework Directive (MSFD) established a framework within which member states are required to "take the necessary measures to achieve or maintain good environmental status" (GES) in the marine environment by the year 2020 at the latest. Good environmental status is determined on the basis of a set of descriptors. The MSFD has been written with the explicit knowledge that marine systems are dynamic and it includes adaptation and exception

[1]Limits on fish caught, total allowable catches (TACs), are set by the Council of Fisheries Ministers, following proposals by the European Commission based upon scientific assessments of managed fish stocks. Once a TAC is agreed for each stock and fishing area, it is allocated as quotas to Member States in accordance with fixed percentages based on historic fishing rights. Exploitation of shellfish stocks in UK waters is generally regulated through national legislation (the Sea Fisheries (Shellfish) Act 1967) or local bylaws. The Straddling Fish Stocks and Highly Migratory Fish Stocks Agreement (1982) is part of the implementation of the United Nations Convention on the Law of the Sea (UNCLOS) and aims to "ensure the long-term conservation and sustainable use" of straddling fish stocks (e.g. cod and halibut) and highly migratory fish (e.g. tuna and oceanic sharks). The need to manage stocks in line with prevailing marine environmental conditions is clearly recognised within the agreement, including the use of best available science to maintain or restore stocks at levels capable of producing maximum sustainable yield (Article 5).

sections that require climate and environmental variability be taken into account. In addition, the Marine and Coastal Access Act (2009), Marine (Scotland) Act (2010) and the Marine Act (Northern Ireland) 2013 set out how marine activities will be managed across the UK. The UK Marine Strategy Regulations (2010) requires the UK Government and Devolved Administrations to develop a UK Marine Strategy that applies an ecosystem-based approach to decisions on activities undertaken in, or affecting, the marine strategy area. The Marine Strategy put in place a comprehensive programme of measures designed to meet the biodiversity targets set to protect marine habitats and species in order to achieve good environmental status (GES) by the end of 2020.

There is also a global target on marine protected areas. The United Nations' Convention on Biological Diversity (CBD) established a target of 10% of the ocean to be protected by 2020 ('Aichi Target 11'). UN Sustainable Development Goal 14 adopts and reinforces this commitment. Furthermore, in 2014, the World Parks Congress recommended increasing this to ≥30%, and following a review (O'Leary et al. 2016), the IUCN World Conservation Congress in 2016 recommended the goal of protecting 30% of the ocean in 'highly protected' areas by 2030. Even though the 30%-by-2030 target is not binding, it does represent the most ambitious target adopted so far for MPAs[2]. The IUCN also produced guidelines in 2012 stating that 'spatial areas which may incidentally appear to deliver nature conservation but do not have stated nature conservation objectives should not automatically be classified as MPAs'. These include areas that are primarily fishery management areas. The UK (excluding its overseas territories) reports that it protects 24% of its seas in 314 MPAs (http://jncc.defra.gov.uk/page-4549), see Table 1. Yet only a small percentage is not categorised as Exclusive Economic Zones[3], which cover an area of some 766,309 km^2 (Napier, 2017).

Table 1 UK Marine Protected Areas

UK waters[4]	UK waters area (km^2)	Number of MPAs	MPA area (km^2)	UK waters covered (%)
All UK waters	884,859	314	209,185	24
Inshore	163,388	276	58,550	36
Offshore	721,472	57	150,635	21

Source: http://jncc.defra.gov.uk/page-7619. Some MPAs cross the inshore/offshore boundary. These MPAs contribute to both the inshore and offshore MPA counts, so these counts cannot be summed to give the total MPA count. The total number of MPAs figure should be taken from the All UK waters row.

Fisheries White Paper

The focus of the Fisheries White Paper is heavily focused on the opportunities offered from Brexit to set fisheries policies (as an independent coastal state). Climate change is mentioned only once in the entire White Paper, in the chapter on promoting sustainable fishing.

Success will ultimately be measured by our ability to rebuild and maintain stocks, while improving the health of our marine ecosystems and adapting to changes including the impacts of climate change. This will require long-term planning on the part of all four Fisheries Administrations and their deployment of the full range of measures within our control including catch limits, discard controls,

[2] 'Fully protected' is an area where all fishing, mining, oil and gas or any other extractive activity or destructive activities such as dumping are prohibited; 'strongly protected' is where only minimal recreational or artisanal fishing occurs.
[3] An Exclusive Economic Zone is a sea area defined in International Law that extends up to 200 nautical miles (371 km) from the coast. The outer limit of the EEZ, and the area of the EEZ, are sometimes referred to as the '200-mile limit' or the 'fisheries limit'. Within its EEZ a country is entitled to control the exploitation of fish and shellfish.
[4] UK waters include: UK Exclusive Economic Zone (EEZ) and the UK continental shelf; Inshore - waters between the coast (here defined by mean high water (springs) and the UK Territorial Sea limit (up to 12 nautical miles out); and Offshore - waters between the UK Territorial Sea limit and the UK Exclusive Economic Zone or UK continental shelf.

gear selectivity, spatial and temporal closures, minimisation of by-catch, and a strong compliance mechanism.

The 2nd National Adaptation Programme (NAP2) (Defra, 2018) sets out that Seafish, the industry body with a remit to support the profitability and sustainability of the seafood industry, will publish a climate change adaptation report under the third Adaptation Reporting Power round. This will describe the steps that the fisheries and aquaculture sectors are taking to respond to climate change, and including risks and opportunities in the UK aquaculture sector (such as new species that can be cultured in warmer waters). Seafish will also continue to produce annual climate change updates for the wild-capture fishing industry to provide surveillance of new fishing opportunities.

A Fisheries Bill is currently progressing through Parliament[5]. The Bill sets out provisions for policy objectives in relation to fisheries, fishing and aquaculture, access to British fisheries, the licensing of fishing boats, the determination and distribution of fishing opportunities, schemes to be established for charging for unauthorised catches of sea fish, grants in connection with fishing, aquaculture or marine conservation, the recovery of costs in respect of the exercise of public functions relating to fish or fishing, and to confer powers to make further provision in connection with fisheries, aquaculture or aquatic animals, and byelaws and orders relating to the exploitation of sea fisheries; and for connected purposes. The Bill does set out sustainability, precautionary, ecosystem and scientific objectives[6], that very much align to the White Paper, i.e. with an ecosystem-based approach and maximum sustainable yield. There is not any mention of climate change in the Bill.

The Fishing Industry in the UK and England

The gross value added (GVA) for fishing has fluctuated in recent years. In 2017, GVA for fishing stood at £795 million. In 2017, the UK fishing industry had 6,148 fishing vessels, 43 vessels fewer than in the previous year. There were an estimated 11,692 fishermen in 2017, of these, 5,299 were based in England (MMO, 2018). In 2017, UK vessels landed 724 thousand tonnes of sea fish (including shellfish) with a value of £980 million. Demersal species accounted for the largest share of English fleet landings, although there were significant shares in pelagic and shellfish too. England has the highest number of vessels among the UK countries, though it is second to Scotland with respect to the fleet's capacity. English vessels landed approximately 200,000 tonnes of fish in 2017, with an estimated value of just above £300 million, second to Scotland (£550 million). The shellfish industry is an important part of the fisheries economy contributing 38% of total landings by value in 2017. In England, the shellfish industry contributed £139m (55,600 tonnes) to the economy; demersal species £153.4m (76,700 tonnes) and pelagic £44m (67,100 tonnes). It is highlighted that the UK is a net importer of fish: in 2017, imports of fish and fish preparations was 705 thousand tonnes; exports were 460 thousand tonnes. There is therefore a trade gap (impacts – exports). These figures are shown in Figures 2, 3 and 4 below.

[5] https://services.parliament.uk/Bills/2017-19/fisheries.html

[6] The "sustainability objective" is to ensure that fishing and aquaculture activities are—
(a) environmentally sustainable in the long term, and
(b) managed in a way that is consistent with the objectives of achieving economic, social and employment benefits, and of contributing to the availability of food supplies.
The "precautionary objective" is—
(a) to apply the precautionary approach to fisheries management, and
(b) to ensure that exploitation of living marine biological resources restores and maintains populations of harvested species above biomass levels capable of producing maximum sustainable yield.
The "ecosystem objective" is—(a) to implement an ecosystem-based approach to fisheries management so as to ensure that negative impacts of fishing activities on the marine ecosystem are minimised, and
(b) to ensure that aquaculture and fisheries activities avoid the degradation of the marine environment.
The "scientific evidence objective" is—
(a) to contribute to the collection of scientific data, and
(b) to base fisheries management policy on the best available scientific Advice

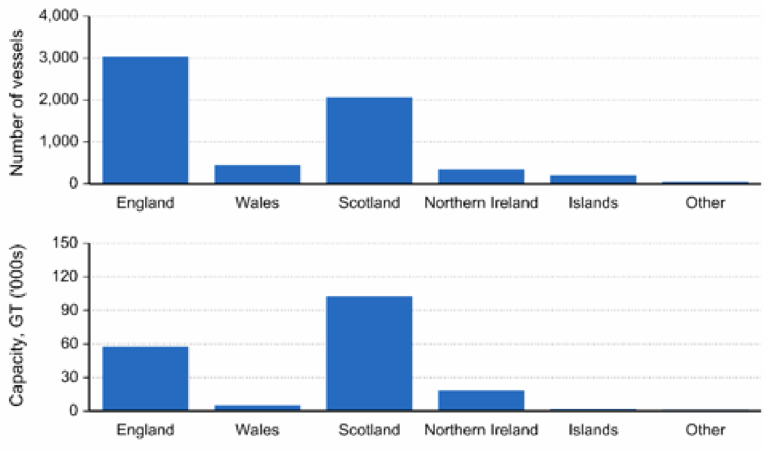

Figure 2 Size of the UK fishing fleet by country: 2017 (MMO, 2018)

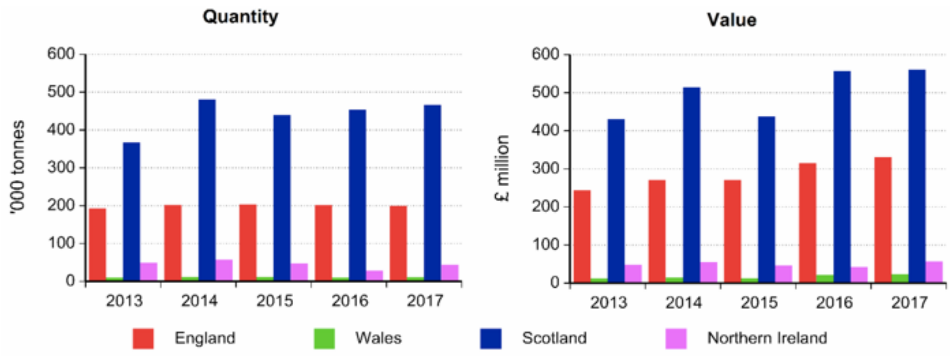

Figure 3 Quantity and value of landings into the UK and abroad by UK vessels by vessel nationality: 2013 to 2017 (MMO, 2018)

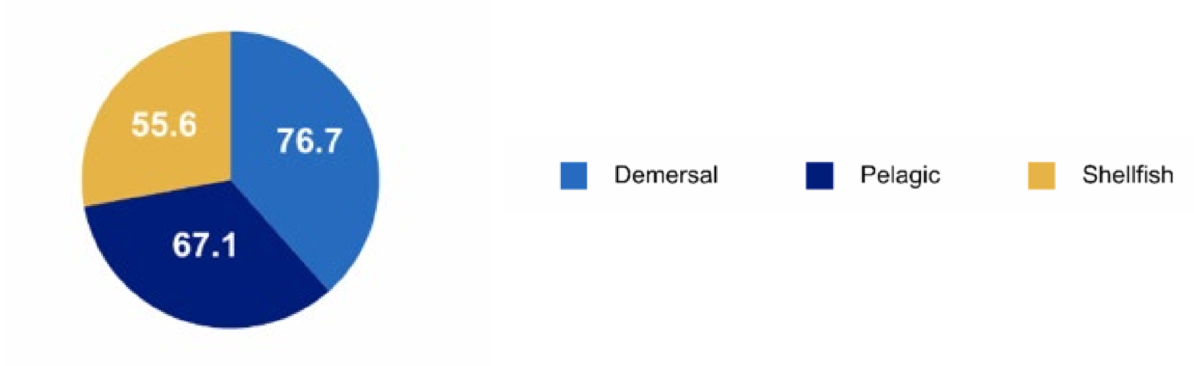

Figure 4 Value of landings for English vessels (into the UK and abroad): 2017 ('000 tonnes)

Step 2: What is the challenge of meeting the outcome in a 2 and 4°Cworld?

The next step is to understand the impact of climate change on the target above, i.e. on ensuring that all fish stocks are recovered to and maintained at levels that can produce their maximum sustainable yield, while protecting the wider marine environment. Fishing is a "harvesting" activity and human activities dominate the abundance and distribution of many marine organisms. Fisheries already face a range of social, economic and environmental pressures. Climate change is an additional pressure on the marine environment (including fish stocks), whose resilience is already low due to these other pressures. However, climate change could have potentially large impacts on the fishery and aquaculture sectors (Porter et al., 2014; Barange et al., 2018). These future impacts are expected to result in a number of changes in the abiotic (i.e. sea level, sea temperature, oxygen levels, salinity, currents, acidity) and biotic (i.e. primary production, food webs) conditions of the sea, affecting reproductive success, growth and size, disease resistance, as well as distributional patterns and composition of fish and shellfish. There are also potential impacts from climate change on critical habitats for fisheries (e.g. corals), as well as potential impacts on vessels and fishermen from changes in the intensity and frequency of storms and other extreme weather events. Finally, there are potential impacts of sea level rise and storm surge, as well as other extremes, on the infrastructure and value chains associated with the fishing industry. However, all of these changes need to be seen against the background of existing human activities, which dominate the abundance and distribution of many marine organisms and fish stocks, i.e. climate change is an additional threat multiplier.

Recent climate trends for the marine environment
Some changes have already been observed in the UK (as reported in the CCRA2 Evidence report (Brown et al., 2016), the progress report (CCC, 2017) and the latest MCCIP report card):

- **Temperature:** Sea-surface temperatures (SST) in UK coastal waters and the North-east Atlantic have risen by between 0.1 and 0.5°C/decade since the 1980s. The EU research project Climate Change Impacts on the Marine Environment (CLAMER) reports clear evidence from all European seas that rising temperatures, along with overfishing, are causing changes to fish stocks, as well as to their ranges and migration routes. Warmer water fish are gradually moving north.
- **Salinity:** The salinity of the upper ocean (0 – 800 metres) to the west and north of the UK has generally been increasing over the last three decades.
- **Storms and wave height:** Waves and storm-force winds are a significant feature of UK waters. Wind and wave time series data show large variability including inter-annual and inter-decadal fluctuation. Some studies indicate that over the last century there has been a significant increase in the intensity of strong winter storms for the high latitude North Atlantic region reaching to the north of the UK (Woolf and Wolf, 2013 in CCRA2). These storms are a factor in safety at sea.
- **Acidification**: Ocean acidification is linked to increasing atmospheric CO_2. North Sea pH has decreased at a rate of around 0.0035 pH units per year (Ostle et al., 2016 in CCRA2). Recent studies have reported an overall decreasing trend in pH of –0.0035 ± 0.0014 per year, indicating acidification for the surface (Williamson et al., 2017). Ocean acidification in UK seas over the last 30 years has been happening at a faster rate than for the wider North Atlantic (MCCIP, 2017).
- **Oxygen concentrations:** Reduced oxygen concentrations in marine waters have been cited as a major cause for concern, and there is evidence that areas of low oxygen saturation have started to proliferate in the North Sea (Breitburg et al., 2018). Dissolved oxygen is an important component of aquatic systems.
- **Plankton production**. There have been impacts on plankton production, biodiversity and species distribution, and in the North Sea the population of the previously dominant coldwater zooplankton species have declined and warmer water species are moving northward.

These changes are leading to fish stock movements and changes in geographical distribution. For example, CCRA2 (2017) reports that warming has led to some cold-water demersal (bottom-dwelling) fish species moving northwards and into deeper water (e.g. cod, plaice), while some warm-water demersal species have become more common (e.g. John Dory, red mullet). Warm-water species with smaller maximum body size have generally increased in abundance while cold-water, large-bodied species have decreased. Pelagic fish species are showing marked distributional shifts, with mackerel now extending into Icelandic and Faroe Island waters, whilst sardines and anchovies are moving into Irish and North Sea environments (CCRA 2). Analysis of Scottish and English commercial catch data spanning the period 1913-2007 has revealed that the peak catches of target species such as cod, haddock, plaice and sole have all shifted distribution latitudinally, albeit not in a consistent way (Engelhard et al., 2011 in CCRA 2): over the past century, for example, cod catches have also shifted steadily north-eastward and towards deeper water in the North Sea. The MCCIP (2017) reports that for the past 10 years, the number of juvenile cod entering the population has remained very low despite dramatic decreases in fishing mortality and this sustained reduction is thought to be a result of climate change. Also, cephalopod (squid, cuttlefish and octopus) populations around the UK are expanding in response to warming: squid numbers have increased dramatically, allowing an important summer trawl fishery to be developed (Kröger et al. 2018). Changes in mackerel distribution have also been recorded and been linked to a combination of factors, including warmer seas, changes in food availability and a range expansion of the stock into Faroese and Icelandic waters (MCCIP, 2017). There is also evidence of changes in sole, sandeels (Fincham et al., 2013; Heath et al. 2012 in CCRA 2, Chapter 3). There is also evidence that warming has been influencing the relative timing (phenology) of fish annual migrations and spawning events in European waters, which can have significant effects on population sizes and juvenile recruitment. Where spawning is too early or too late to capitalise on available food resources, annual recruitment can be strongly affected.

Future climate change impacts on the marine environment

Looking at future changes, climate change is expected to act as a further challenge, compounding threats to the sustainability of fisheries (FAO, 2018). However, these linkages are extremely complicated, as shown in Figure 5 below. They include both positive and negative effects, depending on the region and latitude, and are expected to affect not only fish production but the entire value chain, with effects also on prices, trade and consumption of fish and fish products, by changing competitiveness and patterns.

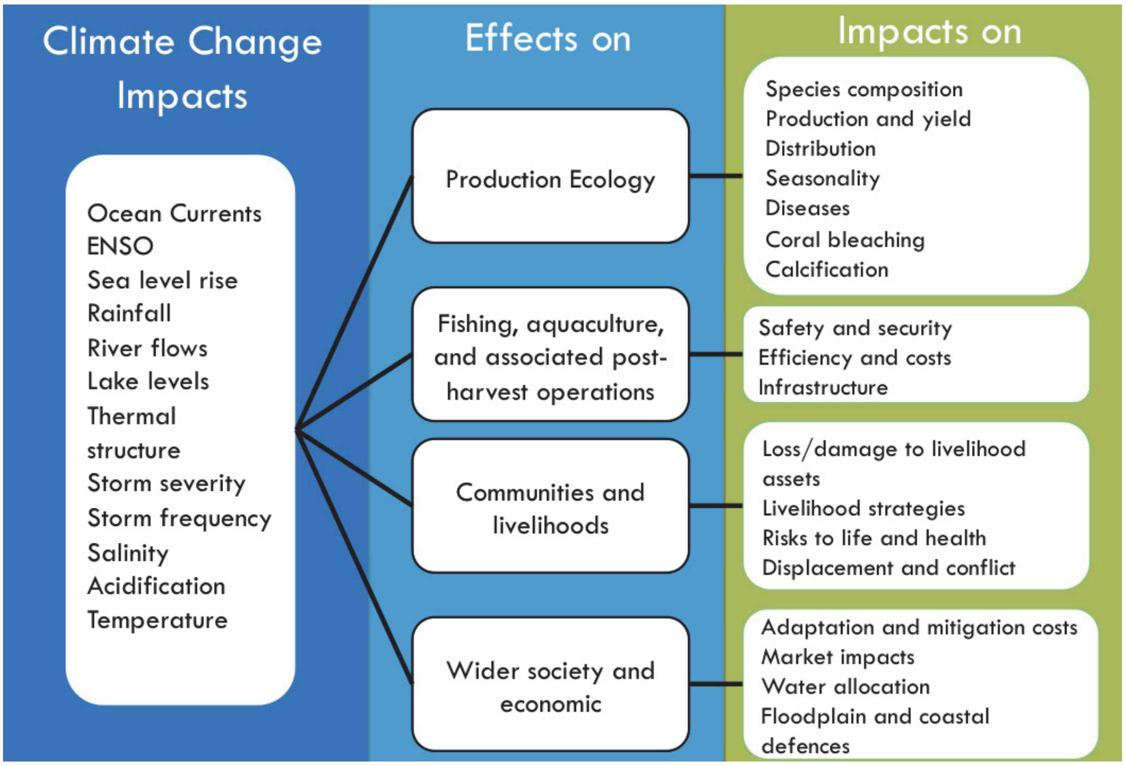

Figure 5 Climate Change and Fisheries. FAO, developed from Badjeck et al, 2010.

It is clear that climate change has the potential to affect the White Paper fisheries outcome. However, assessing the impacts of climate change on fisheries is challenging, because of the complexity of pathways outlined above. There are a number of methodological approaches that have been used (Barsley et al., 2013; Brugère and De Young, 2018). For economic analysis, a number of approaches have been used (Tröltzsch et al., 2018) including ecological trophic modelling, statistical analysis, statistical forecasting, time-series analysis, GIS based analysis and coupled modelling approaches.

Impacts of climate change on fisheries

The main focus to date has been on the impact of climate change on rising sea surface temperature – and changes in the distribution of fish biomass and productivity, and thus catch potential. MCCIP (2017) reports that climate change models project that SST will continue to rise in all waters around the UK, with strongest warming in the south- east (1.5 – 4.0°C over the 21st century in the southern North Sea) and weakest in the north-west (0.5 - 2.0°C at Rockall). These changes can be used to model the potential changes in annual catch (including in monetary terms) and the redistribution of stocks or catch potential with climate change (Cheung et al., 2009; Cheung et al., 2010; Cheung et al., 2013; Blanchard et al., 2012; Merino et al., 2012; Barange et al., 2014). Overall, these studies report that fisheries productivity will increase in high latitudes and decrease in mid- to low latitudes (Porter et al., 2014), primarily due to species shift.

Cheung et al. (2010) estimated future changes in maximum potential catch (a proxy for maximum sustainable yield) given projected shifts in the distribution of 1,066 species of exploited marine fish and invertebrates from 2005 to 2055 as a result of climate change and changes in marine primary productivity. This indicates a large-scale redistribution of global maximum catch potential, with an average of 30% to 70% increase in yield of high-latitude regions (north of 50^{o}N in the northern hemisphere), but a drop of up to 40% in the tropics. In this study, the findings indicated the UK might benefit from increased net yields of 1-2% by-2050; although achieving this positive effect would require action to maximise opportunities. An update of this analysis, FAO (2018), shown in Figure 5, based analysis on a slightly modified version of the same bio-climate envelope model (DBEM) and found slightly different results. Globally, the total maximum catch potential in the world's exclusive economic zones (EEZs) was projected to decrease under climate change by 2.8% to 5.3% (RCP2.6) and 7% to 12% (RCP8.5) by 2050 relative to 2000. The projected decrease in catch under RCP8.5 becomes 16% to 25% by the end of the century. The projected changes in maximum catch potential varied substantially across EEZs in different regions, with EEZs in tropical countries showing the largest decrease. Catch potential in the temperate Northeast Atlantic was projected to decrease in the mid-term (2050s). The projected changes in catch potential in the high latitude regions are much more variable between models, time periods and EEZs because of the high variability in projected oceanographic changes between different Earth system models.

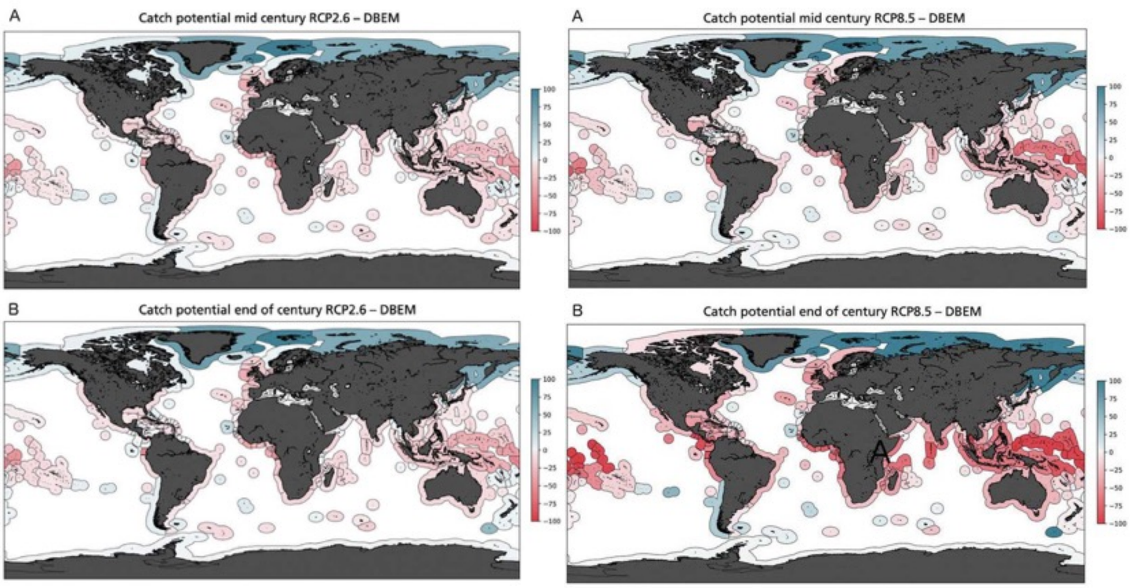

Figure 6 Projected changes in maximum catch potential (%) under RCP2.6 (left) and RCP 8.5 (right) by 2050 (A: 2046 to 2055) and 2095 (B: 2091 to 2100) for the DBEM projections

This study estimated that on average, changes in catch potential for the UK could range from -15% to -18% by mid-century on a 2°C degree pathway (RCP 2.6); and reach -35% by the end of century under a high emission scenario or 4°C pathway (RCP 8.5). Table 2 below summarises the findings, showing the average change for the UK, as well as the variability (range) around the average, representing the different estimates from the array of climate models used to drive the fisheries projections.

Table 2 Projected changes in catch potential (%) by 2050 and 2100 relative to 2000 under RCP2.6 and RCP8.5 (FAO, 2018)

	DBEM model: Mid Century RCP2.6		**DBEM model: Mid Century RCP8.5**		**DBEM model: End Century RCP2.6**		**DBEM model: End f Century RCP8.5**	
	Average	Range	Average	Range	Average	Range	Average	Range
UK	-15.1	29.9	-17.9	43.4	-17.7	25.5	-34.5	49.3

However, other studies provide different findings. A recent study by Gaines et al. (2018) estimated the impact of climate change on fishery productivity and changes in stock distribution (range shifts) under various climate scenarios. The authors report global MSY (weighted mean) is expected to change by 1.0, −1.5, −5.0, and −25.0% under RCPs 2.6, 4.5, 6.0, and 8.5, respectively. However, they find these mask great variation in changes across stocks. While some stocks essentially go extinct (MSY declines by 100%), others increase. Overall, approximately 41, 53, 66, and 91% of global stocks experience a projected decline in total MSY by 2100 under RCPs 2.6, 4.5, 6.0, and 8.5, respectively. They also found that the percentage of species stocks that shift across country boundaries by 2100 increases with the severity of the climate projection. The percentage of individual species that will shift across EEZs ranges from 36% (RCP 2.6) to 81% (RCP 8.5). These shifting stocks comprise between 27.8 and 71.7% of the current global MSY. Under RCPs 6.0 and 8.5, most species that shift across EEZs experience shifts both into new and out of old EEZs.

This highlights that it is the distribution of species, as well overall catch potential, that is important, especially as values differ. Jones et al. (2013) used the estimates from three species distribution models for 14 commercial fish in the Northeast Atlantic to look at the UK EEZ, under an IPCC A2 scenario. Their findings projected poleward shifts at an average rate of 27 km per decade. That is slightly faster than (20 km per decade) currently observed for fish in the North Sea (Dulvy et al., 2008).

Table 3 Results of modelling of changes in habitat suitability and latitudinal centroid shift between 1985-2050 Jones et al, 2012

Common Name	Change in habitat suitability across the UK EEZ (1985-2050)		Latitudinal centroid shift northward (km) (1985-2050)	
	Median of three models	Range of three models	Median of three models	Range of all three models
European squid	31%	+9 to +53%	445	308-625
European sea bass	20%	-9 to +24%	275	224-399
European pilchard	17%	+2 to +30%	314	178-322
European sprat	13%	+4 to +21%	224	148-278
Veined squid	7%	+4 to +11%	211	140-251
John Dory (Atlantic)	7%	-16 to +17%	264	-153(s) -428
European anchovy	5%	+1 to +7%	320	18-1192
Common sole	2%	-18 to +18%	112	-24(s) - 232
European plaice	2%	+1 to +8%	205	105-389
Whiting	1%	-14 to +4%	97	-14(s)-190
Atlantic cod	0%	-12% to +3%	223	149-343
Atlantic Herring	-2%	-20 to -1%	168	62-748
Atlantic mackerel	-3%	-7 to 0%	206	97-337
Atlantic halibut	-4%	-15 to +1%	172	27-311
Haddock	-6%	-12 to 0%	195	50-454
Red mullet	-10%	-14 to +28%	263	-27(s)-432
European hake	-10%	-11 to +2%	150	29-293
Saithe	-12%	-18 to -2%	172	78-596

A further important effect is the impacts on shellfish. Fernandes et al. (2017) estimated that under different climate scenarios, warming and acidification impacts together could reduce the biomass levels of demersal species and shellfish. Figure 7 reports the percentage decadal changes in biomass for the five shellfish and demersal species in 2090–99 vs. 1990–2000. In general, their findings suggest that in England biomass of demersal species are likely to increase under low emission scenarios (up to +40% for sea bass) and diminish under high emission scenarios (over -60% for cod); and that shellfish biomass is generally expected to decline gradually under higher-emission levels, potentially reaching -80% for some species (cockle). As one would expect, impacts are more significant under a 4^{o}C degree pathway (RCP 8.5) than under a 2^{o}C degree pathway (RCP 2.6). Note that the spread of pathogens in warm waters is also likely to increase, potentially posing a threat to human health through shellfish contamination.

The increase in seawater temperature will also impact the wider marine environment and ecosystems, though the net overall change is hard to predict. Although there is high confidence that climate change is causing physical changes to the marine environment, the ecological impacts are much harder to assess because of the complexity of ecosystems and the potential for threshold effects when key species are lost (CCRA 2, 2017, Chapter 3).

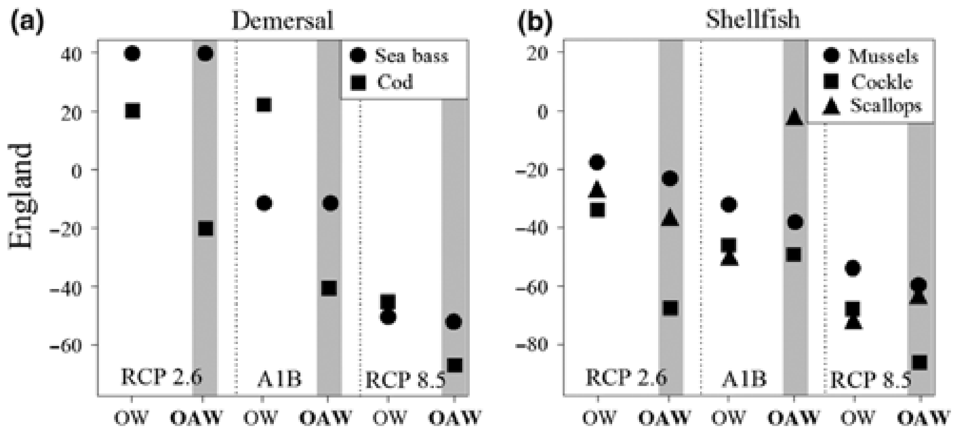

Figure 7 Percentage decadal changes in biomass for the five species shellfish and demersal species in 2090–99 vs.1990–2000

The scenarios are ordered from lower (RCP 2.6) to higher emissions (RCP 8.5) and with increased parameterization: OW, only warming impacts considered, OAW, considering both warming and acidification impacts. A1B refers to an intermediate climate scenario. Pelagic species are excluded due to lack of combined OAW experiments.

MCCIP (2017) reports that some established non-native species have expanded their range in the UK which may be in response to warming sea surface temperatures (e.g. Pacific oyster). However, there is still poor understanding of the link between SST and long vs. short term trends, information on species lifestyles, life histories and their thermal affinities. Similarly, many seabird species in the UK are likely to face a continuing shift northwards in habitat suitability and prey availability and some species could become extremely rare or even extinct.

There is also an increasing concern about extreme temperature, as these are important drivers of change for the marine environment. Marine heatwaves (MHW)[7] can have greater and longer-term impacts than slow mean temperature changes on ecosystems. A recent study (Oliver et al. (2018) found significant increases in both the frequency and duration of marine heatwaves, amounting globally to a 54% increase in annual marine heatwave days between 1925–1954 and 1987–2016. The literature reports that marine heatwaves result in substantial ecological and economic impacts.

There are also a number of other potential effects from other changes in marine conditions, including salinity, storminess, acidification and oxygen concentrations (see Met Office, 2018). Of these, the most concern is around acidification. In the Regional Ocean Acidification Modelling (ROAM) project of the recently completed UK Ocean Acidification Research Programme (UKOA), a coupled physical-ecosystem model was used to project future values for pH and aragonite saturation state for the North Western European Shelf (see Ostle et al., 2016). The model suggests a clear decrease in both pH and saturation state, with areas around the south coast of Norway showing the strongest decrease. Surface waters will start to become under-saturated gradually from around 2030 and more rapidly from 2080. Importantly, the UK is ranked third among the 25 nations most vulnerable to ocean acidification due to the high level of catch within its exclusive economic zone (EEZ) and the level of acidified water along its coast predicted by 2050 (Harrould-Kolieb et al., 2009). The evidence suggests that the effect of ocean acidification on marine ecosystems will be negative, although some algae and seagrasses may benefit from increased availability of CO_2 (MCCIP, 2017).

Potential for threshold effects and lock-in

The analysis of risks has also considered thresholds and the potential for lock-in. There are clearly many thresholds associated with the marine temperature environment and the suitability for species.

[7] MHWs occur when SSTs exceed a seasonally varying threshold, defined as the 90th percentile of SST variations based on a 30-year climatological period (1983–2012), for at least five consecutive days.

These also include extreme temperature thresholds. A key issue, however, is whether there is the potential for irreversible losses for marine ecosystems (or particular species). This could threaten important marine environments, e.g. cold-water corals. It is also noted that historic climatic change does seem to have some correlations with past fishery collapse (Hannesson, 2011), including for European seas, suggesting at least some role in addition to human influence, and highlighting the potential for threshold effects that might exceed the limits of some of these options.

The study has also identified an interesting issue of lock-in (i.e. the potential for large increases in future risk from a lack of early policy action that are difficult or costly to reverse later) with marine protected areas. MPAs, particularly where these are set up on the basis of biogenic habitats, are chosen based on their historic marine climate suitability. With climate change, the potential suitability of these areas might change. This highlights the need to consider climate change when looking at MPA siting. Many features for which MPAs have been designated are potentially vulnerable to climate change, meaning the ongoing utility of MPAs as a conservation tool could be affected. Where an MPA has been identified for its physiographic features (e.g. large shallow inlet and bay) or seabed features (e.g. mudflats or rocky reef), climate change could result in changes to the constituent flora and fauna, rather than the distribution or extent of the feature itself. Such changes are unlikely to compromise the achievement of conservation objectives (CCRA2, 2017). In contrast, where the main feature of an MPA is a named biogenic habitat (e.g. seagrass beds) or a species, the consequences of climate change could compromise the achievement of conservation objectives. In a worst-case scenario, species or habitats could be lost entirely (CCRA2, 2017). The designation of MPAs therefore carries a lock-in risk, when areas are selected based on their current characteristics and ignore the changes projected to occur under a changing climate.

Step 3. What are the economic costs of climate change, i.e. the effect on the outcome?

The next step in the analysis is to estimate the economic costs of failing to achieve the outcome (as a result of climate change). Following on from above, these costs are challenging to estimate. The loss of potential/sustainable catches have both economic and environmental impact, with the latter being potentially substantial if such losses are in ecosystems and habitats and are irreversible. Some studies that are available have been summarised below, with estimates of £hundreds of millions, however, we stress that these estimates are partial, i.e. they do not include all species or all impacts.

There is some literature that provides some potential values. Fernandes et al. (2017) modelled the potential effects of ocean warming and acidification on fisheries catches, resulting revenues and employment in the United Kingdom under different climate scenarios (RCP2.6 and 8.5, with a comparison of SRES A1B). They estimated that stock biomasses were projected to decrease significantly by 2050 and the main driver of this decrease was sea surface temperature rise. Overall, losses in revenue were estimated to range between 1% and 21% in the short-term (2020 to 2050) with England and Scotland being the most negatively impacted in absolute terms. They also estimated losses in total employment (fisheries and associated industries) could reach 20% during 2020 to 2050 with the small vessel (less than 10 m) fleet and associated industries bearing most of the losses. The analysis found that for England, the high-emission scenario would have the most significant negative impacts by 2090s, for demersal and pelagic fish (-15%), and most significantly for shellfish (-40%). Longer-term impacts by 2100, relative to current projected yields under MSY showed that a lower emission scenario would involve decreases up to 30%, similar to shorter term projections, whereas a higher emission scenario could drive decreases of up to 60%.

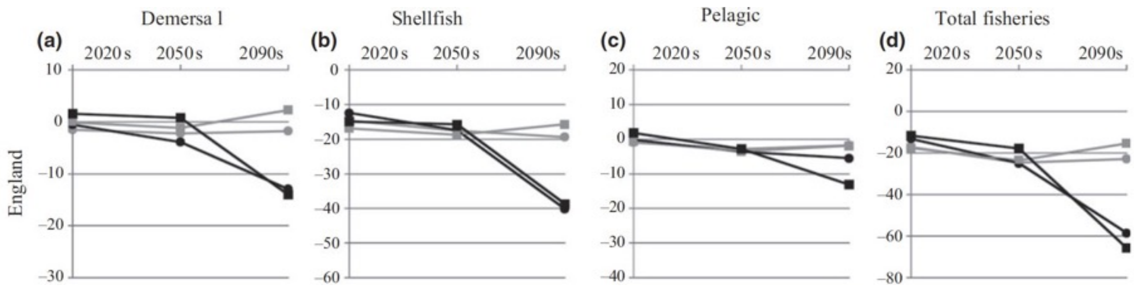

Figure 8 % change in average catch potential during three 'future' decadal periods (2020s: 2011–20, 2050s: 2041–50 and 2090s: 2090–99) relative to the 'present' (1991–2000). Fernandes et al. (2017)

The 'total fisheries' represents the effect on total catches that would occur with the projected changes in demersal and shellfish species. These results are presented for lower (RCP 2.6) [grey line] and higher (RCP 8.5) [black] emission scenarios using OAW reparameterization, and for both >10 [square] m and <10 m [round] fleet.

The study also estimated the monetary impacts of such changes, and the implications on employment. Table 4 below shows that, in general, losses are driven by the negative impacts on shellfish total catches, particularly for larger vessels and under higher emission scenarios (-£100m, or 80% of total losses, by the end of the century). For England the <10 m vessels would be more highly impacted post-2050. Some positive impacts on demersal and pelagic species catch could be seen by 2020 in the >10 m fleet under high-emission scenarios, but not enough to mitigate losses to the shellfish harvest. This will affect the profitability of the fleet, and even if prices go up in the future, they are unlikely to compensate for demersal and shellfish catch losses that are more targeted by smaller vessels fleet at the country level. No other positive impacts on pelagic species catch were observed by 2050 and 2100 for England. There will also be indirect impacts. For example, losses will be greatest for the associated industries (e.g. boat building), as well as direct losses from the fishing industry itself. Employment could be affected directly in the fishing sector. Fernandes et al. (2017) estimated that of the total jobs lost by 2050 for the low-emission scenarios, England would lose 1446 FTE directly in the fisheries sector (63% of total estimated jobs).

There are a number of other studies. Using cost-benefit analysis, Mangi et al. (2018) estimated the potential economic losses to UK shellfish wild capture and aquaculture under medium and high CO_2 emission for molluscs and crustaceans. They found – see Table 5 - that losses (expressed in NPVs using a 3.5% discount rate up to 2100) could reach up to £300m and £599m for molluscs; and £387m and £775m for crustaceans under medium and high emission scenarios respectively. Looking at all shellfish, in England, reduced production could range from 16% to 33% of fishery NPV. This equates to annual economic costs of between £1 and £2 billion, for medium and high scenarios.

For large vessels (>10m) Pinnegar et al. (2012) assessed the costs of travelling further to catch current species at £1 to 9 million annually in the 2020s across the range of emissions scenarios; and potentially £10 to £99 million in later periods. Small vessels are restricted from travelling and so are not as likely to be able to benefit from opportunities arising further way from the UK shoreline. Access to capital and cost of new vessels is a critical issue, especially for smaller enterprises. The Economics of Climate Resilience study (Frontier Economics, 2013) estimated a new boat can cost up to £1m, and a second hand one £750,000.

Finally, even those areas which have been designated as Marine Protected Areas (MPAs) could be at risk, or efforts to protect them could become unsustainable. In the UK, as of March 2018 approximately 24% of UK waters were within MPAs. Of 314 MPAs, there are 115 Special Areas of Conservation (SACs) with marine components, 112 Special Protection Areas (SPAs) with marine components, 56 Marine Conservation Zones and 31 Nature Conservation Marine Protected Areas (http://jncc.defra.gov.uk/page-4549).

Table 4 Total economic impact (direct, indirect and induced) of ocean acidification and warming (OAW) on fisheries activities by 2020s, 2050s and 2090s in terms of output revenue (£ m) and full-time equivalent (FTE) employment disaggregated between small and large fleets in the four nations and the two emission scenarios in relation to present (1991–2000). Source Fernandes et al. (2017)

				2020s		2050s		2090s	
Country				£ m	FTE	£ m	FTE	£ m	FTE
England	RCP2.6	<10 m	Demersal	−0.9	−17	−2.6	−49	−1.1	−21
			Shellfish	−14.3	−479	−17.2	−578	−19.0	−636
			Pelagic	−0.1	−1	−0.2	−2	−0.1	−1
			Total	−15.3	−497	−20.0	−628	−20.2	−658
		>10 m	Demersal	−0.2	−3	−2.0	−36	3.9	72
			Shellfish	−43.6	−1461	−48.5	−1624	−40.7	−1363
			Pelagic	−0.1	−1	−0.6	−7	−0.3	−4
			Total	−43.8	−1465	−51.0	−1668	−37.1	−1295
	RCP8.5	<10 m	Demersal	−0.4	−6	−2.4	−44	−7.9	−147
			Shellfish	−12.2	−409	−17.1	−573	−39.3	−1318
			Pelagic	0.0	0	−0.2	−3	−0.4	−4
			Total	−12.6	−415	−19.7	−620	−47.6	−1470
		>10 m	Demersal	2.6	49	1.2	23	−23.5	−437
			Shellfish	−38.6	−1292	−40.7	−1364	−100.0	−3351
			Pelagic	0.3	4	−0.4	−6	−2.1	−26
			Total	−35.7	−1240	−39.9	−1346	−125.5	−3814

Table 5 Time integrated NPV by 2100 of the potential economic losses to UK shellfish wild capture and aquaculture

Region	Scenario	Molluscs	Crustaceans	Wild capture	Aquaculture	All shellfish (wild + aquaculture)
UK	NPV with no impact of CO2	1847	4265	6995	1305	8301
	Medium Emissions	185–739	426–1279	700–2448	131–457	830–2905
	High Emissions	923–1478	1706–2559	2798–4897	522–914	3320–5810
	% loss from fishery NPV	10.6–21.1	18.3–36.6	11.8–23.6	2.2–4.3	14.0–28.0
England	NPV with no impact of CO2	749	1291	2572	466	3039
	Medium Emissions	75–300	129–387	257–900	47–163	304–1064
	High Emissions	374–599	516–775	1029–1801	187–326	1215–2127
	% loss from fishery NPV	11.6–23.3	15.1–30.1	13.8–27.7	2.5–5.0	16.3–32.7

NPV are in millions based on 2013 GB pounds sterling. The low and high end of each range is based on different effects sizes to show how sensitive the economic figures are to changes in biological impact. Source: Mangi et al. (2018)

Step 4. What are the potential additional adaptation options to address impacts?

While the 25 YEP does not mention climate change adaptation for fisheries, there is some discussion in the NAP2 (Defra, 2018).[8] However, there is almost no mention of climate change in the Fisheries white paper and no mention in the draft Fisheries Bill[9]. As these are the core policy documents for

[8] This sets out that the Marine Management Organisation will, by 2021, have prepared 10 marine plans, covering the whole of the English marine area, which will include policies for climate adaptation. The preparation of new plans will include horizon scanning to evaluate the potential longer-term risks and opportunities from climate change. In relation to MPAs, the NAP2 reiterates the 25YEP Goal: Increasing the proportion of well managed seas and better manage existing protected sites and continue to establish Marine Conservation Zones to contribute to an ecologically coherent network of Marine Protected Areas (MPAs).

[9] https://publications.parliament.uk/pa/bills/cbill/2017-2019/0305/18305.pdf

future fisheries policy, we **consider that there is a need for integration of adaptation into policy to ensure the future sustainability of fisheries as the climate changes.**

There are a number of studies that have looked at adaptation options for fisheries. Poulain et al. (2018), as part of the FAO fisheries adaptation toolbox. This splits adaptation into 1) institutional adaptation 2) livelihood adaptation and 3) risk reduction and management for resilience. This is set out below.

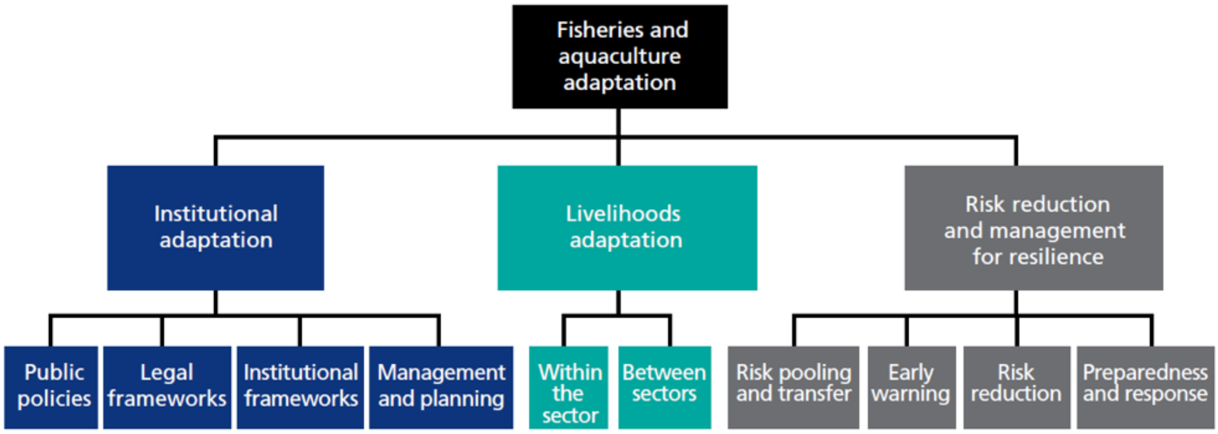

Figure 9 Categories of Adaptation Activities. Source Poulain et al., 2018.

Institutional adaptation

There are a range of institutional options which are already used, that can be introduced or enhanced in the face of climate change. These include public policy, legal frameworks, institutional frameworks and management, and planning, with examples such as fishing policies, fisheries management and planning, access rights, quotas, and fisheries buybacks. Note that this includes the enhanced enforcement and compliance of existing regulations and policies. Much of the focus has been on management options that try and address the issues of unsustainable practice (to enhance recovery of fish stocks). These management controls can be grouped into four types (Grafton, 2010):

- Catch controls – such as total allowable catch; dedicated catch shares; trip catch limits;
- Input controls – such as vessel licence controls; effort quotas; gear and vessel restrictions;
- Technical and temporal controls – such as season length; fishing gear specifications; size (minimum size) and gender selectivity restrictions;
- Spatial controls – such as 'no take' areas; territorial user rights in fisheries; individual vessel spatial licencing.

The European Environment Agency[10] reports that since the early 2000s, better management of fish and shellfish stocks has contributed to a clear decrease in fishing pressure in European regional seas. Signs of recovery in the reproductive capacity of several fish and shellfish stocks have started to appear. However, some studies highlight that the standard tools for fisheries management may not be sufficient to build resilience for future climate change (Grafton, 2010: Lane, 2010), as they focus on maintaining adequate levels of recruitment and maintaining (more sustainable) fishing stocks.

A number of studies have identified that spatial controls could be an important adaptation option, especially options that focus on conservation and protection. These natural resource management and ecosystem-based approaches are often reported in the literature as being cost effective, flexible, and broadly applicable (Munang et al., 2013 in Miller et al., 2018). While these are generally responses to current fishery levels, they are cited as a promising adaptation option. These include the

[10] https://www.eea.europa.eu/data-and-maps/indicators/status-of-marine-fish-stocks-3/assessment-1

introduction of marine protected areas (MPA) – see earlier discussion - and locally managed marine areas, as well as conservation and restoration of near-shore ecosystems, which are important for fisheries or play an important role in breeding or ecosystems.

The policy options include institutional options, such as strengthening and capacity building. There is general evidence on the benefits of capacity building and training in climate sensitive sectors, which report high BCRs for technical assistance (Mullan et al., 2015), although this review has found no specific evidence for fisheries in the climate domain.

An important set of management options relate to awareness raising. There are a set of options to take advantage of the threats and opportunities of climate change on fisheries (Frontier Economics, 2013). There can also be management choices to try and ensure opportunities for small vessel operators (e.g. it would be possible to look at prioritising new opportunities for smaller boats that operate on shorter distance, as compared to larger deep-water vessels).

Linked to this, there is a key need for enhanced monitoring. This is needed to capture the trends in the marine climate, in species (both fished species, but also the wider food chain and marine ecosystems), especially given the high uncertainty highlighted on future impacts. Monitoring is a key part of an iterative approach. This information can – over time – be used to raise awareness and inform fishermen. For example, with the emergence of new species, as well as the shift in current species. Monitoring is also strongly linked to the institutional options, and the setting of maximum catch potential. This highlights that there would be large benefits from fisheries policies moving to an adaptive management approach, i.e. to have an iterative cycle of monitoring, review, and learning.

Well-managed fish stocks are much less susceptible to climate impacts than those that are already heavily degraded as a result of overfishing. In some cases, fish stocks will not be able to sustain the same level of fishing pressure in the future as they have experienced in the past as a consequence of climate change. As highlighted above, other adaptation measures could include catch limits, discard controls, gear selectivity, spatial and temporal closures, minimisation of by-catch, and a strong compliance mechanism. These measures will require continued and close cooperation between the UK and European countries.

In the UK, fisheries are currently managed using a Total Allowable Catch or TAC (corresponding to a particular harvesting rate), and technical measures (mainly mesh sizes and minimum landing sizes, but sometimes closed areas, which determine the smallest fish that can be caught and landed) based on scientific advice. In past years, some seriously depleted stocks have become the subject of emergency measures and recovery plan proposals. Since 2003, the TAC for some of these stocks have been linked to effort control measures that restrict the number of fishing days at sea per annum permitted for fleets capturing recovery species (MMO, 2018).

It is worth noting that fishing restrictions and quotas could become increasingly challenging instruments to enforce given the continuous chances in stock distribution as a result of climate change, which clashes with the rigidity of the current rules and regulations. Moreover, such rigidity could itself constrain the ability of fishermen to spontaneously adapt to climate change. For example, rigid quota allocations have been the subject of disagreement between Norway and the EU in the past. Territorial and quota disagreements could become more frequent in the future (CCRA 2, 2017). The distribution of property rights are contentious, involve very high transaction costs and rent-seeking behaviour, and may be very difficult to reverse. This could be very important when the optimal outcome changes over time, for example due to natural fluctuations or to changes in demand and other economic factors (eftec, 2015).

Defra (2018) reports that the UK has been working together with EU Member States and other coastal states such as Norway towards setting exploitation rates that are consistent with Maximum Sustainable Yield (MSY). Out of 45 stocks that are MSY-assessed and targeted by the UK, 31 are now being exploited in line with MSY. Further, to prevent fishermen from discarding some of their catch before they are landed at ports to respect quota obligations (resulting in up to a million tonnes of fish being thrown back into EU waters each year), UK Ministers introduced a 'discard ban'. The EU landing obligation first came into force in 2015 for pelagic species (such as mackerel and herring). Demersal species (such as cod and haddock) were covered from 2016, with additional fisheries being gradually phased in each year until all quota species were covered by 1 January 2019.

Diversification
A further set of adaptation options are centred on diversification, within the sector and to other sectors. Many of these adaptations will be reactive, including autonomous and market responses. Under future climate change, the fishing industry will adjust reactively to declining catches or changes in distribution, and take advantage of the opportunities that may occur from changes in fish stocks and the distribution of species/changes in species composition. However, these responses could be facilitated with information, awareness, etc. from the public sector.

The costs and benefits of reactive changes will depend on the localised losses or opportunities faced, and thus have strong distributional patterns. This means that some areas of fishing sub-sectors will experience improvements in catch potential or value, while others will lose. These reactive adaptation options (Frontier Economics, 2013) may include increasing vessel capacity and changing equipment to fish for different species. Where there are losses, fishermen may also adapt reactively to try and enhance falling catches, e.g. with longer trips, fish aggregating devices, though these will involve additional costs from longer distances travelled, or the need to change equipment or to deeper water vessels. It is highlighted that an early low regret adaptation option is to increase awareness and communicate these changes to fishermen, noting enhanced monitoring of new species (Frontier Economics, 2013) falls to the public sector. Fishing vessel operators are used to dealing with constantly changing weather, stock sizes and market prices, hence there is an expectation that they will be able to autonomously adapt to climate change in the future. However, the adaptive capacity of some segments (e.g. small vessel operators) is likely to be more constrained than others. A range of actions currently being taken include: travelling further to fish for current species, if stocks move away from UK ports; increasing vessel capacity if stocks of currently fished species increase; changing equipment to fish for different species if new or more profitable opportunities arise (Resilience (ECR) report on "sea fisheries" for Defra, 2013). However, all these actions would come at a cost and/or have implications for the sector more broadly.

Further, stakeholders report that a shift from a medium-sized vessel to larger vessels might involve a change in their entire supply chain. Many skippers or vessel owners rely on the competitive advantage of getting fresh fish to supermarkets, restaurants or fishmongers within 24 hours. This relies on operating within a small, local area. Larger vessels, however, require more days at sea to exploit efficiency advantages, and resulting in fewer, larger landings. This could affect who their buyers are (ECR report, Defra, 2013).

In the ECR report (Frontier Economics, 2013) possible adaptation measures were presented as in a roadmap (Figure 10), though they are not monetised. In the short term, these were mainly focussed on ways to advance from the opportunities presented to the industry, with relatively less focus on the sustainability of yields and the health of marine environment in the face of climate change.

There can also be market (autonomous) adaptation from changes in aggregate production, prices and trade. This may lead to changes in supply chains (longer supply chains or alternatives) or it could lead to change in demand. For example, the CIRCLE modelling analysis of future climate change (OECD, 2015b) modelled changes in global fishery catch potential (linking to analysis from Cheung et al., 2008). Again, these changes can be encouraged by governments, e.g. stimulating domestic demand for a broader range of species, or through joined up retailer and media campaigns (Frontier Economics, 2013). Government is also likely to have a role if increased international trade is used to compensate for local falls.

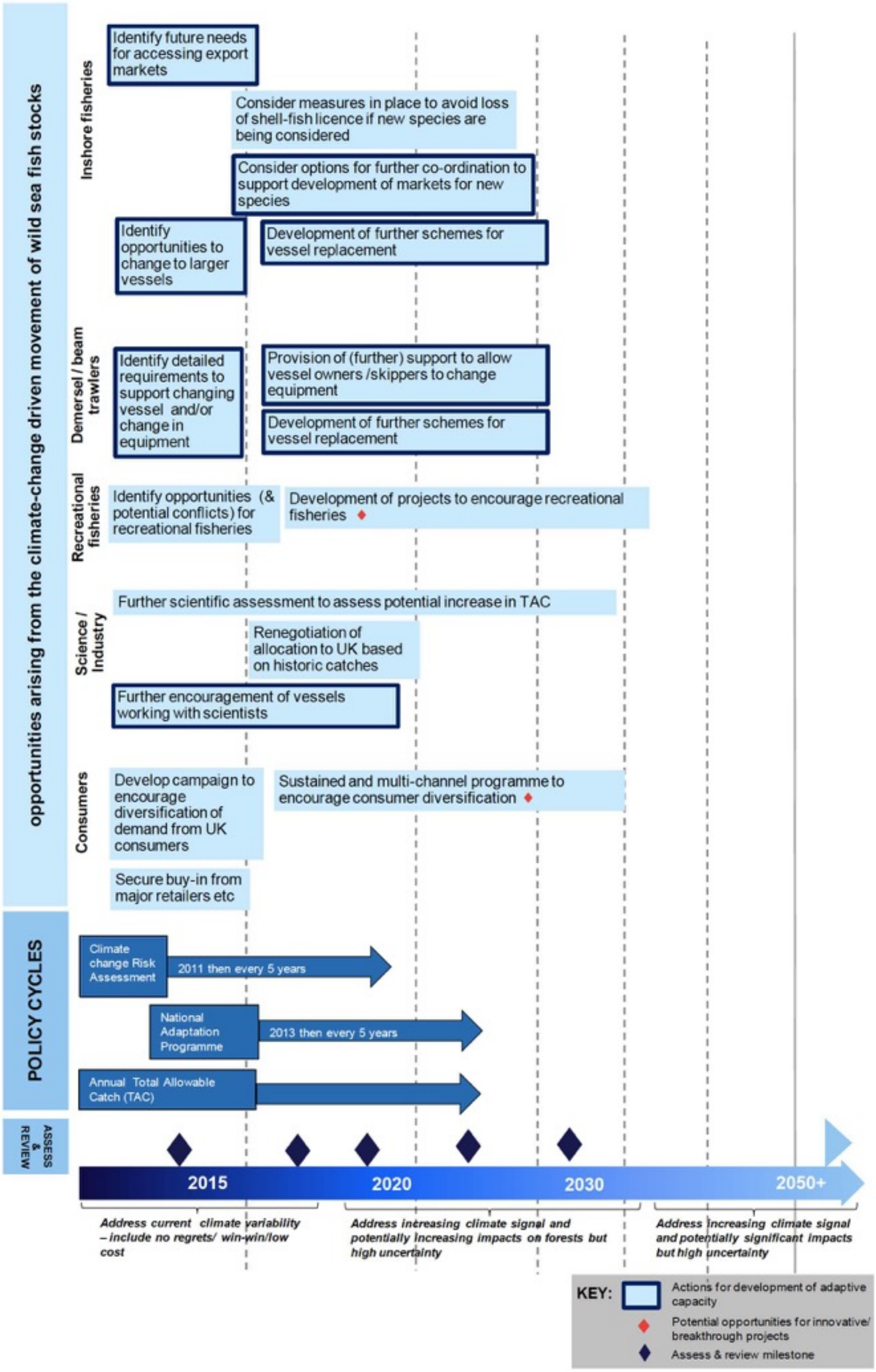

Figure 10 Adaptation Road Map for the fisheries Sector. ECR. Source: Frontier Economics 2013.

Raising awareness and stimulating domestic demand for a broader range of species could help build the resilience of the marine environment. For example, in 2011 Sainsbury's ran a campaign "switch the fish", that encouraged the supermarket's customers to try an "alternative" finfish species at reduced cost, including some of those that are more reflective of current climatic conditions in waters around the UK (e.g. mackerel, seabass, pollack, hake etc.). They also noted that it can take years to change preferences. Amongst the main barriers identified was taste, time of preparation, and price.

Alongside this, there is a set of diversification options within the sector which will be important for smaller-scale fishing, where reactive responses may be more difficult due to financial, information, barriers, i.e. there is a need for planned support. These impacts are likely to be relevant for near-shore fisheries, including shellfish. This might consider fisheries value chain development, e.g. support to diversification to other species or different markets. In the global context, there has included a major focus on mariculture and aqua-culture (i.e. diversification within the sector). It also extends to diversification between sectors, e.g. such as into tourism for smaller scale fishing.

There are a number of options that are focused on reducing and managing risks to fishermen, but these are less the focus of this case study. The one thing that is potentially relevant is enhanced weather and climate services for fisheries. While much of this has been focused on safety at sea, longer-term weather and seasonal forecasts can help fisheries management (Clements et al., 2013).

A high-level adaptation pathway

There is increasing use of a portfolio approach for fisheries. In 2015, Seafish published a report 'Understanding and responding to climate change in the UK wild capture seafood industry', which distinguished between domestic and international adaptation response:

- In a domestic context, suggested adaptation responses included: improving scientific advice and data collection through partnership working, reviewing fisheries governance for regulated and non-regulated species, enhancing vessel operational safety, investing in port resilience, and assessing freight ferry vulnerability.
- In an international context, suggested adaptation responses included: reviewing of key sources of existing supply and available options, assessing the impact of changes on specific regional supplies, ensuring international management regimes provide early resolution on 'rights to fish', incorporating climate change into vessel and gear design, and improving resilience and capacity of overseas facilities.

For this case study, we have extended the matrix of options above to a high-level adaptation pathways framework. This draws on Poluain et al. (2018) and a forthcoming FAO review of the economics of fisheries adaptation options. This uses the framework from CCRA2 and CCRA3 to focus on:

- Early low and no regret options that address current risks and build resilience;
- 'Climate-smart' incl. decision making under uncertainty (for early decisions with a long life-time / risk of lock-in);
- Early planning / iterative adaptive management, in cases where there are benefits from early activities / or adaptation that involves long-lead times.

Early low regret options

There are some early low-regret options that are explicitly focused on current climate risks, and either have large benefits now or else have low costs. These include capacity building (institutional strengthening, mainstreaming, technical assistance for climate change and adaptation), and awareness raising (of opportunities and threats). These actions would help address the impacts on the outcome, from the perspective of policy makers (setting fisheries policy) and fishermen (enhancing catch, or maintaining value under changing conditions). Frontier et al. (2013) – as part of the UK Economics of Climate Resilience study - identified low regret options as the enhanced monitoring of risks and opportunities (for the latter, new and more abundant species) and awareness raising to the industry – although we primarily place these in the type iii adaptation (iterative change).

There are also a set of early options that are recommended as part of climate smart fisheries and aquaculture (FAO, 2013)[11]. For capture fisheries, these include increasing productivity and efficiency in aquatic systems (reducing excess capacity, ensuring improved fisheries management, and maintaining healthy and productive stocks and systems), as well as reduced post-harvest losses. Some no-regrets measures could also include the protection of certain habitats. For example, the potential benefits of existing seagrass beds justify their active conservation, not least because they also represent important ecosystems and breeding/ nursery grounds for fish (UKOA Research programme, 2010-2016). This has, however, linkages with life-time and lock-in, and is discussed in the context of early decisions below. It is noted, however, that options that enhance the efficiency and effectiveness of the fishing industry, do not actually enhance the MSY, in fact if anything, they are likely to increase the pressure on targets.

Early decisions with lock-in or a long-life time

One option that is often promoted as a low-regret option is marine protected areas (see earlier discussion). However, these involve opportunity costs in the short-term (from loss of area access) even though they can increase catch potential in the long-term. As highlighted above, there is also a need to ensure the identification and designation of MPAs, conservation objectives, are sustainable under future climate scenarios.

An alternative might be to look at mariculture (or aquaculture). This involves a capital-intensive response, and thus has a degree of lock-in and a longer life-time. A key factor is that the choice of mariculture has to be climate smart, i.e. to make sure investment is in species/values chains that are robust to the future climate, to avoid maladaptation (i.e. not investing in species that are themselves vulnerable to rising sea surface temperatures). Philips and Perez-Ramirez (2018) highlight the need to consider climate change in new mari-aquaculture developments, both in relation to siting/location (taking account of the changing climate) and management practice. While primarily focused on warmer areas, the insight is relevant: the choice of location in the coastal zone needs to consider exposure to weather events, changes in currents, sudden influx of freshwater as well as longer-term trends such as rising temperature and salinity and decreasing oxygen levels.

It is stressed that further research is needed (especially on the implications of climate change the target achievability and the costs and benefits of adaptation for the target), including under 2 and 4°C worlds.

Early investments for long-term climate change/long lead times

The final set of options are those targeted at early planning to help preparing for long-term climate change. The main focus is on enhanced monitoring, research and pilots (to the changes from climate change) to help build the evidence base to inform future adaptation and broader fisheries management, i.e. the first steps in adaptive management. This includes investment in biophysical monitoring (i.e. sea surface temperature, acidification levels, etc.) as well as monitoring of fish species and distribution, complemented with modelling analysis. It also includes early research into potentially major long-term impacts (acidification). This is likely to be a key priority for achieving the 25YEP and Fisheries White Paper, i.e. for monitoring to help inform the maximum sustainable yield, and to subsequently adjust fisheries policy responses, e.g. future quotas, fishing rights etc. There is also an iterative feed-back loop to pass this information back to fishermen, to make sure that they make climate smart investment decisions.

---

[11] Climate smart fisheries and aquaculture aim to deliver a triple win of sustainably increasing output productivity and efficiency within the sector, enhancing the resilience of the sector to climate change impacts, and to contribute to the mitigation of greenhouse gases emissions (across the value chain).

Technology could support the collection and use of data and information to develop a much more transparent regime, learning from coastal states such as Norway, Iceland and the Faroe Islands (Defra, 2018). In the UK, scientific work on ocean acidification and its impacts is being carried out by a wide range of UK research centres, university groups, government bodies and other organisations. In 2010 most of that effort was brought together by the UK Ocean Acidification (UKOA) research programme, a £12.4 million, five-year initiative funded by Defra, DECC and NERC that reached its conclusion in June 2015. Subsequent work funded by Defra (the PLACID initiative) has aimed to sustain monitoring programmes and to investigate consequences for commercial shellfish specifically. Efforts are also underway (funded by NERC) to collate all available pH and carbonate chemistry measurements for UK waters as an input to the next OSPAR Quality Status Report Intermediate Assessment, scheduled for 2017 (CCRA2, 2017).

In 2016 two EU-funded Horizon 2020 research projects (CERES and CLIMEFISH) were commissioned with the aim to "provide the knowledge, tools and technologies needed to successfully adapt European fisheries and aquaculture sectors in marine and inland waters to anticipated climate change". This will include economic assessments of climate change impacts on these two sectors, but also the development of practical adaptation measures that fishermen, farm managers and aquatic resource managers can adopt to successfully adapt to forthcoming climate change threats or to capitalise on emerging opportunities (CCRA2, 2017).

There is scope for improving the largely trend-based methodology of sustainable stock assessments, to a full assessment of each species. However, attempts to change the process have been resisted by the European regulators. Reactive assessments to build scientific knowledge take time and therefore could lead to maladaptation (Defra, 2013).

Step 5. What are the benefits and costs of adaptation, including trade-offs?

The final step has been to consider the costs and benefit of adaptation. A recent study (FAO, 2019: FAO forthcoming) reviewed the information base on the costs and benefits of adapting fisheries to climate change, and found the evidence base is low, although many of the early promising options align to existing sustainable fisheries policy. At the global level, most studies generally look at the increased costs of enhanced fisheries management, as a way of addressing catch potential reductions.

Early studies (e.g. World Bank study, 2010), assessed the costs of adaptation to address catch reductions, considering the costs of government action to manage fisheries, both to conserve fish stocks and to help communities that depend on fishery resources to adapt (buybacks, introduction of transferable quotas, and investments in alternative employment). The study estimated the adaptation costs for Europe of USD 0.03 and USD 0.15 billion. Stefansson and Rosenberg (2005) compared fishery management through quota control, effort control and closed areas and combinations of these measures. They found that given implementation (control) issues in quota and effort-based systems, MPAs provided a 'buffer' against uncertainty. They found that when the collapse probability increases (due to high mortality or high uncertainty), MPAs allow long-term yield to be maintained by reducing the probability of stock declines and collapse. A further conclusion was that minor closures have little effect, and if MPAs are to be used on their own very large areas need to be closed to fishing. They recommended portfolio approaches.

Gaines et al. (2018) estimated the benefits of adopting management responses to address both productivity and distributional changes in fish stocks under different climate scenarios (productivity adaptation and range adaptation). Their 'full adaptation scenario' assumed a dynamic harvest control rule that optimally adjusts fishing mortality on the basis of available biomass and is therefore naturally adaptive to climate-driven productivity changes. They also assume that management addresses challenges posed by shifting stocks (through new proactive institutions, such as effective transboundary agreements), ensuring that effective management does not degrade because of spatial shifts. Therefore, under this management scenario, all species, including those expected to shift across management boundaries, are managed with an optimized harvest control rule. Their findings are that with such adaptation, there would actually be gains (not just reduced losses).

There have been economic studies valuing marine protected areas, estimating their potential costs and benefits for fisheries, although there are less examples of the benefits under future climate change. Economic valuation studies of MPAs have been undertaken in the UK (Kenter et al., 2013; eftec, 2014), including for specific value chains on shellfish and cod (eftec, 2015).

For this case study, we focus on the costs of a number of key adaptation options that could help address the impact of climate change on the 25 YEP / Fisheries White Paper goal and target in England. These comprise the costs of implementing measures aimed at reducing pressures on stocks, as well as closing the existing knowledge gap and moving to an iterative adaptive management approach. This analysis is only indicative but provides some initial analysis.

- The first option is to develop an adaptive management cycle for the fisheries sector in England (the UK). This involves a scale up in monitoring, scientific information and awareness raising.
- The second option is to increase Marine Protected Areas to improve the marine environment, and achieve the second component of the outcome – in the face of climate change. This would require more MPAs to deliver the same level of ecosystem service function/benefit as now, due to the marginal impact of climate change
- The third option has looked at other options to enhance the sustainable catch potential in the face of climate change.

Option 1. Developing an adaptive management approach for fisheries in England

Building on the discussion above, this package of measures would develop an adaptive management approach to inform fisheries policy, and to raise awareness with fishermen. It would include monitoring (marine climate, acidification, species abundance and distribution), etc. with this information fed back into fisheries policy (e.g. to set maximum catch potential for current species, but also to include new species in policy) and to raise awareness on changes to fisherman, to provide information to help them adapt. This is an enhancement of the existing SeaFish activities. It could also include specific research to better understand new climate risks, for example, enhanced ocean acidification monitoring, plus experiments to understand real world effects, it could include pilot studies on expanding seagrass areas.

The concept of this approach has been demonstrated using real options analysis (ROA) to look at cold water corals (Jackson et al., 2013). This looked at how better climate information could be provided for coral protection and regrowth options, in response to deep-water fishing and ASH shoaling, as well as acidification. The analysis focused on the extent and quality of cold water Lophelia reefs in the North East Atlantic (in their role in providing a highly productive habitat for a number of fish species. The ROA comes from the potential learning over time in the decision-making process, and the prospect that new information will become available on the impacts on, and benefits of options to address these impacts, for these reef systems.

For this case study, we look at the potential costs and benefits of enhancing current fisheries monitoring, research and awareness raising to develop a strong iterative risk management approach. At present, Defra's Marine and Fisheries budget (17/18) was £99million. Of this, approximately 20% was spent to fund research and monitoring carried out by Cefas[12], the Centre for Environment, Fisheries and Aquaculture Science. Cefas collects, manages and interprets data on the aquatic

[12] Defra. Main Estimate 2018-19 for Select Committee Memorandum.

environment, biodiversity and fisheries, and advises Defra, as well as other public and private sector customers, on issues connected to the aquatic environment, including stock assessment and climate change. An increase in fisheries climate funding, linked to increasing monitoring and research efforts, would have potential economic benefit through the value of information. Benefits arise from the use of this information to improve decisions (the value of information/quasi-option value) which could reduce losses or enhance gains.

Previous studies have applied such approaches. Costello et al. (2009) found that improved spatial information increased fishery value by approximately 10%, and that it changes the efficient management approach—switching from diffuse effort to a strategy where fishing is spatially targeted, with some areas under intensive harvest and others closed to fishing. They also found that optimally sited networks of marine reserves become considerably larger with improved information. While there are some issues with this study, notably around the assumed level of competition among fishermen, it does illustrate how better information can translate through to enhanced benefits.

We use the benefits indicated in Costello et al. (2010) to derive indicative figures for England. English vessels landed approximately 200,000 tonnes of fish in 2017, with an estimated value of just above £300 million. Assuming climate monitoring costs increase by 100% (£20 million, using last year Defra's funding figure to Cefas as an indicative figure) to close existing information gaps and improve the existing fishery management approach, this would result in benefits worth up to £30 million, and thus a positive benefit to cost ratio.

Option 2. Increasing MPAs in English waters

The second option is to increase Marine Protected Areas to enhance the protection of the marine environment in the face of climate change. MPAs have the potential to benefit adjacent fisheries (Heal and Rising, 2014). These effects have been studied as "benefits over boundaries", in which increased fish biomass diffuses into exploited areas (Gell and Roberts, 2003), and as "savings accounts", able to buffer fluctuations and support resilience (Grafton et al., 2010). MPAs can also preclude bycatch of non-target species at least within the closure, protect habitat from fishing gear damage and provide a refuge for a broad range of species in the ecosystem (Stefansson and Rosenberg, 2005).

The use of closed areas or marine protected areas has gained greater attention, mainly due to the difficulties of fully monitoring and controlling catches. They also reflect the failure in effort control-based systems, because increased technology investments lead to increased efficiency (higher catch) of fishing vessels (Stefansson and Rosenberg, 2005). The literature reports that a properly implemented quota system (i.e. that achieves its goals of moderate exploitation) appears to give much higher profits than a system based on closed areas alone. However, when there are problems with implementation of the quota or effort system, then the resultant fishing mortality rate will be higher (Stefansson and Rosenberg, 2005). However, to rebuild stock without any other controls, a very large percentage of the biomass needs to be protected - so as to obtain, for example, a 20% exploitation rate, a protection of 80% of the biomass will be needed (Stefansson and Rosenberg, 2005). Therefore, a mix of management approaches is usually recommended.

A number of studies have estimated the value (benefits) of preserving the marine environment, and showed that they generally outweigh the costs of preservation. Costello et al. (2009) found that closures of 50% or more of the area always increase long-term economic yield, although the full effects depend on the migration rates: if there is no feeding migration, then there is no added gain in closing too much.

Moran et al (2008), for Defra, present a monetary estimate of the environmental benefits expected from the implementation of nature conservation measures in the UK Marine Bill. The ex-ante study estimates on-site benefits of a potential network of Marine Conservation Zones (MCZs) across the UK, in the form of changes in ecosystem goods and services, and off-site benefits to fisheries through a production function model. It includes direct and indirect use values and arrives at a present value estimate of benefits over 20 years of £ 10.3-22.7 billion.

Kenter et al. (2013) investigated the recreational use and non-use values of UK divers and sea anglers for 25 Scottish potential Marine Protected Areas (pMPAs), 119 English recommended Marine Conservation Zones (rMCZs) and 7 existing Welsh marine Special Areas of Conservation (SACs) using a combination of monetary and non-monetary valuation methods and an interactive mapping application to assess site visit numbers. The research aimed to elicit values of cultural ecosystem services of UK sea anglers, divers and snorkelers for candidate marine protected areas in England and Scotland and existing marine SACs in Wales. The study found that the monetary benefits of the two marine user groups are likely to outweigh best estimates of the cost of designation. The English MCZ[13] impact assessment estimated aggregate costs at present value over a 20-year time scale for all 127 rMCZs at £227 - 821 million[14]. The baseline, one-off non-use value of protecting the sites to divers and anglers alone would be worth £730 – 1,310 million, excluding divers and anglers' willingness to pay for specific restrictions on other users; i.e. this is the minimum amount that designation of 127 sites is worth to divers and anglers. Only taking these non-use values into account indicates a benefit - cost ratio for designation of -1.1 (lower bound of minimum benefits vs. highest estimate costs) to 5.8 (upper bound of minimum benefits vs. lowest estimate costs). Comparing the impact assessment best estimate costs scenario (£331 million) to a central estimate of the minimum benefits expected (£957 million) leads to a benefit - cost ratio of 3.1. Although these figures come with a number of limitations (see above), designation of 127 sites is most likely efficient.

In a study by eftec for Defra (2014), two similar studies are reported: one by Christie et al (2011), the other by Jobsvogt et al. (2013). Christie et al. (2011) investigated a wide range of ecosystem services related to the delivery of UK biodiversity action plan (BAP) targets for 19 terrestrial BAP habitats. The study focussed on the value of conservation of 'non-charismatic' biodiversity. This is interpreted as relating to the conservation of and unknown species in an unknown location. Using value transfer technique, the Christie et al. study identifies a value per UK household of £3.33 per year for the conservation of non-charismatic species in 2011. The Jobstvogt et al. (2013) study assessed WTP per Scottish household per year representing existence value and possible medicinal use value of deep-sea species based on additional MPAs in the Scottish deep sea. It estimated lower bound estimates derived from the value reflecting an increase from 1,000 to 1,300 species of £24 per Scottish household; and higher bound estimates are derived from the value representing an increase from 1,000 to 1,600 species of £36 per Scottish household. He noted that values of some non-Scottish UK households might be lower than Scottish households as large parts of the non-Scottish UK population live further from the sea than most of the Scottish population.

In the 2014 impact assessment of the proposed second tranche of 23 Marine Conservation Zones (MCZs) in the UK, Defra estimated the costs that would be incurred on different sectors, giving a best estimate annual cost to business of £0.31million, primarily related to ports and shipping, oil, gas and CCS and commercial fisheries. The study calculated a final present value of costs of -£31 million over 20 years (Defra, 2015). However, the study was not able to provide an estimate of the monetary value of benefits that the network would provide. The conclusion was qualitative: 'An overall network of

---

[13] MCZs are a type of MPA to protect nationally important marine wildlife, habitats, geology and geomorphology and they can be designated anywhere in English and Welsh inshore and offshore waters. Sites are selected to protect not just the rare and threatened, but the range of marine wildlife. Unlike other MPA designations, social and economic factors may also be taken into account when identifying new sites. The first tranche of 27 MCZs was designated in 2013 and the second tranche of 23 sites in 2016. The third tranche started will be designed in 2019.

[14] Including costs to the renewable energy sector, the fisheries sector, oil and gas, commercial shipping, recreation, and implementation, management and enforcement costs (Kenter et al. 2013).

marine protected areas is likely to have high additional benefits (both in the short and long term) such as conservation of marine biodiversity, protection or enhancement of ecosystem services and recovery of depleted stocks of exploited species.' Some quantitative attempts were made at non-market benefits (e.g., indicative monetary estimates of diving and angling based on contingent valuation and expert opinions on likely level of spill-over from protected sites to surrounding fisheries) which are referred to as 'illustrative' because of uncertainty concerning the scale of benefits (Defra, 2015).

A limited number of studies have attempted to estimate the economic benefits to fishers of MPAs. The utility of closed areas for fishermen results from the mobility and dispersal of fish: while fish stocks can benefit from MPAs directly by gaining higher levels of biomass and yearly recruitment, fishermen only benefit when a portion of this greater stock reaches exploited areas (Heal and Rising, 2014). One study by Heal and Rising (2014) found that on average, a 1% increase in protected area results in an increase in the growth rate of fish populations by about 1%, and the average break-even point for economic benefits (expressed as landed catch values) of MPAs is at 8.5% of marine area. Based on their estimates, they concluded that in 2014 about 60% of country regions currently had insufficient protected areas to generate economic benefits.

A review of the literature conducted by the European Commission (2017), found only few studies that have provided comprehensive comparisons of the costs and benefits of MPAs and Spatial Protection Measures (SPMs). The review found net benefits are generally positive and significant. It identified three studies as the most robust examples of CBAs of MPAs in Europe, but only one study that accounts for benefits in quantitative terms, using site-specific data in an ex post context. This study is by Mangos and Claudot (2013), which includes three CBA case studies from the Mediterranean Sea. In this study, in addition to a business-as-usual scenario based on a retrospective trend analysis and including actual projects, two other scenarios were developed; one built on the hypothesis of increasing protection and the other on decreasing protection. The results of the three CBAs carried out contradict the perception of MCPAs as obstacles to development and show that, although the protection of marine and coastal ecosystems modified the redistribution of benefits within the area of influence, the effect is positive overall: the NPV of the increasing-protection scenarios is higher than that of the business-as-usual scenarios or decreasing- protection scenarios for the three study sites, which indicates that the protection of these sites overall generates more benefits than costs for 2030. However, the distribution of benefits between ecosystem services and economic activities vary by case study. For example, increasing protection results in increasing revenues for the commercial fishing sector in Tunisia, but not in Spain and Turkey.

Finally, it should be highlighted that the costs and benefits of adaptation to the commercial vs. the recreational sector are not directly comparable. The large values (cultural, recreational, bequest) attributed to the preservation of the marine environment cannot and should not be compared to the value of fish and shellfish landed or fleet operating profits to determine their relative importance, and hence the best allocation of resources (including adaptation resources) between the two sectors. Whether preserving the marine environment would come at the expenses of the commercial sector is disputable. For instance, much of the commercial catch comes from fisheries of little or no interest to recreational anglers (Eftec, 2015). The relevant resource allocation questions – and therefore the relevant comparisons - arise where angling and commercial fishing are in conflict for the same stocks.

In June 2018, Defra launched a consultation on "sites proposed for designation in the third tranche of Marine Conservation Zones". Thirty-nine of the sites proposed were in English waters and two in Northern Irish offshore waters. The total area covered by the new sites would be 11,713 km^2: 3,441km^2 in the inshore area and 8,272 km^2 in the offshore area. 201 features will be covered, including features to be added to existing sites. A final decision will be taken in 2019. In the consultation document, it is estimated that annual average costs to the private sector for all sites is £418,000 per year; and the best estimate annual average total cost to the public sector for all sites is £4 million per year. This includes the cost of managing sites and carrying out ecological surveys to monitor site condition. This gives an average annual total cost of £377 per Km^2.

Currently, 24% or 884,859 Km^2 of UK waters are classified as MPAs, However, these also include EEZs, i.e. areas that are primarily fishery management areas, representing 87% of MPAs. This means that only 3% or 118,550 Km^2 are effectively fully protected. Increasing fully protected areas to achieve a 20% goal of UK waters would require approximately additional 619,000 Km^2 to be designated to fully protected areas. Based on Defra 2018 estimates, on average this would cost businesses and the public sector £233 million annually. The benefits of such measures cannot be monetised but based on the literature are likely to be substantial and outweigh the costs. However, Heal and Rising (2014) found that the average break-even point for economic benefits (expressed as landed catch values) of MPAs is at 8.5% of marine area. This would mean additional 195,000 Km^2 should be protected for economic benefits to realise, at an estimated annual average cost of approximately £73,500,000.

Option 3. Adaptation and maximum sustainable yields

The third area has looked at other options that might be introduced to ensure maximum sustainable yields. This involves some complex issues around trade-offs. On the one hand, there are a set of low regret options that could be introduced into the fishing industry. These include, for example, weather and climate services. Clements et al. (2017) identified six studies that had looked at the benefits of W&CS for the fisheries sector, although several of these were for recreational fisheries and all were US-based. These normally value the increased number of fishing days (commercial or recreational) or enhanced value of catch, but they include examples for shellfish (forecasts of algal blooms). These show high benefit to cost ratios, and deliver benefits through the value of information. However, these merely enhance the efficiency and effectiveness of the fishing industry, they do not address the threshold limit of a maximum sustainable yield. Indeed, if the fishing industry is more efficient, it will put greater pressures on MSY.

Climate change is likely to reduce maximum sustainable yields, based on the analysis above. It is possible for fisheries policy to adapt to this change, by introducing stricter policy or management actions, i.e. reducing licences, fishery buy-back, etc. However, these will not address the underlying risk, they merely set a lower MSY due to climate change. The final question is therefore whether there are any options which can increase maximum sustainable yield, i.e. that would offset the loss of MSY from climate change. While the potential for MPA and no take zones is highlighted above, there is a need to consider other potential options for this. The analysis of additional options, and trade-offs, is highlighted as a key question for future analysis.

Conclusions

The analysis (option 1) supports the use of an adaptive management approach for the fisheries sector in England (the UK). This involves a scale up in monitoring, scientific information and awareness raising. Indicative costs have been assessed, based on the scale-up of current research and monitoring activities indicate this could increase fishery value (through the value of information) by approximately 10%, and has a positive benefit to cost ratio.

The analysis also suggests an increase in 'no-take' Marine Protected Areas (option 2) to enhance the marine environment in the face of climate change. This would require more marine areas – with full protection - to deliver the same level of ecosystem service function/benefit as now, due to the marginal impact of climate change. The literature indicates MPAs deliver significant benefits, both environmental and economic: when used as a fishery management approach alongside quota and effort-based approaches, they can contribute to increasing yields. The literature indicates that the average break-even point for economic benefits (expressed as landed catch values) of MPAs is 8.5% of marine area. This would mean that in the UK an additional 195,000 Km^2 should be protected for economic benefits to be realised, at an estimated annual average cost of approximately £73.5 million. It is stressed, however, that additional MPAs need to be designed and sited with future climate change in mind, i.e. to be climate smart.

Finally, there is a question of whether other options might be introduced to ensure maximum sustainable yields are maintained under climate change (option 3). This involves some complex issues because of trade-offs. There are many options that could enhance the efficiency and effectiveness of the fishing industry, and thus help address climate risks, but if the fishing industry is more efficient, it will put greater pressure on maximum sustainable yields. An alternative is to introduce stricter policies to reduce maximum sustainable yields, or to reduce fishing pressure in the short-term to allow stock enhancement and larger MSY later, in effect to build in contingency for climate change. However, this would involve important downsides (catch potential) for the fishing industry. Other than MPAs, the review has not found any obvious answers. The analysis of additional options, and trade-offs, is highlighted as a key question for future analysis.

Overall, the key finding is that an early adaptation priority is to enhance existing activities that use adaptive management, improving information (from monitoring, research etc.) to iteratively adapt fisheries policy. This would involve the use of this information to inform policy, e.g. in setting maximum catch potential, including new species), combined with information of threats and opportunities to fisherman.

References

Allison, E.H., Perry, A.L., Badjeck, M.C. et al. (2009) Vulnerability of national economies to the impacts of climate change on fisheries. Fish and Fisheries 10, 173–196.

Armstrong, M. A. Brown, J. Hargreaves, K. Hyder, S. Pilgrim-Morrison, M. Munday, S. Proctor, A. Roberts, K. Williamson (2013). Sea Angling 2012 – a survey of recreational sea angling activity and economic value in England. Defra, 2013.

ASC (2017). The Climate Change Risk Assessment 2017, Evidence report. Available at https://www.theccc.org.uk/tackling-climate-change/preparing-for-climate-change/uk-climate-change-risk-assessment-2017/

Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & Poulain, F., eds. 2018. Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options. FAO Fisheries and Aquaculture Technical Paper No. 627. Rome, FAO.

Barange, M., Merino, G., Blanchard, L., Scholtens, J., Harle, J., Allison, E., Allen, I., Holt, J., Jennings, S. (2014). Impacts of climate change on marine ecosystem production in societies dependent on fisheries. Nature Climate Change. 4. 10.1038/nclimate2119.

Barsley, W., De Young, C & Brugère, C. 2013. Vulnerability assessment methodologies: an annotated bibliography for climate change and the fisheries and aquaculture sector. FAO Fisheries and Aquaculture Circular No. 1083. Rome, FAO. 43 pp

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

Blanchard, J.L., Jennings, S., Holmes, R., Harle, J., Merino, G., Allen, J.I., Holt, J., Dulvy, N.K. & Barange, M. (2012). Potential consequences of climate change for primary production and fish production in large marine ecosystems. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 367(1605): 2979–2989.

Boot KJ, Flynn KJ, Heath M, Speirs D, Turley C, Williamson P (2015). UK Ocean Acidification research programme synopsis: Fisheries, food-webs and ecosystem services. UKOA/PML)

Brown, I., Thompson, D., Bardgett, R., Berry, P., Crute, I., Morison, J., Morecroft, M., Pinnegar, J., Reeder, T., and Topp, K. (2016) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.

Cecile Brugère, C and De Young, C (2015). Assessing climate change vulnerability in fisheries and aquaculture Available methodologies and their relevance for the sector. FAO FISHERIES AND AQUACULTURE TECHNICAL PAPER 597.

Cheung, W., Lam, V., Sarmiento, J., Kearney, K., Watson, R., Pauly, D. (2009). Projecting Global Marine Biodiversity Impacts under Climate Change Scenarios. Fish and Fisheries 10. 235 - 251. 10.1111/j.1467-2979.2008.00315.x.

Cheung, W., Lam, V., Sarmiento, J., Kearney, K., Watson, R., Zeller, D., Pauly, D. (2010). Large-scale Redistribution of Maximum Fisheries Catch Potential in the Global Ocean under Climate Change. Global Change Biology 16. 24 - 35. 10.1111/j.1365-2486.2009.01995.x.

Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney, K., Watson, R., Zeller, D. & Pauly, D. (2010). Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Global Change Biology, 16(1): 24–35. (also available at https://doi.org/10.1111/j.1365-2486.2009.01995.x).

Cheung, W.W.L., Sarmiento, J.L., Dunne, J., Frölicher, T.L., et al. (2013). Shrinking of fishes exacerbates impacts of global ocean changes on marine ecosystems. Nature Climate Change, 3, 254–258.

Cheung, William & Lam, Vicky & Pauly, D., Herrick, S., Sumaila, R. (2011). Climate Change Impacts on the Biophysics and Economics of World Fisheries. Nature Climate Change. 1. 10.1038/nclimate1301.

Christie et al. (2011). Economic Valuation of the Benefits of Ecosystem Services delivered by the UK Biodiversity Action Plan. Report to Defra.

Clements, J et al (2013). The Value of Climate Services Across Economic and Public Sectors. Report to the United States Agency for International Development (USAID). Available at http://www.climate-services.org/sites/default/files/CCRD-Climate-Services-Value-Report_FINAL.pdf

Cook, E. J., Jenkins, S., Maggs, C., Minchin, D., Mineur, F., Nall, C. and Sewll, J. (2013). Impacts of climate change on non-native species. MCCIP Science Review, 2013, 155-166. doi:10.14465/2013.arc17.155-166.

Costello et al. (2009). The value of spatial information in MPA network design. PNAS October 26, 2010 107 (43) 18294-18299; https://doi.org/10.1073/pnas.0908057107.

Defra (2013) Economics of climate resilience: natural environment – fisheries. February 2013. Department for Environment, Food & Rural Affairs (Defra), UK.

DEFRA (2015) Designation of the second tranche of Marine Conservation Zones in waters for which the Secretary of State has responsibility (English inshore, English, Welsh and Northern Irish offshore). Defra 1810, Department for Environment, Food and Rural Affairs.

Defra (2018). Sustainable fisheries for future generations. Consultation Document.

Presented to Parliament by the Secretary of State for Environment, Food and Rural Affairs by Command of Her Majesty July 2018. file:///C:/Users/paul_/Documents/PWA/ASC%20indicator%20economics/fisheries-wp-consult-document.pdf

Defra (2018). Marine Conservation Zones Consultation on sites proposed for designation in the third tranche of Marine Conservation Zones, June 2018.

Defra (2018b). The National Adaptation Programme and the Third Strategy for Climate Adaptation Reporting. Making the country resilient to a changing climate. Published by Defra. Ref: ISBN 978-1-5286-0758-2, CCS0718089334 07/18, HC 1403 2018-19. Available at https://www.gov.uk/government/publications/climate-change-second-national-adaptation-programme-2018-to-2023

Defra (2018). Annual Report and Accounts 2017–18. (For the year ended 31 March 2018). Accounts presented to the House of Commons pursuant to Section 6(4) of the Government Resources and Accounts Act 2000.

Dulvy, N.K., Rogers, S.I., Jennings, S., Stelzenmüller, V., Dye, S.R. & Skjoldal, H.R. (2008). Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. Journal of Applied Ecology, 45: 1029–1039.

Dye, S. R., Holliday, N. P., Hughes, S. L., Inall, M., Kennington, K., Smyth, T., Tinker, J., Andres, O. and Beszczynska-Möller, A. (2013b). Climate change impacts on the waters around the UK and Ireland: Salinity. MCCIP Science Review, 2013, 60-66. doi:10.14465/2013.arc07.060-066.

Dye, S. R., Hughes, S. L., Tinker, J., Berry, D. I., Holliday, N. P., Kent, E. C., Kennington, K., Smyth, T., Nolan, G., Lyons, K., Andres, O. and Beszczynska-Möller, A. (2013a). Impacts of climate change on temperature (air and sea), MCCIP Science Review, 2013, 1-12. doi:10.14465/ 2013.arc01.001-012.

European Commission (2017). Study on the economic benefits of Marine Protected Areas Literature review analysis. Written by ICF Consulting Services Limited, in association with IEEP and PML, September.

Eftec (2014). Valuing the UK Marine Environment – an Exploratory Study of Benthic Ecosystem Services. Report prepared for Defra.

Eftec (2015). Comparing Industry Sector Values, With a Case Study of Commercial Fishing and Recreational Sea Angling. Report prepared for UKFEN, supported by Seafish, Defra and Marine Scotland.

Engelhard, G. H., Pinnegar, J. K., Kell, L. T. and Rijnsdorp, A. D. (2011). Nine decades of North Sea sole and plaice distribution. ICES Journal of Marine Science, 68, 1090-1104.

European Commission (2013). Climate change adaptation, coastal and marine issues. Communication from the commission to the european parliament, the council, the European economic and social committee and the committee of the regions. Commission staff working document.

FAO (2018). Impacts of climate change. on fisheries and aquaculture Synthesis of current knowledge, adaptation and mitigation options. FAO FISHERIES AND AQUACULTURE TECHNICAL PAPER 627.

Fernandes, J.A., Papathanasopoulou, E., Hattam, C., Queirós, A.M., Cheung, W.W.L., Yool, A., Pope, E.C. et al. (2017). Estimating the ecological, economic and social impacts of ocean acidification and warming on UK fisheries. Fish and Fisheries, 18(3): 389–444.

Fincham, J. I., Rijnsdorp, A. D. and Engelhard, G. H. (2013). Shifts in the timing of spawning in sole linked to warming sea temperatures. Journal of Sea Research, 75, 69-76.

Frontier (2013). Economics of Climate Resilience Natural Environment Theme: Sea FishCA0401. A REPORT PREPARED FOR DEFRA AND THE DEVOLVED ADMINISTRATIONS. February 2013. Frontier Economics, Irbaris, Ecofys. Available at http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=18016

Gaines D.S., C. Costello, B. Owashi and al. (2018). Improved fisheries management could offset many negative effects of climate change. Science Advances 29 Aug 2018: Vol. 4, no. 8, eaao1378. DOI: 10.1126/sciadv.aao1378

Gell, F. R. and Roberts, C. M. (2003). Benefits beyond boundaries: the fishery effects of marine reserves. Trends in Ecology & Evolution, 18(9):448–455.

Grabemann, I. and Weisse, R. (2008). Climate change impact on extreme wave conditions in the North Sea: an ensemble study. Ocean Dynamics, 58, pp199-212.

Grafton, R. Q., Pham, V. H., Kompas, T., et al. (2010). Saving the seas: the economic justification for marine reserves. Made available in DSpace on 2010-12-20T06: 03: 29Z (GMT). No. of bitstreams: 1 Kompas Saving2004. pdf: 376160 bytes, checksum: e774826bb428351e3c1d15104dd20d98 (MD5) Previous issue date: 2010-10-28T00: 25: 01Z.

Hannesson (2011). OECD (2010): Climate Change, Adaptation and the Fisheries Sectors. IN The Economics of Adapting Fisheries to Climate Change. OECD Publishing. http://dx.doi.org/10.1787/9789264090415-en

Harrould-Kolieb, E., Hirshfield, M., Brosius, A., 2009. Major emitters among hardest hit by OA: an analysis of the impacts of acidification on the countries of the world. Oceana Rep. 11.

Heal G. and J. Rising (2014). Global Benefits of Marine Protected Areas. NBER Working Paper Series; Cambridge, Mar 2014. DOI:10.3386/w19982

Heath M. R. et al. (2012). Review of climate change impacts on marine fish and shellfish around the UK and Ireland. Aquatic Conservation: Marine And Freshwater Ecosystems 2012. Published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/aqc.2244

HMG (2018). A Green Future: Our 25 Year Plan to Improve the Environment. Published by Defra.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf

IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P. M. eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IUCN (2016). Explaining Ocean Warming: causes, scale, effects and consequences. Edited by D. Laffoley and J. M. Baxter. September, 2016.

Jackson, E.L., Hall-Spencer, JM., Hunt, A., Herman, P., Davies, A.J., Howell, K., and P. Kershaw, (2013). Anthropogenic impacts on cold-water coral reefs in the North East Atlantic. Deliverable 10.3. European Commission DG Research KNOWSEAS Project. Grant Agreement no.: 226675

Jennings, S. & Blanchard, J.L. (2004). Fish abundance with no fishing: predictions based on macroecological theory. Journal of Animal Ecology, 73(4): 632–642.

Jobsvogt et al. (2013). Twenty Thousand Sterling Under the Sea: Estimating the value of protecting deep-sea biodiversity. Stirling Economics Discussion Paper 2013-04. Online at http://www.management.stir.ac.uk/research/economics/working-papers

Jones, M.C., Dye, S.R., Fernandes, J.A., et al. (2013). Predicting the impact of climate change on threatened species in UK waters. PLoS ONE, 8(1): e54216 [online].

Kenter, J.O., Bryce, R., Davies, et al. (2013). The value of potential marine protected areas in the UK to divers and sea anglers. UNEP-WCMC, Cambridge, UK.

Kröger S, Parker R, Cripps G & Williamson P (Eds.) 2018. Shelf Seas: The Engine of Productivity, Policy Report on NERC-Defra Shelf Sea Biogeochemistry programme. Cefas, Lowestoft. DOI: 10.14465/2018.ssb18.pbd

Lindkvist, K. (2000) Dependent and independent fishing communities in Norway. In: Fisheries Dependent Regions. (ed D. Symes). Blackwell Science, Oxford.

Mangi S.C. et al. (2018). The economic impacts of ocean acidification on shellfish fisheries and aquaculture in the United Kingdom. Environmental Science and Policy 86 (2018) 95–105.

Mangos A and Claudot M.A. (2013) Economic study of the impacts of marine and coastal protected areas in the Mediterranean. Plan Bleu Papers 13, Plan Bleu, Valbonne.

Marine Climate Change Impacts Partnership. Report card 2017. Available at http://www.mccip.org.uk/impacts-report-cards/full-report-cards/2017-10-year-report-card/

Merino, G., Barange, M., Blanchard, J., Harle, J., Holmes, R., Allen, I., Allison, E., Badcheck, M-C., Dulvy, N., Holt, J., Jennings, S., Mullon, C., Rodwell, L. (2012). Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate? Global Environmental Change. 22. 795-806. 10.1016/j.gloenvcha.2012.03.003.

Met Office (2018). UKCIP18 Marine report. November 2018.

Moran, D, Hussain, S, Fofana, A, Frid, C, Paramour, O, Robinson, L and Winrow-Giffin, A (2008) The Marine Bill – Marine Nature Conservation Proposals – Valuing the Benefits. DEFRA.

Morrissey, K. (2014) An inter and intra-regional exploration of the marine sector employment and deprivation in England. The Geographical Journal 181, 295–303.

Napier I.R. (2017). Fish Landings from the UK Exclusive Economic Zone and UK Landings from the EU EEZ. NAFC Marine Centre, 31 January 2017.

O'Leary B.C. et al (2018). Effective Coverage Targets for Ocean Protection. Conservation Letters, November/December 2016, 9(6), 398–404.

OECD (2010): The Economics of Adapting Fisheries to Climate Change. OECD Publishing. http://dx.doi.org/10.1787/9789264090415-en

Ostle C., P. Williamson, Y. Artioli, D. C. E. Bakker, et al. (2016). Carbon dioxide and ocean acidification observations in UK waters: Synthesis report with a focus on 2010 - 2015.

Perry, A. L., Low, P. J., Ellis, J. R. and Reynolds, J. D. (2005). Climate change and distribution shifts in marine fishes. Science, 308, 1912-1915.

Poulain, F, Himes-Cornell, A and Shelton, C. (2018). Chapter 25: Methods and tools for climate change adaptation in fisheries and aquaculture. In Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & Poulain, F., eds. 2018. Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options. FAO Fisheries and Aquaculture Technical Paper No. 627. Rome, FAO.

Sala E. et al (2018). Assessing real progress towards effective ocean protection. Marine Policy 91 (2018) 11–13.

Smale, D. et al (2019). Marine heatwaves threaten global biodiversity and the provision of ecosystem services. Nature Climate Change. Nature Climate Change volume 9, pages 306–312 (2019). https://doi.org/10.1038/s41558-019-0412-1

Symes, D. (2000) Fisheries dependent regions: scoping the problem. In: Fisheries Dependent Regions. (ed D. Symes). Blackwell Science, Oxford.

Stefansson G, Rosenberg A. A. (2005). Combining control measures for more effective management of fisheries under uncertainty: quotas, effort limitation and protected areas. Phil.Trans.R.Soc.B, 360,133–146 doi:10.1098/rstb.2004.1579 Published online 29 January 2005.

The Marine Management Organisation (2018). UK Sea Fisheries Statistics 2017.

Tesselaar, M., Granadillos, J. R., Ščasný, M., Máca, V. (2018). D1.2 Knowledge synthesis and gap analysis on climate impact analysis, economic costs and scenarios. Deliverable of the H2020 COACCH project. Available at https://www.coacch.eu/

Tröltzsch, J., McGlade, K., Voss, P., Tarpey, J., Abhold, K., Watkiss, P., Hunt, A., Cimato, F., Watkiss, M., Jeuken, A., van Ginkel, K., Bouwer, L., Haasnoot, M., Hof, A., van Vuuren, D., Lincke, D., Hinkel, J., Bosello, F., De Cian, E., Scoccimaro, E., Boere, E., Havlik, P., Mechler, R., Batka, M., Schepaschenko, D., Shvidenko, A., Franklin, O., Knittel, N., Bednar-Friedl, B., Borsky, S., Steininger, K., Bachner, G., Bodirsky, B. L., Kuik, O., Ignjacevic, P.,

Watson, R.A., Cheung, W.W., Anticamara, J.A., Sumaila, R.U., Zeller, D. and Pauly, D. (2013) Global marine yield halved as fishing intensity redoubles. Fish and Fisheries 14, 493–503.

Williamson, P., Turley, C., Ostle, C., 2017. Ocean acidification. MCCIP Sci. Rev. 2017, 1–14. http://dx.doi.org/10.14465/2017.arc10.001-oac.

Woolf, D. and Wolf, J. (2013). Impacts of climate change on storms and waves. MCCIP Science Review 2013: 20-26.

World Bank (2010). The costs to developing countries of adapting to climate change: new methods and estimates. Global report of the economics of adaptation to climate change study (consultation draft). Washington, DC, World Bank. 84 pp.

Zacharioudaki, A., Pan, S., Simmonds, D., Magar, V. and Reeve, D.E. (2011). Future wave climate over the west-European shelf seas. Ocean Dynamics, 61, 807-827.