Projections and perceptions: Using an interdisciplinary approach to explore climate change impacts on south-west UK fisheries

Submitted by Katherine Maltby to the University of Exeter
as a thesis for the degree of
Doctor of Philosophy in Biological Sciences
in August 2018.

I certify that all material in this thesis which is not my own work has been identified and that any material that has previously been submitted and approved for the award of a degree by this or any other University has been acknowledged.

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Abstract

Climate change is one of the greatest threats to marine environments globally. Fisheries are being increasingly affected, with impacts not only to fish stocks but also the fishers who rely on marine resources for their livelihoods. This thesis uses an interdisciplinary, mixed methods approach to examine climate change impacts on fisheries within the under-studied, yet rapidly warming, south-west region of the UK. The thesis begins with a comprehensive review of the literature regarding climate change impacts on UK fisheries, the vulnerability of these fishery systems to future climate change and how climate change is perceived among fishers. In Chapter 2 a methodology is developed to standardise abundance data across multiple scientific fisheries survey datasets in order to facilitate future projections to be generated for the south-west UK region. Chapter 3 presents future projections of abundances and distributions for eight key commercial fish species under future warming scenarios until the end of the century. Results suggest that increasing temperatures and limitations of bathymetry are key drivers of species responses. Certain cold-water species including Atlantic cod (*Gadus morhua* L.) and anglerfish (*Lophius piscatorius* L.) will experience declines, while warm-water species such as red mullet (*Mullus surmuletus* L.) and John dory (*Zeus faber* L.) are expected to expand across the region. The uncertainty associated with future projections is explored through the use of 11 separate climate-ensembles. Chapter 4 uses information gained through interviews with fishers from a UK fishing port—Brixham—to explore how climate change is perceived and the factors influencing these perceptions. Findings suggest that while fishers generally felt that climate change posed a low risk to the future of their businesses and fisheries in the region, three groups emerged that showed differences in the extent to which they perceived climate change as a risk. A number of key factors were important in influencing these three groups. Chapter 5 develops further insight into fishers' perceptions by exploring how fishers anticipate climate change to affect the physical environment, fishery resources, and their own practices in the future. Many fishers felt they would not need to alter their fishing practices in the future, with various reasons cited including personal preferences and perceived constraints to their adaptation. Fishers' ability to adapt was further explored and three main groups were identified who differed according to a number of core dimensions of their adaptive capacity. Through adopting an interdisciplinary approach, the research in this thesis presents a number of new findings that have important implications for fisheries management and climate adaptation policies.

Acknowledgments

My PhD has been a huge personal journey and one that has only been made possible due to the people who have inspired and helped me. I start off with someone who, had I not attended her first lecture at the University of Sheffield (which also happened to be my very first fisheries lecture), I know that my path in life would have gone in a very different direction. Julia Blanchard, thank you for igniting my passion for fisheries science and for your enthusiasm, wisdom and confidence in my abilities throughout my career so far. You still manage to inspire me despite now being on the other side of the world!

I'm very grateful to my supervisors who have supported me through this PhD and gave me the opportunity and freedom to explore my interests and own research questions. Thank you, Steve Simpson, for your guidance, for being so positive throughout and for your constant faith that I could do it. Rachel Turner, thank you for introducing me to the (wonderful) social science world and for your humour, advice and support. Martin Genner, your wisdom and wit throughout this process has been invaluable and no question ever seemed too stupid. Thank you, Jon Tinker, for your ability to explain a climate science or statistical concept multiple times until I understood it and for putting up with my poor coding abilities! Simon Jennings, your knowledge, guidance and kindness is much appreciated and has always been so useful, particularly when I was starting out. Of course, I also thank my funders – the Natural Environment Research Council and Cefas for supporting this project. An extra thank you to Jo Smith and Ian Holmes at Cefas for allowing me to partake in fisheries surveys – they were great experiences that I absolutely loved. Thank you also to the GW4+ Doctoral Training Partnership for support and training, and to my cohort for the laughs along the way.

I must also say a huge thank you to people from the south-west fishing industry and wider community that got involved in my project in one way or another. To everyone that I rang, interviewed, hung out with, went to sea with or generally hassled, thank you for your interest and help in providing me with information and answers. A special thank you of course goes to Brixham's fishermen – you made this project happen and without you a lot of my research wouldn't have

been possible. Fiona and Dave, my ‘Brixham parents’, thank you for your support and kindness during my fieldwork especially when things got tough.

I also wouldn’t have been able to do this PhD without the support of my friends. Mols and Minty, you have been my pillars throughout this process, providing support, humour, wisdom and generally great friendship. I frankly couldn’t have done it without you both. Becca and Emily thanks for being wonderful and supportive housemates and friends. Bryony and Lou thank you for your advice, friendship and being there in times when I got stuck. Thanks also to Sara, Becca, Anna-Marie, Jen, Julie – always being shoulders to lean on and offering wine and laughs, despite our distances. To everyone in lab 201, particularly Amy, Rich, Bas, Becca, Hannah, Ross, Gaz and Adam. Thanks for making it a fun place to be part of, for the wild swims and for always helping me to de-stress with a pint. To my Wirral chums, despite us being spread around the country now, I know I can always rely on you for support and humour. Melissa, Annabel, Rachel and Kat, ever since Sheffield you have been brilliant, supportive friends who have always been there and given me advice whenever I needed it.

Finally, to my family (including Rosie pony), thank you for your support and being there always. I couldn’t have done it without you. Grandma, thank you for encouraging my independence and spirit to always keep going. I hope this makes you proud.

A final thank you to the wonderful Julie (Chapter 1), Amy (Chapter 6) and Toni (Chapters 2–5) for generously providing me with the beautiful artwork within this thesis!

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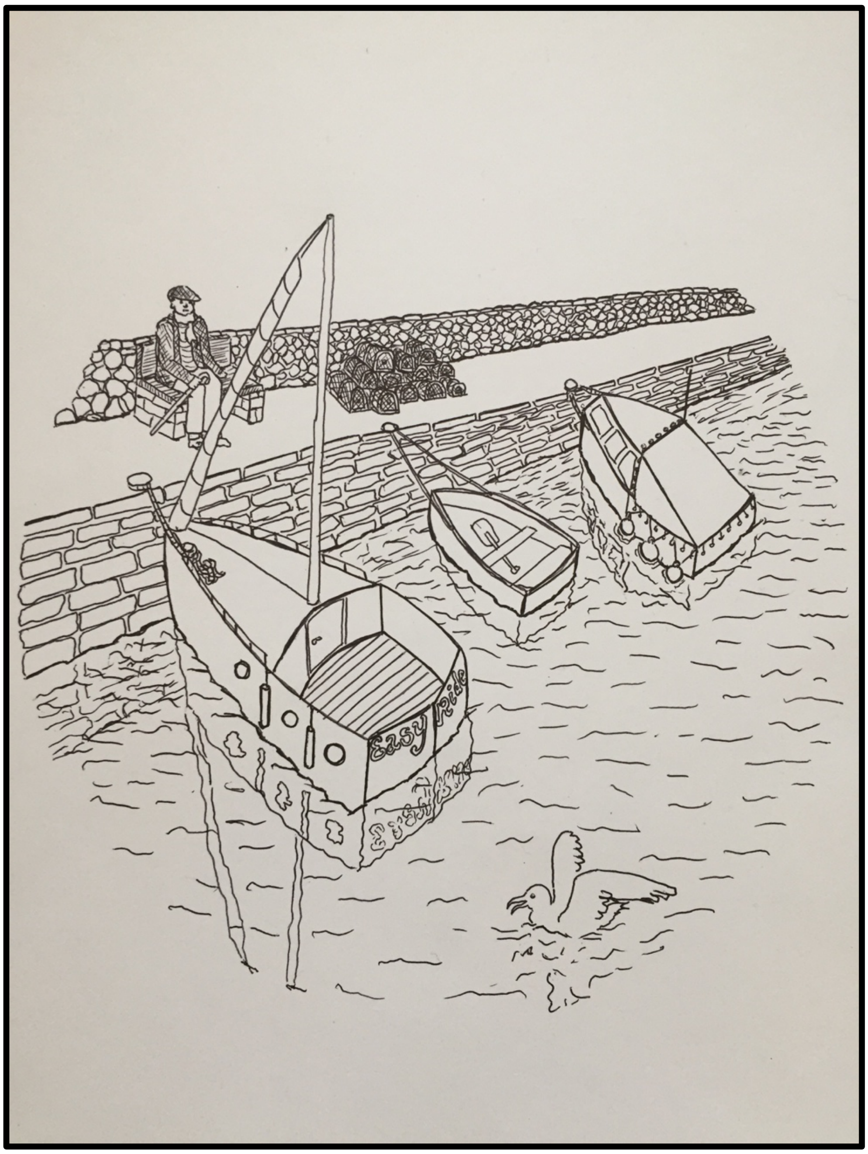
Chapter 1

Introduction:

Climate Change and Fisheries



Drawing by Julie Day, 2018

Introduction

Climate change is having widespread impacts on marine environments globally, altering their physical and biogeochemical properties and consequently affecting marine organisms and the ecosystem services they provide (Brierly and Kingsford 2009; Brander 2010; Hoegh-Guldberg and Bruno 2010; Doney *et al.,* 2012; Hollowed *et al.,* 2013; Poloczanska *et al.,* 2016; Cheung, 2018). In the last 40 years, ocean surface temperatures have warmed globally by more than 0.1°C per decade and estimates suggest that by the end of this century sea surface temperatures could rise between 1°C and ~3°C depending upon the region (upper 75 m, Collins *et al.,* 2013; Pörtner *et al.,* 2014). Furthermore, oceans have absorbed between 24–33% of anthropogenic CO_2 released (Billé *et al.,* 2013) leading to acidification, whilst hypoxic zones are also increasing in number and size (Helm, Bindoff and Church, 2011; Rhein *et al.,* 2013; CBD, 2014).

Physical changes in the marine environment have had direct and indirect effects on marine ecosystems. These effects act at a range of temporal and spatial scales, may propagate through trophic webs and may have synergistic effects with other additional anthropogenic stressors such as fishing and pollution (Harley *et al.,* 2006; Rijnsdorp *et al.,* 2009; Doney *et al.,* 2012; Cheung and Pauly, 2016). Evidence shows that all components of marine ecosystems can be affected by climate change, from individuals and populations through to communities and broader ecosystem function and structure, via a range of processes and mechanisms (Pörtner and Farrell 2008; Drinkwater *et al.,* 2010; Otterson *et al.,* 2010; Pörtner and Peck, 2010; Munday *et al.,* 2013). Whilst current impacts are still being explored, increasingly research is expanding to generate future projections of how species and ecosystems may respond (Cheung *et al.,* 2010; Pinnegar *et al.,* 2013; Cheung *et al.,* 2016a; Planque, 2016).

Given that humans rely heavily upon marine ecosystems for the services that they provide, the ecological impacts of climate change have wider social, economic, political and institutional implications (Perry *et al.,* 2010; Charles 2012; Savo, Morton and Lepofsky, 2017). Marine capture fisheries, for example, support the livelihoods of 8% of the world population and contribute US$230 billion to the global economy, with demand for fish products set to increase into the future (Barange *et al.,* 2014). Seafood is also one of the world's most traded commodities (Gephart and Pace, 2015). Because these socio-ecological fishery systems are complex and dynamic, climate change can have multiple impacts on the people who rely on marine ecosystems for their wellbeing and livelihoods (Daw *et al.,* 2009; Cooley 2012; Haynie and Pfeiffer, 2012; Savo, Morton and Lepofsky, 2017; Barange *et al.,* 2018).

Research regarding fishery level socio-economic impacts of climate change suggests that there could be significant implications surrounding the availability, productivity and catchability of fishery resources, presenting both new opportunities as well as challenges to current fishing operations (OECD, 2010; Cheung *et al.,* 2012; Barange *et al.,* 2018). Some fisheries are already responding to climate change through alterations in fishing gear, location choice and targeted species, while wider socio-political consequences may also arise on account of shifting species distributions, including disputes between countries regarding fishing opportunities (Pinnegar *et al.,* 2013; Gänsbauer, Bechtold and Wilfing, 2016; Pinsky *et al.,* 2018). However, a current lack of fisheries management and policy that accounts for climate change impacts has meant that there are potential barriers to adaptation (Brown *et al.,* 2012; Defra, 2013; Frost *et al.,* 2016). Barriers can include fishing quotas not reflecting changes in stock abundance or distributions due to rigid, historical allocation structures, thus limiting fishers' diversification or restricting their practices (Burden *et al.,* 2017; ABPmer, 2018). Other issues can include a lack of governance structures that account for shifting stocks, thus creating uncertainty over future access and opportunities for fishers (Pinsky *et al.,* 2018), and slow advisory processes limiting management from being more rapid and responsive in light of climate change (Burden *et al.,* 2017).

Efforts are now being made to directly link the ecological effects of climate change to social and economic consequences. For instance, connected biological–ecological–socio–economic models are being used to understand future changes in catch potentials and production and the effects on society (Barange *et al.,* 2014; Mullon *et al.,* 2016). Research is also increasing to explore the resilience and vulnerability of fisheries to climate change, with studies focused on different scales including individuals, fleets, fishing and wider coastal communities, and whole supply chains (Allison *et al.,* 2009; Plagányi *et al.,* 2014; Hare *et al.,* 2016; Blasiak *et al.,* 2017). These assessments can be undertaken from ecological, socio-economic or socio-ecological perspectives to understand climate effects, using a range of approaches to explore how people may respond to impacts, their ability to do so, and the consequences climate change poses both on the fishery system and beyond (Allison and Basset, 2015; Metcalf *et al.,* 2015; Colburn *et al.,* 2016; Cinner *et al.,* 2018). Such work can use both subjective personal perceptions and understandings of change, alongside objective measurements such as financial dependency on marine resources to gain insights into overall vulnerabilities (Metcalf *et al.,* 2015; Seara, Clay and Colburn, 2016; Whitney *et al.,* 2017). Much of this research has focused upon fisheries in tropical areas which are expected to be at heightened vulnerability compared to those in more temperate or developed nations (Cinner *et al.,* 2015; Blasiak *et al.,* 2017; Ding *et al.,* 2017). This work is vital to help inform decision making regarding future management measures and adaptation strategies or policies.

Research into climate change impacts therefore requires an understanding and appreciation of the effects climate can have on both parts of these coupled socio-ecological systems, and how they interact with each other (Perry, Barange and Ommer, 2010; Charles, 2012). While there have been great efforts to understand past, present and future climatic impacts at global and broad levels (e.g. Cheung *et al.,* 2009; Blanchard *et al.,* 2012; Tittensor *et al.,* 2018), there is an increasing need to further research at smaller spatial scales, such as regional or local (Charles, 2012). While larger scale studies are useful to determine overall patterns and trends, arguably climate change impacts will be most acutely felt at these smaller scales, particularly from socio-economic perspectives when considering responses of fishers and coastal communities. Managers and policy-makers developing adaptation strategies will need to consider the contexts within which climate change impacts are being felt and responded to and are likely to regard research at finer scales important and increasingly necessary.

The Northeast Atlantic Ocean has experienced considerable warming in recent decades (Dye *et al.,* 2013; ICES, 2013), with consequent effects on fish stocks and their associated fisheries (Rijnsdorp *et al.,* 2010, Poloczanska *et al.,* 2016). The UK's position in the Northeast Atlantic has meant that many of the stocks fished by UK fleets have already shown responses to climate change (Simpson, Blanchard and Genner, 2013; Pinnegar *et al.,* 2017). Fishers have capitalised on some of these opportunities but have also been exposed to some of the wider socio–economic and political challenges that changes in stock abundance and distribution have presented (Pinnegar *et al.,* 2013). Fisheries in the UK support 11,757 fishermen and landings into the UK and abroad by UK vessels were valued at £936 million in 2016 (MMO, 2017a). Whilst having a small contribution to overall national GDP, UK fisheries can have significant social and economic importance particularly at the regional level (Reed *et al.,* 2013; Depledge *et al.,* 2017). UK fisheries are regionally diverse and complex (MMO, 2017a) and as such it may be expected that the effects of climate change will differ depending on the region and fishery. However, as yet most work exploring climate change impacts on fisheries within UK seas have been limited to studying particular areas such as the North Sea, with comparatively little known about other regions, such as the south-west UK, despite their ecological and socio-economic importance. The overarching aim of this thesis is to provide insight into how climate change may impact fisheries using a regionally-focussed interdisciplinary approach. It uses the south-west UK as a case study; an area that has felt climate change impacts already but for which relatively little specific research exploring these topics has been applied.

This thesis begins with Chapter 1 which is a comprehensive review of the literature that has informed and shaped this thesis. Here, the physical and ecological impacts of climate change on the UK and wider northeast Atlantic marine environment are discussed before future impacts and projections are reviewed. The fisheries implications of climate change are then discussed before then exploring vulnerability of fisheries to climate change. The importance of understanding individual actors including their climate change perceptions and beliefs to gain insight into possible adaptive responses is then discussed. The chapter concludes with knowledge gaps identified and an outline of the thesis structure and chapters, including further background regarding the south-west UK and its relevance for climate change research.

Physical impacts of climate change

Climate change is impacting the physical and chemical marine environment, altering sea temperatures, sea level, ocean chemistry as well as oceanographic properties such as waves, circulation and currents (Doney *et al.,* 2012; Pörtner *et al.,* 2014). The extent of these impacts varies spatially and temporally, such that research which has focused at a regional level, despite inherent difficulties, is extremely useful (Holt *et al.,* 2016).

The Northeast Atlantic has warmed significantly in the last 40 years, with temperatures in the seas surrounding the UK and Ireland increasing up to six times faster than the global average (Dye *et al.,* 2013). Between 1985–2014, surface water temperatures have risen on average 0.28°C per decade, with the Eastern English Channel and Southern North Sea having particularly intense warming (Dye *et al.,* 2013; Hughes *et al.,* 2017). The slowest rates of warming were in the Celtic Sea (Hughes *et al.,* 2017). Whilst there are clear long-term trends, annual and seasonal variability exists, as well as differences between coastal and deep ocean areas (Dye *et al.,* 2013; Tinker *et al.,* 2015).

Projections of future warming in the Northeast Atlantic have a relatively high degree of uncertainty, particularly at more localised levels, due to high annual variability (Ting *et al.,* 2009; Dye *et al.,* 2013). Recent predictions suggest that UK sea temperatures will rise by a further 2–4°C by the end of the 21st Century (Lowe *et al.,* 2009; Tinker *et al.,* 2016), whilst also becoming around 0.2 practical salinity units (psu) fresher and more acidic (Lowe *et al.,* 2009; CBD, 2014). Significant efforts are now underway to further downscale global and Northeast Atlantic wide projections to explore responses at regional scales, such as seas around the UK (Tinker *et al.,* 2015, 2016; Holt *et al.,* 2016). A new round of climate projections—UKCP18—will be released later in 2018 (Met Office Hadley Centre, 2018).

Climate change can affect physical ocean properties, such as surface wave heights, swells and circulation patterns (Rhein *et al.,* 2013), in addition to changes in the severity and frequency of extreme events, which will have direct influences on fishing operations (Collins *et al.,* 2013; Kirtman *et al.,* 2013; Sainsbury *et al*., 2018). These physical properties and extreme events are much harder to predict. Historical evidence regarding storminess shows that there has been an increase in number and intensity of strong winter cyclones between 1871–2010 in the high latitude North Atlantic, but only an increase in intensity for those occurring in more southerly areas of the North Atlantic (Wang *et al.,* 2012). Future projections of extreme events have significant uncertainty attached due to a lack of historical data, differences in methods to predict them and difficulties in distinguishing occurrence of extreme events due to climate change from those occurring naturally (Haigh and Nicholls, 2017; Sainsbury *et al.,* 2018). Some studies suggest that there may be a northward shift of the Northern Hemisphere Storm Track (Kirtman *et al.,* 2013) which could influence storminess within seas of the Northeast Atlantic, including the UK.

Ecological impacts of climate change on fish

Changes in ocean biogeochemistry have substantive impacts on marine organisms. As ectotherms, fish are particularly vulnerable to alterations in sea temperature, which can significantly influence key biological and ecological processes such as metabolism, growth rates and reproductive processes (Pankhurst and Porter 2003; Pankhurst and Munday 2011) and result in changes in behaviour, abundances and distributions (Otterson *et al.,* 2010; Cheung *et al.,* 2012).

Physiological effects

Species-specific physiological changes at the molecular, cellular and organismal level can result in effects at population and community levels, and are important to study to fully understand shifts in distributions and other ecological responses to rising sea temperatures (Rijnsdorp *et al.,* 2009; Pörtner and Peck, 2010). Temperature changes can affect metabolic rates and scope, growth, maturation and even mortality (Pörtner and Peck, 2010; Heath *et al.,* 2012). Thermal preferences of fish have received particular attention, focussing upon tolerances and limits such as upper and lower lethal temperatures and critical thermal maxima and minima which can differ both between and within species (Pörtner and Peck, 2010). Such tolerances can differ with location, with subtropical and temperate species tending to have wider thermal tolerances, or ‘thermal windows’, than species occupying the extreme latitudes. This is partly due to the strong seasonal variability in sea temperatures, compared to those species at higher or lower latitudes (Pörtner and Peck, 2010). Such insights can be used to classify species into broader groups based on this biogeography, for example boreal, Lusitanian or polar (Rijnsdorp *et al.,* 2009; Payne *et al.,* 2016a). Tolerances and thermal windows can also differ with life stage; windows are narrow in earlier life stages but tend to widen at juvenile and young adult stages (Pörtner and Farrell, 2008), posing possible bottlenecks and differences in vulnerabilities of these life stages to future warming (Pörtner and Peck, 2010). Larger adult stages can also be sensitive to warmer temperatures due to their increased oxygen demands which are needed to support their investments in reproduction and/or growth (Pörtner and Farrell, 2008).

A prominent concept has emerged linking temperature tolerances and oxygen consumption, the so called ‘Oxygen and Capacity Limited Thermal Tolerance’ (OCLTT), which can be applied to marine invertebrates and fish (Pörtner and Peck, 2010; Pörtner, Bock and Mark, 2017). Fundamentally this concept assumes that once temperatures reach limiting values, an animal becomes increasingly constrained to supply oxygen to tissues to meet its demands, resulting in overall declines in performance (Pörtner, Bock and Mark, 2017). This can lead to important effects on aspects such as reproduction and growth if temperatures go above or below thermal thresholds (Pörtner *et al.,* 2014). Limits to oxygen supply at larger body sizes are emphasised, and so heat tolerance limits can shift to lower temperatures (Pörtner *et al.,* 2014). As such, OCLTT predicts that larger individuals are less heat tolerant compared to smaller individuals, as has been observed in warmer seas with smaller fish present (Pörtner *et al.,* 2014). This concept can be applied in wider modelling contexts to explore how future warming may influence fish body size in warmer and more hypoxic waters (Cheung *et al.,* 2013; Pauly and Cheung, 2017).

Changes in spawning and recruitment

Recruitment —the number of fish surviving to enter the fishery— is an important driver of fisheries production and has the potential to be affected by climate change through alterations in the phenology of species spawning and migration (Rijnsdorp *et al.,* 2009). A recent global meta-analysis found that the North Atlantic has experienced significant declines in recruitment capacity across stocks (but not for every individual stock), thought to be due to a combination of overfishing and environmental change of which climatic variables have played a role (Britten, Down and Worm, 2016). Other large-scale analyses in the North-east Atlantic have also shown declines in recruitment for over 40 fish stocks, including cod (*Gadus morhua*), plaice (*Pleuronectes platessa*), and sole (*Solea solea)*, thought to driven by increasing sea temperatures (Brunel and Boucher, 2007). There have been numerous documented effects of climate change on recruitment of fish around UK seas. Within the northern North Atlantic, temperature has had significant effects on the relationship between spawning stock biomass and recruitment success for 19 commercial fish stocks (Ottersen *et al.,* 2013). Around the UK and Ireland, four out of seven sole stocks were found to be spawning earlier by ~1.5 weeks/decade since 1970 due to changes in sea surface temperatures (Fincham, Rijnsdorp and Engelhard, 2013). Western stocks of Atlantic mackerel (*Scomber scombrus*) also appear to be migrating earlier, with eggs and larvae found further north in warmer years, suggesting that temperature has an influence on its spawning and, potentially, recruitment (Jansen and Gislason, 2013). Other alterations in spawning have also been observed amongst Atlantic cod, European plaice and pollack (*Pollachius pollachius*), although effects can vary depending on geographic location and interannual variability (Genner *et al.,* 2010b; Simpson *et al.,* 2011; Simpson, Blanchard and Genner, 2013).

While climate effects upon recruitment can occur at both early and later life stages (Rijnsdorp *et al.,* 2009), successful recruitment depends heavily on a match in occurrence of larvae and food availability (Edwards and Richardson 2004; Hollowed *et al.,* 2013). Mismatches in timing can impact larval survival, leading to potential effects on future fisheries productivity (Pinnegar *et al.,* 2013), whilst others suggest that mismatches can prolong the growing season and instead may lead to bigger recruits into the fishery such as seen in sole (Teal *et al.,* 2008). For example, whilst recruitment in cod has been shown to be influenced by temperature, recent years of poor recruitment in North Sea stocks despite cold waters (which favour spawning in this stock) could be in part attributable to changes in planktonic prey availability for larvae (Beaugrand and Kirby 2010; Pinnegar *et al.,* 2013). A more recent study has also found that recruitment of seven commercial fish stocks including cod, haddock (*Melanogrammus aeglenus*) and whiting (*Merlangius merlangus*), has declined within the North Sea, with declines associated with temperature-driven declines in primary production and food (copepod) availability (Capuzzo *et al.,* 2018).

Although evidence highlights the influence of temperature on spawning and recruitment, more research into interannual variability, differences between stocks and life cycle stages, and interacting factors such as fishing, is needed to gain greater understanding of population and fishery level climate change impacts on recruitment (Heath *et al.,* 2012; Simpson, Blanchard and Genner, 2013; Szuwalski *et al.,* 2015).

Changes in abundance and distributions

There is a now a substantial body of research aimed at understanding how fish abundance and distributions change with warming, with responses often linked to thermal preferences and tolerances (Rijnsdorp *et al.,* 2009; Pecl *et al.,* 2017). Simpson *et al.* (2011) found that 36 out of 50 abundant European fish species responded to warming by altering their local abundances, which in turn generated larger-scale patterns of distributional change. How species respond differs depending on their biology and biogeographic affinities (Rijnsdorp *et al.,* 2009; Bates *et al.,* 2014; Hal *et al.,* 2016). For some species, an increase in temperature presents a new colonisation opportunity and enables range expansion; in Europe this has been observed in Lusitanian species (warm water affinity) in particular, such as red mullet (*Mullus surmuletus*), John dory (*Zeus faber*), European anchovies (*Engraulis encrasicolus*) and sardines (*Sardina pilchardus*) which have become more abundant and widespread around Ireland and in the south-west of the UK (Beare *et al.,* 2004; Lynam *et al.,* 2010; Pinnegar *et al.,* 2013; Simpson, Blanchard and Genner, 2013). Hiddink and ter

Hofstede (2008) found that eight times as many North Sea fish had increased (mostly Lusitanian, small bodied) rather than decreased in range.

For other species, often those with a boreal affinity, warming temperatures pose a greater challenge to their physiological mechanisms and as such may induce them to retract their range, track polewards or move deeper in order to seek cooler waters (Perry *et al.,* 2005; Dulvy *et al.,* 2008; Cheung *et al.,* 2012; Pinnegar *et al.,* 2013; Simpson, Blanchard and Genner, 2013). In a landmark study focused on the North Sea, Perry *et al*., (2005) found that of the 36 demersal fish species examined, including non-commercial and commercial species, 21 had shifted northwards and/or to deeper waters due to warming temperatures. More recent literature has also documented shifting distributions. For example, in the North Sea, cod has shifted towards the deeper waters in the north-east, plaice has moved north-westerly, whilst the southern boundary of haddock distribution has moved 130 km northwards over the past 80–90 years (Engelhard *et al.,* 2011; Pinnegar *et al.,* 2013). Sole distributions have retracted further south into the Eastern Channel (van Keeken *et al.,* 2007). Dulvy *et al.,* (2008) reported that an assemblage of 28 demersal North Sea fish deepened by ~3.6 m decade^{-1} between 1980–2004, again attributed to warming sea temperatures.

What enables or restricts species temperature responses is linked intimately not only to their physiology but also their wider ecology (Rjinsdorp *et al.,* 2009; Pörtner and Peck 2010). While thermal preferences heavily dictate the extent to which a species can tolerate warming temperatures, temperature alone does not always fully determine species movement (Doney *et al.,* 2012). Some may be constrained in their movement due to their reliance on particular habitats for spawning, foraging or nursery grounds (Heath *et al.,* 2012; Simpson, Blanchard and Genner, 2013; Rutterford *et al.,* 2015). Dispersal capacity, biological interactions and wider abiotic conditions have also been posited as influencing a species' ability to respond to increasing temperatures (Doney *et al.,* 2012; Heath *et al.,* 2012). North Sea cod has been observed to stay within sub-optimal thermal conditions despite warming, which may be due to other biotic factors such as food availability playing a role in habitat choice (Neat and Righton, 2007). Additionally, synergistic effects of other anthropogenic stressors also have a role. For example, fishing can make particular stocks more sensitive to temperature changes that they previously may have tolerated (Jennings and Blanchard 2004; Rjinsdorp *et al.,* 2009; Genner *et al.,* 2010a).

Future projected climate impacts on fish

In recent years there has been growing interest in understanding future impacts of climate change on fish, particularly with regard to how their abundance and distributions will alter. A number of modelling approaches have been developed, which in part may explain why as yet there is limited consensus regarding some future projections, especially at the species level (Pinnegar *et al.,* 2013).

Distributions and abundances

Species Distribution Models (SDMs), also known as bioclimatic envelope models (BEMs), have become a popular method to predict fish distribution shifts (Cheung *et al.,* 2016a; Payne *et al.,* 2016b; Robinson *et al.,* 2017). Grounded in ecological niche theory, these models characterise a species' current 'bioclimatic envelope' based on a set of physical and biological conditions suitable to a species and its spatial occurrence, which can then be used to predict how future warming will affect its distribution (Jones *et al.,* 2012). Projections from such models suggest that fish will continue to shift their distributions into the future. In a study by Cheung *et al.,* (2009) using a dynamic BEM, 83% of 1,066 fish and invertebrate species showed polewards movements under a high warming scenario between 2001–2005 and 2040–2060, with pelagic species moving up to 600 km north and demersal species 223 km north. Other studies adopting SDMs also suggest poleward shifts, and consequentially high latitude regions are expected to have increased fisheries potential compared to the tropics (Cheung *et al.,* 2010).

Whilst providing useful insights, SDMs have received some criticism regarding the uncertainty surrounding their predictive abilities and underlying assumptions (Pearson and Dawson 2003; Elith and Graham 2009; Jennings and Brander 2010; Robinson *et al.,* 2011). Such models can neglect the biotic interactions, dispersal abilities and evolutionary processes that are important determinants of a species range (Robinson *et al.,* 2011), and assume that the observed distributions are in equilibrium with their environment (Cheung *et al.,* 2009; Jennings and Brander 2010). This can lead to overestimation of a future species range (Hattab *et al.,* 2013) or misinterpretation of future scenarios.

To address these critiques, there have been a number of developments in research directions. One approach has been to compare model performances; for example, Jones *et al.,* (2012) ran three different SDMs (Maxent, Aquamaps and Sea Around Us Project algorithm) using the same datasets of commercial fish in the North Sea and Northeast Atlantic to explore the suitability of future environments for focal species. The three models provided general agreement in predicted distribution ranges, but did show differences due to the model structure. As such, a multi-model approach was advocated to reduce uncertainty, bias and quantify the variability in projections. This suggestion has further been supported in a comparative modelling study of threatened and commercial UK species in the North Sea, which despite all three projecting northward shifts showed large variation between model projections (Jones *et al.,* 2013).

Another approach has been to develop SDMs that include more complex mechanisms and processes. Cheung *et al.* (2011) adapted their 2009 model to include biogeochemical projections from an Earth System Model (NOAA's ESM2.1). Outputs suggested that the 120 exploited demersal fish and invertebrate species modelled would experience an average 52 km northwards shift per decade (based on distribution centroid) and shift 5.1 m deeper between 2005 and 2050 (Cheung *et al.,* 2011). In a further study Cheung *et al.,* (2015) used ocean projections from three different Earth System Models and predicted poleward shifts of an average rate of 30 km per decade for pelagic marine fish in Northeast Pacific shelf seas (Cheung *et al.,* 2015). In order to account for trophic interactions that occur between species, Fernandes *et al.* (2013) combined a dynamic bioclimatic envelope model (Cheung *et al.,* 2011) with a sized-based trophic model (Jennings *et al.,* 2008) to generate predictions for 48 marine fish within the North Atlantic from the period 1970–2004. This study found that predicted latitudinal shifts were reduced by up to 20% when compared to DBEM projections, suggesting that competition for prey would be an important factor in species movements.

Given the discrepancy between SDM outputs, alternative approaches have also been adopted to counter their limitations and uncertainties. Some studies have placed greater emphasis on the physiological dynamics of species (see Peck *et al.,* 2009 and Teal *et al.,* 2012), whilst others have argued that it is desirable to compare SDM predictions with outputs from more "data driven" approaches, such as Generalised Additive Models (GAMs; Rutterford *et al.,* 2015). GAMs have been used to explore the influence of environmental drivers on marine species abundances and distributions (Hedger *et al.,* 2004; Belanger *et al.,* 2012; Sagarese *et al.,* 2014), and an advantage of GAMs is that there are few assumptions of the nature of associations between predictors and response variables required to made *a priori* (Araújo *et al.,* 2005; Rutterford *et al.,* 2015). Using this GAM approach upon commercially important North Sea fish species, Rutterford *et al.* (2015) predicted that species would not necessarily shift polewards to track their preferred thermal habitats as has been found with SDMs; instead species may be constrained by availability of suitable habitat and depth and generally remain within current distribution limits. This study also highlighted the ability of GAMs to predict known abundance and distributions using historical data, providing confidence in this method for future work.

Recruitment and productivity

Less focus has been paid to understanding future changes in recruitment, in part due to a limited understanding of the factors accounting for recruitment dynamics of species and a limited capacity to predict climate variability (Pinnegar *et al.,* 2013; Szuwalski *et al.,* 2015). Much recent work has focused upon Atlantic cod, due to the large quantity of available data for this commercially valuable species. Although there is consensus that there are links between recruitment, climate and fisheries catches for a range of other species, there can be difficulty in using these trends to generate future recruitment predictions in those species with limited data availability (Petitgas *et al.,* 2012a; Szuwalski *et al.,* 2015; Britten, Down and Worm, 2016).

Modelled projections of cod have suggested future responses will differ depending on location of stocks; in Iceland stock productivity may increase, in the southern North Sea and Georges Bank productivity may decline, and those in the Irish and Celtic Sea may disappear by 2100 (Drinkwater, 2005; Pinnegar *et al.,* 2013). This model has since received criticism however including for neglecting seasonal temperature cycles (Pinnegar *et al.,* 2013). Other analyses that include management scenarios have suggested that long-term climate change will have greater impact on stock status than short-term management that encourages stock recovery (Kell, Pilling and O'Brien, 2005). Despite differing projections, models have agreed that fishing has a significant impact on recruitment and as such allowing for interactions between climatic variables and fishing in models is needed for realistic and appropriate predictions.

An alternative method of examining the association between climatic variables and productivity is to quantify 'catch potentials', that serve as a proxy for productivity (which itself is a function of recruitment). Catch potentials have been estimated using dynamic BEMs (Cheung *et al.,* 2011) and size structured food web models (Blanchard *et al.,* 2012). Different projections have been generated, with Cheung *et al.*'s (2011) BEM projecting catch potential reductions in the North Sea of 30% whilst Blanchard *et al.*'s (2012) food web model predicts increases of 25% around the UK. These models used different projections of net primary production, which may account for why the results differed. Importantly, this highlights the sensitivity of models to different inputs and mechanisms that are included within them as well as the need to further develop an empirical understanding of species biology and ecology that underpin these models.

Climate change impacts on UK fisheries

Climate change impacts at the fishery level will typically manifest themselves through changes in the availability of the resource and its productivity, with knock on socio-economic impacts for fishery operations, management and policy. As such, understanding fishery implications of climate change typically requires consideration of the socio-ecological links and feedbacks within these systems, and how these relationships may alter in response to both internal and external changes induced by climatic and non-climatic drivers.

Resource availability and productivity

Resource availability will typically be affected by climate change through changes in stock abundance, distribution, and catchability to gear used, whilst productivity is largely determined by recruitment success (Cheung *et al.,* 2012). Increases in abundances and range expansions of Lusitanian fish species have already been capitalised on by fishers around the UK and Ireland, providing new commercial opportunities (Pinnegar *et al.,* 2013). For example, boarfish (*Capros aper*) fisheries have emerged in Ireland, in response to stock increases thought to be due to positive strengthening in the North Atlantic Oscillation (Pinnegar *et al.,* 2013). Fishers have invested in new gear and technology to improve catchability as well as investing in science for more accurate stock assessments. Despite unrestricted fishing in the early 2000s, catch limits have since been put in place since 2011 to manage increasing fishing effort on the stock (ICES, 2017a).

Similar cases have also been observed with increased landings of John dory (*Zeus faber*) off the south-west UK coastline and Irish coast (Briggs, Dicky-Collas and Rooney, 2008) and triggerfish (*Balistes capriscus*) along the southern UK coast (Pinnegar *et al.,* 2013). European anchovies and sardines off the Cornish coastline and further into the North Sea have also experienced a population boom due to warmer waters, thus creating new opportunities (Cheung *et al.,* 2012). However, whilst these increases and expansions provide new opportunities for fishers, there is often little known about the biology or status of the stock (e.g. Dunn 2001; ICES, 2014). This can result in species having limited or no formal stock assessment, which if fishing remains unregulated or unmanaged, may lead to overfishing and subsequent declines.

Shifts in stocks can also lead to far-reaching, politically sensitive situations; the ‘mackerel wars’ between Scotland, Norway and Iceland between 2009 and 2014 resulted from mackerel stocks shifting into different territorial waters with subsequent disagreements over quota allocations and access to fish these resources (Pinnegar *et al.,* 2013; Spijkers and Boonstra, 2017). Similar issues have arisen regarding anchovy stocks in the English Channel, Irish Sea and southern North Sea. In these regions Spanish and French fleets have argued for quota when historically they have had none (Pinnegar *et al.,* 2013). Genetic studies have since identified that this stock is in fact a remnant sub-stock that is now benefiting from warmer temperatures, and not one that had moved northwards. As such, EU policy did not grant access to these fleets (Petitgas *et al.,* 2012b; Pinnegar *et al.,* 2013).

Studies have also now begun to focus on understanding finer scale socio-economic observed and future impacts of climate change within the UK. In an attempt to quantify the economic impacts of shifting fish stocks, Jones *et al.,* (2015) combined species distribution models with a cost–benefit analysis to predict future profitability of UK fisheries under climate change. Projections from scenarios suggested that maximum catch potential in the UK EEZ will decrease by 2050, leading to a 10% decrease in net present value, which could further decline when changing fuel costs are incorporated and capacity-enhancing subsidies are removed (Jones *et al.,* 2015). Other work by Fernandes *et al.* (2017) assessed the combined impacts of ocean acidification and warming on UK fisheries using both observational and laboratory data and modelling approaches, focussing on bivalve and fish species. The study found that apart from for the Scottish >10 m fleet, fish and shellfish catches would decrease between 10–30% by 2020 with losses in revenues of 1–21% between 2020 and 2050 would occur in addition to employment declines (Fernandes *et al.,* 2017). Currently these remain some of the few UK studies generating specific socio-economic predictions that extend further than impacts on catch potential, yet such research is important as it can provide crucial information to industry, management and policy (Haynie and Pfeiffer, 2012).

The socio-economic impacts of climate change on stock availability and productivity will likely be felt differently throughout the UK given the distribution of different sectors of the UK fishing fleet. Fleets operating from ports in northern England and Scotland such as Peterhead and Fraserburgh land large amounts of pelagic stocks, which are known to have dramatic responses to environmental changes (Cheung *et al.,* 2012; MMO, 2017a). Conversely, the majority of the UK's demersal fleet operates from ports in south–west England including Newlyn, Brixham and Plymouth (MMO, 2017a). Fisheries in this region, whilst having benefitted from recent population expansions of certain stocks in the 'western approaches', have also experienced recent declines in more traditional target species such as Atlantic cod (Cheung *et al.,* 2012). As such, there is a growing need for regional level projections to help inform how opportunities and threats may affect different fisheries (Daron *et al.,* 2015).

Fishing operations

Fishing activities and fleet operations will also be influenced both directly and indirectly by climate change. Storm severity and frequency pose direct climate impacts and can affect the ability of fishers to access resources as well as causing damage to static gear and port infrastructure (Cheung *et al.,* 2012; Sainsbury *et al.,* 2018). The UK storms of winter 2013–14 were some of the most substantial in the UK in the past 66 years (Matthews *et al.,* 2014) and resulted in significant impacts on the UK fishing industry, damaging gear and vessels, causing days lost at sea and affecting harbour structures (Andrew and Read 2014; Pinnegar *et al.,* 2017). Such storms could become more frequent into the future, posing questions over the adaptive capacity of these fishing communities (Kirtman *et al.,* 2013). Climate change influences the availability, productivity and catchability of fish stocks, which in turn may require changes in gear used, fishing location as well as overall fishing behaviour (Cheung *et al.,* 2012; Pinnegar *et al.,* 2013; van Putten *et al.,* 2014).

Fishers' responses to climate change impacts also depends on consideration of wider social, economic and political trade-offs, as well as the time frames in which changes are occurring and the directionality of the impact (Daw *et al.,* 2009; van Putten *et al.,* 2014). Direct impacts typically require immediate responses to limit their effect, favouring short-term 'coping' responses, for example a redistribution of effort (OECD 2010; Perry *et al.,* 2011). Indirect impacts of climate may occur over broader and longer time scales and thus will require greater planning, preparation and emphasis on adaptation (OECD 2010; Perry *et al.,* 2011). As such, climate change may affect both the short-term fishing trip behaviour of fishers (tactics), as well as their long-term investment perspectives (strategies), but as yet there is limited understanding of how this will manifest among different fishers and sectors.

Some attempts have been made to explore future fisher behaviour under climate change. A study of a Tasmanian rock lobster fishery used a range of fleet dynamic models to predict changes in fisher behaviour under different climate change and market price scenarios (Hamon *et al.,* 2014). More recently, projected changes of fishery dynamics in the Northeast Atlantic have been generated using a coupled climate-driven bio-physical model with a scenario driven ecological-economic model which incorporates fleets, governance and management as well as ecological and climatic changes (Mullon *et al.,* 2016). Given that future impacts are inherently uncertain and difficult to predict, increasing research in this area and the ways to model socio-economic with biological and ecological processes needs greater attention. This can help inform management and policy to support and enable fishers to respond appropriately and in a way that won't be ecologically damaging in the future (Pinsky and Fogarty 2012; Defra, 2013). Such information may also be useful to inform strategies that may be needed to assist fishers cope and adapt to future change.

Management and policy

The effectiveness of management and policy measures, including effort controls, spatial closures, and quota allocations, all have the potential to be impacted by climate induced changes in availability and productivity of stocks (Miller *et al.,* 2010a; Cheung *et al.,* 2012; Hollowed *et al.,* 2013; Melnychuk, Banobi and Hilborn, 2014; Frost *et al.,* 2016). Spatial fisheries management in particular may be affected if stocks shift out of areas that were originally established to help them recover. An example of this is the North Sea plaice box set up in 1970s to protect juvenile plaice from overfishing, but which appears to be less effective in more recent years (van Keeken *et al.,* 2007; Pinnegar *et al.,* 2013). Cheung *et al.* (2012) provided projections suggesting that five UK fishery closure areas will have limited effectiveness in the future as stocks will shift due to significant temperature increases in these areas. Others have also raised potential issues over marine protected area designations in the

UK and their future effectiveness under climate change (MCCIP, 2015). However, some studies argue that marine protected areas may help to buffer some climate change effects, for example providing, ‘stepping stones’ for dispersal and ‘landing zones’ for migrants, promoting ecosystem recovery and genetic diversity for adaptation to climate change, and protecting large populations with high reproductive outputs (Davies *et al.,* 2017; Roberts *et al.,* 2017).

Stocks occurring throughout UK waters (and within Europe more widely) are predominantly managed to achieve Maximum Sustainable Yield (MSY) approaches (Maltby and Wentworth, 2018). Given that species productivity and availability can be influenced by climate change, adjustments in MSY and subsequent quota allocations may result. This may include reducing limits/quotas to ensure that vulnerable stocks do not become overfished, while for other species potentially increasing limits/quotas to allow species benefiting from warming to be exploited, preventing challenges for fishers. One challenge associated with achieving MSY for species that are positively and negatively affected by climate change is likely to result from ‘choke species’, for which quota is exhausted even when quota remains for other species (Rihan, 2018; Ulrich, 2018). Given many UK fisheries, especially bottom fisheries, are mixed, and take many species with the same gear at the same time, ‘choking’ is often hard to avoid. Additionally, there is an increasing need to account for climate effects within the models used to inform management. More widely in Europe, Ecosystem Based Management approaches to fisheries management are being increasingly advocated, and these may provide other mechanisms or approaches to help manage climate effects due to the emphasis upon managing the wider environment as opposed to just single stocks (Pikitch *et al.,* 2004; King and McFarlan, 2006; Jennings and Rice, 2011).

As yet however, little fisheries legislation in the UK currently references climate change explicitly or stipulates specific actions for managing its impacts, although there are mechanisms within them that might allow for it to be better incorporated (Frost *et al.,* 2016). While the recent UK Government’s 25 Year Environment Plan references that they ‘will deliver effective management of our seas to make sure they are resilient to climate change while delivering the full range of goods and services' there is still limited specific fisheries management and policy measures developed to explicitly deliver this as yet (Defra, 2018a). Many have advocated that fisheries management may have to become more flexible and adaptive in its approaches in the future in order to manage the impacts of climate change on both ecological and social aspects of fishery systems (Johnson and Welch, 2009; Ogier *et al.,* 2016; ABPmer, 2018; Queirós *et al.,* 2018). Increasingly the need to consider the effects of shifting stocks and potentially to have the need for dispute resolution mechanisms to deal with possible issues arising across jurisdictional boundaries will also be important (Pinsky *et al.,* 2018), particularly for the UK which lies in a multi-jurisdictional sea region and given its withdrawal from existing European Union frameworks.

Vulnerability of fishers and fisheries to climate change

To appropriately manage climate change impacts and support people to adapt to climate change, understanding how they cope with and react to environmental change forms a key part of gaining insight into the effectiveness of current and future climate change adaptation strategies (Turner *et al.,* 2003; Wisner *et al.,* 2004; Adger, 2006; Marshall and Marshall, 2007; Adger *et al.,* 2012; Johnson, Henry and Thompson, 2014; Metcalf *et al.,* 2015). The vulnerability concept has gained particular attention in regard to climate change, with the IPCC developing a framework to simplify and better capture the array of perspectives and dimensions regarding vulnerability that currently exist (Oppenheimer *et al.,* 2014). The IPCC defines vulnerability as 'the propensity or predisposition to be adversely affected; vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt' (Oppenheimer *et al.,* 2014). This definition and framework has been adopted and used in many systems, including fisheries (Soares, Gagon and Doherty, 2012; Brugère and De Young, 2015). Vulnerability can be viewed from purely ecological or social perspectives, or as increasingly common, from socio-ecological and interdisciplinary perspectives in order to understand the links and dependencies between the two aspects of such systems (Adger, 2006; Marshall *et al.,* 2013a; Oppenheimer *et al.,* 2014; Metcalf *et al.,* 2015).

Vulnerability frameworks typically consider three main components: the *exposure* of the system (or sub system or individuals within the system) to the stress/change, the *sensitivity* to the stress it is exposed to, and the ability of the system and those within it to cope with and adapt to the impacts—its *adaptive capacity* (Adger, 2006; Oppenheimer *et al.,* 2014). Through examining these components, insight into the range of physical, ecological, socio-political and economic dimensions that influence subsequent responses to change can be gained (Birkmann 2006; Miller *et al.,* 2010b; Ciurean*,* Schtöter and Glade, 2013). This provides knowledge that can underpin assessments of risk (Oppenheimer *et al.,* 2014), identify enablers and barriers to adaptation (Metcalf *et al.,* 2015), inform prioritisation and urgency of action and highlight cost–effectiveness and efficiency of potential adaptation mechanisms (Marshall *et al.,* 2013a), in addition to more broadly increasing understanding into the drivers of vulnerability (Cardona *et al.,* 2012; Sutton and Tobin 2012).

Vulnerability of UK fisheries to climate change

A range of methodologies and approaches have been used to understand the vulnerability of fishing communities to climate change (Brugère and De Young 2015). Many assessments have been applied in tropical or developing countries, partly because these countries are expected to be heavily impacted by climate change, and partly due to their high dependency on fish for their livelihoods and wellbeing (Moser, Williams and Boesch, 2012; Blasiak *et al.,* 2017; Ding *et al.,* 2017). While a full analysis of the different types of vulnerability assessments undertaken in the fisheries sector is beyond the scope of this chapter, some discussion is given in the context of the UK. Few vulnerability assessments of UK fishing communities have been undertaken explicitly, despite many communities already experiencing impacts associated with climate change (Pinnegar *et al.,* 2013).

One of the first fisheries vulnerability assessments which included the UK was undertaken by Allison *et al.* (2009), which compared the vulnerability of 132 national economies to climate change impacts on capture fisheries. Within this, the UK was identified as having a high adaptive capacity with very low vulnerability. Further work to explore this as part of the QUEST-Fish project (see http://www.quest–fish.org.uk/), using improved estimates of sea surface temperatures and fisheries catches, ranked the UK as 215th out of 225 countries in terms of vulnerability, rating it as having low vulnerability (Pinnegar *et al.,* 2012). Other recent global studies have also indicated that the UK in general has relatively low vulnerability to climate change (Blasiak *et al.,* 2017; Ding *et al.,* 2017).

Two wider national climate change risk assessments, one in 2012 and another in 2017, have also taken place in the UK which have provided a technical assessment of climate change risks in relation to fisheries (Pinnegar, Watt and Kennedy, 2012; Brown *et al.,* 2016). Regarding fisheries aspects, the 2017 report provides an update to the initial 2012 assessment. Within the 2012 assessment 11 risks were identified that climate change posed to fisheries as well as other marine sectors (Pinnegar, Watt and Kennedy, 2012). Within the assessment was a basic social vulnerability assessment which used a checklist to examine how the characteristics of marine communities such as their location or their physical/mental health, could affect their vulnerability to certain risks. Although limited in scope, it highlighted the need for more work to be undertaken in order to increase understanding of how climate change impacts among fishing communities will be felt and subsequently responded to.

An economic analysis by Defra also explored fisheries vulnerability to climate change, with a specific focus on the adaptive capacity of the whole UK fishing industry to impacts associated with warming sea temperatures (Defra, 2013). This highlighted some adaptive responses that are already being seen, and may increasingly occur into the future, including traveling further to catch current species, diversifying livelihoods, increasing vessel capacity, and changing gear to catch different species (Defra, 2013). However, several barriers to adaptation were identified such as market failures, lack of information flow, policy barriers and consumer constraints (Defra, 2013). A more recent Seafish report consulted seafood industry stakeholders to help identify a number of ‘adaptation responses’ the industry could adopt in response to future climate change risks (Garrett, Buckley and Brown, 2015). These were assessed based on the speed at which the adaptation response could take place, e.g. in 2 years’ time, in 15 years’ time, and the scale of resources available to facilitate adaptation. The adaptation responses identified included reviewing quota allocations and ‘relative stability’ principles in fisheries management, improving safety of crew and vessels, developing the evidence base for climate impacts on fisheries, and improving relationships between science and industry to improve knowledge sharing (Garrett, Buckley and Brown, 2015).

While it is generally considered that, at a national level, UK fisheries have relatively low vulnerability to climate change, there remains a need to further explore this finding at a more local and regional level. Additionally, UK vulnerability assessments of fisheries are also often made in comparison to other countries at a global level and therefore neglects the regional differences that may exist and deserve greater insight. Fisheries around the UK are regionally diverse, from port, catch and sector perspectives (HOCEEUC, 2018). For example, according to the MMO (2017a) England has the greatest number of vessels (3,098) while Scotland has the greatest gross tonnage of the UK fleet (105,395 GT). Eighty percent of the UK fleet is 10 m and under, but this varies regionally (MMO, 2017a). Of the larger vessels, Scotland and Northern Ireland have the largest proportions (MMO, 2017a). Welsh fishers predominantly operate from under 10 m vessels and are heavily dependent upon shellfish (Carpenter, Williams and Walmsley, 2018). In Northern Ireland, most fisheries are centred upon nephrops and use large vessels (MMO, 2017a). In Scotland, there are fleets targeting pelagic and demersal fish and shellfish species, and the majority of the commercial industry operates from the north east of Scotland, such as Peterhead and Fraserburgh, while a smaller section of the industry operates from smaller ports scattered along the west coast (Marine Scotland, 2011; MMO, 2017a). In England, there is a large demersal sector operating from the south-west of the UK. Shellfish also form important catches for many regions, including the east and south English coast (MMO, 2017a).

UK fleet differences should also be considered against a broader background of social and economic factors that could affect fishing communities’ vulnerability. For example, fishers are members of coastal communities which are also more likely to be exposed to other climate change impacts compared to more inland communities, such as sea level rises, flooding and coastal erosion (Wong *et al.,* 2014; Colburn *et al.,* 2016). Coastal communities also face wider socio-economic problems such as low incomes, physical isolation and high deprivation (Zsamboky *et al.,* 2011; Seafarers, 2018). As such, adaptation to climate change by fishers will be challenged from ecological, social and economic perspectives which will vary among regions and localities. Understanding the vulnerability of fisheries to climate change at these smaller scales, and what enhances or constrains fishers in their ability to adapt to future impacts, is therefore increasingly necessary.

Adaptive capacity

While a system may have high exposure and/or sensitivity to climate change, it is the capacity of the system, and individuals within it, to adapt which influences the extent of its vulnerability (Yohe and Tol, 2002; Engle, 2011). The IPCC defines adaptive capacity as ‘The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences’ (IPCC, 2014). Adaptive actions can therefore reduce vulnerability, with higher adaptive capacity seen as a desirable, even critical, state for individuals and/or systems to exhibit (Yohe and Tol, 2002; Gallopin, 2006; Engle, 2011). As such, exploring what contributes to adaptive capacity has become the focus of increasing amounts of research given the use of this information in adaptation planning and decision making (Smit and Wandel, 2006; Adger, Lorenzoni and O’Brien, 2009; Cinner *et al.,* 2013, 2018, Whitney *et al.,* 2017).

In socio-ecological systems, adaptive capacity can be assessed from different perspectives (Marshall *et al.,* 2010; Whitney *et al.,* 2017; Fig. 1.1). Ecological approaches can explore short term individual species responses to variation in climatic variables using field or laboratory data, or they can undertake longer-term and larger scale analyses on aspects such as fisheries catches, thermal tolerance or species traits (Wheatley *et al.,* 2017; Whitney *et al.,* 2017). From social perspectives, approaches also focus on numerous aspects at a range of scales from individuals, households and community levels to wider regional or national scales (Engle, 2011; Brugère and De Young, 2015; Whitney *et al.,* 2017). Earlier work used ‘capitals’ to explore social adaptive capacity, including financial and social, but more recently it has been viewed through a number of core dimensions: 1) peoples’ assets which can be drawn upon when needed, 2) flexibility to change strategies, occupations and/or areas, 3) ability to organise and act accordingly, 4) learning to reorganise and respond to change and 5) agency to determine whether to change or not (Bennett *et al.,* 2014; Cohen *et al.,* 2016; Whitney *et al.,* 2017; Cinner *et al.,* 2018). Integrated approaches are also used to bridge understanding between ecological and social adaptive capacity to generate broader insights into adaptive capacity from a socio-ecological perspective (Marshall *et al.,* 2013a; Whitney *et al.,* 2017).

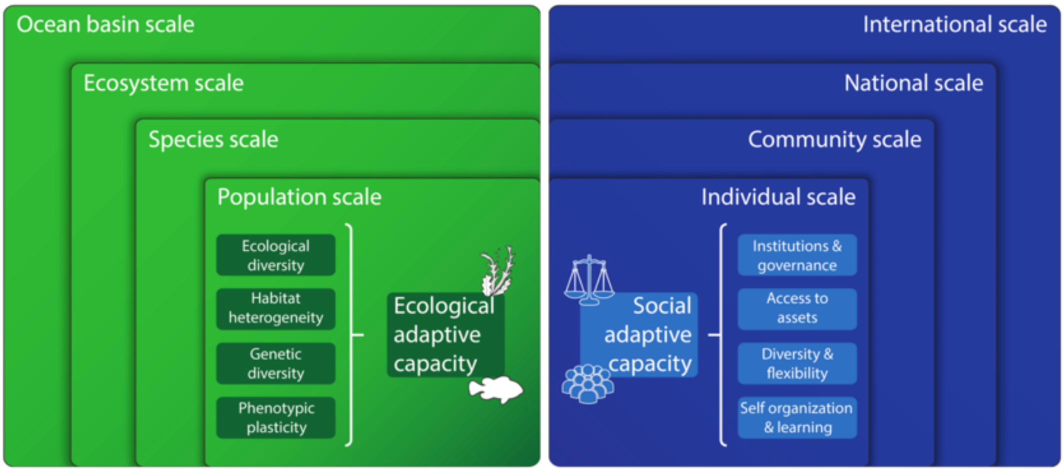


Figure 1.1. Example measures of adaptive capacity for ecological (left) and social parts of the fishery system (right). Taken from Whitney *et al.* (2017).

Socio-economic factors have been argued as particularly important in shaping social and wider socio-ecological vulnerability because of the role human actions have in influencing the ability of individuals and systems to adapt, e.g. through governance systems, management rules and institutions (Engle, 2011; Williamson, Hesseln and Johnston, 2012). Within resource dependent communities such as fishing, adaptive capacity is also associated with people's sensitivity (Marshall *et al.,* 2013a; Marshall and Stokes, 2014). The assumption is that if people are more dependent on a natural resource, the more sensitive they are if it changes. This can strongly link to adaptive capacity in the sense that aspects of dependency can act as both barriers or enablers to adapt and change, and as such measures of sensitivity and adaptive capacity can often overlap (Marshall *et al.,* 2010; Marshall *et al.,* 2013a). Using a simple example, fishers who use a greater diversity of fishing gears and who do not depend upon a limited range of target species may have greater flexibility to change their fishing practices in the future with climate change because they have other opportunities available to them (Brugère, Holvoet, and Allison, 2008; Badjeck *et* *al.,* 2010; Stoll, Fuller and Crona, 2017). As such these fishers may therefore be considered to have higher adaptive capacity compared to fishers who are highly specialised because they can adapt their practices more easily.

Exploring adaptive capacity can take objective and subjective approaches. Objective methods can use measures such as incomes, employment and assets to explore aspects of peoples' adaptive capacity, often utilising secondary data sources e.g. collected by government agencies or industry (Allison *et al.,* 2009; Johnson, Henry and Thompson, 2014; Colburn *et al.,* 2016; Seara, Clay and Colburn, 2016). Subjective approaches can also be used, and often centre at smaller scales such as individuals or households to explore peoples' perceptions, values, priorities and motivations which can influence their adaptive capacity and actions (Grothmann and Pat, 2005; Brown and Westaway, 2011; Seara, Clay and Colburn, 2016; Elrick-Barr *et al.,* 2017; Grunblatt and Alessa, 2017). How people perceive themselves to be able to cope or adapt to change, as well as their wider perceptions of the change and risks itself, presents an important aspect of exploring adaptive capacity and wider vulnerability, particularly because *perceived* ability and *actual* ability to adapt can be quite different (Dolan and Walker, 2006; Marshall and Marshall, 2007; Johnson, Henry and Thompson, 2014; Dominicis *et al.,* 2015; Seara, Clay and Colburn, 2016; Elrick-Barr *et al.,* 2017). These 'psycho-social' influences can affect peoples' potential and realised response to adaptation strategies, as well as support for initiatives addressing climate change, willingness to act in response to such initiatives and wider preparedness for responding to change (Slovic 1987; O'Connor, Bord and Fisher, 1999; Brody *et al.,* 2008; Weber, 2010; West and Hovelsrud, 2010; Tam and McDaniels, 2013; Oppenheimer *et al.,* 2014; Metcalf *et al.,* 2015). Exploring such aspects therefore provides important insights into wider overall vulnerability and also help identify social limits or enablers to adaptation (Grothmann and Pat, 2005; Adger *et al.,* 2009; Brown and Westaway, 2011; Lockwood *et al.,* 2015).

Many studies have found that fishers perceive themselves as having high adaptive capacity, as well as high confidence that their industry will be able to adapt, due to their ability to be flexible and reactive based on the changes they face day-to-day (Nursey-Bray *et al.,* 2012; Garrett, Buckley and Brown, 2015;

Seara, Clay and Colburn, 2016). Such perceived ability to adapt can be attributable to many factors, including those stemming from social, economic and psychological dimensions (Grothmann and Pat 2005; Béné *et al.,* 2016; Seara, Clay and Colburn, 2016). Fisheries are naturally volatile systems, undergoing constant change both from actors within the system as well as outside of it. For some fishers this constant change can affect their perceived ability to cope in the future: if the climate is changing, so what? How will it present change they have not coped with before?

Exploring climate change perceptions and beliefs

Perceptions and beliefs of climate change itself form an important aspect of how people may respond and adapt to future change (Grothmann and Patt, 2005; Gifford, Kormos and McIntyre, 2011; Oppenheimer *et al.,* 2014). There has been a substantive research focus on climate change perception to gain understanding on the levels of climate change concern, awareness, scepticism and perceptions of risk (e.g. Weber, 2010; Taylor, Dessai and Bruin de Bruin, 2014; van der Linden, 2017). Concern and awareness of climate change vary throughout the world, among individuals, communities and countries, and is influenced by a multitude of factors (Capstick *et al.,* 2015; Lee *et al.,* 2015; van der Linden, 2017). Globally, concern and awareness have increased over time, with general awareness being higher in developed countries, but heightened concern among people with higher awareness in developing countries (Lee *et al.,* 2015; van der Linden, 2017). In a European survey, UK respondents appeared to be least worried about climate change and showed ambivalent emotions regarding climate change (Steentjes *et al.,* 2017). Research suggests that scepticism may have increased (2006–2010) within the UK, and that sceptical views in regard to whether human-induced climate change is occurring is also higher compared to other countries (Pidgeon, 2012; Steentjes *et al.,* 2017).

Climate scepticism is tightly linked to wider perceptions of climate change (Smith and Leiserowitz 2012; Brügger, Morton and Dessai, 2016; Steentjes *et al.,* 2017), but it is not a single dimension and instead has many sub-dimensions that can vary and differ in their extent (Rahmstorf, 2004; Whitmarsh, 2011; Capstick and Pidgeon, 2014; van Rensburg, 2015). Early work indicated that people can have sceptical views regarding the trend of climate change (i.e. is it warming), the attributions (human vs. natural causes) and its impacts (Rahmstorf, 2004). While exploring these aspects provides a useful framework which has been applied in UK contexts as well as more widely (e.g. Poortinga *et al.,* 2011; Whitmarsh, 2011), there are also other aspects of scepticism that require attention. This includes scepticism about the evidence base, how scientific knowledge is researched and produced, the ways in which information is communicated (e.g. agenda pushing, industry biasing, media exaggeration) as well as the effectiveness and willingness of actors to address climate change at individual, societal and political levels (Capstick and Pidgeon, 2014; van Rensburg, 2015). Examining these different aspects of scepticism is important to avoid pigeonholing people as being purely 'sceptics' or 'deniers'.

Understanding and interpreting climate change

An important assumption widespread throughout the literature on climate change beliefs and perceptions, and contested by some, is that increased knowledge can help to heighten concern, awareness and risk perceptions and thus shape future motivations and behaviours in a way that helps to address the problem or respond to the impact (Milfont, 2012; Ranney and Clark, 2016; Shi *et al.,* 2016). However, there are discrepancies among the literature regarding the extent to which knowledge affects these aspects (van der Linden, 2017). Some have found little evidence to suggest knowledge affects levels of concern regarding climate change (Brody *et al.,* 2008), or that it is in fact negatively associated (Kellstedt, Zahran and Vedlitz, 2008). More recently however a growing literature has shown that level of knowledge does play a key role in influencing concern and perceptions, and can even predict them (Sundblad *et al.,* 2007; Hidalgo and Pisano, 2010; Milfont, 2012; Reser *et al.,* 2012; Shi *et al.,* 2016).

Discrepancies regarding the extent to which knowledge influences perceptions could exist for a number of reasons. Some suggest that study designs do not appropriately conceptualise and thus capture all knowledge forms, or instead use self-reported knowledge rather than explicitly test it (Schwarz, 1999; Roser-Renouf and Nisbet, 2008; Whitmarsh, 2009; Reynolds *et al.,* 2010). Indeed, what people think they know—their 'subjective' knowledge—and the real evidence can often be different and thus this can influence interpretations (van der Linden, 2015). Arguably this can also influence the extent to which people engage in subsequent efforts aimed at increasing knowledge on a subject. Studies can also capture different forms of knowledge relating to different aspects of climate change, such as the causes, impacts or responses, and thus misinterpret the perceived level of knowledge and its effect on perceptions and concern (van der Linden, 2015; Shi *et al.,* 2016).

Interpretation of the same information can also differ between people and across groups as a function of their cognitive abilities, personal experiences, beliefs and cultures, and pre-existing knowledge (Whitmarsh, 2011; Reser *et al.,* 2012; van der Linden, 2015). People often seek out information that fits with their current beliefs and identity, and when attributing information to particular causes is too complex, people often filter or ignore information that they receive (Gifford, 2011; van Putten *et al.,* 2015a). Additionally, the source of information and how it is communicated also influences knowledge and perceptions – most members of the public rely on third parties, such as the media, to distill complex scientific information to them. However, these sources may have less trust, legitimacy, transparency and consistency in the messages conveyed (Stamm, Clark and Eblacas, 2000; Kellstedt, Zahran and Vedlitz, 2008; Gifford 2011; Pidgeon, 2012). This can not only affect public concern and risk perceptions relating to climate change itself, but mixed messages and information can also influence uncertainty and scepticism over the scientific consensus on the subject (Malka, Krosnick and Langer, 2009; Whitmarsh, 2011). Increasingly researchers are asking how climate change and its associated risks are communicated to and among the public (e.g. Moser, 2010a; 2014).

People’s values and beliefs can also affect the extent to which they accept or reject information and risks, which can subsequently influence a person’s knowledge and their degree of willingness to act (Hidalgo and Pisano, 2010; Weber, 2010). Pro-environmental beliefs have been found to have particular influence on belief in climate change and concern about it (Hidalgo and Pisano 2010; Poortinga *et al.,* 2011; Whitmarsh; 2011). People with values that are altruistic and express concern for nature and the biosphere tend to be less sceptical about climate change, and in turn show greater concern about its potential risks and impacts (Corner*,* Markowitz and Pidgeon, 2014). Those that hold worldviews associated with community and equality perceive climate change as a greater risk compared to those with more individualistic views (Kahan, Jenkins-Smith and Braman, 2011; Corner, Markowitz and Pidgeon, 2014).

Risk perceptions of climate change

Intimately linked to overall perceptions and understanding of climate change are people's risk perceptions. Risk perceptions are important to consider when understanding an individual's or community's adaptive capacity (Brooks, 2003; Adger *et al.,* 2009), and can influence their subsequent preparedness and responses to adaptation initiatives (O'Connor, Bord and Fisher, 1999; Lowe and Lorenzoni 2007; Marshall and Marshall, 2007; Barnett *et al.,* 2014). It has been argued that understanding risk perceptions is as equally important to policy makers as scientific assessments of risk (Kellstedt, Zahran and Vedlitz, 2008), because most citizens rely on intuitive judgments of potential risks to guide their decisions and actions rather than technical calculations (Slovic, 1987; Cardona *et al.,* 2012).

Risk is produced through an interaction between the hazard event itself and the exposure and vulnerability of the system or community to the hazard (Cardona *et al.,* 2012; Oppenheimer *et al.,* 2014). The IPCC defines risk as 'the potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur' (Oppenheimer *et al.,* 2014). In this developed definition and framework (Fig. 1.2), risk is shown to both influence and be influenced by vulnerability, recognising the complex economic, social, political and ecological dimensions that determine the magnitude of risk and its subsequent extent (Oppenheimer *et al.,* 2014).

Framing risk within a wider psychology and social science context as opposed to the traditional, technical risk–hazard literature is important as many have argued that risk is also a mental and social construct developed by those within the exposed system (Kasperson *et al.,* 1988; Sjöberg 2000; Whitmarsh and Kean 2005). Estimation of risk is as much a value–dependent social process as it is a technical one, with the magnitude and intensity of risk being determined heavily by psychological, socio-economic, and political influences (Cardona, 2003; Etkin and Ho, 2007; Cardona *et al.,* 2012).

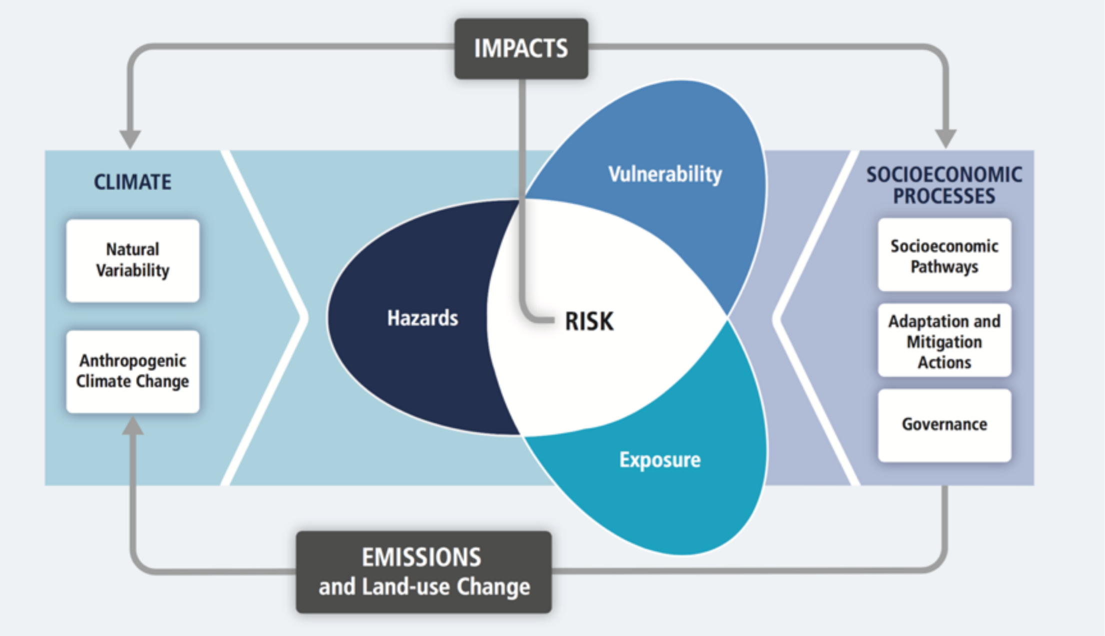


Figure 1.2: Framework representing how climate-related hazards, exposure and system vulnerability (ecological and socio-economic) determine, and interact with, risk (Oppenheimer *et al.,* 2014). Changes in both the climate system and socio-economic processes will influence the three inner components, which relate to overall risk.

Climate change differs from other environmental hazards and has been described as an ‘evolutionary novel’ type of risk that people aren’t necessarily well equipped to understand and act upon (van der Linden, 2015). It cannot be felt directly and is not a risk in itself; rather it is the resulting impacts from climate change that impose the risk. As such climate change risks can be described as both ‘unknown’ (difficult to observe or quantify, impacts may be new or delayed in their effect) and ‘dreaded’ (uncontrollable feelings of dread) (Weber, 2010; Nursey-Bray *et al.,* 2012; Oppenheimer *et al.,* 2014).

Climate change has also been described as being ‘psychologically distant’, removed in space and time with intangible qualities difficult to interpret, leading people to perceive it as a distant and impersonal threat, and therefore having low levels of concern about the issue (Lowe and Lorenzoni, 2007; Spence*,* Poortinga and Pidgeon*,* 2012; Marshall *et al.,* 2013a; Leviston *et al.,* 2014). By psychologically distancing themselves from the threat of climate change, people often dissociate with it and thus characterise it as something that is of low risk which will happen to other people in other places and can be solved in the future when more information is available (Weber, 2010; Nursey-Bay *et al.,* 2012; Metcalf *et al.,* 2015; van der Linden, 2015). In this way, risks that are more pressing and closer in time or space are valued more than those further into the future (Gifford, 2011; McDonald, Chai and Newell, 2015).

Factors influencing risk perceptions

In addition to climate change belief and knowledge, a wide range of other factors have been identified as affecting overall judgment of risk, including social amplification and attenuation, personal experience and place attachment (van der Linden 2015). Risk perceptions can also very according to the socio-demographics of individuals and groups, with gender, age, level of education and income being found to have a role (O'Connor, Bord and Fisher, 1999; Slovic, 1999; Kellstedt, Zahran and Vedlitz, 2008). People use both analytical processing to interpret risk, relying upon rules and algorithms, as well as affective processing which evaluates risks in the context of feelings and generates affective responses (an evaluation or emotion, e.g. fear, dread) (Loewenstein *et al.,* 2001; Kobbeltved *et al.,* 2005; Sjöberg, 2006; Weber, 2010). Whilst often used in parallel, analytical processing requires greater cognitive effort; as such when faced with risks that are for example unknown or people have little experience of, associative processing often becomes the overriding process to interpret the risk. The extent to which these two main cognitive processes influence how risks are perceived is debated (van der Linden, 2015).

Factors influencing climate change risk perceptions can vary both at the individual and community level, and also depend on other external risks that may be present. There have been some attempts to develop theoretical frameworks to bring together and capture the influence of factors upon climate change risk perceptions, although despite the breadth of literature, such attempts are few in number (van der Linden, 2017). This may be due to the array of factors that can affect perceptions of risk. Alternatively, it may be because research has highlighted the importance of context regarding perceptions, and/or found that they act in different ways, thus complicating how to describe them in a generic way that is applicable across different individuals or groups (van der Linden, 2017).

Some have developed frameworks to enhance understanding of climate change risk perceptions. Kellstedt (*et al.,* 2008) developed a framework to look at how information, attitudes and self-efficacy influenced risk perceptions, incorporating aspects such as trust, ecological values and political ideologies. While a useful framework to capture particularly how information and knowledge can be influential, other factors such as personal experience and affective evaluations (emotions) may also have strong influences. Van der Linden proposed a framework in 2015 that groups factors affecting risk perceptions into four core dimensions: cognitive factors, experiential processing, socio-cultural influences and socio-demographics (Fig. 1.3). Although not comprehensive and not capturing all aspects, such as trust or self-efficacy, it helps to bring together the wide-ranging literature looking at influences upon climate change risk perceptions. The main factors influencing climate change risk perceptions are described in Table 1.1.

Fishers' knowledge of climate change and its impacts on fisheries

Due to the intimate connection fishers have with the sea and its marine resources, it could be assumed that fishers will have a greater awareness and understanding of the impacts of climate change on fisheries (Savo, Morton and Lepofsky, 2017) and thus concern. But whilst research exploring fishers' ecological knowledge and wider understanding of climate change has provided useful insights and found they can detect changes within the marine environment (Savo, Morton and Lepofsky, 2017; Martins and Gasalla, 2018), including ecological impacts such as stock changes and status (Eddy, Gardner and Pérez–Matus, 2010; Carter and Neilsen 2011; Nursey-Bray *et al.,* 2012; Geetha *et al.,* 2015; Lima *et al.,* 2017) there is still limited research regarding how fishers perceive change within their environment and its links to their climate change awareness or concern.

Some studies have focused on linking fishers' observations of environmental changes with climate change concern or awareness. For example, in the rock lobster fishery in Tasmania, fishers gave observations of changes in their marine environment consistent with climate change, but had reservations and scepticism as to whether climate change was a real process and expressed views that its impact was overrated (Nursey-Bray *et al.,* 2012).

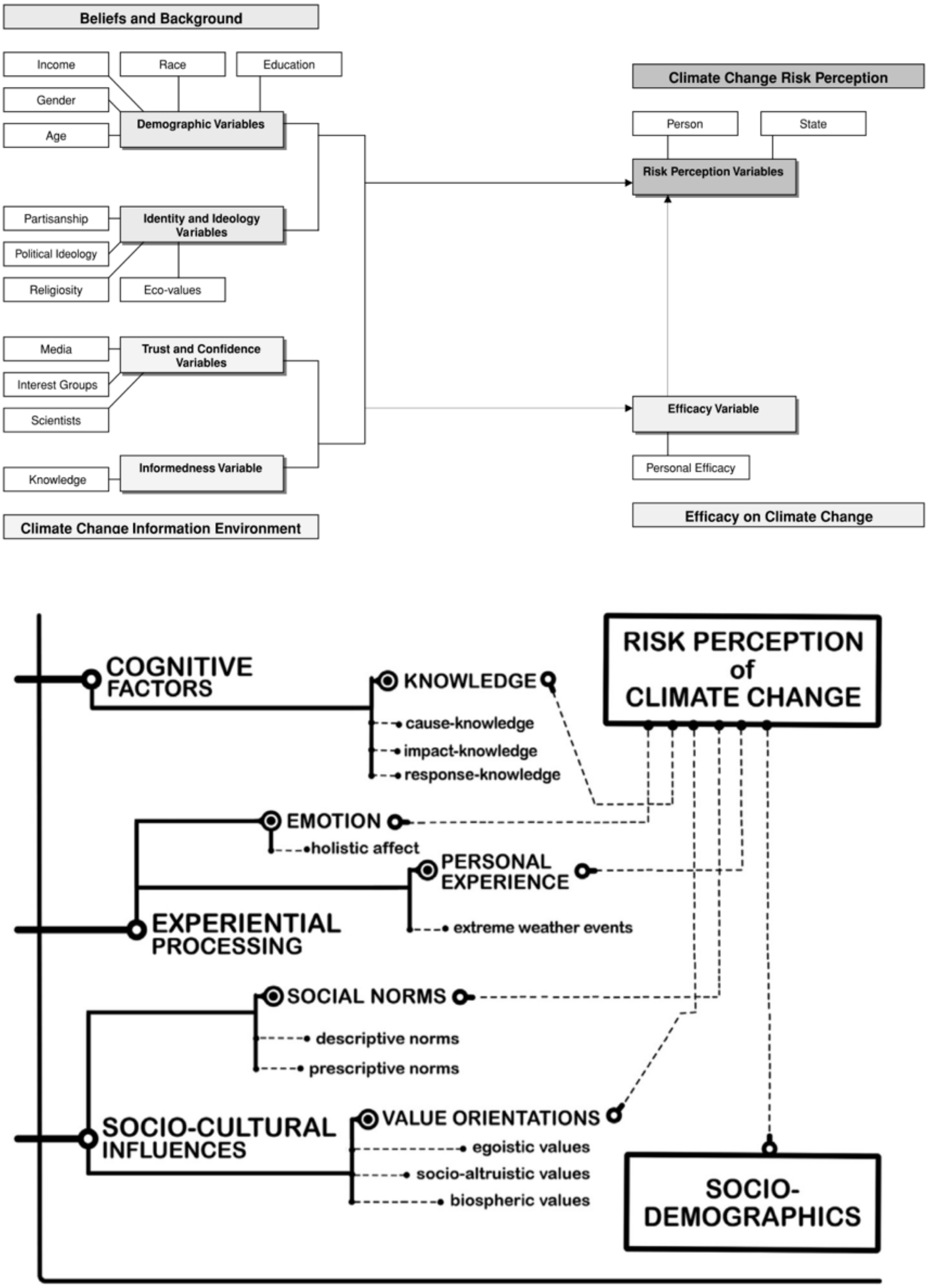


Figure 1.3. Climate change risk perception frameworks developed by Kellstedt, Zahran and Vedlitz (top; Kellstedt, Zahran and Vedlitz, 2008) and van der Linden (bottom; van der Linden, 2015). Each framework demonstrates the complex factors that can influence climate change risk perceptions, which can vary at individual as well as broader scales.

Similar results have also been observed amongst fishers in San Diego (Zhang, Fleming and Goericke, 2012). Fishers observed changes in their environment and target species that were attributable to climate variability and consequently changed their fishing practices, for example through targeting other species or going to different fishing grounds. Despite this, only 12.9% of respondents agreed that climate change was a possible driver of these changes. Fishers in Thailand, whilst observing and directly experiencing climate change through increased frequency and severity of storms and rising sea levels, still displayed general lack of knowledge over climate change and its impacts, and as such were not proactively managing the risks that it presented (Bennett *et al.,* 2014).

These results suggest that despite fishers being able to identify climatic variables that affect their target stocks or wider marine environment, as well as potentially being more knowledgeable or aware than other public groups about changes in their environment, there are still factors that prevent them from fully understanding and/or attributing climate change to observed or potential impacts upon fisheries. This is not a phenomenon unique to fisheries (Hodgkinson, Hobday and Pinkard, 2014) and has recently been examined in the context of marine resource users in Australia (van Putten *et al.,* 2015a). This latter study looked at why people struggled to attribute climatic factors to different observed marine range shifts. Three psychological reasons were given: 1) people use pre-existing mental models to attribute changes when there is an absence of accurate or understandable explanations that link climate science to fishery level effects; 2) complexity and/or indirectness of climate impacts are difficult for most to understand; and 3) whether the impact had a positive or negative influence affected the extent to which people accepted climate change as a causal factor.

Attributing climate change to resource fluctuations and wider understanding of climate change is a function of how people interpret information and how this fits with their values, beliefs, experiences and current knowledge levels. Whilst increased communication about climate change impacts has obvious importance in increasing understanding and awareness about it, in the context of fishers it may have limited impact.

Table 1.1. Major factors influencing risk perceptions. These factors were identified using the frameworks in Fig.1.3 as a guide to help inform reading (but other factors were also included if the literature also suggested they may have an effect).

Influencing factor on risk perception	Description and evidence
Information and knowledge	As described above, although there is evidence that suggests knowledge has little or negative effects on risk perceptions (e.g. Brody *et al.,* 2008; Kellstedt, Zahran and Vedlitz, 2008; Hornsey *et al.,* 2016), generally increased knowledge is thought to lead to heightened risk perceptions (e.g. Ranney and Clark, 2016; Shi *et al.,* 2016; van der Linden, 2017). However, there are potential caveats to the extent it has an effect: for example scepticism, levels of trust in the information received, or the types of knowledge that people have (e.g. on causes or impacts), or other factors may be more influential, can also affect how people process and respond to information (see above).
Social amplification and attenuation of risk	The theory of the social amplification of risk helps to explain why, and how, a community can perceive risks as major when they are in fact minor, and vice versa (Kasperson *et al.,* 1988; Renn 2011). This framework recognizes that social and economic impacts arising from adverse effects are the consequence of interactions between the physical effects from the event itself and the combination of social, psychological, cultural and institutional processes that perceive the event and its risks. For example, people who are linked within their social network to someone they trust who is interested in climate change may be more likely to perceive climate change as personally risky (Brody *et al.,* 2008; Dang *et al.,* 2014). As such social norms also can play a role in shaping perceptions (see van der Linden, 2017 for more context).
Social values, worldviews and self-efficacy	Social values, beliefs and worldviews heavily influence risk perceptions (O'Connor, Bord and Fisher, 1999; Leiserowitz 2006; Weber 2010; Leviston *et al.,* 2014) as they can influence the extent to which people acknowledge, ignore or deny risks, and consequently the degree and willingness in which they are prepared to act (Hidalgo and Pisano 2010; Weber 2010). The Cultural Theory of Risk was developed to further contextualise risk perceptions among socio-cultural groups of people, based on their worldviews (Wildavsky and Dake, 1990), but is contested regarding the influence they have (van der Linden, 2015). Self-efficacy also plays a role: those who believe that they are able to positively influence climate change are more likely to consider it as a risk (Hidalgo and Pisano 2010; Milfont, 2012).

Personal experience	Direct, personal experiences can elicit strong emotional responses and can increase the perceived likelihood of a risk if it can be readily imagined or has been experienced recently (Loewenstein *et al.,* 2001; Brody *et al.,* 2008; van der Linden 2015). Events that occur with relative frequency, thus becoming 'familiar', may elicit less fear and lower risk perceptions particularly if few negative consequences arose (Slovic 1987; Halpern-Felsher *et al.,* 2001; Taylor *et al.,* 2014). Differences in extent of personal experiences affecting perceptions can arise when considering whether people have experienced changes in seasonal patterns such as rain or daily/local warming or more extreme events such as storms or hurricanes. The latter appear to provide greater evidence for strong associations with heightened risk perceptions (van der Linden, 2017).
Socio-demographics	Those with higher levels of education, knowledge and income also tend to have lower risk perceptions (O'Connor, Bord and Fisher, 1999; Kellstedt, Zahran and Vedlitz, 2008). Women typically have higher risk perceptions for a range of hazards compared to men (Slovic, 1999; Kellstedt, Zahran and Vedlitz, 2008). Occupation and the level of attachment people hold to that occupation can also heavily influence risk perceptions (Marshall, 2010; Marshall *et al.,* 2014). Political ideology has important effects on perceptions and beliefs more widely, with those of right wing ideologies more likely to have lower risk perceptions (McCright and Dunlap, 2011; Leiserowitz *et al.,* 2013; Hornsey *et al,* 2016). Results are also inconsistent regarding the effect of age (van der Linden, 2017).
Place and place attachment	Living in physically more vulnerable areas which may experience more climate related events, or where the risks are more overt, can heighten climate change risk perceptions (Spence *et al.,* 2011; Reser, Bradley and Ellul, 2014). Yet this isn't always true; a limited understanding on climate change impacts can result in misinterpretations of the severity and scope of risks despite being in a place considered technically as high risk (Brody *et al.,* 2008). Strong feelings of place attachment, which describes the emotions, bonds and feelings that people have with their social and physical environment (Brown and Perkins,1992), are generally considered to reduce risk perceptions on lower probability risks, whilst amplifying perceptions of risk thought to be highly probable, although this can also vary with the scale of place (Bernardo 2013; Devine-Wright, Price and Leviston, 2015; Dominicis *et al.,* 2015). However, consensus is mixed (Armaş 2006; Dominicis *et al.,* 2015) and as such needs more research.

Fishers can be sceptical of scientific evidence (Stanley and Rice 2003; e.g. Fishingforthetruth.co.uk, 2015), they are part of a subculture that emphasises bravery, fearlessness and ability to cope with change (and therefore tends to downplay risks) (Edvardssen *et al.,* 2011; Nursey-Bray *et al.,* 2012; Seara, Clay and Colburn, 2016), and due to them regularly experiencing change in stocks which are attributable to climatic variability they may be resistant to the idea that climate change poses a significant problem to them. Research that is able to both elucidate fishers' level of understanding regarding climate change, as well as how they interpret and feel about the information they receive, would provide useful insights about barriers to raising awareness, and fishers' consequent actions or responses, regarding climate change.

Fishers' climate change risk perceptions

At both a global and UK level, relatively few studies have been undertaken to explore climate change risk perceptions amongst fishers (Chilvers *et al.,* 2014). In 2015 a report by Seafish assessed climate change adaptation in the UK seafood sector, and sought industry (but not fishers) perspectives, attitudes and experiences of climate change as part of this work (Garrett, Buckley and Brown, 2015). Most industry stakeholders consulted placed low priority on needing to adapt to climate change, with many regarding the connection between climate change and its commercial significance as tenuous. Some felt that climate change risks (for larger processors) will be similar regardless of catch type, and that adapting to specific climate risks needs to be considered within the context of risks already experienced by the industry. Other stakeholders noted that if people were to adapt to climate change through, for example, sourcing fish from another location, the risks would just be swapped rather than overcome completely. As such, it can generally be concluded that the industry stakeholders approached within this study had low risk perceptions of climate change. This is somewhat unsurprising given that the industry perceived itself to have a high adaptive capacity—identified as a 'core' strength—and was used to operating under high levels of uncertainty. Time frames did however seem to play a role, with those operating or planning over longer time frames potentially more likely to acknowledge the relevance of climate change consequences to their business than those who are more reactive in their approaches in managing business risks.

Similar findings are also reflected in other studies that have explored fishers' perceptions of climate change. Fishers studied in Tasmania and Northern Norway both perceive themselves to have low vulnerability to climate change, primarily attributed to the fact that fishing activities have to take place amongst high temporal environmental variability (West and Hovelsrud, 2010; Nursey-Bray *et al.,* 2012). As such fishers identify themselves as being able to cope with changes at both annual and seasonal timescales (West and Hovelsrud, 2010; Nursey-Bray *et al.,* 2012; Metcalf *et al.,* 2015). For both locations, climate change was considered a low secondary risk when compared to other risks that are faced by fishers and the wider industry; financial pressures, an aging fisher population, quota and management issues and legal and market factors were all identified as limiting social and economic viability and as such posed bigger threats to livelihoods and business than climate change (West and Hovelsrud, 2010; Nursey-Bray *et al.,* 2012).

Similarly, a study that sought to identify risk perceptions in UK, Icelandic, Greek and Faroese fisheries found that climate change was rarely mentioned and only considered as a risk by fishers in Iceland (Tingley *et al.,* 2010). Fisheries management, policy and financial prosperity were much more commonly mentioned as prominent risks (Tingley *et al.,* 2010). UK fishers cited impacts of fishing on natural resources as the lowest risk to them and instead listed costs of fishing and ineffective or problematic management (particularly in relation to marine protected areas) to be the most significant risks. Factors that led to higher risk perceptions of identified risks related to lack of control and involuntariness of being exposed to a risk, as highlighted by Slovic (1987). The results also support the theory that fishers perceive actors, generally managers and wider decision makers, outside of the system to be the main drivers of risks (Tingley *et al.,* 2010).

Having low climate change risk perceptions could result in fishers being less prepared, willing, or motivated to act or respond to climate change. Indeed, Marshall and Marshall (2007) found that risk perceptions had a key role in determining fishers' responses to general policy change. Nursey-Bray *et al.,*

(2012) also suggested that low risk perceptions among fishers could act as a barrier to adaptation because they did not perceive it as an issue to address. Reasons for low risk perceptions remain relatively unexplored or explicitly tested in a fisheries context, but could be due, as the above studies suggest, to a range of factors including greater concern over other risks that have more obvious and immediate risk on the fishery (such as policy changes), limited understanding amongst fishers of how climate change can impact fisheries, and perceptions that they have relatively high adaptive capacity and therefore can cope and adapt to change.

Conclusions and knowledge gaps

From the literature synthesised in this review it is clear that climate change has had significant ecological and socio-economic impacts on the UK marine environment and its associated fisheries. A range of fish species in UK seas, including those of both commercial and non–commercial importance, have responded to warming sea temperatures and such future changes will continue at the fishery level, altering the availability, productivity and catchability of these resources to fishers. This review focused primarily on the effects of temperatures, but other climate impacts are also likely to have synergistic effects on species, including ocean acidification, hypoxia and storminess (Townhill *et al.,* 2016; Pinnegar *et al.,* 2017).

Model projections suggest that climate change will continue to have an impact into the future, with potentially large consequences for the UK fishery resources and their fishing dependent communities. As yet, however, most projections within the UK have been produced through correlative approaches using Species Distribution Models (SDM) in well studied regions, with limited use of alternative approaches applied to other regions. Additionally, there is limited insight into how these future changes will affect socio-economic aspects of fisheries such as profitability, employment or other aspects such as fleet behaviour. More widely, vulnerability assessments of UK fisheries to climate change impacts have so far been undertaken at a broad national scale and indicate low vulnerability and high adaptive capacity. Individual actors within fishing communities have received less attention in a UK context regarding how they perceive climate change, their overall beliefs and how this can relate to their sensitivity and adaptive capacity to future climate change impacts. Greater emphasis is needed to explore climate change impacts from more holistic and wider interdisciplinary perspectives to help further develop understanding of future implications and how people may cope, adapt and respond. Such approaches are particularly important in the context of fisheries management and policy which will need to consider the complexities climate change impacts will present on these coupled systems and understand different stakeholder perspectives and potential trade-offs.

This chapter has reviewed a breath of disciplines which in themselves have numerous knowledge gaps. However, in the context of climate change impacts on UK fisheries, this review has highlighted a number of areas for further research that are important to consider. A core area that deserves greater attention is the need for more regional approaches to climate change studies. In regard to future projections of ecological impacts of climate change, most studies have centred upon the North Sea or been derived from wider, global studies, leaving other areas of importance to UK fisheries under-represented and poorly understood, for example the south-west UK. While global studies have provided important insights which have informed understanding of climate change impacts within the UK, regional studies are essential to understand potential impacts on fishing communities at these finer scales. Ecological responses to climate change can differ spatially within and among species. As such regional insights into future responses can provide more appropriate information that management can use to inform decision making.

A lot of research generating future projections of ecological responses has been conducted predominantly through the use of SDM approaches. These have provided useful insights but exploring other methodologies can allow other perspectives and comparisons to be made and thus allow greater understanding surrounding the confidence of future species responses. Other modelling approaches such as GAMs can allow relative abundance responses to be explored in more depth as they can use abundance data from fisheries survey datasets as opposed to presence-absence data that many SDMs rely upon. There is also a growing need to explore the uncertainty associated with ecological projections that can arise from both model approaches alongside the data (e.g. climate, abundance) that is used. Adopting other modelling approaches and exploring uncertainty can ultimately help to inform future modelling work and provide insights into uncertainty that can be useful for management and decision-making.

Finally, there is very limited work that has been undertaken within the UK to explore climate change impacts on fisheries from socio-economic perspectives. Broad vulnerability assessments have been undertaken, but understanding of this at regional, port and even individual levels is virtually non-existent, as echoed by others (Pinnegar *et al.,* 2017). Yet fisheries in the UK are diverse and complex and many fishing communities are in areas that may be more vulnerable compared to wider national levels from climate change. There is a need to understand the sensitivity and adaptive capacity of these communities at these smaller scales, and in particular exploring these aspects at the individual level. Gaining insights from individual perceptions provides important information for understanding how individuals may respond and cope or adapt to change. This can generate contextual information that can be of use to managers and policy makers more widely, particularly with regard to developing adaptation strategies at these more refined geographical scales.

The south-west UK

Within this thesis the south-west UK is defined by the English Channel, Celtic Sea and majority of the southern North Sea (Fig. 1.4). This represents the core fishing grounds that vessels operating from ports within the south-west of the UK (such as Newlyn, Plymouth, Brixham) fish within.

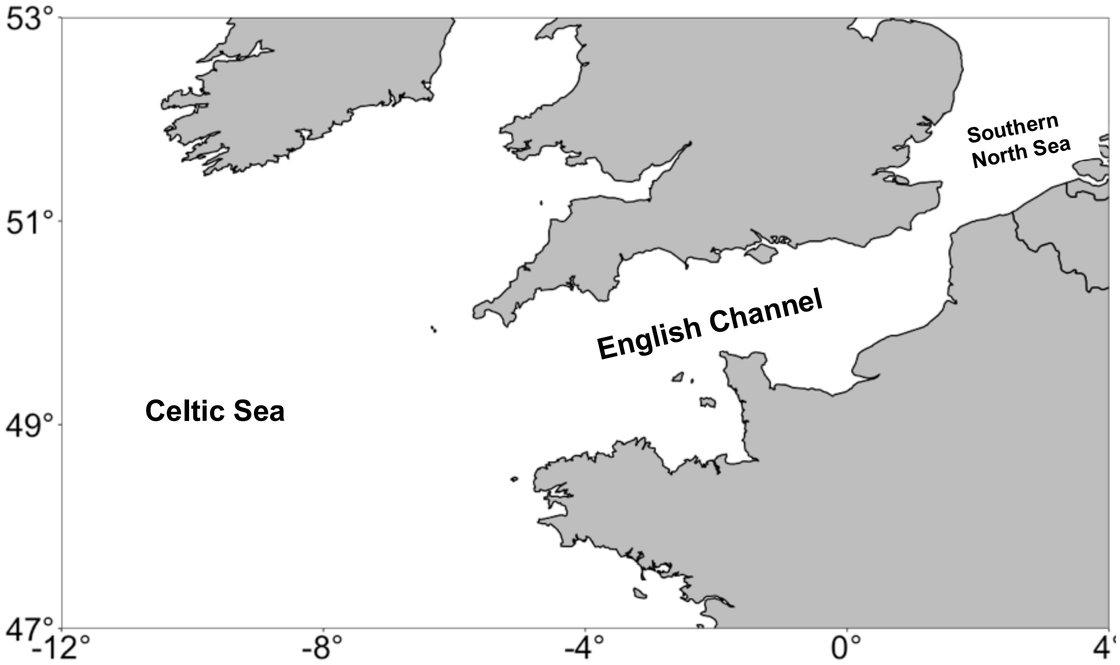


Figure 1.4. South-west case study region

Environmental description

This region serves as a useful case study given that that relatively little research has focused here, at least when compared to the regions such as the North Sea. This is despite the south-western seas having experienced significant warming and projections suggesting sea temperatures will continue to rise (Dye *et al.,* 2013; Hughes *et al.,* 2017; see Chapter 3). Traditionally the area has been seen as a biogeographical boundary zone between cooler waters to the north and warmer waters to the south (Coggan, Diesing and Vanstaen, 2009; Dauvin, 2012), however climate change is increasingly blurring this boundary. The unique environment of the region effects wider biodiversity patterns and distributions (e.g. Hinz *et al.,* 2011; McClellan *et al.,* 2014). To the east of the region depths of the southern North Sea and English Channel are relatively shallow of around 30–50 m (Dauvin, 2012; McClellan *et al.,* 2014). Here there are large freshwater influxes from the river basins of the Thames, Seine, Rhine-Meuse and Scheldt (Quiroz-Martínez *et al.,* 2011). Coarse-grained sediment, sand and mud are found within the southern North Sea, with sediments becoming coarser into the English Channel, which is partly as a result of the tidal currents and hydrodynamics of the area (Quiroz-Martínez *et al.,* 2011).

The English Channel itself covers approximately 75,000 km^2, with the deepest waters to the west where they reach over 100 m. The western area is influenced by Atlantic waters, and as such the Channel can be viewed as having a western and eastern basin, although many characteristics are similar throughout (Dauvin, 2012). Waters tend to be more mixed in the east whereas the west exhibits a thermocline in the summer months (Coggan, Diesing and Vanstaen, 2009; Dauvin, 2012). This affects sea temperatures, with the western Channel exhibiting warmer waters in the winter compared to the eastern Channel. The eastern Channel tends to have warmer waters in the summer and a greater temperature range in general (Coggan, Diesing and Vanstaen, 2009; Dauvin, 2012). The Celtic Sea covers an area of 70,000 km^2 and has much deeper waters compared to the English Channel and Southern North Sea. Here waters tend to be ~9–10°C in winter (similar to the western Channel, eastern basin: 5.9°C (Coggan, Diesing and Vanstaen, 2009)) and 11–16°C in summer (eastern Channel: ~16.7–20°C (Coggan, Diesing and Vanstaen, 2009; Dauvin, 2012).

Fisheries in the south-west

The south-west region also provides important fishing grounds for vessels operating along the Cornwall and Devon coastlines, as well as more widely for other UK and European vessels (Glegg, Jefferson and Fletcher, 2015). Twenty-percent of the landings value of UK vessels (into the UK and abroad) come from these fishing areas, and 14% of landings by weight. Three of England's major fishing ports are located within the south-west – Plymouth, Newlyn and Brixham. In 2016, collectively they accounted for 8 and 10% of UK landings by weight and value respectively (by UK vessels) and 38 and 39% of English landings by weight and value (MMO 2017a). A total of 2,272 fishers fish from these three ports and 1,339 vessels operate, representing 43% of the English fleet and 21% of the UK fleet (MMO, 2017a). Of these vessels, 1,105 were 10 m and under (43% English <10 m fleet) and 234 were 10 m or over (44% English >10 m fleet). Other more minor ports within the area also include Looe, Falmouth, Salcombe, and Mevaggisey.

In 2016, cumulatively across the three ports landings (weight) of demersal, shellfish and pelagic species were fairly similar (35%, 32% and 33% respectively; MMO, 2017a). Most landings values are from demersal (53%) then shellfish (39%) and pelagic species (8%) (MMO, 2017a). Landings into the three ports according to these species groups are summarised in Fig. 1.5. However, there are differences among the ports; for example Brixham gains most of its revenue from demersal species, while Plymouth lands primarily pelagic species. Newlyn catches similar amounts of demersal and shellfish in both weight and value. These three ports catch a variety of species (Fig. 1.6) and many of the fisheries are considered mixed, where multiple species are caught. A variety of gear types are used by vessels in the south-west fleet, although beam trawls and demersal trawling nets are a common gear type for many vessels targeting demersal species.

Aside from the catching sector itself providing income and employment for the region, there is also a substantial processing and wider seafood sector that depends on fisheries. For example, in the Torbay area (Devon), fish processing contributes 11% of the industry’s direct Gross Value Added at UK level and 50% of direct GVA in the south-west (direct quote: ERS, 2016). The south-west region has a rich maritime heritage that extends from medieval times (Kowaleski, 2000) and throughout this long history fishing and wider maritime industries have likely contributed to coastal communities’ social identities and sense of place (Urquhart, Acott and Sanghera, 2014). For example, links to this fishing and maritime heritage is echoed throughout many coastal towns and villages through architecture, place or street names and even annual local events (Fig 1.7).

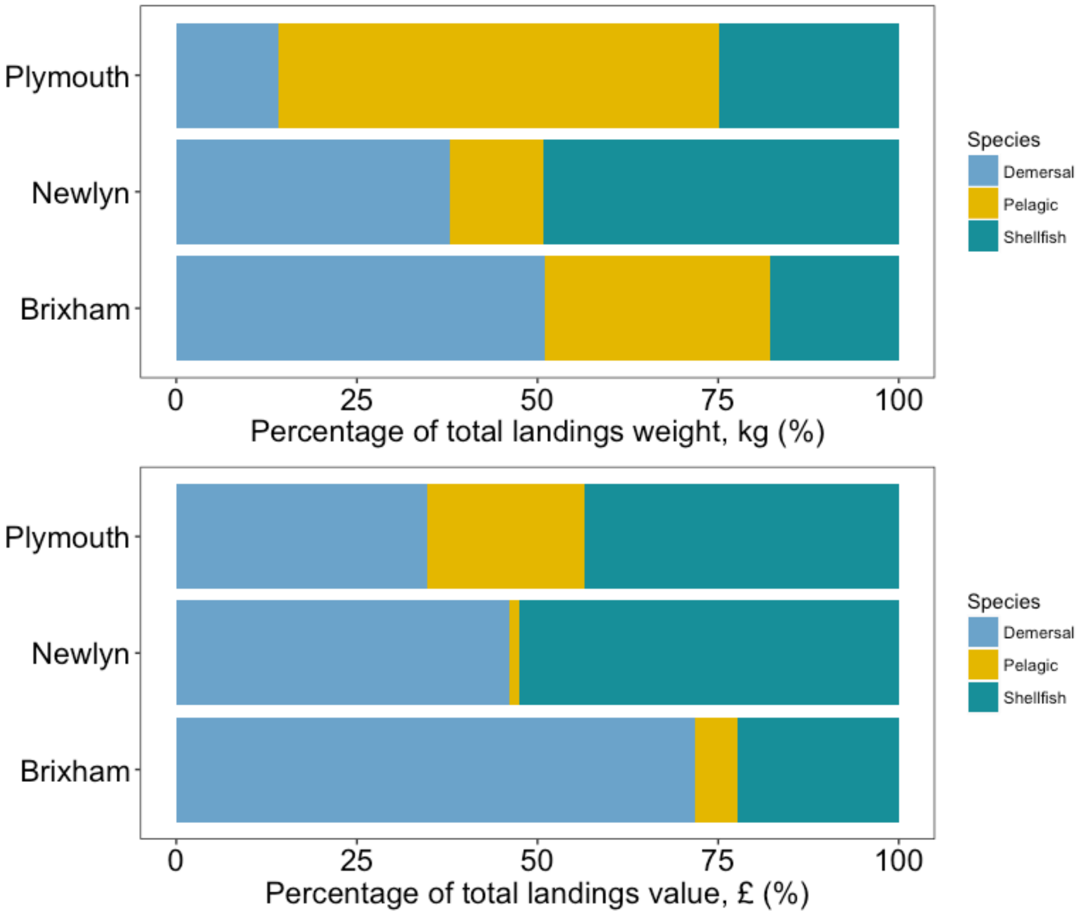


Figure 1.5. Proportions (%) of port landings in 2016 by UK vessels in terms of weight (top) and value (bottom) across three core species groups (MMO, 2017a).

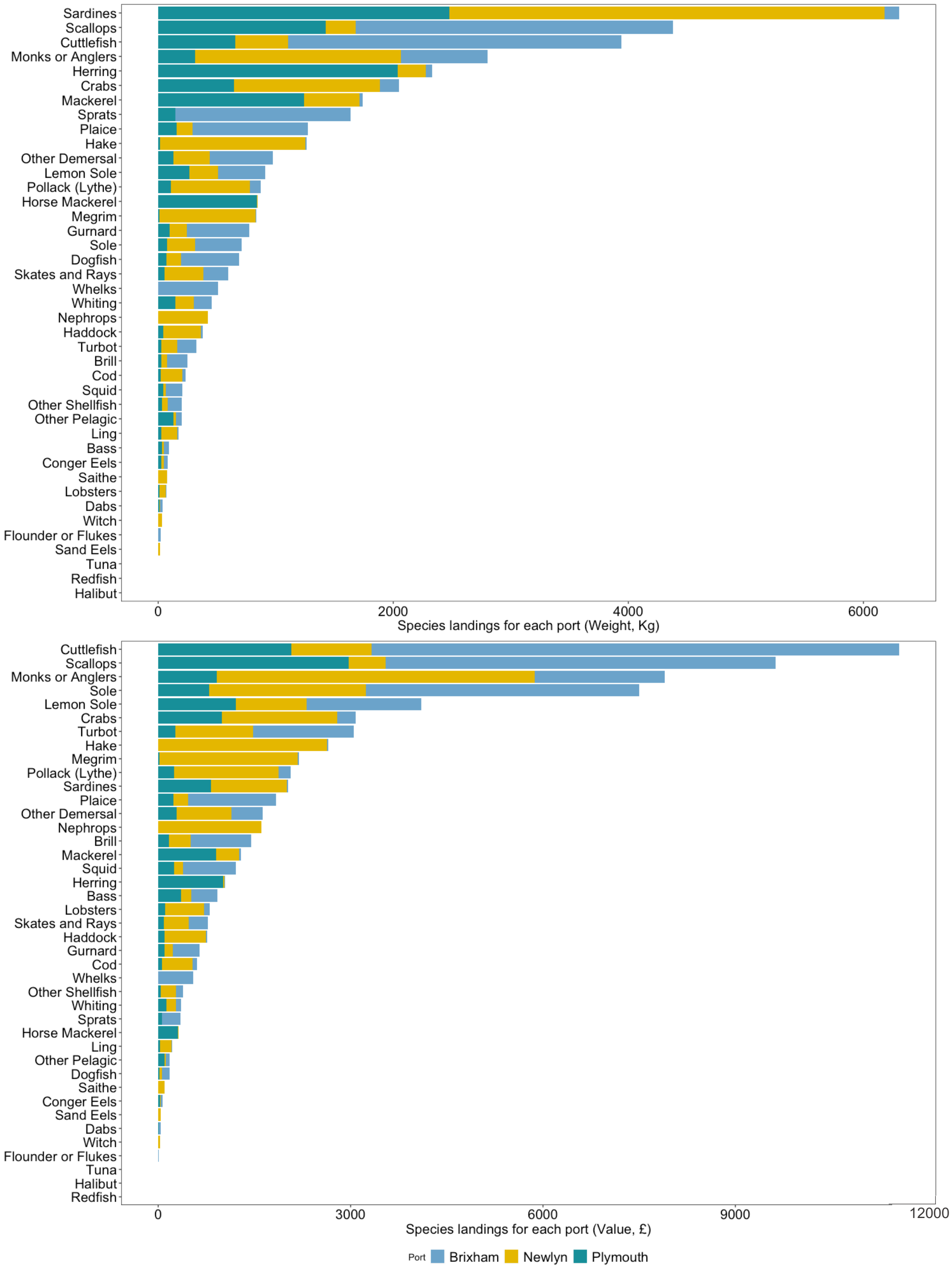


Figure 1.6. Species caught in the three major south-west UK ports in 2016 according to MMO statistics (MMO, 2017a). Top: landings weight; bottom: landings value.

Figure 1.7. The fishing industry of the south-west is represented throughout towns and villages in many forms. From clockwise left: a Brixham community garden; the annual Clovelly Herring Festival; the annual Brixham Trawler Race; example of artwork throughout Brixham town and harbor. Source: K.Maltby, 2016–18

Thesis outline

Exploring climate change impacts on fisheries requires adopting an interdisciplinary approach in order to help develop a greater holistic understanding of its potential effects on these systems (Miller *et al.,* 2010a; Perry, Barange and Ommer, 2010; Leenhardt *et al.,* 2015). Through examining both the environmental and human components of fisheries and the links between them, new insights can be gained that would not necessarily be uncovered through a single discipline approach. This thesis aimed to adopt an interdisciplinary perspective to investigate climate change impacts on the understudied region of the south-west UK. It draws upon disciplines within the natural and social sciences to consider two overall general aspects: 1) how commercial fish species may be affected by future climate change and 2) how fishers perceive climate change and how this links to their wider adaptive capacity to climate change. These form two important questions within the context of the south-west UK fisheries because wider research has been restricted to studying such aspects using well-studied regions or through limited, national approaches. To explore these questions a mixed methods approach was adopted, which used data that was collected by the author as well as obtained from national and international databases. The findings within this thesis provide insights that inform the wider literature as well as helping to generate information which will be useful from fisheries management and climate change adaptation perspectives.

Brixham was chosen as a case study site within the social chapters of this thesis for a number of reasons. It forms the largest fishing port in the south-west and in England in terms of landings value (£31 million: 2016) and fishing forms a significant source of income and employment (as well as providing wider socio-economic benefits through e.g. tourism) for Brixham and the wider Torbay and south-west region (ERS, 2016; MMO, 2017a). Many fishers are also specialised in using beam trawls and demersal gears (MMO, 2017a), and given many demersal species within the region are anticipated to be affected by climate change in the future due to rapid warming (e.g. Simpson *et al.,* 2011; Pinnegar *et al.,* 2013), fishers operating from Brixham are likely to experience climate driven changes in the species they target in the future. Focussing upon one port allowed a more in-depth approach to be undertaken, with greater consideration of the contextual factors influencing fishers' perceptions and their adaptive capacity.

The thesis is split into four main data chapters which are outlined below, one of which (Chapter 2) is a methodology chapter that informs the work of Chapter 3. The thesis concludes with General Discussion (Chapter 6).

Chapter 2

Chapter 2 aimed to develop a methodology to address issues regarding the standardisation of fish abundance data obtained from fisheries-independent survey data. Such issues have previously limited regional projections from being undertaken for the south-west UK. Two quantitative methods are compared to test their effectiveness in producing standardised abundance estimates across six survey datasets for eight demersal fish species. The chapter provides groundwork for Chapter 3 by addressing inherent biases within abundance data, which if left unaccounted for may have caused issues when generating future projections.

Chapter 3

Chapter 3 explores how warming sea temperatures resulting from climate change may impact commercially important demersal fish species within the English Channel, Southern North Sea and Celtic Sea. Through the use of Generalised Additive Models, and adopting methods developed within Chapter 2, future projections in species abundances and distributions until 2098 are generated. Importantly, associated uncertainty with future projections is also assessed through using 11 separate climate ensembles, providing greater insights into the confidence in these future projections.

Chapter 4

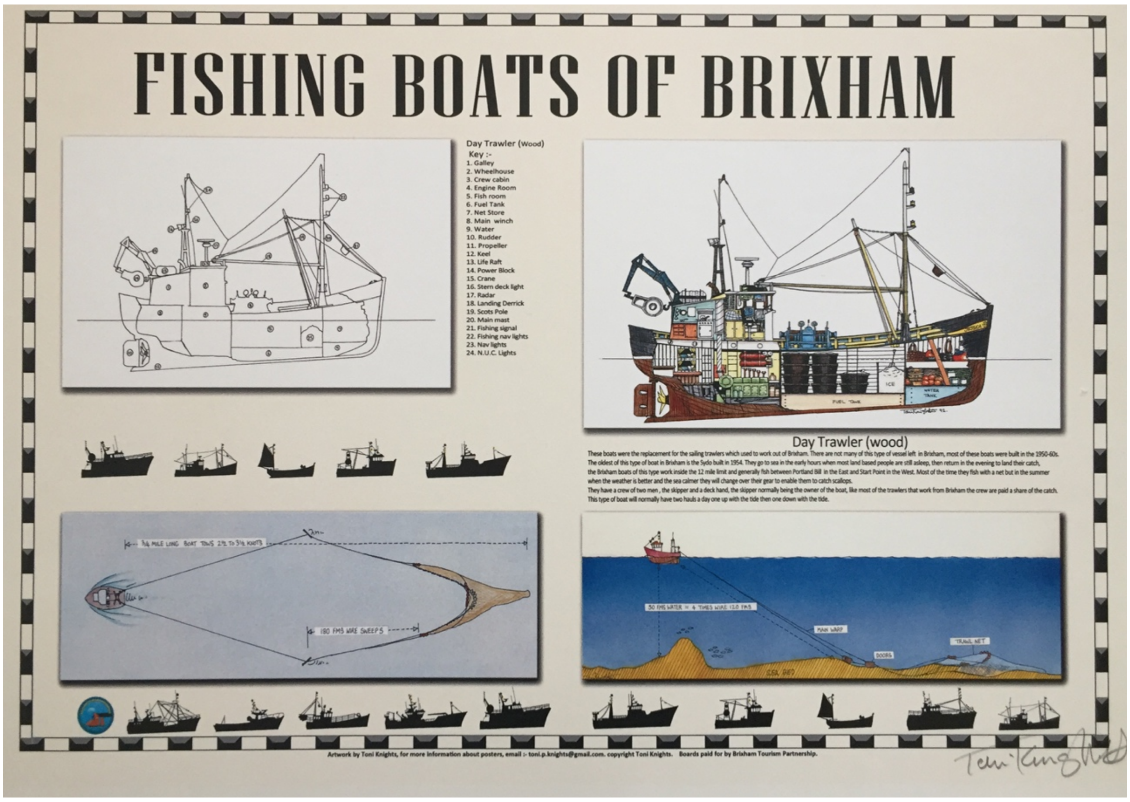
Chapter 4 uses information collected through interviews at a south-west port (Brixham) and a mixed methods approach to explore fishers' perceptions and beliefs of climate change. It firstly identifies the risks that fishers felt would affect fisheries, their fishing businesses and the wider industry in the future, helping to contextualise climate change among other risks facing the fishing industry. Secondly, fishers' climate change risk perceptions are explicitly examined. Thirdly, the factors influencing these perceptions are examined to understand how, and why, perceptions differ among fishers.

Chapter 5

Chapter 5 adopts a mixed methods approach and uses information collected through interviews with fishers. It firstly explores what impacts fishers felt climate change would present in the future and how they anticipated adapting to such impacts. Perceived constraints to fishers' adaptation are also identified. Using an indicator-based approach, fishers' ability to adapt to future climate change impacts is further investigated through examining their flexibility, social organisation and personal agency.

Chapter 2

Standardising fish abundance data across trawl surveys to enable broad-scale ecological analyses



Day Trawler (Wood)
Key :-
1. Galley
2. Wheelhouse
3. Crew cabin
4. Engine Room
5. Fish room
6. Fuel Tank
7. Net Store
8. Main winch
9. Water
10. Rudder
11. Propeller
12. Keel
13. Life Raft
14. Power Block
15. Crane
16. Stern deck light
17. Radar
18. Landing Derrick
19. Scots Pole
20. Main mast
21. Fishing signal
22. Fishing nav lights
23. Nav lights
24. N.U.C. Lights

Day Trawler (wood)

These boats were the replacement for the sailing trawlers which used to work out of Brixham. There are not many of this type of vessel left in Brixham, most of these boats were built in the 1950-60s. The oldest of this type of boat in Brixham is the Sydo built in 1954. They go to sea in the early hours when most land based people are still asleep, then return in the evening to land their catch, the Brixham boats of this type work inside the 12 mile limit and generally fish between Portland Bill in the East and Start Point in the West. Most of the time they fish with a net but in the summer when the weather is better and the sea calmer they will change over their gear to enable them to catch scallops.
They have a crew of two men , the skipper and a deck hand, the skipper normally being the owner of the boat, like most of the trawlers that work from Brixham the crew are paid a share of the catch.
This type of boat will normally have two hauls a day one up with the tide then one down with the tide.

Artwork by Toni Knights, for more information about posters, email :- toni.p.knights@gmail.com. copyright Toni Knights. Boards paid for by Brixham Tourism Partnership.

Toni Knights

Drawing by Toni Knights

Abstract

Fisheries research is increasingly being undertaken at broader spatial, temporal and ecological scales to understand the effects of large scale processes such as climate change upon these systems. However, studies seeking to explore species abundance patterns from these perspectives can be limited by the geographical ranges, temporal consistency and inherent biases of fisheries-independent scientific survey data. This study used the south-west UK region and investigated two methodologies to standardise abundance data across six survey datasets. Eight fish species were used within the analysis, representing a range of biogeographical affinities and fisheries importance. The first method generated least square means from a linear model, accounting for the effects of survey and sampling period. The second approach used Bayesian Principal Components Analysis which interpolated missing abundance data from surveys, establishing average abundance across surveys for each sampling location. Both sets of results were compared to original abundances to assess deviations of standardised data from observed spatial patterns. While both methodologies provide useful mechanisms to standardise abundance data, the least square methodology appeared to be the most robust for the species and region investigated here. This work demonstrates a simple yet effective methodology that can standardise abundance data across multiple scientific surveys, thus facilitating future studies seeking to undertake ecological research over broad spatial and ecological scales.

Introduction

Within the North East Atlantic, multiple scientific trawl surveys are undertaken to provide fisheries managers with information on the status of fish populations (ICES, 2018a). These surveys are typically organised and undertaken by individual countries, with data being fed into national and international databases, often coordinated through the International Council for the Exploration of the Seas (ICES). Historically, the aims of such surveys have primarily been to collect information for particular commercial stocks to inform stock assessments, such as assessing mackerel (*Scomber scombrus)* abundance and distributions within the Celtic Sea (Tidd and Warnes, 2006) and abundances of juvenile plaice (*Pleuronectes platessa*) and sole (*Solea solea*) within the eastern English Channel (ICES, 2009a). Over time, however, the importance of these long-term surveys has grown as they are used to address broader macroecological questions, such as how populations and communities have been affected through fishing and climate change (e.g. Hiddink and Hofstede, 2008; Simpson *et al.,* 2011).

Collating and merging scientific survey abundance data across spatial and temporal scales provides the opportunity for modelling large-scale and long-term associations between species abundances and environmental variables. This in turn can allow projections of future distributions and abundances under projected environmental regimes. To date, however, studies investigating long-term changes over large spatial scales have typically avoided combining abundance data across surveys. Instead, research has either focussed on abundance in single survey datasets within well sampled regions, or restricted use of multiple surveys to simplified metrics of species occurrence (e.g. Perry *et al.,* 2005; Simpson *et al.,* 2011; Montero-Serra *et al.,* 2015; Rutterford *et al.,* 2015; Sguotti *et al.,* 2016; Robinson *et al.,* 2017). One reason for this stems from the difficulties of standardising trawl survey abundance data to account for the inherent and complex biases across surveys (Pelletier, 1998; Trenkel *et al.,* 2004; Fraser *et al.,* 2008; Thorson and Ward, 2014; Sguotti *et al.,* 2016).

Scientific surveys can differ in a number of ways. They can be undertaken in different seasons within a similar area, resulting in different species at different life stages being caught by different surveys (Arreguín-Sánchez, 1996; Pelletier, 1998; Harley and Myers, 2001; ICES, 2018b). Surveys can also differ in the gears and vessels used, leading to differences for example in efficiency and selectivity of gear in catching species (Fraser, Greenstreet and Piet, 2007; Cadigan and Dowden, 2010; Thorson and Ward, 2014; ICES, 2018a). Finally, scientific aims, expertise and data recording can also differ between surveys and over time, leading to potential biases in species recorded or the taxonomic level of identification.

Due to the differences between surveys, accounting for survey biases when analysing fish abundance data is important for future studies conducting research over large spatial and/or temporal scales. This study uses the south-west UK as a case study to investigate approaches for standardisation of species-level abundance data across multiple demersal trawl surveys. This region is useful for this work as six surveys have been conducted by different countries using different vessels and gears, with variation in their spatial and temporal coverage. Two standardisation methodologies were compared. The first approach fitted a General Linear Model (ANOVA) to the data, using survey identity, sampling location (grid cell) and sampling period (year) as predictor variables for the abundance data. This enabled standardised least square mean values to be estimated for each sampling location, while accounting for survey and sampling period effects. The second approach employed Bayesian Principal Components Analysis (BPCA) to interpolate missing abundance data for surveys within each sampling location (grid cell) and sampling period, using associations between surveys that overlapped in space and time. This enabled an average abundance to be calculated for each sampling location over the sampling period.

Methods

Region and species

The study region spans 47 – 53° N latitude and -12 – 3° E longitude. The eight species used within this study were chosen for their commercial importance for fisheries within the region, and their contrasting patterns in biogeography and depth occupancy. Atlantic cod (*Gadus morhua*) has considerable commercial and cultural significance within the UK, and has a clear boreal affinity. European plaice (*Pleuronectes platessa*) and lemon sole (*Microstomus kitt*) also have boreal affinities, and form substantial catches for fishing ports in the study region. Anglerfish (*Lophius piscatorius*) and megrim (*Lepidorhombus whiffiagonis)* have northerly, deep water distributions within the region, and are important species for regional fisheries. John dory (*Zeus faber*) and red mullet (*Mullus surmuletus*) currently do not form large catches within south-west fisheries but have a southerly geographic distribution. Dover sole (*Solea solea*) is highly important for commercial fisheries for the region and has a clear Lusitanian affinity.

Survey data

Six survey datasets were analysed within this study, overlapping in space and time to different extents (Figs. 2.1 and 2.2). Data were obtained from the ICES Database of Trawl Surveys (DATRAS) and the Centre for Environment, Fisheries and Aquaculture Science (Cefas) in 2015.

Cefas Eastern English Channel Beam Trawl Survey (EEC)

Since 1989, Cefas have carried out a beam trawl survey using a 4 m beam in the Eastern Channel, usually in July and August of each year (ICES, 2009a). Originally developed to assess relative abundance of European plaice and Dover sole in ICES divisions VIId, the survey has gradually expanded to sample more areas including the southern North Sea Belgium coast (Fig. 2.1). Sampling occurs at the same stations each year, with haul duration lasting for approximately 30 minutes. Data from 1989 onwards (up to 2014; most recent data available at time of sourcing) were obtained.

Cefas South-Western Beam Trawl Survey (WESTERN)

Established in 2006, this survey takes place in the first quarter (February/March) and uses two 4 m beams (with and without a blinder) towed simultaneously during hauls. This survey uses a random stratified sampling design, and originally sampled the Western Channel before being extended into the Celtic Sea in 2013. Areas sampled include divisions VIIe,h, and g (Fig. 2.1). Data from 2006 onwards (up to 2015; most recent data available at time of sourcing) were obtained.

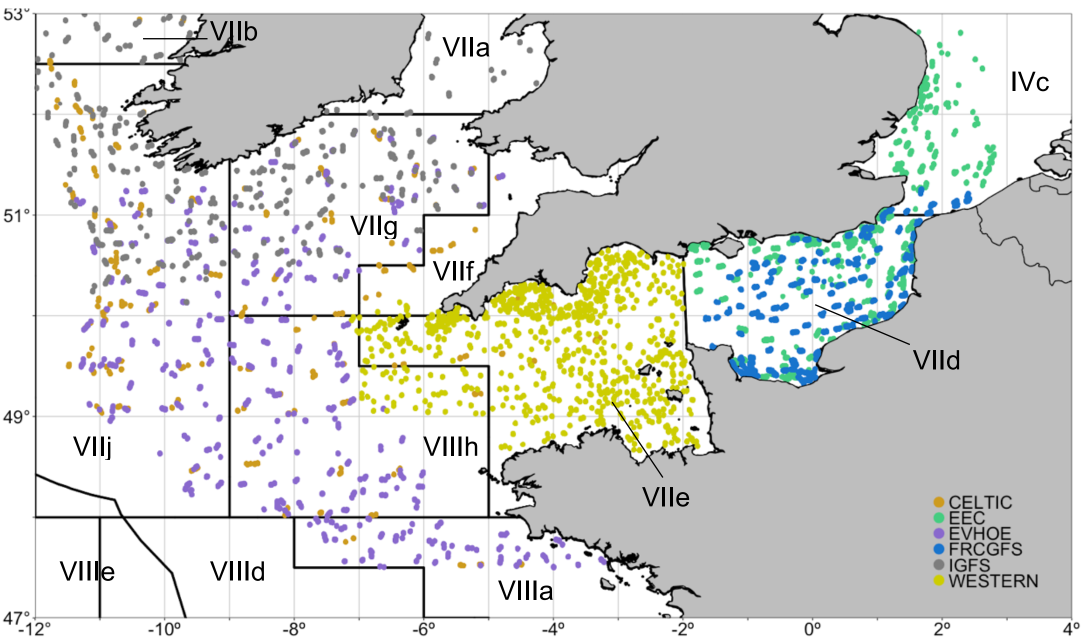


Figure 2.1. ICES Fishing Division areas and haul locations for each survey from 2000–2015, which is the most consistent sampling period for all surveys.

Cefas Celtic Sea Groundfish Survey (CELTIC)

This survey took place between 1987–2004 in spring (usually March) and was subject to several gear and spatial changes over the time period. From 1992–2004, a Portuguese High Headline Trawl was used, sampling primarily within divisions VIIf,g,h,j. Prior to 1992, some sections of VIIg were not covered. From 2003–2011 the survey shifted to winter using a Grande Ouverture Vertical Trawl (GOV), or GOV with rockhopper ground gear. Data from 1992–2004 only were used in this analysis as this forms the most consistent sampling period (Fig. 2.1).

Irish Marine Institute Irish Groundfish Survey (IGFS)

This time-series was initiated in 2003, and uses a semi-random depth stratified design with a GOV gear. It covers ICES divisions VIa and VIIb,c,g,j, and is carried out in the 4th quarter, usually October and November (Fig. 2.1). This survey uses GOV gear. Only data from 2003 to 2008 were available for analysis.

IFREMER French Southern Atlantic Bottom Trawl Survey (EVHOE)

Started in 1987, this survey samples within divisions VIIf,g,h,j (Celtic Sea) and the French part of the Bay of Biscay in divisions VIIIa,b (Fig. 2.1) using a GOV trawl. Usually occurring at the end of October, this survey uses stratified random allocation to select sampling points. Data from 1997 onwards (up to 2013; most recent data available at time of sourcing) were obtained.

IFREMER French Channel Groundfish Survey (FRCGFS)

Established in 1988, this survey takes place every October within divisions VIId and IVc (Fig. 2.1). The survey is based on a grid design and uses a GOV. Data obtained from this survey contribute to the wider International Bottom Trawl Survey. Data from 1988 onwards (up to 2013; most recent data available at time of sourcing) was obtained.

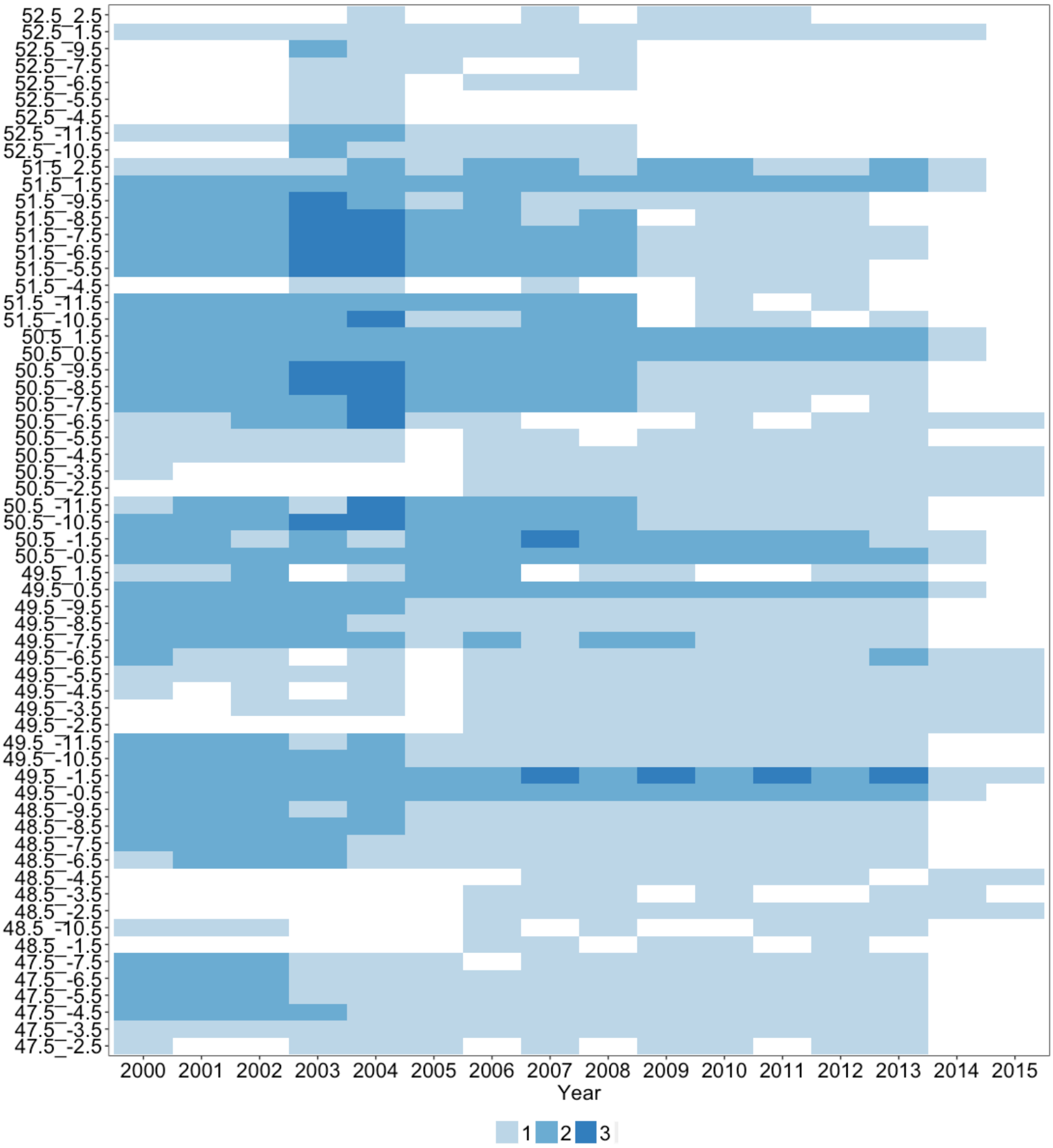


Figure 2.2. Spatial and temporal survey overlap of grid cells, for each 1° latitude and 1° longitude. Shading represents the number of surveys that have been undertaken within each grid cell within each year. A maximum of three surveys took place within a grid cell in any one year.

Data analysis

The period 2000–2015 was chosen for analysis as this formed a consistent period when all surveys took place and pairs of surveyed overlapped. First, the annual mean catch per unit effort per 1° by 1° grid cell was calculated for each survey for each year to account for different haul durations, sizes and number. Data were then 4th root transformed to reduce the influence of outliers in later analyses. Zero abundance represented instances where a grid cell was sampled, but the species was not caught.

General linear model and least square means

For each species, a linear model was developed to assess the effect of survey, alongside year and grid cell, upon CPUE index of abundance:

$$\text{CPUE} \sim \text{Grid cell} + \text{Year} + \text{Survey}$$

When calculating least square means, the variables over which to generate estimates can be specified (Searle, Speed and Milliken, 1980). In this case the least square mean values for each grid cell were generated using the package *lsmeans* within R, accounting for effects of survey and year (Lenth, 2016; R Core Team, 2018). To assess the influence of the method on spatial patterns of abundance, these standardised abundance indices were then compared to observed abundance for the same time period (4th rooted) for each survey using Spearman's rank correlations.

Bayesian Principal Component Analysis

Mean CPUE per year was averaged for the whole time period for each grid cell, species, survey combination. For each species, a Bayesian PCA (BPCA) was then performed on the abundance per grid cell for the whole time period using the *pcaMethods* package in R (Stacklies *et al.,* 2007). As opposed to traditional PCA, BPCA allows missing data to be imputed using Bayesian estimation methods (Nounou *et al.,* 2002; Audigier, Husson and Josse, 2016). In the context of this study, this method therefore generated CPUE abundance estimates for grid cells which had missing data, using information of the associations between other surveys overlapping within the grid cell in the same year. Five principal components were specified within the BPCA as this provided the maximum number of components that could be used to capture enough variance within the data. Once imputed estimates were generated to complete the matrix for every cell for each survey for the time period, an overall mean was then generated across the surveys for each cell. These standardised abundance indices were then compared to observed abundance (4th rooted) for each survey using Spearman's rank correlation.

Results

Least square means

The linear model demonstrated significant effects of survey, year and grid cell on all species abundances (Table 2.1). Survey consistently produced the greatest variation in abundance, as shown through higher *F* scores compared to year or grid cell effects (Table 2.1; Fig. 2.3).

Table 2.1. ANOVA results for each species

Species	Variable	*F* value	df	*p* value
Anglerfish	Survey	432.83	5	<0.001
	Years	5.38	15	<0.001
	Cell	4.59	61	<0.001
Atlantic Cod	Survey	63.22	5	<0.001
	Years	2.75	15	<0.001
	Cell	13.86	61	<0.001
Dover sole	Survey	536.65	5	<0.001
	Years	1.57	15	0.07
	Cell	16.23	61	<0.001
European plaice	Survey	488.62	5	<0.001
	Years	8.90	15	<0.001
	Cell	31.13	61	<0.001
John dory	Survey	74.98	5	<0.001
	Years	2.35	15	0.002
	Cell	7.53	61	<0.001
Lemon sole	Survey	31.11	5	<0.001
	Years	1.21	15	0.28
	Cell	28.66	61	<0.001
Megrim	Survey	947.06	5	<0.001
	Years	2.47	15	0.001
	Cell	47.68	61	<0.001
Red mullet	Survey	190.01	5	<0.001
	Years	5.29	15	<0.001
	Cell	11.62	61	<0.001

For most species and surveys there were strong positive correlations between observed and standardised least square mean abundances for each survey, with Spearman's *rho* above 0.70 in 91% of cases (Table 2; Fig. 2.4). The methodology appeared most effective for European plaice, lemon sole and megrim, as represented in the higher average correlations. The strongest correlations for each survey (averaged over species) were obtained for the Western Channel and Irish Groundfish Surveys. Overall, the average *rho* for all species and survey combinations was 0.85 (Table 2.2). Least square mean abundance indices for each species also fitted within similar ranges to individual survey abundances and reflected original abundance patterns of species (Figs. 2.4, 2.5a, 2.5b).

Table 2.2. Spearman's rank correlations between observed abundance (average 4th rooted) and standardised abundance (least square mean).

Species	CELTIC	EEC	EVHOE	FRCGFS	IGFS	WESTERN	Average across survey
Anglerfish	0.54	*	0.67	*	0.64	0.87	0.68
Atlantic cod	0.78	0.85	0.92	0.74	0.95	0.82	0.84
Dover sole	0.67	0.99	0.94	0.76	0.94	0.84	0.85
European plaice	0.85	0.92	0.83	0.89	0.95	0.89	0.88
John dory	0.63	0.72	0.90	0.84	0.72	0.75	0.76
Lemon sole	0.74	0.88	0.89	0.92	0.93	0.94	0.88
Megrim	0.92	**	0.94	**	0.98	0.94	0.94
Red mullet	0.76	0.24	0.64	0.83	0.76	0.81	0.67
Average across species	0.73	0.76	0.84	0.83	0.85	0.85	**0.85**

* Not calculated, as standardised abundance values were all zero
**The species was not caught in these surveys.

Bayesian PCA

Positive correlations between observed and standardised abundance were observed for all surveys and all species, with one exception (Table 2.2; Fig. 2.6). In 80% of cases Spearman's *rho* was above 0.70. The highest mean correlations across surveys for each species were observed for lemon sole and Dover sole. The standardised data were most consistent with the data in the Celtic survey when correlations were averaged across all species (Table 2.2). Spatial patterns were similar to those obtained through the least square mean methodology, although in areas of low abundance, standardised abundances obtained through BPCA were relatively higher than those observed using the least square mean methodology (Figs. 2.5a and 2.5b).

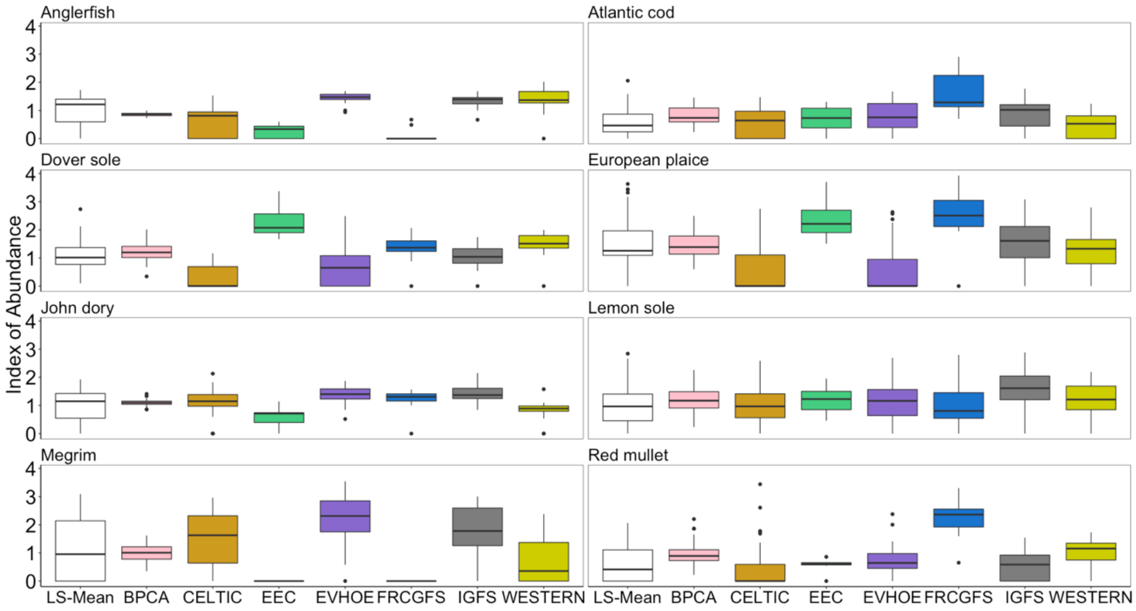


Figure 2.3. Comparison of abundance indices for individual surveys and standardised abundance indices from least square mean and BPCA methodologies.

Table 2.3. Correlations between observed abundance (average 4th rooted) and standardised abundance (Bayesian PCA).

Species	CELTIC	EEC	EVHOE	FRCGFS	IGFS	WESTERN	Average across survey
Anglerfish	0.83	0.95	0.40	0.70	0.73	-0.27	0.55
Atlantic cod	0.84	0.59	0.92	0.95	0.89	0.70	0.81
Dover sole	0.79	0.93	0.95	0.91	0.82	0.89	0.88
European Plaice	0.83	0.85	0.78	0.93	0.73	0.80	0.82
John dory	0.76	0.73	0.83	0.34	0.65	0.63	0.65
Lemon sole	0.88	0.86	0.90	0.95	0.85	0.86	0.88
Megrim	0.96	*	0.88	*	0.96	0.34	0.78
Red mullet	0.82	0.14	0.65	0.95	0.87	0.85	0.71
Average across species	0.83	0.72	0.78	0.81	0.81	0.60	**0.76**

*The species was not caught in these surveys.

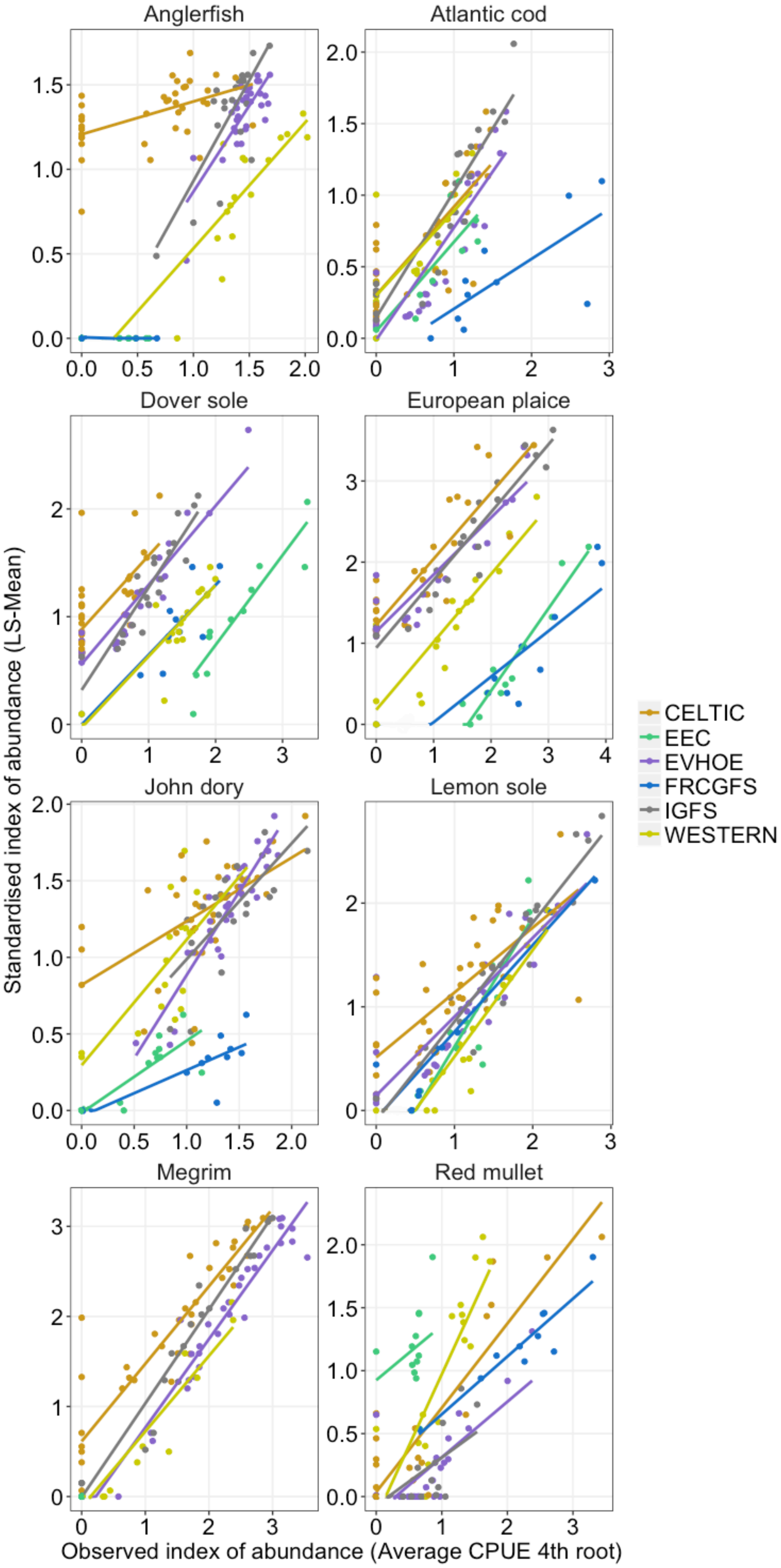


Figure 2.4. Relationship between observed index of abundance and standardised index of abundance generated using least square mean methodology.

Discussion

This study sought to evaluate methodologies that standardised scientific survey abundance data to enable future research over broader temporal and spatial scales. Our results demonstrate that both of the tested methodologies could provide standardised abundance indices within the south-west UK region. However, the least square mean methodology appeared to maintain spatial patterns of abundance most effectively, as indicated by higher overall correlations with original indexes of abundance for individual surveys. This methodology also includes the requirement to perform a linear model prior to generating abundances, providing opportunity to look at the effect and variance of different factors or covariates on abundances. Although not presented here, confidence intervals can also be obtained through this methodology, providing additional insight into the robustness of this method if required. Thus, the least square mean approach could provide a relatively simple means of allowing survey biases to be accommodated, while still retaining and consequently reflecting original spatial patterns of abundance. Spatial patterns of least square mean abundance for the species tested were also similar to wider work that has focused on examining species abundance patterns using scientific survey data (Heessen, Daan and Ellis, 2015).

The issues surrounding standardising abundance data can account for why some regions within the Northeast Atlantic region are more commonly researched than others. For example, the North Sea has had relatively consistent sampling since the 1960s and consequently the spatial and temporal variation in patterns of species abundance, and drivers of such patterns including climate change, are reasonably well researched (Dulvy *et al.,* 2008; Hiddink and Hostede, 2008; Queirós *et al.,* 2018). By contrast, the south-west region has seen multiple surveys change in their spatial and temporal coverage and therefore comparative work across the region has been less common. The application of standardisation methods therefore enables work focussed on how drivers, such as climate and fishing, have or could influence abundances and distributions at the population and community levels. Testing the methodologies presented within this study in other regions could allow future research to be extended across broader geographical areas.

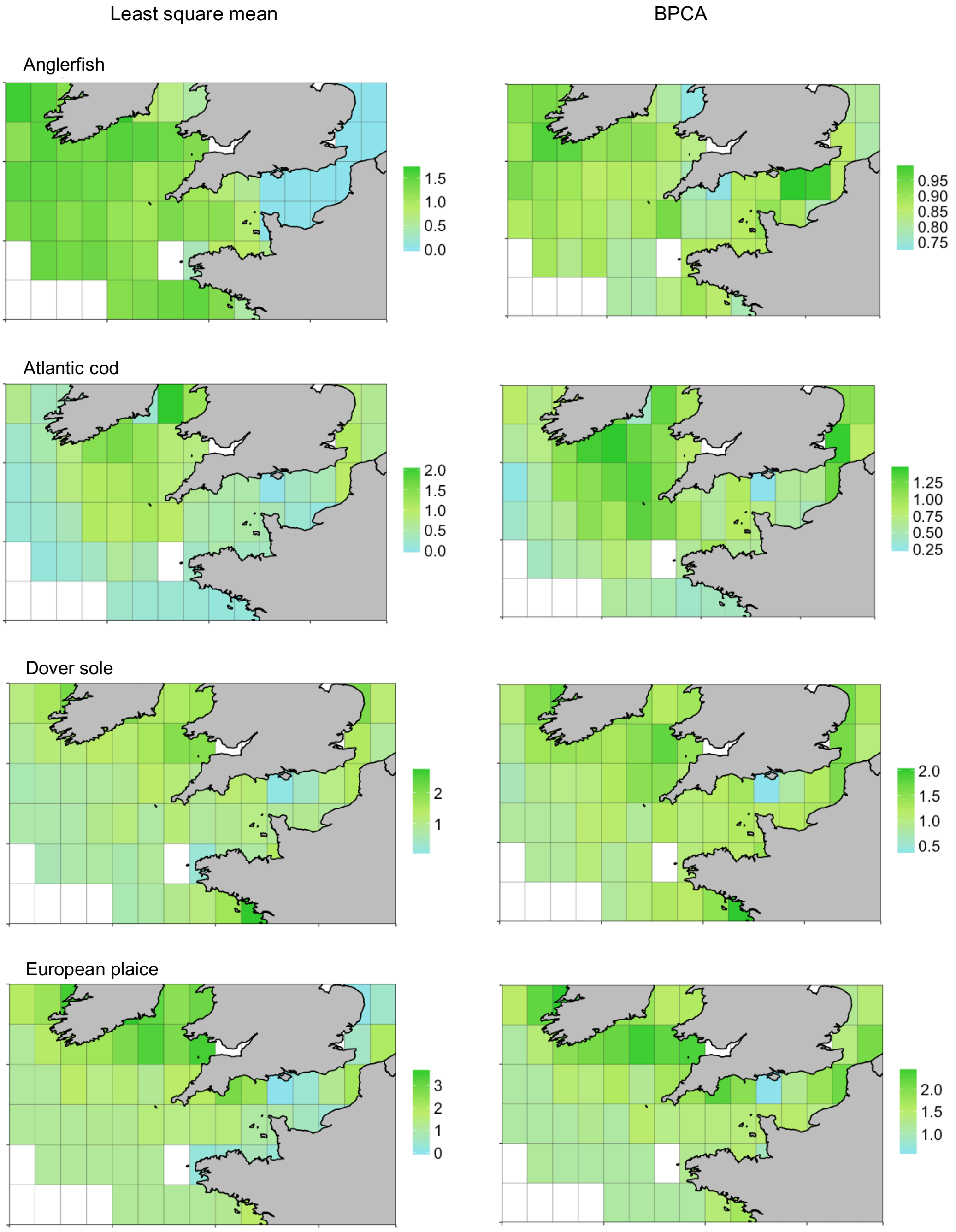


Figure 2.5a. Spatial patterns of standardised abundance indices generated by least square means (left) and BPCA (right).

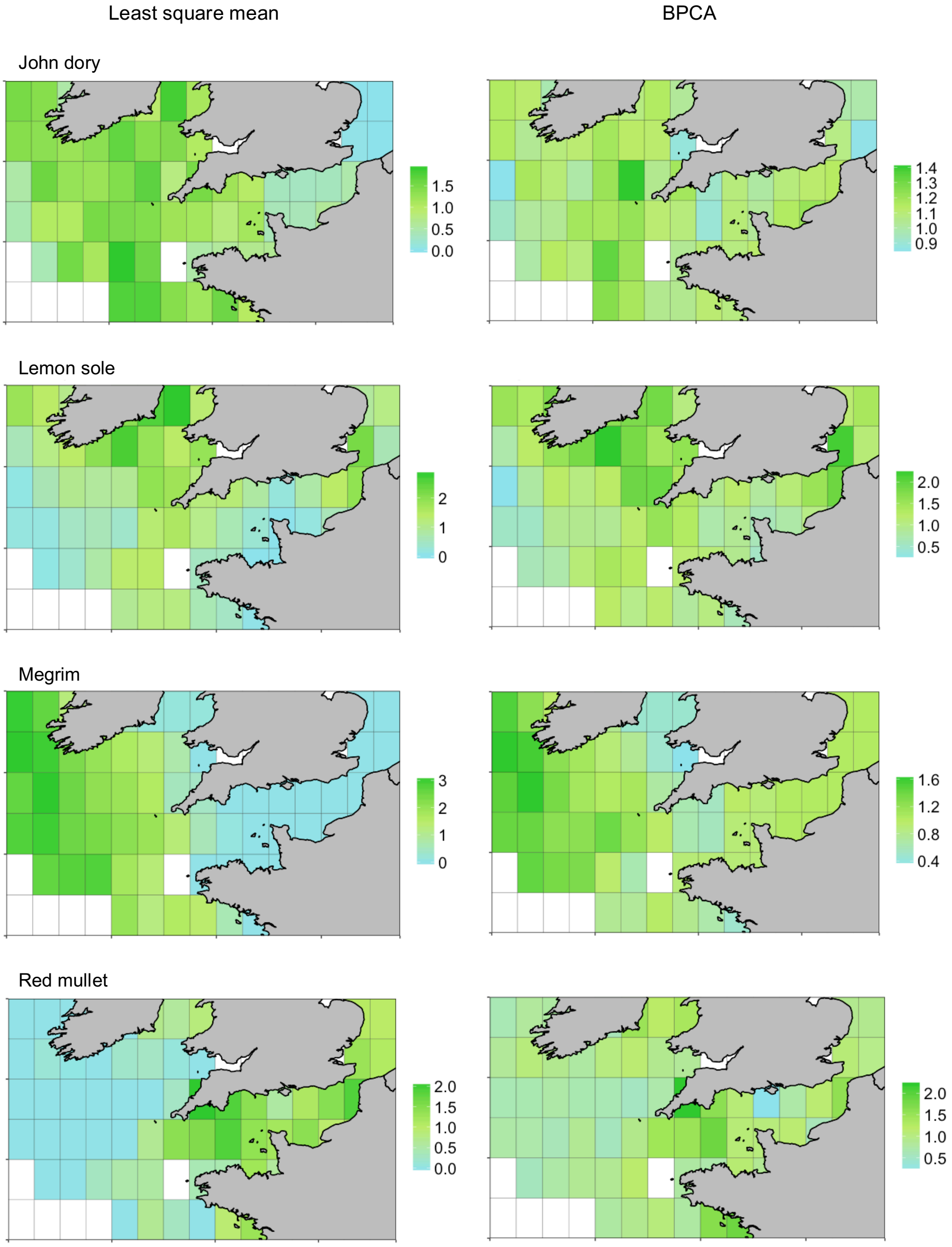


Figure 2.5b. Spatial patterns of standardised abundance indices generated by least square means (left) and BPCA (right).

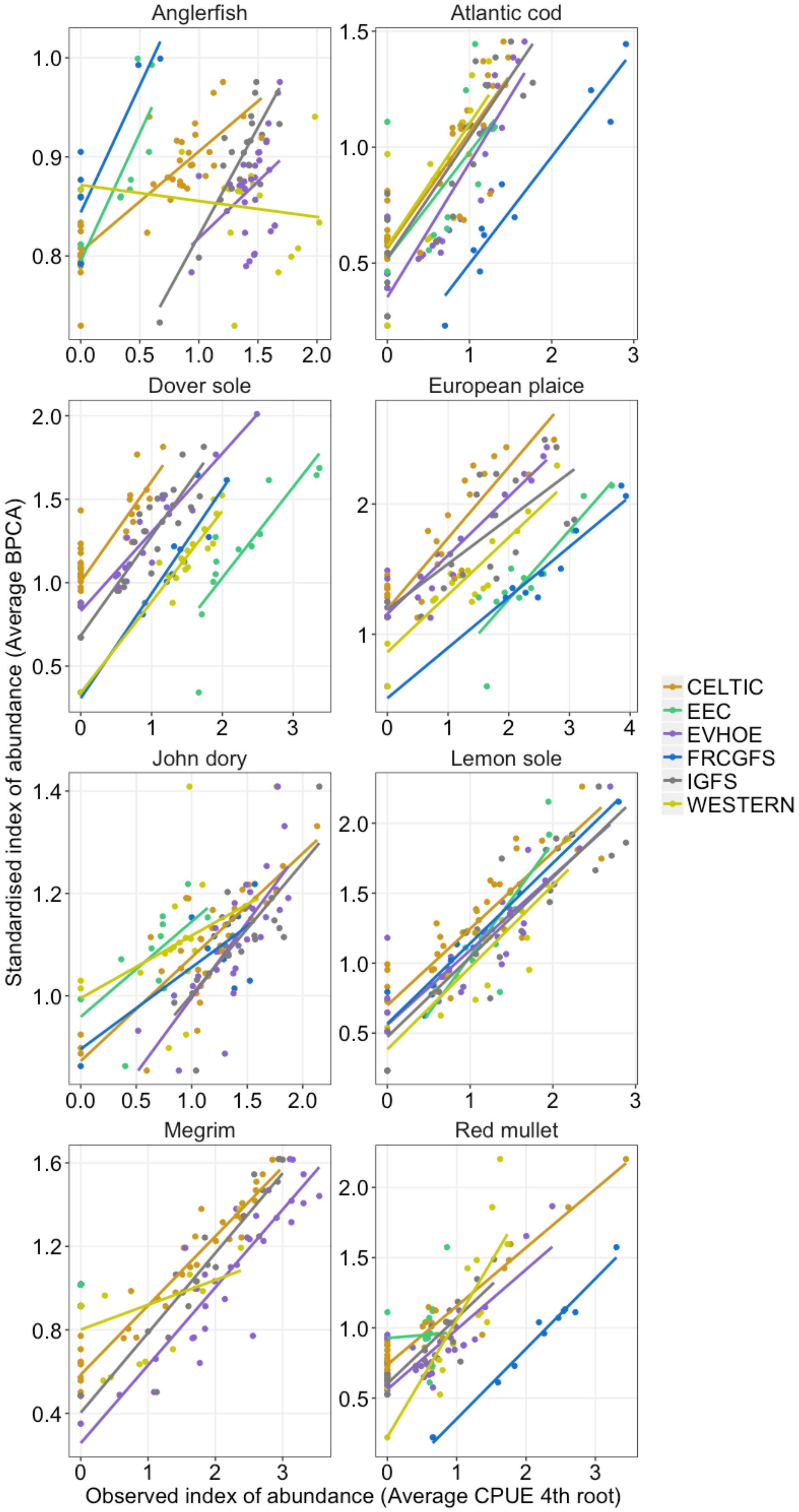


Figure 2.6. Relationship between observed index of abundance and standardised index of abundance generated using Bayesian PCA methodology.

For example, these methods could allow projections of future climate-driven change on fish populations to be developed across the whole of UK seas, therefore providing insight into potential climate impacts on fisheries and the wider marine ecosystem.

The least square mean methodology has several limitations that are also important to highlight. This study had limited spatial and temporal overlap of surveys in grid cells, and it is expected that greater overlap between surveys can increase robustness of generated standardised abundances due to more data being available to underpin the analysed associations. Results also indicated that the standardised abundance indices from the method were somewhat low compared to original values, although the strong correlations obtained indicated that standardised abundances were reliable and reflected original spatial trends.

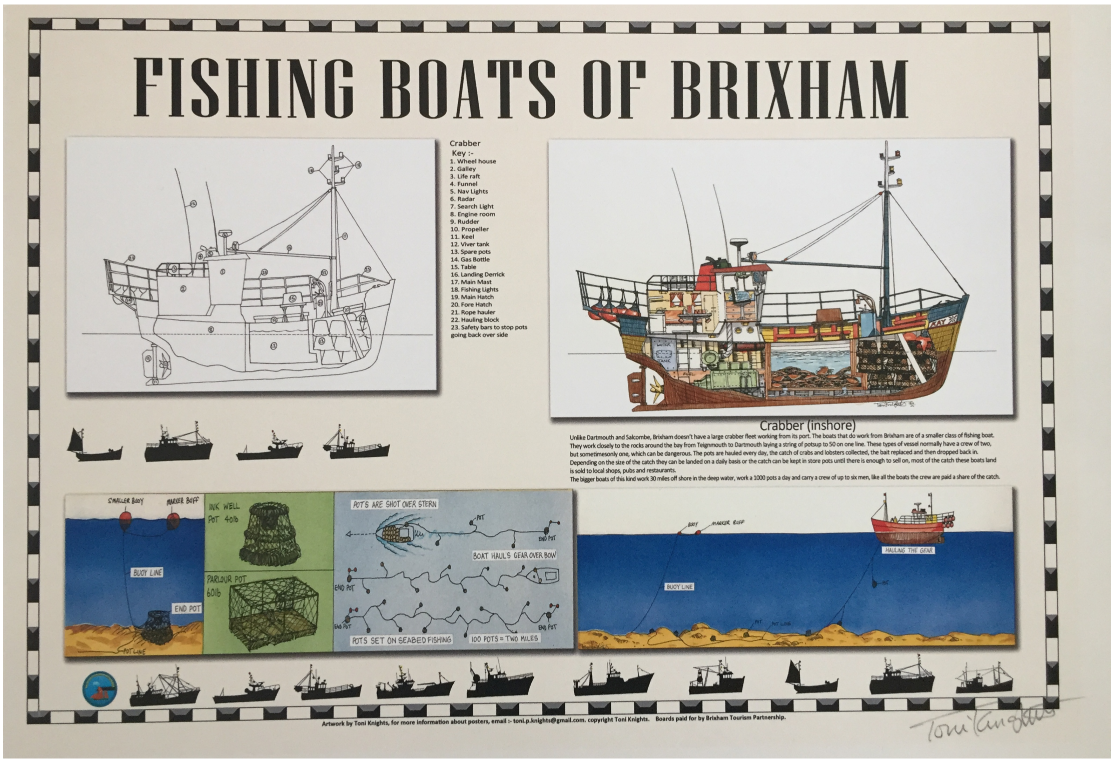
Importantly, the method used to generate standardised data is limited to addressing broader patterns of species abundance, enabling analyses of changes over larger spatial and temporal scales. For formal stock assessment purposes, a more technical literature focuses on accounting for survey biases through determining the catchability of individual species, including variation among life stages (Arreguín-Sánchez, 1996; Fraser, Greenstreet and Piet, 2007; Maunder and Piner, 2015; Walker *et al.,* 2017). Such catchability standardisation approaches must accommodate the efficiency of the gear at catching and retaining fish (Arreguín-Sánchez, 1996; Marchal *et al.,* 2003; Fraser, Greenstreet and Piet, 2007; Walker *et al.,* 2017). These efficiencies in turn will be related to characteristics of individual species, such as their behaviour within the water column and behaviour with fishing gear, both of which will be influenced by extrinsic variation in the environment (Arreguín-Sánchez, 1996; Harley and Myers, 2001; Trenkel *et al.,* 2004; Fraser, Greenstreet and Piet, 2007). Typically, due to this complexity, catchability estimates focus upon direct pairwise comparisons of pairs of gears and/or surveys (e.g. Fraser, Greenstreet and Piet, 2007; Walker *et al.,* 2017).

The approaches we investigated do not necessarily allow comparisons of the efficiencies of gears in different habitats and over different life stages. Instead, they represent a relatively straightforward statistical approach enabling large scale macroecological patterns of populations and communities to be compared over broad spatial scales. Such methodologies should prove useful until such a time that the catchability of many more species using more gear types has been estimated.

This study presented a comparison of two methodologies to standardise fish abundance data derived from scientific surveys. Fisheries independent survey data, while generally less biased compared with commercially-derived fisheries data, also have numerous biases which need to be accounted for in ecological studies. Although both methodologies tested here appear to work well, the approach using least square means appeared to provide consistent and suitable standardised abundances across all species tested and generally retained spatial patterns of abundance. While the approach has limitations, it provides a mechanism for future work seeking to address macroecological questions within the marine environment and account for biases within survey data. This is particularly useful for climate change research wishing to generate future projections that extend beyond species distributions, and generate greater insight into how species abundances may be affected in the future. Accounting for such biases within these data will ultimately help to increase the reliability and robustness of projections which has particular importance if they are to help inform fisheries policy and management decision-making processes.

Chapter 3

Projected impacts of warming seas on commercially fished species at a biogeographic boundary of the European continental shelf



Unlike Dartmouth and Salcombe, Brixham doesn't have a large crabber fleet working from its port. The boats that do work from Brixham are of a smaller class of fishing boat. They work closely to the rocks around the bay from Teignmouth to Dartmouth laying a string of potsup to 50 on one line. These types of vessel normally have a crew of two, but sometimesonly one, which can be dangerous. The pots are hauled every day, the catch of crabs and lobsters collected, the bait replaced and then dropped back in. Depending on the size of the catch they can be landed on a daily basis or the catch can be kept in store pots until there is enough to sell on, most of the catch these boats land is sold to local shops, pubs and restaurants.

The bigger boats of this kind work 30 miles off shore in the deep water, work a 1000 pots a day and carry a crew of up to six men, like all the boats the crew are paid a share of the catch.

Artwork by Toni Knights, for more information about posters, email :- toni.p.knights@gmail.com. copyright Toni Knights. Boards paid for by Brixham Tourism Partnership.

Toni Knights

Drawing by Toni Knights

Katherine M. Maltby, Louise A. Rutterford, Jonathan Tinker, Martin J. Genner, Simon Jennings, Stephen D. Simpson

Abstract

Climate change is already affecting the distribution, abundance and productivity of marine fish populations. With further warming predicted, projections of further effects on fished populations will help prepare the fishing industry, management systems and markets, and the wider supply chain for resulting social, economic and ecological changes. We use an ensemble of 11 climate projections (hereafter ensemble-members) from a single climate scenario to model the distribution and abundance of eight commercially important bottom dwelling fish species in the Celtic Sea, English Channel and southern North Sea through the 21st century. This shelf-sea region spans a faunal boundary between cooler northern waters and warmer southern waters. Mean sea surface temperature in this region has already increased by 0.17 to 0.45°C per decade between 1985 and 2014 and is projected to rise a further 2 to 4°C by 2098. For each species, Generalised Additive Models (GAMs) were trained on spatially explicit distribution and abundance data from six surveys between 2001 and 2010. Temperature and depth were key drivers of species' spatial abundance, with weaker effects of fishing effort and salinity. The optimal GAM, as selected based upon a suite of model statistics, was consequently used to project abundance of each species over each climate ensemble-member for each decade through to 2090. Mean projections suggest an increase in abundance of warm water species such as red mullet (*Mullus surmuletus* L.) and John dory (*Zeus faber* L.) and a decrease in abundance of cool water species including Atlantic cod (*Gadus morhua* L.), anglerfish (*Lophius piscatorius* L.) and megrim (*Lepidorhombus whiffiagonis* L.). Dover sole (*Solea solea*) and lemon sole (*Microstomus kitt*) were less affected by projected temperature changes. Projections were comparable among climate ensemble-members, but uncertainty in rate and magnitude of change often increased substantially beyond 2040.

Synthesis and applications: Projected climate effects may lead to greater risks and fewer opportunities for those fishing vessels with less flexibility to change fishing gear or grounds and switch to alternative target species. Management systems that enable such flexibility will support adaptation.

Introduction

Climate change has globally affected the abundance, dynamics and distribution of marine fish populations and their associated fisheries, resulting in substantive social and economic consequences (Perry *et al.,* 2005; Brander, 2010, Pecl *et al.,* 2017; Savo, Morton and Lepofsky, 2017). Projections of climate change impacts on marine systems provide important insights into future species responses to increased temperatures, as well as the future availability, productivity and catchability of stocks for dependent fisheries (Cheung *et al.,* 2010; Blanchard *et al.,* 2012; Hollowed *et al.,* 2013; Barange *et al.,* 2014).

A marine region that has warmed particularly rapidly over the last four decades is the Northwest European shelf (Hughes *et al.,* 2017). This warming has affected the phenology, behaviour, physiology, abundances and distributions of many fish species inhabiting these waters (Perry *et al.,* 2005; Rijnsdorp *et al.,* 2009; Simpson *et al.,* 2013; Poloczanska *et al.,* 2016; Pinnegar *et al.,* 2017). For species with Lusitanian affinities such as red mullet (*Mullus surmuletus* L.), anchovy (*Engraulis encrasicolus* L.) and red gurnard (*Chelidonicthys cuculus* L.), warming temperatures have led to abundance increases and range expansion leading to fishery level effects (Simpson *et al.,* 2011; Montero-Serra, Edwards and Genner, 2015; Pinnegar *et al.,* 2017). Boreal species such as Atlantic cod (*Gadus morhua* L.), anglerfish (*Lophius piscatorius* L.) and European plaice (*Pleuronectes platessa* L.), which typically prefer cooler waters, have in some cases declined in abundance, shifted polewards, and/or deepened as they track preferred thermal ranges (Perry *et al.,* 2005; Dulvy *et al.,* 2008; van Hal, van Kooten and Rijnsdorp, 2016).

Spatially-explicit projections of the effects of future climate change on the abundance and distribution of fish populations underpin assessments of fisheries consequences. For the Northeast Atlantic region, Species Distribution Models (SDMs) have generally projected further poleward movements and/or deeper distributions of those species with preference for cooler waters (Cheung *et al.,* 2011; Jones *et al.,* 2012; Fernandes *et al.,* 2013; Jones *et al.,* 2013). However, for the North Sea, a study using Generalised Additive Models (GAMs) suggested that many bottom dwelling (demersal) species could not move further polewards because they were constrained by availability of habitat at suitable depth (Rutterford *et al.,* 2015).

Identifying and disclosing the sources and extent of uncertainty associated with modelled projections provides insight into their strengths and weaknesses and can guide appropriate responses to the projections (Planque *et al.,* 2011; Payne *et al.,* 2015; Cheung *et al.,* 2016a; Freer *et al.,* 2018). Such information can inform model development and the treatment of projections in decision-making (Payne *et al.,* 2015; Cheung *et al.,* 2016a). Research comparing model approaches and performances or using different climate scenarios can quantify levels of uncertainty arising from these different potential sources (Hollowed *et al.,* 2013; Cheung *et al.,* 2016a; Cheung *et al.,* 2016b; Freer *et al.,* 2018). Recent attempts range from exploring future long-term responses of individual species (Jones *et al.,* 2012; Gårdmark *et al.,* 2013) to wider marine biodiversity patterns and invasions (Jones and Cheung 2015), habitat suitability (Jones *et al.,* 2013) and fisheries catch potentials and revenues (Cheung *et al.,* 2016b; Lam *et al.,* 2016).

The Celtic Sea, English Channel and southern North Sea sections of the European continental shelf comprise a faunal boundary between cooler northern waters and warmer southern waters (Hinz *et al.,* 2011), and have warmed 0.17–0.45°C per decade between 1985–2014 (Hughes *et al.,* 2017). Climate projections suggest further sea temperature increases of 2–4°C by 2098 (Tinker *et al.,* 2016). The region is fished by many countries including the UK, Ireland, France and the Netherlands, with major fishing ports based along the coastline including Newlyn, Brixham and Le Havre. Given the significance of this region for fisheries (STECF, 2017), and extent of projected climate change within the region (Tinker *et al.,* 2016), we aimed to project future responses of commercially important species while incorporating climate uncertainty. Specifically, we trained GAMs based upon a dynamically downscaled climate ensemble dataset for the Northwestern European shelf seas alongside extensive fisheries survey data, and used these models with climate projections to estimate changes in the abundance and distribution of eight demersal fish species through the 21st century.

Methods

Study area

The region of study included all marine areas from 47–53°N and 12°W–3°E, represented in our analyses as 72 1x1° sea grid cells. Collectively the region spans the English Channel, Celtic Sea, the Bristol Channel and parts of the southern North Sea (Fig. 3.1a).

Data sources

- Depth, fishing effort and habitat

Average depth was calculated for each 1x1° grid cell using bathymetry data generated by the Met Office Hadley Centre (Fig. 3.1b). Average decadal fishing effort (total hours yr^{-1}) per 1x1° grid cell (Fig. 3.1c) was calculated using data from the European Commission's Scientific, Technical and Economic Committee for Fisheries (STECF) database for the available time period 2003–2013 (STECF, 2014; see Appendix A and Table A3.1, Fig. A3.1). Broad habitat type was assigned to 1x1° grid cells using data from the European Marine Observation and Data Network (EMODnet; http://www.emodnet-seabedhabitats.eu/; Appendix A). A total of 12 habitat types were assigned across the region (Fig. 3.1d).

- Temperature and salinity

Climate projections for the region were obtained from the Met Office Hadley Centre, generated from a project which dynamically downscaled, through the use of the POLCOMS shelf seas model, an ensemble of perturbed global Atmosphere-Ocean climate model projections (based upon the IPCC A1B scenario) for the entire Northwest European shelf seas region (Tinker *et al.,* 2015, 2016).

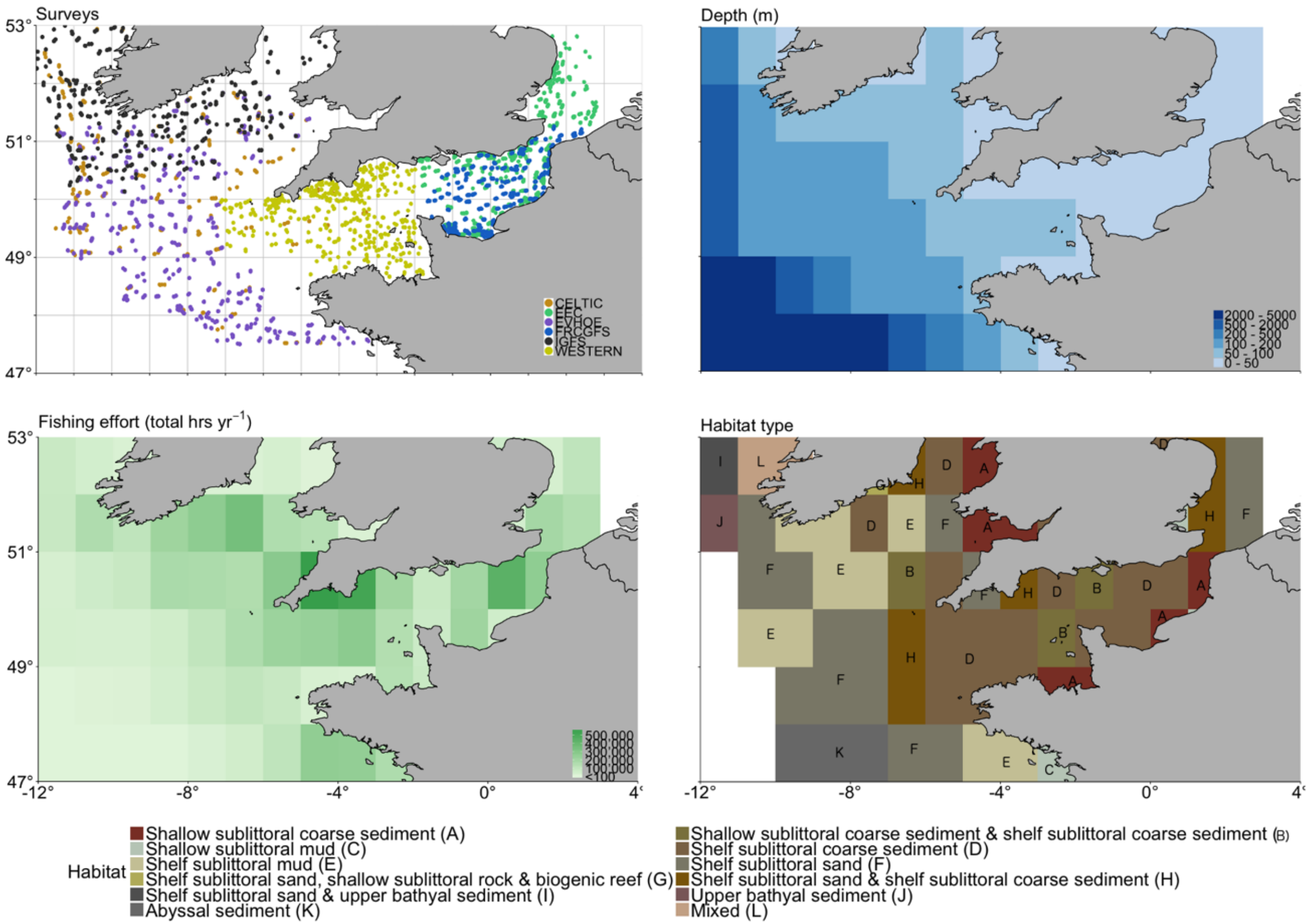


Figure 3.1. Study region and environmental data; a) survey haul locations 2001–2010; b) average depth in metres; c) average total fishing effort in hours; d) habitat type (letters correspond to habitat types).

The resulting ensemble of climate projections encompasses 11 ensemble-member projections (hereafter termed ‘ensemble-members’) representing a range of possible future temperature and salinity ranges within a single climate scenario (Fig. 3.2; see Tinker *et al.,* 2016 for full description of individual ensemble-members). This enabled exploration of aspects of the internal variability and uncertainty (represented in Fig. 3.2 through upper and lower standard deviation) within a single climate scenario through using these different ensemble-members and examining their relative effects on projected species responses. Decadal annual and seasonal (winter: Jan–March; summer: July–Sept) average sea surface (SST) and near bottom temperatures (NBT; °C) were calculated per 1x1° grid cell for each decade from 2001–2090 (2001–2010, 2011–2020, etc). Mean near bottom salinity (NBS; psu) was calculated for the same decades. Across the ensemble, there is a mean projected increase in annual SST of 3.26°C (southern North Sea), 3.13°C (English Channel) and 3.01°C (Celtic Sea) and a respective decrease in annual average sea surface salinity of -0.51psu, -0.08psu and -0.11psu by 2069–2098 when compared with 1960–1989 (Tinker *et al.,* 2016).

- Fish abundance data

Eight demersal fish species with a range of biogeographic affinities were selected, based on prior assessment of landing statistics and their social and economic importance to fisheries operating within the region (Table 3.1). These were anglerfish, Atlantic cod, Dover sole (*Solea solea* L.), European plaice, John dory (*Zeus faber* L.), lemon sole (*Microstomas kitt* L.), megrim (*Lepidorhombus whiffiagonis* L.) and red mullet. Abundance data were derived from six survey datasets (Cefas Eastern English Channel Survey (EEC), Cefas South Western Beam Trawl Survey (WESTERN), Cefas Celtic Sea Groundfish Survey (CELTIC), Irish Marine Institute Irish Groundfish Survey (IGFS), IFREMER French Southern Atlantic Bottom Trawl Survey (EVHOE) and IFREMER French Channel Groundfish Survey (FRCGFS), which were obtained through the ICES DATRAS online database [http://www.ices.dk/marine-data/data-portals/Pages/DATRAS.aspx] and from the UK Centre for Environment, Fisheries and Aquaculture Science (Cefas) (Fig. 3.1a).

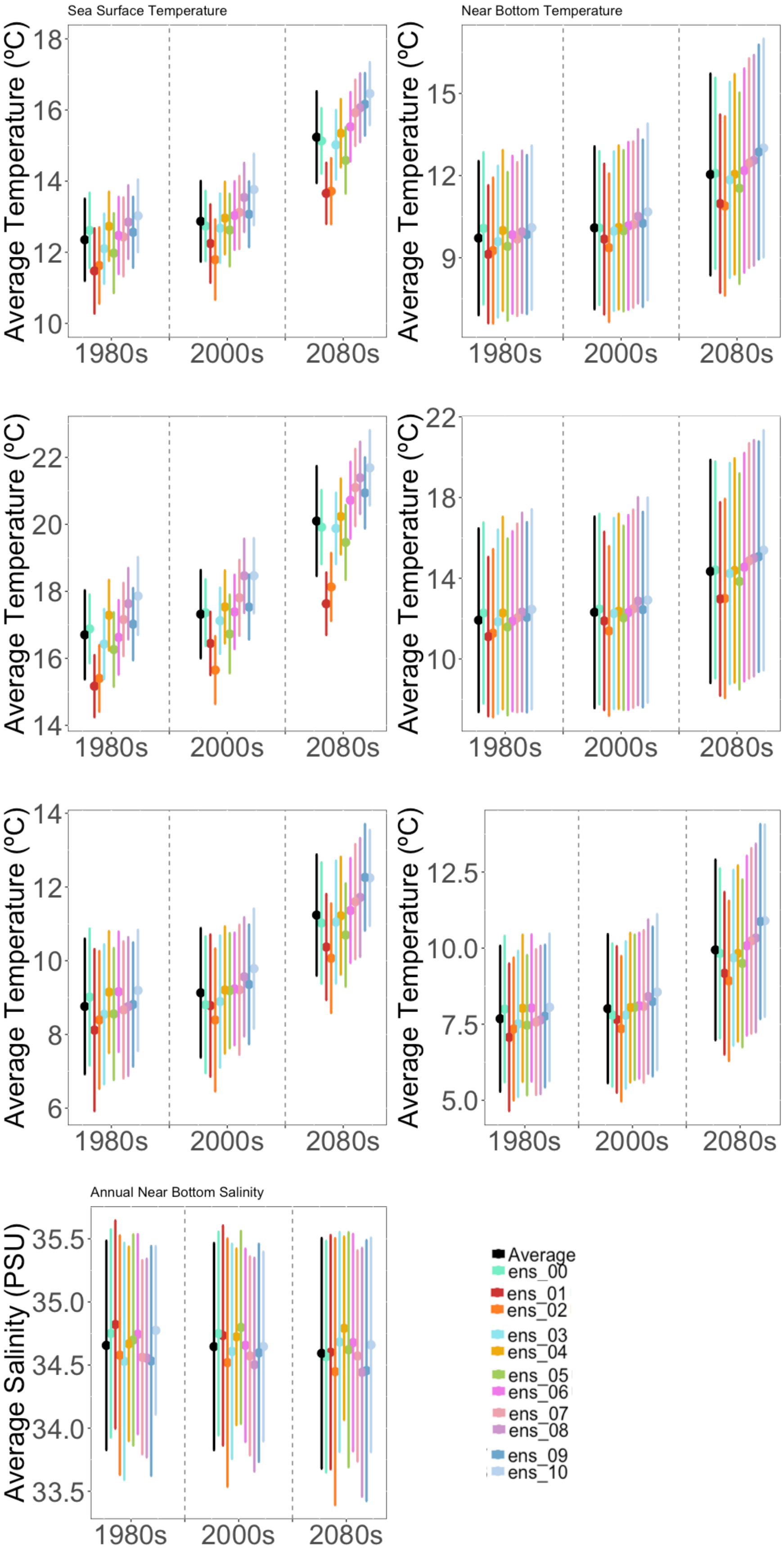


Figure 3.2. Decadal climate trends as projected for the 11 ensemble-members (ens 00-ens 10 and mean). Y axes are independently scaled. Uncertainty in projections is represented by upper and lower 1σ. Top row: annual sea surface temperature (SST) and near bottom temperature (NBT); Second row: summer SST and NBT; Third row: winter SST and NBT; Bottom: annual near bottom salinity.

Table 3.1. Species current geographical tendencies, thermal experience and fisheries commercial catch weights within the study region.

Species	Central latitude (°) *	Central longitude (°) *	Mean temperature (°C) *	Fisheries catch (2015; tonnes, live weight) †
Anglerfish	50.2	-7.1	12.84	2956
Atlantic cod	50.8	-5.1	12.36	7300
Dover sole	50.4	-4.8	12.52	14192
European plaice	50.9	-5.0	12.37	16233
John dory	50.1	-6.5	12.88	2068
Lemon sole	50.8	-4.9	12.37	3029
Megrim	50.1	-9.0	13.13	1814
Red mullet	50.0	-3.3	12.61	5027

* Calculations from dataset for the region

† Total catch calculated from EU vessels in 2015 for ICES areas 27.4c, 27.7d, 27.7e, 27.7f, 27.7g, 27.7h, 27.7j1 and 27.7j2 (ICES Catch Statistics, 2015).

These multiple surveys, which only partially overlap in space, differ in temporal coverage and use different sampling methods and gears (Appendix A: Table A3.2). Consequently, we used data from the period 2001–2010 (2000s) when all surveys were operational. We standardised abundance data to reduce inherent survey biases, using methods developed in Chapter 2 (see Appendix A). Species abundances from individual hauls were converted to a catch per unit of effort (CPUE, effort = 1 hour), averaged for the whole time-series and each 1x1° grid cell, and 4th root transformed to reduce the influence of outliers. Sixty-two grid cells with sufficient abundance data (more than three hauls recorded) were used for further analysis. To standardise species CPUE values across different survey methods and gears, CPUE was included in a general linear model (CPUE~grid cell + decade + survey) using R v.3.4.1 (R Core Team, 2018) to generate standardised least-square mean CPUE estimates for each 1x1° grid cell using the *lsmeans* package (Searle, Speed and Milliken, 1980; Lenth, 2016; see Appendix A: Tables A3.3–5 and Fig.A3.2).

- Generalised Additive Models

Eight sets of GAMs were developed; a ‘full’ model incorporating all variables and seven other models developed with the removal of particular variables (Table A3.6). These were then trained with climate and abundance data for each species for 2001–2010, for each of the 11 ensemble-members (= 88 GAM runs per species). GAMs were run using the *mgcv* package in R (Wood, 2011), and GAMs were fitted with a Gaussian distribution and 'identity' link function. A smoothing term was applied to all explanatory variables except habitat type, with knots set to k = 5 for smoothing to limit the degrees of freedom and avoid overfitting. Model fit was checked using *gam.check* and *gam.plot* functions. The relatively short time series prevented further training and testing of the predictive ability of GAMs and their robustness into projecting into the future using different lengths of time series. However, previous work where equivalent historic fisheries and climate data were used with GAMs to project forward in time suggest that training with data from a single decade can provide meaningful projections (e.g. Rutterford *et al.,* 2015).

To identify which predictor variables should be considered for generating future projections, GAMs were compared and selected based on a range of model statistics; AICc (recommended for small sample sizes by Burnham and Anderson, 2002), Akaike weights, adjusted R squared, Generalised Cross Validation (GCV) scores and correlations between projected and observed abundances. The optimal GAM was chosen based on a balance between model simplicity and predictive ability (Table A3.7). Using the same GAM across species allowed the effect of different ensemble-members to be assessed while keeping all other explanatory variables constant. The selected model was subsequently run for each species ensemble-member combination for each decade separately from 2001–2010 to 2081–2090. The present spatial pattern of fishing effort, driven largely by suitable fishing grounds and proximity to ports, was assumed to be constant when generating future projections. In addition to projecting abundance responses for each species over each separate climate ensemble-member, 'mean abundance' projections for each species were also calculated by averaging projections across the 11 ensemble-members. The difference in mean abundance between 2040s and 2000s was also determined for each species using log transformation of back transformed projections, to allow comparison of abundances within the timeframe over which there was strong agreement between ensemble-member projections.

- Projected changes in distribution

Projected species distribution shifts within the region of study were calculated from central latitudinal and longitudinal tendencies for each decade as (example for latitude):

$$Central\ latitude = \sum_{cell,decade=1}^{=n} \frac{abundance\ \times\ latitude_{grid\ cell,\ decade}}{abundance}$$

Results

GAM performance

In 93.1% of cases across all species ensemble-member combinations, Model ‘G’, including depth, fishing effort, SST, NBT and NBS, but excluding habitat type, was identified as the optimal GAM to use for projecting species responses (Fig. 3.3). This was the most parsimonious model owing to low AICc and GCV scores (Fig. 3.3; Table A3.7) and a high mean Pearson correlation score of 0.91 between observed and projected abundances across all species and ensemble-members (Table A3.7). For the few species ensemble-member combinations where Model G was not optimal, GAM delta AICc scores and other model statistics suggested using Model G (which was adopted to ensure consistency of approach) led to projections that were similar to those from the optimal model (Table A3.7). Inclusion of habitat type did not improve model performance and predictive ability. Model statistics indicated that temperature was a key driver of species responses; models that did not include temperature variables, particularly Model D, had some of the highest AICc and GCV scores and often poor fit and/or predictive ability compared to other models (Fig. 3.3; Table A3.7).

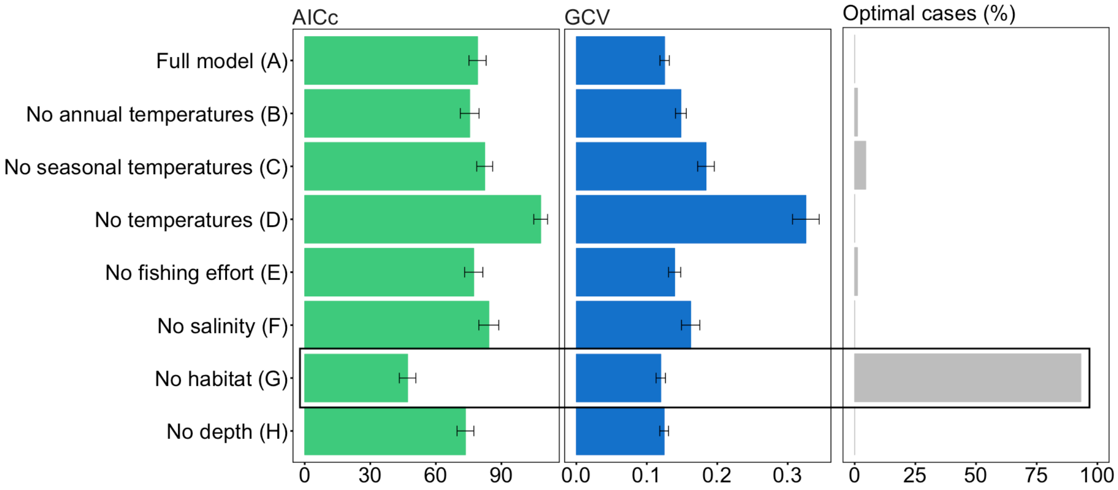


Figure 3.3. Mean model statistic scores across all species and ensemble-members for each trialled model. Left panel: Akaike Information Criterion; Mid panel: Generalised Cross Validation; Right panel: Percentage cases where model considered optimal for each species climate ensemble-member combination. Bars show standard error. Alongside other model statistics (Appendix A: Table A3.7), low AICc and GCV scores for Model G indicated it was the most parsimonious model (outlined in plot).

Mean abundance responses

Region wide declines in abundance were projected until the 2080s for anglerfish, Atlantic cod, European plaice and megrim (Fig. 3.4). The majority of ensemble-members generated similar declining trends, although there was variability in the extent of declines as shown in Table 3.2. Increases in red mullet were projected with all ensemble-members (Fig 3.4; Table 3.2). John dory and lemon sole increased in mean abundance, but responses projected with different ensemble-members were more variable, particularly after 2040. Projected mean abundance of Dover sole was relatively stable through time, showing a marginal increase until the 2040s. Ensemble-members implied increased uncertainty for future abundance of this species later in the 21st century.

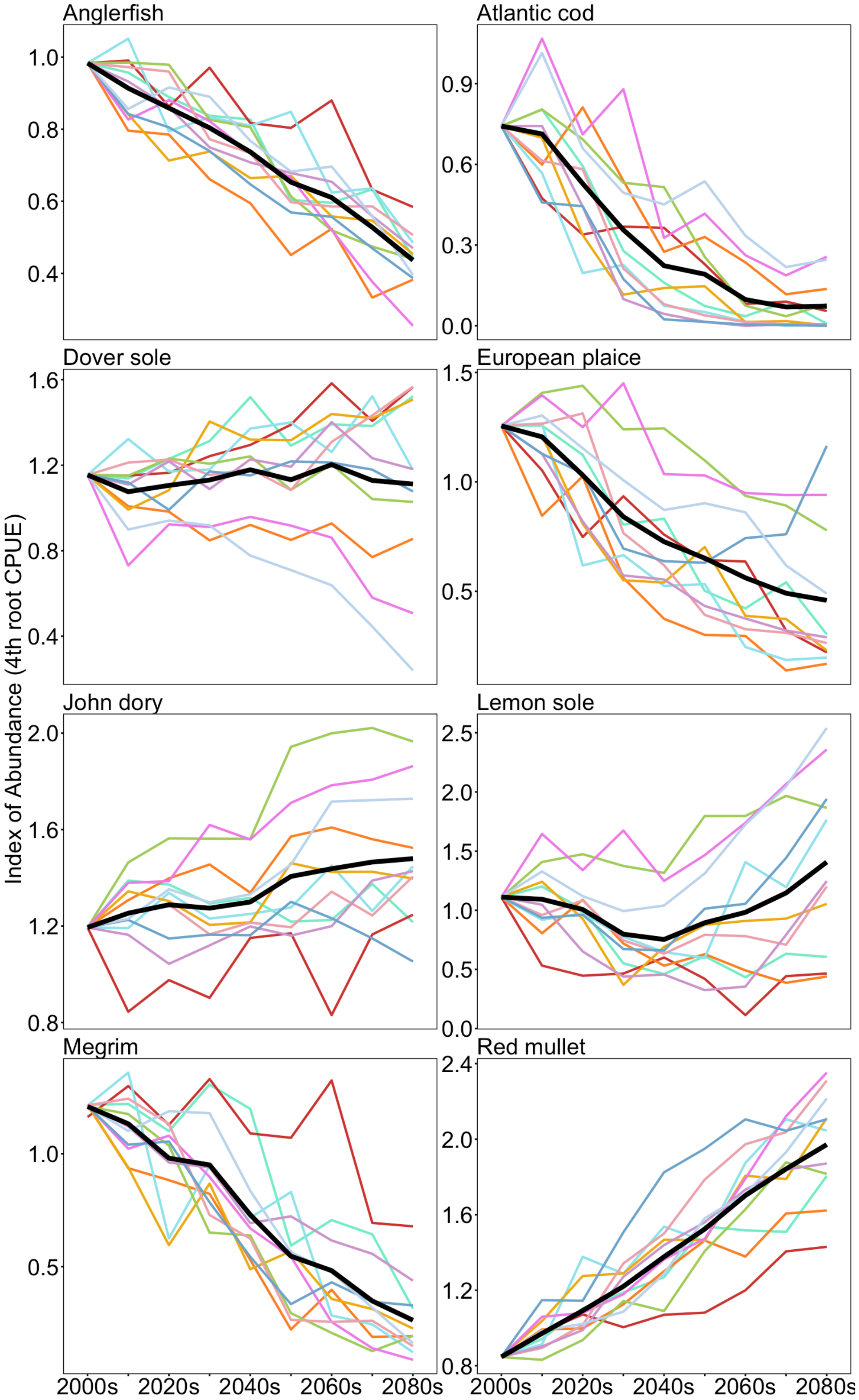


Figure 3.4. Projected changes in an index of abundance (4th rooted CPUE) from 2000s until 2080s for all species. Each line represents a climate ensemble-member (colour codes follow Figure 3.2), black lines represent the mean across all ensemble-members.

Table 3.2. Mean CPUE index of abundance (back transformed CPUE) for each time period. Bold numbers represent mean abundance across all ensemble-members and grid cells. The range generated across ensemble-members is shown through minimum and maximum values.

Species	**Mean CPUE 2000s** (min/max)	**Mean CPUE 2040s** (min/max)	**Mean CPUE 2080s** (min/max)
Anglerfish	**2.07** (2.05/2.09)	**1.14** (0.69/1.88)	**0.33** (0.06/0.96)
Atlantic cod	**0.93** (0.90/0.98)	**0.12** (0.00/0.27)	**0.06** (0.00/0.53)
Dover sole	**3.59** (3.52/3.68)	**4.29** (1.31/9.26)	**4.94** (0.15/10.82)
European plaice	**10.93** (10.57/11.27)	**4.58** (0.62/9.97)	**1.75** (0.91/7.42)
John dory	**3.57** (3.50/3.72)	**5.03** (2.64/11.48)	**10.14** (2.04/28.63)
Lemon sole	**5.35** (5.11/5.51)	**2.15** (0.32/5.88)	**25.08** (0.63/69.42)
Megrim	**17.35** (15.39/17.78)	**12.79** (5.62/22.02)	**16.01** (0.81/69.82)
Red mullet	**2.07** (1.91/2.24)	**19.88** (3.99/91.96)	**61.08** (11.63/250.67)

Distribution responses

Red mullet was projected to show a region wide increase in abundance from the 2000s to 2040s, particularly in the Channel (Figs. 3.5a–b; A3.3h). Dover sole and John dory were also projected to increase in most parts of the study area, particularly in the inshore (Dover sole) and offshore (John dory) regions off southern Ireland (Fig. 3.5a–b; A3.3c,e). Projected shifts in the centres of distribution for Dover sole were, however, relatively small while John dory showed little projected change in its central latitude but shifted eastwards (Fig. 3.6). European plaice and Atlantic cod were projected to shift north easterly in their distributions due to abundances being either maintained (Atlantic cod), or increasing (European plaice) within the southern North Sea (Figs. 3.5a–b, 3.6; A3.3b,d).

Anglerfish, lemon sole and megrim were all projected to shift westwards but differed in their latitudinal responses; anglerfish and megrim showed projected northward shifts while lemon sole was projected to move south (Fig. 3.6). Anglerfish and megrim were projected to decline across their range, with some localised increases for megrim in some areas to the west (Fig. 3.5a–b; A3.3a,g). Lemon sole was projected to decline in the northern extent of the region but increase towards the south (Fig. 3.5a–b, A3.3f). Spatial patterns of mean abundance across ensemble-members and the associated variability also suggested increasing uncertainty in projections and the magnitude of change for certain species through time, such as Dover sole and lemon sole (Fig. 3.5a–b, A3.3a–h). Spatial patterns also provided insights into sub-areas within the region where confidence in projections for species was reduced by differences in the directionality of projected change (Fig. 3.5a–b, A3.35a–h). Ensemble-member projections for anglerfish, Atlantic cod, European plaice and to a lesser extent megrim and red mullet were generally consistent across the region while for John dory, lemon sole and Dover sole there was greater variability (Fig. 3.5a–b, A3.3a–h).

Discussion

On average, projections towards 2090 suggest increased abundance for species currently associated with warmer waters and declines for those associated with cooler waters. These are the first projections of species abundance and redistributions in response to future warming for the region that are based on an ensemble of downscaled climate projections and use detailed survey information to identify variables influencing these responses. Such projections can help to inform the fishing industry, supply chains, and management systems about the future availability of these species. Additionally, projections can also help to inform stakeholders about the associated social, economic and ecological risks and/or opportunities resulting from changes in species abundance and distribution.

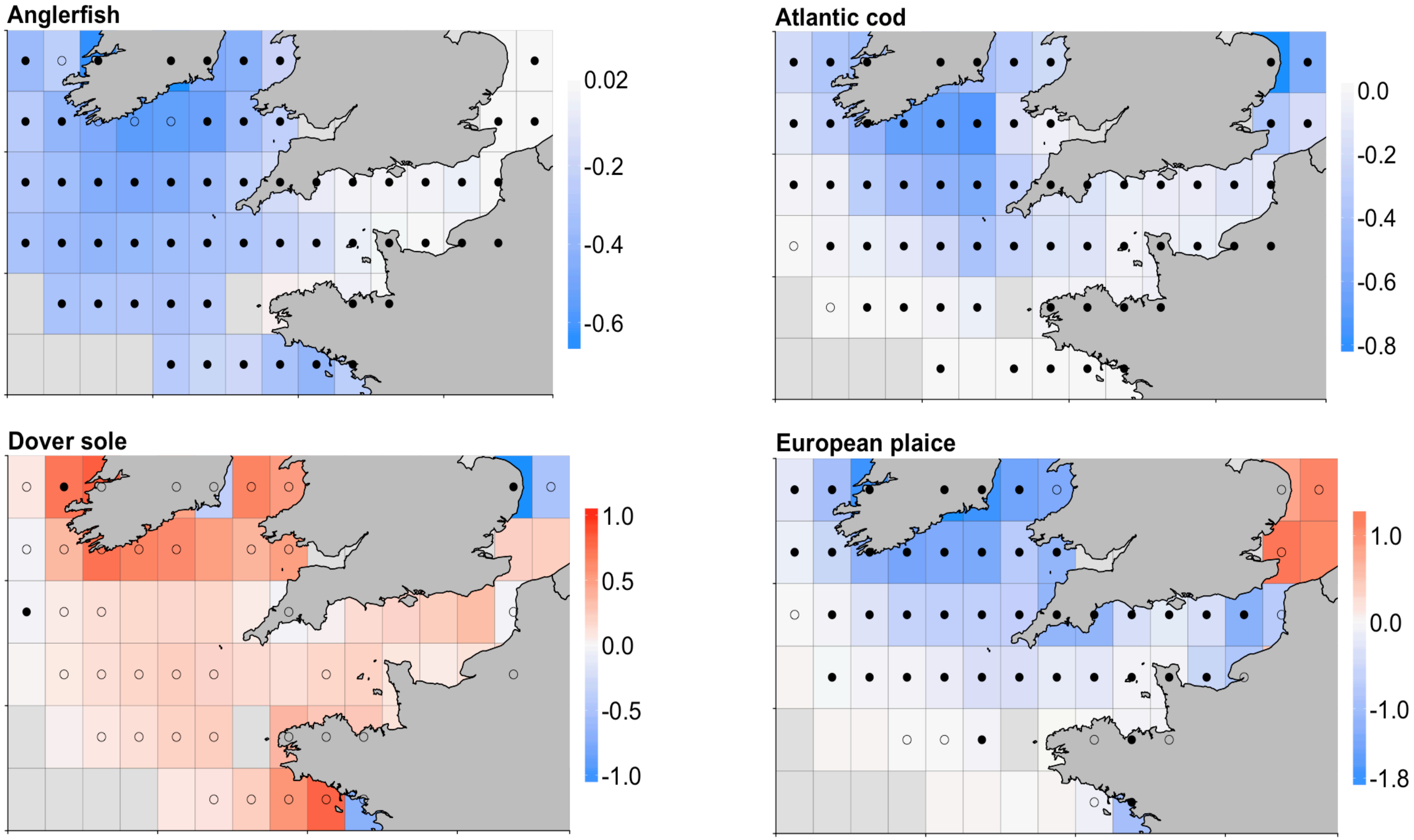


Figure 3.5a. Logged differences in mean projected abundance across ensemble-members between 2000s and 2040s using back transformed CPUE. Scales are independent for each species. Proportion of individual ensemble-members agreeing in directionality of projected change is reflected through closed dots • (90% or more ensemble-members agree), open ○ (50–90% ensemble-members agree) or no dots (less than 50% ensemble-members agree) for each grid cell. Grey grid cells represent no data and therefore no projections.

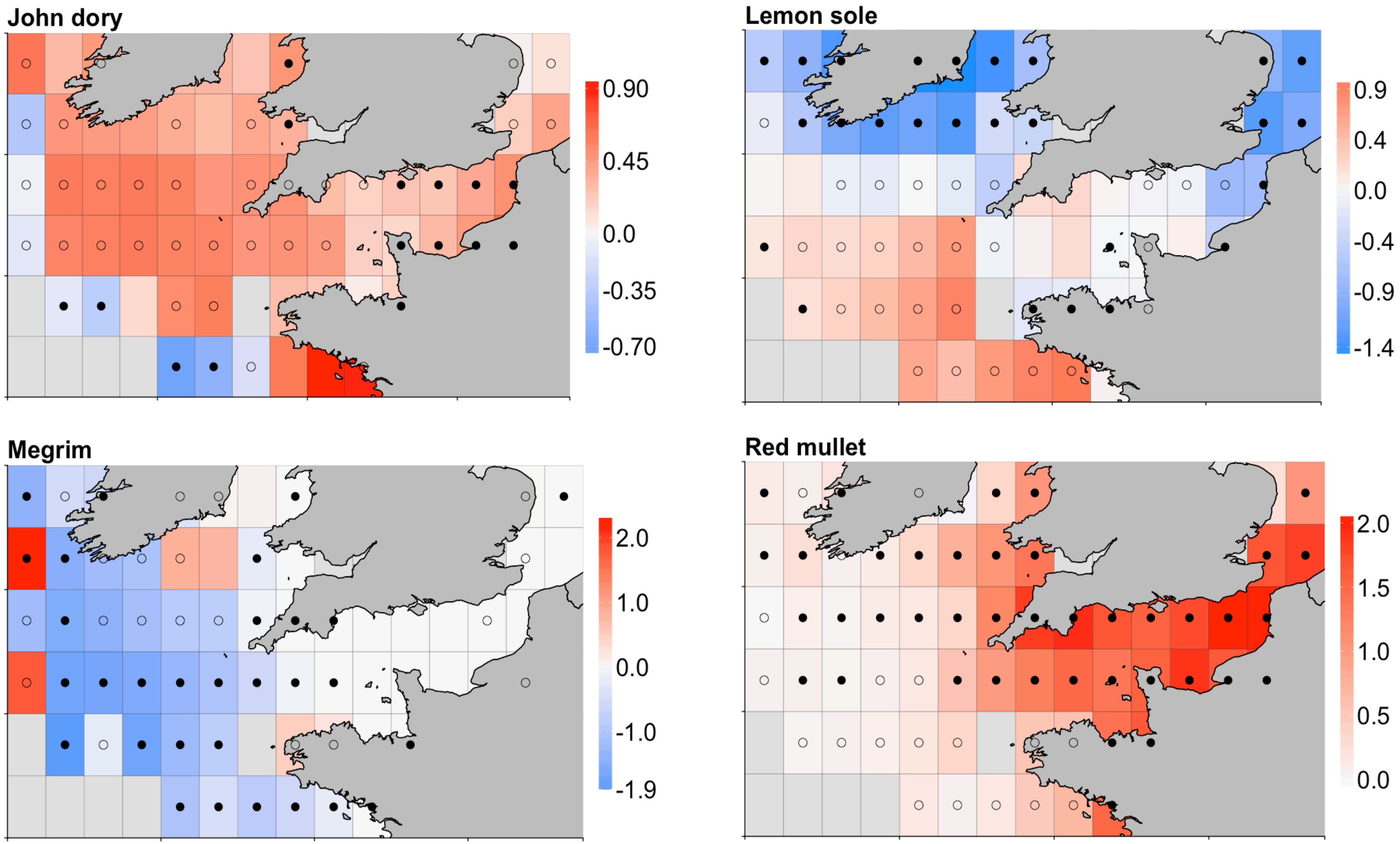


Figure 3.5b. Logged differences in mean projected abundance across ensemble-members between 2000s and 2040s using back transformed CPUE. Scales are independent for each species. Proportion of individual ensemble-members agreeing in directionality of projected change is reflected through closed dots • (90% or more ensemble-members agree), open ○ (50–90% ensemble-members agree) or no dots (less than 50% ensemble-members agree) for each grid cell. Grey grid cells represent no data and therefore no projections.

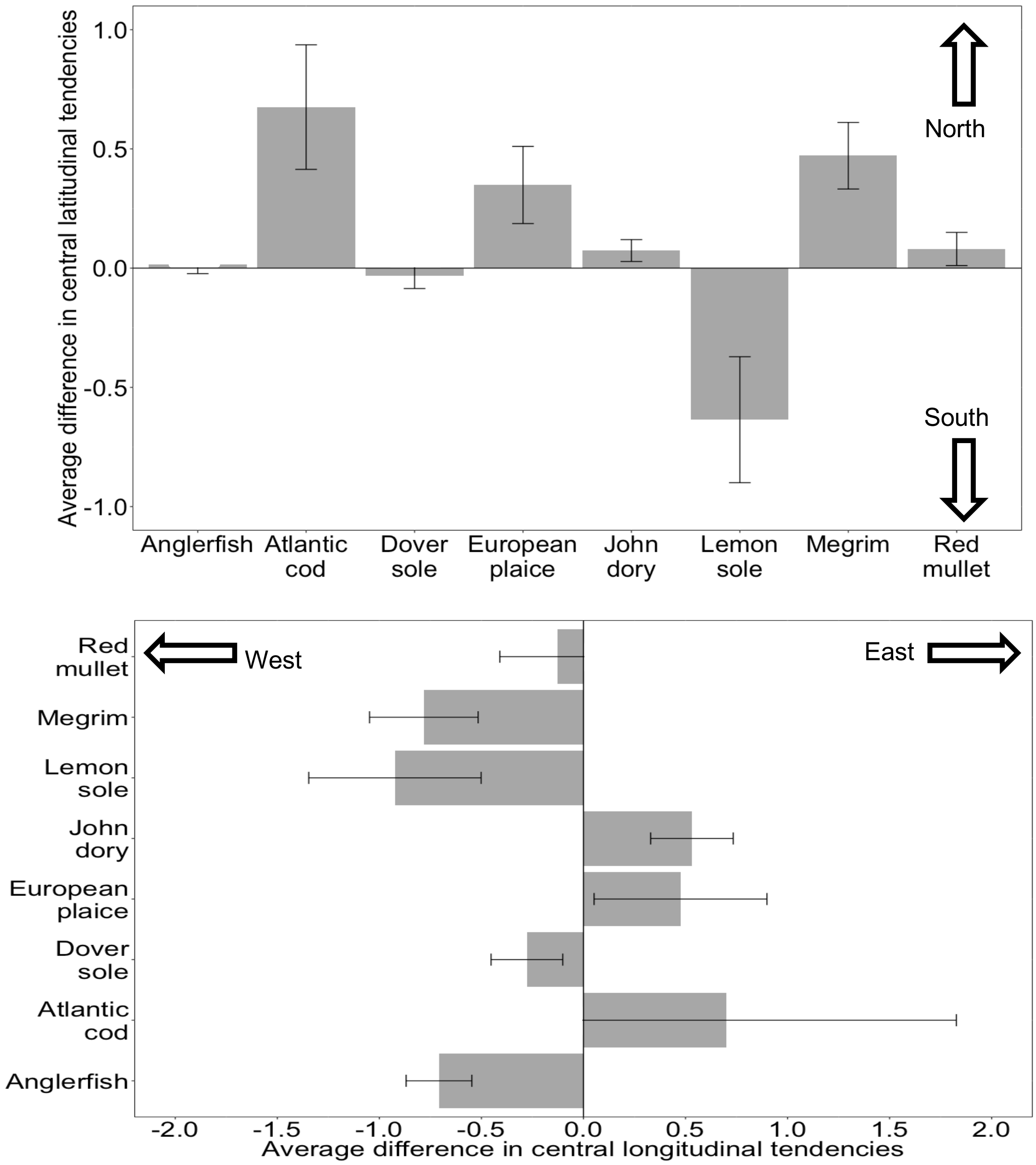


Figure 3.6. Difference in central latitudinal and longitudinal tendencies between 2000s and 2040s, averaged across ensemble-members. Error bars represent 95% confidence intervals.

Mean model projections presented here are relatively consistent with observed responses and future projections for other Lusitanian and boreal species in mid- to high-latitude Northeast Atlantic regions (Hollowed *et al.,* 2013; Montero-Serra, Edwards and Genner, 2015; Poloczanska *et al.,* 2016; Pinnegar *et al.,* 2017). We project that warming will allow the Lusitanian species John dory and red mullet to further increase and expand across the region, continuing a trend that has been documented in the North Sea and Celtic Sea since the mid-1990s (Beare *et al.,* 2004; ter Hofstede, Hiddink and Rijnsdorp 2010; Simpson *et al.,* 2011). Such expansions may provide opportunities for new fisheries as seen with other emerging species in recent years (Pinnegar *et al.,* 2013). The extent to which opportunities are realised will depend on factors including fishers' capacity to modify fishing practices, a management system that facilitates access to emerging species, consumers developing a taste and demand for the species and/or the emergence of export markets (Johnson and Welch, 2009; Perry *et al.,* 2010; Defra, 2013; Pinsky and Mantua, 2014; Jennings *et al.,* 2016). Fisheries within the region may continue to target the commercially valuable Dover sole in coming decades due to projections indicating that abundances and distributions will remain relatively similar, with marginal increases expected before 2040s. This is expected given the species high optimal growth temperature of 22.7°C (Schram *et al.,* 2013) and is consistent with observations of Englehard *et al.,* (2011) and van Hal *et al.,* (2016) that imply tolerance of this species to warming in the southern North Sea.

Fishing opportunities for other traditionally valuable species may be negatively affected, as seen by projected declines for the boreal species European plaice, anglerfish, Atlantic cod and megrim. Poleward (northward) shifts and/or deepening in response to warming has been previously identified for these species in other studies using fisheries survey data (Perry *et al.,* 2005; Dulvy *et al.,* 2008; van Hal *et al.,* 2016). Given the narrow thermal ranges for anglerfish, cod and megrim in particular, it is highly likely that future warming will reduce their availability to fisheries within the study region. Since many of the fisheries operating within this region are multispecies in nature (e.g. Gerritsen *et al.,* 2012; Mateo *et al.,* 2016), catching many species simultaneously with the same gears, these projected climate effects have implications for the likely composition of catches (Rihan, 2018). Species experiencing localised declines will most likely become targets for reductions in fishing mortality in adaptive management systems, thus traditionally targeted species may become 'choke' species, restricting the capture of species that are becoming more abundant.

Impacts of species responses to changes in future fishing effort or changes in management systems were not incorporated in our projections. Yet, alterations and redistributions of fishing effort and activities may result if distributions of available species and management decisions change (Haynie and Pfeiffer, 2012). For example, recommended Total Allowable Catches (TAC), and hence quotas, will track the overall productivity of stocks in management systems with regular stock assessments and associated harvest control rules (McIlgorm *et al.,* 2010; Melnychuk, Banobi and Hilborn, 2014; Haynie and Pfeiffer, 2012). Projected abundance decreases would likely be linked to requirements to reduce fishing mortality rate (*F*) (and consequently, in most cases, effort) to meet lower reference points for spawning stock biomass (Brander, 2007). If abundances increased, the converse would occur. Increases in stock distribution owing to distribution–abundance relationships (Fisher and Frank, 2004) may also lead to fishing opportunities in new areas and effort spreading more widely, depending on management restrictions. A next step to build upon the projections generated here would be to explore how different distributions of fishing activity and mortality for particular vessels and gears, resulting from prescribed or climate responsive management regimes, may affect the distribution, volume and value of catches and the implications for the fishing industry and markets. Several studies have started to address general aspects of these questions by linking projected ecological responses to fishing revenues (Lam *et al.,* 2016), profitability scenarios (Jones *et al.,* 2015), management scenarios (Thøgersen, Hoff and Frost, 2015) and societal fisheries dependency (Barange et al., 2014).

Although the GAM models indicated an influence of fishing effort and salinity on abundance, iterative removal of individual parameters suggested that these variables were less important than the mean effects of temperature followed by depth. The role of temperature and depth in influencing species responses has been documented previously with increasing depths often providing thermal relief for species unable to tolerate significant warming (Perry *et al.,*2005; Dulvy *et al.,*2008; Pörtner and Peck, 2010; Poloczanska *et al.,*2016). Within the region, a strong summer thermocline is present in deeper waters of the western approaches (Dauvin 2012; Glegg, Jefferson and Fletcher 2015), resulting in less extreme seasonal bottom temperatures compared to the eastern Channel. Future climate projections suggest that rates of warming on the seabed (NBT) in the west of the region, particularly in summer and autumn, will be slower than surface (SST) warming (Tinker *et al.,* 2016).

Our projections suggest that many species, including anglerfish, megrim and lemon sole, will move westerly. This indicates species moving away from the mixed and unstratified waters associated with the Channel into waters with cooler seasonal summer and autumn temperatures, thus allowing species to experience greater seasonal temperature differences into the future and avoid temperatures that may exceed their maxima. Westerly movements within this region could therefore be somewhat analogous to poleward responses for species within the Northeast Atlantic and the mid-latitudes more widely (Perry *et al.,* 2005; Poloczanska *et al.,* 2016). If fisheries pursue these species further to the west this may result in increased fishing effort in deeper waters with increased distances travelled to meet market and consumer demands.

Habitat type was not a significant driver of species responses within this study. Although associations between demersal fish species and seabed habitats are well recognised at small scales, typically less than 10s of km (e.g. Persohn *et al.,* 2009; Johnson *et al.,* 2013; de Castro *et al.,* 2015), habitats are heterogenous within the large grid cells that we considered and it was unsurprising that habitat, as opposed to depth, was not a predictor of responses at this scale. Further research projecting future responses at smaller scales, for example on specific inshore fishing grounds, may find that highly resolved habitat maps identify stronger links between species abundance and local habitats, with a greater influence of habitat on potential for response.

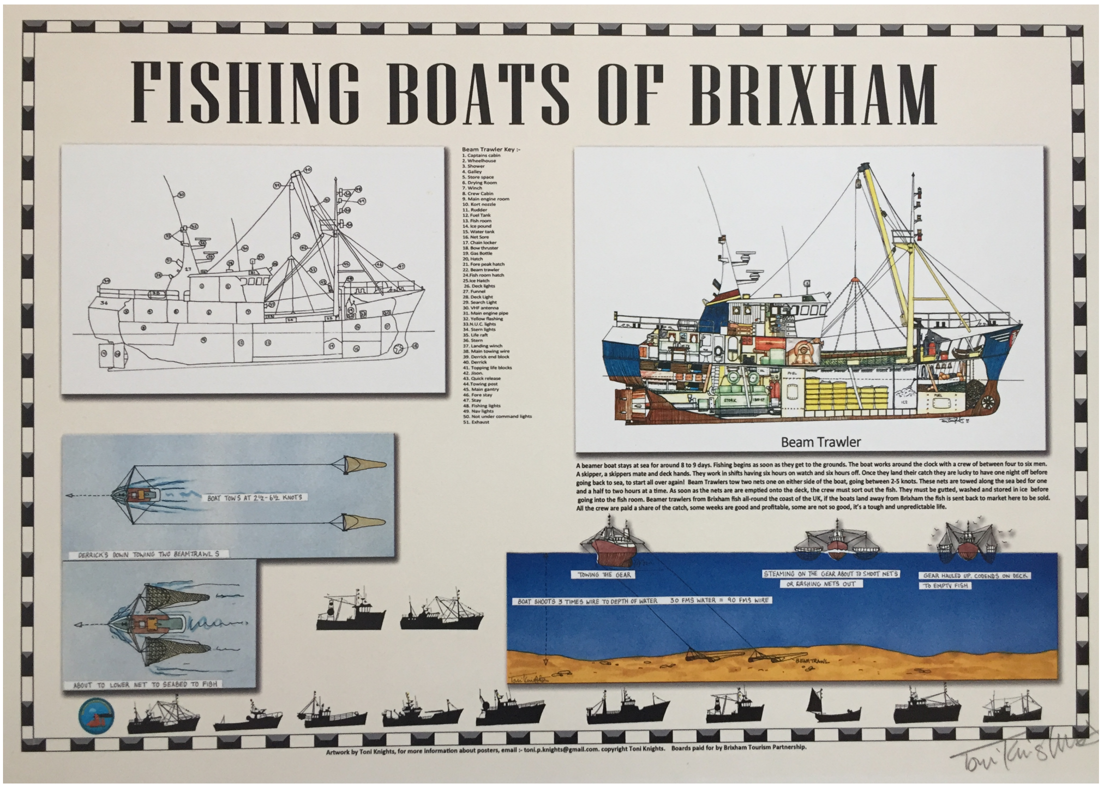
Assessing the performance of modelling approaches and understanding the uncertainty in associated projections is becoming increasingly important from both scientific and management contexts (Punt *et al.,* 2014; Cheung *et al.,* 2016a; Planque *et al.,* 2016). Here, using GAMs provided a data driven and statistical approach, but changes and differences in the design, coverage and duration of fisheries surveys in the study region limited the duration of training data and precluded testing of GAMs using iteratively partitioned time-series. However, we have relatively high confidence in the adequacy of our approach for making projections through to 2040, and potentially beyond, as model statistics and comparisons for the tested time period indicated suitable predictive power. Additionally, the performance of the approach has been systematically tested in the North Sea where annual surveys have been conducted in a relatively standardised way since the early 1980s (Rutterford *et al*., 2015). This study showed that projections using GAMs trained on data from the early part of the time-series provided relatively reliable predictions of distribution and abundance for eight of 10 bottom-dwelling species over a period of 30 years.

There are recognised uncertainties in temperature projections upon which our models were based (Tinker *et al.,* 2015, 2016), and several studies have highlighted the need to quantify the effect of this on species projections (Brander *et al.,* 2013; Cheung *et al.,* 2016a, Freer *et al.,* 2018). Using an ensemble approach, we examined the consequences of an important aspect of climate projection uncertainty (atmosphere physics uncertainty) within a single climate scenario on species abundances and distributions. The resulting uncertainties, captured by the spread of projections within the ensemble, implied that we should have high confidence in the direction of changes for the majority of species but the magnitude of change was more uncertain. Agreement among projections was especially strong for cold adapted species with narrow thermal ranges, such as anglerfish and megrim, indicating high confidence that the fishing industry will have to adapt to declining opportunities to catch these species. For other species there was greater variability among projections that also increased towards 2090, which may have arisen because these species have wider thermal ranges or tolerances. Additional uncertainty about mid- to long-term projections and their consequences will also result from factors we do not address directly such as changes in interspecific interactions (e.g predator-prey dynamics, competition) or fishing activity. This could be addressed in the future using multispecies and size-structured models.

In summary, our analyses suggest that climate change will continue to modify the abundance and distribution of commercially important fishes in the Celtic Sea, English Channel and southern North Sea. For species likely constrained by the coolest and warmest conditions, the projected directions of change in abundance are consistent among ensemble-members and imply that the fishing industry, management systems and markets will likely have to adjust their operations to address the changes in catch composition that result. Industry practices and management systems that support flexible responses to changes in species’ relative abundance and distribution will support and facilitate adaptation.

Chapter 4

Fishers’ risk perceptions of climate change: does climate change really matter?



FISHING BOATS OF BRIXHAM

Beam Trawler Key :-
1. Captains cabin
2. Wheelhouse
3. Shower
4. Galley
5. Store space
6. Drying Room
7. Winch
8. Crew Cabin
9. Main engine room
10. Kort nozzle
11. Rudder
12. Fuel Tank
13. Fish room
14. Ice pound
15. Water tank
16. Net Sore
17. Chain locker
18. Bow thruster
19. Gas Bottle
20, Hatch
21. Fore peak hatch
22. Beam trawler
24.Fish room hatch
25.Ice Hatch
26. Deck lights
27. Funnel
28. Deck Light
29. Search Light
30. VHF antenna
31. Main engine pipe
32. Yellow flashing
33.N.U.C. lights
34. Stern lights
35. Life raft
36. Stern
37. Landing winch
38. Main towing wire
39. Derrick end block
40. Derrick
41. Topping life blocks
42. Jison.
43. Quick release
44.Towing post
45. Main gantry
46. Fore stay
47. Stay
48. Fishing lights
49. Nav lights
50. Not under command lights
51. Exhaust

Beam Trawler

A beamer boat stays at sea for around 8 to 9 days. Fishing begins as soon as they get to the grounds. The boat works around the clock with a crew of between four to six men. A skipper, a skippers mate and deck hands. They work in shifts having six hours on watch and six hours off. Once they land their catch they are lucky to have one night off before going back to sea, to start all over again! Beam Trawlers tow two nets one on either side of the boat, going between 2-5 knots. These nets are towed along the sea bed for one and a half to two hours at a time. As soon as the nets are are emptied onto the deck, the crew must sort out the fish. They must be gutted, washed and stored in ice before going into the fish room. Beamer trawlers from Brixham fish all-round the coast of the UK, if the boats land away from Brixham the fish is sent back to market here to be sold. All the crew are paid a share of the catch, some weeks are good and profitable, some are not so good, it’s a tough and unpredictable life.

Artwork by Toni Knights, for more information about posters, email :- toni.p.knights@gmail.com. copyright Toni Knights. Boards paid for by Brixham Tourism Partnership.

Drawing by Toni Knights

Abstract

Climate change is increasingly impacting fisheries globally, posing both risks and opportunities to those dependent on these marine resources. How fishers perceive climate change and what factors contribute to these perceptions can provide insights into behavioural intentions and support for climate change focused strategies and management. This study interviewed demersal fishers from a south-west UK fishing port to explore three main aspects: 1) the risks fishers identified that may affect their business and the industry in the future; 2) fishers' beliefs and risk perceptions of climate change and 3) the factors influencing these perceptions. Fishers identified a number of risks including those centering on environmental, socio-economic and fisheries governance themes. However, climate change was rarely mentioned. While overall fishers generally had low risk perceptions of climate change, further exploration of their risk perceptions revealed three main groups of fishers who differed in the extent to which they perceived climate change as a risk. Climate change scepticism and high perceived ability to adapt to climate change were particularly associated with lower risk perceptions. Other factors such as personal observations and experiences and informedness about climate change appeared less influential. These findings provide new insights into how fishers perceive climate change and, importantly, greater focus on the possible drivers of such perceptions. This information has important implications for understanding how fishers may respond to future impacts, perceive future management that seeks to address climate change impacts, as well as how climate change impacts may need to be communicated among fishing groups.

Introduction

Coastal communities globally are increasingly affected by climate change (Hanson *et al.*, 2011; Zsamboky *et al.*, 2011; Wong *et al.*, 2014). Both direct impacts such as rising sea levels and increasing storm events, and indirect effects through alterations in marine resources can lead to substantial impacts upon people who rely on the marine environment for their livelihoods (Badjeck *et al.*, 2010; Marshall *et al.*, 2013a; Barange *et al.*, 2014; Wong *et al.*, 2014). Fishers are particularly exposed to potential climate change impacts given their close and daily interactions with the sea and its resources (Daw, Adger and Brown, 2009; Savo, Morton and Lepofsky, 2017). Warming seas can affect the productivity, catchability and availability of stocks, potentially requiring fishers to alter fishing practices including species targeted or areas fished (Daw, Adger and Brown, 2009; Cheung *et al.,* 2012). Storm events can lead to damage of fishing gears and port/harbour infrastructure and can also affect trip length and access to fishing grounds (Sainsbury *et al.,* 2018).

Understanding fishers' future responses to climate change impacts requires information on how they perceive and understand climate change in the first place (Gifford, 2011). Knowledge levels, attitudes towards and beliefs about climate change and its impacts, as well as associated risk perceptions, have important consequences on behavioural intentions, willingness to support initiatives or policies aimed at addressing climate change, and preparedness to act and respond to climate impacts (Leiserowitz, 2006; Zahran *et al.,* 2006; Adger *et al.,* 2009; Gifford, Kormos and McIntyre, 2011; Bichard and Kazmierczak, 2012; Tam and McDaniels, 2014; Máñez-Costa, Shreve and Carmona, 2017). As such, climate change perceptions are of increasing interest from management and policy perspectives, providing useful insights which can help to inform decision making processes regarding, for example, adaptation (Allison and Basset, 2015; Máñez-Costa, Shreve and Carmona, 2017). In the context of fisheries, fishers' climate change perceptions can indicate whether they regard themselves as vulnerable to climate change, how, or if, they may change their fishing practices in the future, and whether they would support fisheries management strategies addressing climate change impacts (Nursey-

Bray *et al.,* 2012; Allison and Bassett, 2015; Martins and Gasalla, 2018). Climate change beliefs, levels of awareness and perceived risk can vary among individuals, groups and countries (Leviston, Walker and Morwinski, 2013; Lee *et al.*, 2015; van der Linden, 2017). For instance, awareness of climate change is generally highest among developed countries, but concern is higher among those in developing countries with high awareness (Lee *et al.,* 2015). Some studies suggest UK citizens see climate change as a more serious problem compared to those within other countries such as the USA (Lee *et al.*, 2015; van der Linden, 2017), while others have shown UK citizens to be less worried about climate change than citizens in other European countries (Steentjes *et al.,* 2017). Differences reflect the complexity of exploring perceptions and attitudes and/or may reflect different methodologies or comparisons (van der Linden, 2017). This highlights the need to determine how and why perceptions vary among groups of individuals.

Although risks and associated uncertainty linked to climate change impacts can be technically assessed, lay-peoples' responses under risk are more likely to be informed or guided by their intuitive, subjective judgments (Sundblad, Biel and Gärling, 2007; van der Linden, 2015). Compared to other environmental hazards or risks, climate change presents unique dimensions and qualities that can make it difficult for people to interpret (Gifford, 2011; van der Linden, 2015). Climate change occurs over long time periods, is cumulative in its impacts and many impacts are more indirect in their effect (Weber, 2010; van der Linden, 2014). Climate change is also psychologically distant, with people often thinking it will happen to other people in other places sometime in the future (Spence *et al.* 2011; Pahl *et al.,* 2014). People can also be sceptical about climate change, and in different ways. Evidence scepticism centres upon beliefs in the trend of climate change (i.e. warming), attribution of climate change to humans and its impacts (Rahmstorf, 2004; Capstick and Pidgeon, 2014). Process scepticism focuses on, for example, how science may be biased through funding by lucrative climate industries, exaggeration of the issue by the media, and that environmental or political groups push an agenda (van Rensburg, 2015). Scepticism can also focus upon doubts over individual, political and societal willingness, capacity or effectiveness of responding to climate change (Capstick and Pidgeon, 2014; van Rensburg, 2015).

Climate change risk perceptions and the factors influencing them has been researched from many disciplines including psychology, sociology, anthropology and behavioural decision research (Weber, 2010; Hornsey *et al.,* 2016; van der Linden, 2017). Influential factors can include psychological determinants such as knowledge levels, heuristics and cognitive judgements (Whitmarsh, 2011; Shi *et al.,* 2016); experiential processing including emotions, affect and personal experiences (Leiserowitz, 2006; Weber, 2006; Akerlof *et al.,* 2013; Reser, Bradley and Ellul, 2014; van der Linden, 2014); socio-cultural influences including peoples' values, worldviews, cultures as well as wider social factors such as social networks and norms (Brody *et al.,* 2008; Kellstedt, Zahran and Vedlitz, 2008; Renn, 2011; Kahan *et al.,* 2012; Leviston *et al.,* 2013); and socio-demographics such as age, gender, political beliefs and education (Leiserowitz, 2006; Lee *et al.,* 2015; Hornsey *et al.,* 2016; van der Linden, 2017). Determining which factors influence risk perceptions can be complex given the interconnected nature of many factors, the sometimes-conflicting evidence over the directionality of influence or the extent to which some factors are influential, and differences in how these factors are measured within studies (Hornsey *et al.,* 2016, van der Linden, 2017).

Climate change risk perceptions have been studied amongst resource dependent sectors such as agriculture (e.g. Mase, Gramig and Prokopy, 2017) but to a lesser extent within a fisheries context, despite the wide-ranging impacts climate change may have on these systems (Savo, Morton and Lepofsky, 2017). Fishers are able to detect change within the physical ocean environment and observe extreme weather events that are linked to climate variability and change (Geetha *et al.*, 2015; Martins and Gasalla, 2018). Yet, beliefs in climate change vary among fishers, with many having sceptical views regarding trends of warming and whether it can be attributed to humans (Nursey-Bray *et al.*, 2012; Zhang, Fleming and Goericke, 2012). In the few existing studies exploring risk perceptions of fishers, climate change is often regarded as a relatively low risk compared to other threats perceived within fisheries (West and Hovelsrud, 2010; Nursey-Bray *et al.*, 2012; Garrett *et al.*, 2015), although there are some exceptions (Tingley *et al.,* 2010).

Greater insight into fishers' climate change risk perceptions, particularly from an individual level perspective, is necessary to help understand their future responses to climate change. These perceptions may link to fishers' support for or responses to fisheries management measures developed to tackle climate change effects on fishery resources. As one of the first of its kind in a UK context, this study sought to elicit climate change risk perceptions and beliefs amongst fishers operating from Brixham, Devon. Through interviews with fishers, the aims of the study were to: 1) understand the risks that fishers identified to the future of fish stocks and fisheries more widely in the south-west of the UK; 2) examine fishers' beliefs surrounding climate change and their climate change risk perceptions; and 3) explore which factors may be important in influencing these risk perceptions.

Methods

Case study site: Brixham

The port of Brixham is situated in Devon in the south-west of the UK (Fig. 4.1). In 2016 it was the largest port in England in terms of landings value (£31 million), and second to Newlyn in terms of landings weight (13,000 tonnes of fish and shellfish; MMO, 2017a). Fishing forms a substantial industry for Brixham town and the Torbay and south-west region more widely (ESR, 2016). The port is also home to the Brixham Fish Market, which holds a daily auction and vessels from the UK and abroad land and sell their fish through the market (BTA, 2018). Landings into the port are predominantly shellfish and demersal species, with the top five species by value being cuttlefish, scallops, Dover sole, anglerfish and lemon sole (MMO, 2017a,b). The top five species by weight are cuttlefish, scallops, sprat, plaice and anglerfish (MMO, 2017a,b). Many of the fisheries in the south-western waters are mixed demersal fisheries, with fishers from Brixham catching up to 40 different fish and shellfish species within a single tow (pers. comm). In 2016, a total of 475 fishers were registered at Brixham (administration port; explained below), of which 356 were 'regular' fishers and 119 were part time (MMO, 2017a). A total of 248 vessels (185 of 10 m and under, 63 over 10 m) were registered at Brixham (administration port) in 2016 (MMO, 2017a).

Figure 4.1. Locality of Brixham port in south-west UK (50.39°N, 3.51°W; black dot). Inset: Brixham is located in a sheltered harbour to the south of Tor Bay, which is defined by the outcrops of Hope’s Nose to the north and Berry Head to the south (source of inset: Google images).

Interviewing

Fishers operating from Brixham were interviewed to collect information on their climate change beliefs and risk perceptions alongside other socio-demographic data. Skippers were targeted as they are typically the main decision makers aboard vessels, planning their future activities and fishing trips. Determining the exact number of active vessels based at, and consistently operating from, Brixham required several steps in order to generate confidence in the ‘true’ number. The MMO listed 248 vessels as having their administrative port as Brixham, but administration port for a vessel can differ from the home port. Fishers and vessels register with an administration port for licensing reasons, and the administrative ports’ responsibilities also extend to ensuring compliance of vessels to safety regulations as well as collating catch information (Devon Fisheries Factsheet, 2015). Home ports are where vessels and fishers operate from. These differences can result in different estimates of the number of fishers and vessels physically operating from the port.

The initial list was therefore reduced to include vessels only registered at Brixham for both their administrative and home ports. This increased the likelihood that the remaining vessels were consistently operating from Brixham and resulted in a list of 114 vessels (70 10 m and under vessels and 44 over 10 m vessels). However, official vessel lists for the port were not necessarily fully accurate or up to date. Further investigation showed that some vessels were now operating from another south-west or UK port while other vessels were registered but were no longer active, active for an only one or two months in the summer or used for angling purposes. Therefore, to ensure the fishers who may be interviewed were those that routinely worked and operated from Brixham, several methods were used: 1) asking each interviewed fisher to suggest who routinely fished from Brixham based upon the vessel list; 2) personal observations each day at the quayside and market to determine which boats were frequently based and landing there; and 3) asking key informants and BTA— Brixham Trawler Agents (the authority running the Brixham market)—to list who they considered to be full time fishers based at Brixham. The final number of vessels deemed to be routinely operating from Brixham was therefore ~65 vessels, comprising 30 vessels of 10 m and under and 35 vessels over 10 m.

This vessel list helped to identify fishers to interview and contact details were obtained either from key informants, other fishers or through directly approaching individuals. A total of 31 fishers were interviewed, representing approximately 47% of the total fleet; 46% of the 10 m and under sector and 46% of over 10 m sector (Table 4.1). A further four declined to take part, and three were contacted and agreed to take part but were not interviewed because it was not possible to arrange a suitable time. Interviewing took place with full ethical approval from the University of Exeter from January–April 2017. They were held face-to-face at convenient locations and times for fishers and lasted between 30 minutes to 2 hours. Written consent was obtained prior to questioning.

Table 4.1. Key characteristics and demographics of fishers

Characteristic	Description	Number of fishers
Gender	Male	31
Age	25–34 years	2
	35–44 years	3
	45–54 years	15
	55–64 years	9
	65–74 years	2
Sector and boat owners	Under 10 m sector	14
	Owner in under 10 m sector	12
	Non-owner in under 10 m sector	2
	Over 10 m sector	17
	Owner in over 10 m sector	6
	Part owner in over 10 m sector	1
	Non owner in over 10 m sector	10
Education and qualifications*	Left school at 16 with no qualifications	24
	School qualifications e.g. GCSEs, O levels	6
	Obtained relevant seafaring certificates (e.g. skippers' ticket, Seafish certificates)	31
Number of years spent fishing	Mean	34
	Range	17–56
Gear types *	Beam trawl	13
	Scallop dredge	14
	Bottom trawl	12
	Static nets	5
	Pots and traps	5
	Rod and line	5
	Longlining	1
	Mid water net	1

* NB. Number doesn't total 31 fishers due to multiple responses being feasible

Pilot interviews were undertaken with three active fishermen from another south-west port to test the interview for wording and structure. In addition, 10 key informants were interviewed using open questions to help provide background information on the industry and fisheries within Brixham and the surrounding region. These included a fisheries manager, a staff member of a shellfish association, a staff member of Brixham Trawler Agents, a staff member of South Western Fish Producer Organisation, a charity worker and four vessel owners. Results reported here are from interviews with fishers unless otherwise stated.

Interviews were semi-structured and split into sections using open, closed and statement-based questions (see Appendix B for interview questions and statements). When explaining the research to fishers, and in introductory questions, climate change was not mentioned to avoid influencing initial responses to open-ended questions regarding target species, observed changes over time and risks envisaged for the future to fish stocks, their business and the wider industry (Appendix B interview sections A–C).

The latter part of the interview used open-ended and statement-based questions to understand people's beliefs regarding climate change, perceived risks and impacts of climate change on fisheries, and some of the factors influencing these perceptions (Appendix B interview sections A–L). Socio-demographic information was collected at the end of the interview (Table 4.1). Interviews were recorded through written notes and audio recording (with permission) and later transcribed. Qualitative explanations of responses to statement-based questions was also transcribed. Responses were stored in separate word document files in addition to a Microsoft Excel spreadsheet. Fisher identities were kept anonymous and confidential.

Analysis

Given the small sample size and the contextual nature of the study, a mixed methods approach was used. Qualitative analysis was undertaken using NVivo 11.0 to code responses and quantitative analysis was undertaken using R software (R Core Team, 2018).

- Future risk landscape

Types of risks identified by fishers were coded and then subsequently grouped into higher classifications. Due to the exploratory nature of this aspect of the study initial coding was done inductively. Wider literature was consulted after initial coding to help inform the grouping of risks into a higher-level classification (drawing on examples in Tingley *et al.,* 2010; Booth and Nelson, 2014).

- *Climate change risk perceptions*

Climate change risk perceptions were explored through descriptive statistics of the main statements and questions alongside qualitative analysis of the overall interview to qualify and contextualise fishers' responses and provide further insight. Risk perceptions can be measured in a variety of ways with limited overall consensus in the literature regarding exactly which statements to use, although studies commonly use statements regarding concern, worry, seriousness of the issue or its negative impacts (van der Linden, 2017). In this study five statements were used to increase robustness of understanding perceptions as well as capture how or if these statements may differ among each other (Table 4.2). These statements were obtained from review of the literature and adapted into a fisheries context; concern (Leiserowitz, 2006); worry (Capstick *et al.,* 2015); negative impact (Brody *et al.,* 2008), and 'other fishermen will be more affected than me' (developed from Spence, Poortinga and Pidgeon, 2012). The statement regarding uncertainty about climate change when planning for the future was a novel item. Statements had five possible answers, ranging from strongly disagree (1) to neither agree nor disagree (3) to strongly agree (5).

A Cronbach alpha score of 0.69 indicated reliability of the five core statements used to measure risk perceptions. (Cronbach, 1951). A Principal Component Analysis (PCA) was performed on the five risk perception statements using the R packages *FactoMineR* and *factoextra* to identify patterns across fishers regarding their risk perceptions and how these statements may differ (Lê, Josse and Husson, 2008; Kassambara and Mundt, 2017). The statement '*Climate change will affect other fishermen more than it will affect me*' was reversed before inclusion within the analysis to ensure directionality of responses. Using the axes generated within the PCA, a Hierarchical Agglomerative Cluster analysis (HAC) using Euclidian distances and Ward's algorithm was used to determine whether individuals could be grouped according to their risk perceptions (Ward, 1963; Husson, Lê and Pagès, 2017).

Table 4.2. Mean scores with standard deviation (SD) and median for each statement asked regarding risk perceptions and the main factors influencing perceptions. Percentage of fishers agreeing (likert items 4 & 5) with each statement asked and overall scale is also shown.

Statements (and where obtained)	Mean (SD)	Median	% fishers agreeing to statement
Risk perception statements[a]			
I am concerned about the impact of climate change on my fishing business	2.3 (0.95)	2	15.3
Climate change makes me feel uncertain when I try to plan for the future	2.0 (070)	2	6.4
I am worried about the impacts climate change could have upon fisheries in the south-west	2.3 (0.95)	2	19.3
Climate change will have a negative impact on the future sustainability of fish stocks	2.5 (0.84)	2	16
Climate change will affect other fishermen more than it will affect me	2.7 (0.96)	2	32
Scepticism statements[a]			
Recent climate change is mostly caused by human activities*,†	3.4 (0.97)	4	60
Increased greenhouse gas concentrations have contributed to recent climate change*,†	3.6 (0.77)	4	63.3
I am uncertain that climate change is really happening	2.6 (0.95)	2	19.3
The seriousness of climate change is exaggerated	3.3 (1.08)	3	46.6
Climate change is too complex and uncertain for scientists to make useful forecasts**	3.3 (0.88)	4	62.9
The effects of climate change are uncertain	3.8 (0.79)	4	77.4
Self-efficacy – environment and addressing climate change[a]			
There are simple things I can do that would have a meaningful effect to alleviate the negative impacts of climate change	3.3 (0.94)	4	61.2
Self-efficacy – ability to cope/adapt	3.6 (0.69	4	75.7
I have the ability to adapt to any potential impacts of climate change on my fishing business	3.5 (0.88)	4	70.9
I have the necessary skills to adapt to any potential impacts of climate change on my fishing business	3.7 (0.73)	4	80.6
Informedness statements[b]			
How informed do you feel about climate change… in general	3.2 (0.81)	3	48.3
… in terms of its potential impact on fisheries	2.5 (0.85)	2	19.3
… in terms of its potential impact on your fishing business	2.6 (0.85)	2	20
Impacts informedness scale mean	2.5 (0.75)	2.5	19.65
Personal experience (Number of fishers answering yes, no, don't know)	Yes	No	Don't know
Would you say that you and your fishing business have personally been affected by climate change?	3	27	1

* reported statistics for individual statements here **are not reversed**

†: 1 missing value (mean calculated with N=30)

**: 4 missing values (mean calculated with N=27)

a: likert scale – 1: Strongly disagree, 5: Strongly Agree

b: likert scale – 1: Very uninformed, 5: Very informed

- *Factors influencing perceptions*

This study explored how six main factors influenced risk perceptions and how they varied according to groups identified through clustering. Many factors can influence risk perceptions, but it is thought that the natural variability within fishery resources and perceived high resilience of fishers to cope with change, in addition to scepticism regarding climate change itself, are particularly influential (West and Hovelsrud, 2010; Nursey-Bray *et al.*, 2012). Within this study the factors explored were: scepticism, informedness, personal experience, self-efficacy in addressing climate change; self-efficacy in adapting to climate change and socio-demographics.

Scepticism among fishers was examined as other studies have highlighted that fishers hold sceptical climate change views (Nursey-Bray et al., 2012; Zhang, Fleming and Goericke, 2012), which may lead to lower risk perceptions (Brügger, Morton and Dessai, 2016). Informedness and knowledge of climate change and its related impacts, alongside fishers' personal observations and experiences of climate change, were explored to see if these increased climate change risk perceptions. Positive associations between these factors and heightened climate change risk perceptions have been shown in other non-fisheries contexts (Ranney and Clark, 2016; Shi *et al.,* 2016). Some studies have shown that fishers have high perceived ability to cope and adapt to change, 'self-efficacy', which is thought to lower their risk perceptions (West and Hovelsrud, 2010; Nursey-Bray *et al.,* 2012). This relationship was explored by examining fishers' personal self-efficacy to address climate change more widely as well as in the context of ability to cope and adapt to impacts. Socio-demographics in terms of age, education and fisheries sector and vessel ownership were also explored.

Six scepticism statements were derived from Whitmarsh (2011) and Poortinga *et al.* (2012) and capture the core evidence scepticism dimension (Rahmstorf, 2004; van Rensburg, 2015). Mean scores and percentage of fishers agreeing or strongly agreeing with the statements were calculated (Table 4.2 and Appendix B interview section D). To obtain a robust scepticism scale, a PCA was used to reduce dimensionality across the statements following Whitmarsh, 2011

(Appendix C: Fig. A4.1). Statements regarding human cause and greenhouse gases were reversed. Missing answers to particular statements were imputed using a mean score (N=7 across the six statements). Statements that loaded onto the first Principal Component (PC1) were used, representing 0.46 of variance (Appendix C: Table A4.1). A higher score on this evidence scepticism scale indicated a higher degree of climate change scepticism.

Climate scepticism views throughout the entire interview and surrounding the six scepticism statements were further analysed through thematic analysis using a scepticism framework developed by van Rensburg (2015). This helped to capture other forms of climate scepticism (process and response scepticism) that were not explicitly asked within the interview itself but emerged as key themes throughout discussion with fishers. This framework captures three main dimensions of climate change scepticism: evidence scepticism, process scepticism and response scepticism, thus allowing all climate scepticism aspects to be considered.

Knowledge was measured as self-reported informedness through level of agreement with three statements: one statement regarding climate change in general, and two regarding climate change impacts on fisheries and on individual fishing businesses (Table 4.2). The two statements regarding impacts were averaged to create an overall scale as similar distributions of response frequencies were obtained (Appendix C: Fig. A4.2). Sources of information and levels of trust people had overall in these sources were also captured and analysed. Personal experience of climate change was measured by asking fishers '*Would you say that you and your fishing business have personally been affected by climate change?*', with answers recorded as yes, no or don't know (Table 4.2).

Self-efficacy regarding ability to mitigate climate change impacts *in a general sense* was measured through a single statement '*There are simple things I can do that would have a meaningful effect to alleviate the negative impacts of climate change*'. The scale for self-efficacy in regard to ability to adapt to climate change was created through averaging scores for two statements centering on disagreement/agreement that fishers felt that they had the ability and the skills to adapt to any potential impacts of climate change on their fishing business.

Thematic analysis of the entire interview was undertaken to identify other factors that weren't necessarily captured in specific statements but may have influenced perceptions. Themes were derived semi-deductively using knowledge from findings presented within the thesis literature review (Table 1.1) but also allowing other themes that were more context specific to fisheries and fishers to emerge.

Results

Future risk landscape

Fishers identified a total of 19 different risks for the future of fisheries within Brixham, which were categorised into six main themes (Fig. 4.2. and Appendix C: Table A4.2). Environmental risks were the most frequently discussed risks (67% fishers), which were perceived to present problems for the future health and sustainability of fish stocks. Socio-economic and fisheries governance risks were also frequently discussed (58% fishers for both) in the context of stocks, fishing businesses and the industry more widely.

Overfishing was the predominant environmental risk that fishers identified, perceived to be leading to stock declines in their fishing grounds and subsequent reduced fishing opportunities. As one fisher stated:

> *"It's all getting too clever. I mean a lot of the beamers now work in places they never used to work cos they all got, it's all technology. They got their ground discriminators and really the fish have got no hiding places anymore. There used to be a lot of places that didn't get fished much but they do now… Modern technology hasn't helped fishing."*

A range of factors were provided regarding what was driving overfishing (Appendix C: Table A4.2).

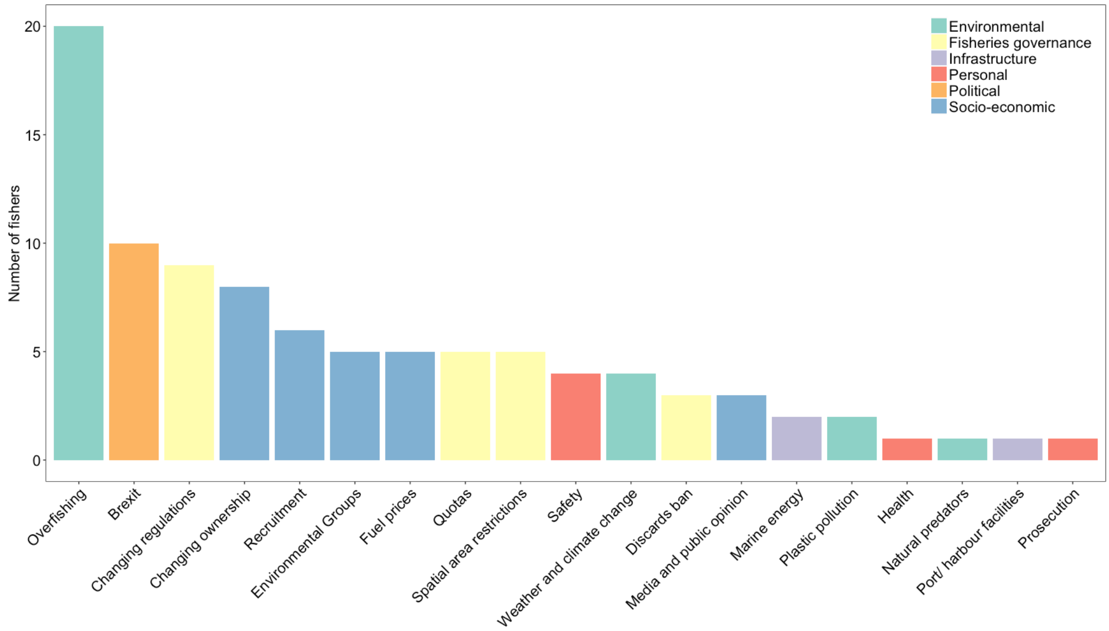


Figure 4.2. Risks identified by fishers. A total of 19 risks were identified.

Weather and climate change were discussed by four fishers, including warming waters and the effects this could have on fish stocks and how increasing storm events may affect shoals, or lead to greater risks for fishers by having to operate in more stormy weather conditions. For example:

> *"So long as water temperatures and things, which seems to be the main thing that affects fishing, water temperature and weather. So long as that stays similar I think there will always be a fishery."*

Other environmental risks discussed less frequently included plastic pollution and the effects on fish health, and an increasing number of seals and dolphins which were thought to affect fish or catches.

Socio-economic risks were frequently discussed (Appendix C: Table A4.2). Increasing fuel prices and the impact this would have on operating costs and profitability of the vessels was perceived as a risk by fishers within both under and over 10 m sectors:

> *"The only thing that could cripple the fishing industry is the fuel prices. That is one of the biggest things* [to worry about] *if fuel keeps going up."*

Others discussed the fact that many fishers were near retirement age and that the future of the industry may be affected due to a lack of new people entering the industry, making it harder for people to source crew and leading to uncertainty about how the industry may be sustained into the future:

> *“It's getting harder, there’s not enough youngsters coming into it. It's getting quite hard to get crew, and good crew as well. It's hard.”*

Environmental groups, the media and public opinion were seen as problematic for the industry, with fishers concerned about the negative images such groups had of the industry and the impacts this could have, alongside other concerns regarding their influence and involvement with management or policy decisions.

> *“Wildlife Trusts, you know they're far more of a problem than any global warming. They are killing the industry… especially the inshore. Polluting the general public’s opinions of what happens.”*

Many fishers described that within Brixham, as well as more widely within the south-west, larger vessels within the fleet and their associated quota were increasingly being bought by companies. Fishers saw this as a risk to the industry because of the increased uncertainty regarding future access to quota for those outside of the companies and the perceived instability resulting from consolidation of vessel ownership and quota, such as whether the companies would sell their assets to another company in the future. More widely the different mentality of companies compared to independent fishers, perceived as being driven by profit, was also seen as problem. As one fisher described:

> *“That's our biggest threat at the moment, these companies. They're owning all the quotas now and that is the biggest worry of the lot… Well, it's big, they're not fishermen. When they get bored of it, they'll just throw it all away and they'll just sell it on to the next big player.”*

Risks within the theme of fisheries governance were frequently described by fishers (Appendix C: Table A4.2). The most commonly described risk within this category centred on the changing rules and regulations of domestic fisheries management and wider policy, which made fishers feel uncertain and unprepared about what was coming next and whether their practices were in line with the rules. As one fisher explained:

> *"You know they can't keep moving the goalposts the whole time, they got to say this is happening and stick with it, instead of half way down the line of 'oh right we're going to change this now' cos then it's instant confusion… So we're out there thinking we're doing something legal and then actual fact it's illegal… Those at the bottom we think we're doing alright, we get pulled in an they say 'no you've done that wrong' and we get done."*

Some discussed the perceived problems with the new EU 'Landings Obligation' legislation which has been implemented to tackle discarding of fish. Others spoke about increasing restrictions to the areas they could fish as a result of closed areas being implemented through for example Marine Conservation Zones, which posed a risk to future access to fishing grounds and opportunities. Quota issues regarding future restrictions and access were discussed, alongside the risks the current quota system presents by allowing companies or countries to buy quota and thus restricting access or opportunities for individual fishers. Linked to fisheries governance risks but more political in nature was withdrawal from the EU (Brexit), perceived as a risk by ten fishers due to the uncertainty this created about the future of fisheries management and policy within the UK. Who and how fisheries would be managed, the implications negotiations could have for future trade and market access alongside uncertainty about the unknown outcomes and impacts from withdrawal were all seen as being a risk to businesses and the industry more widely. For example:

> *"It's all to do with Brexit. Are we going to get more fish, are we going to get less fish, who's going to govern, you know what I mean. There's a lot of questions to be asked and answered you know over what's going to happen to the fishing industry."*

Finally, other risk types less frequently identified by fishers included other marine developments threatening fishing opportunities and insufficient port facilities, or more personal risks, regarding safety, health and even an upcoming prosecution regarding fishing activities (Appendix C: Table A4.2).

Climate change risk perceptions

All fishers had heard about climate change and 31% of fishers said that they had thought about climate change in relation to their fishing business prior to the interview. Most fishers had low risk perceptions of climate change: when asked to self-assess how much of a risk climate change posed to the future of their fishing business, 67% fishers ranked it as no or a low risk (Fig. 4.3). For example, fishers commonly made statements such as:

> *"I just don't see it as a risk"* and
>
> *"I don't see it making any difference. Nothing, you know?"*

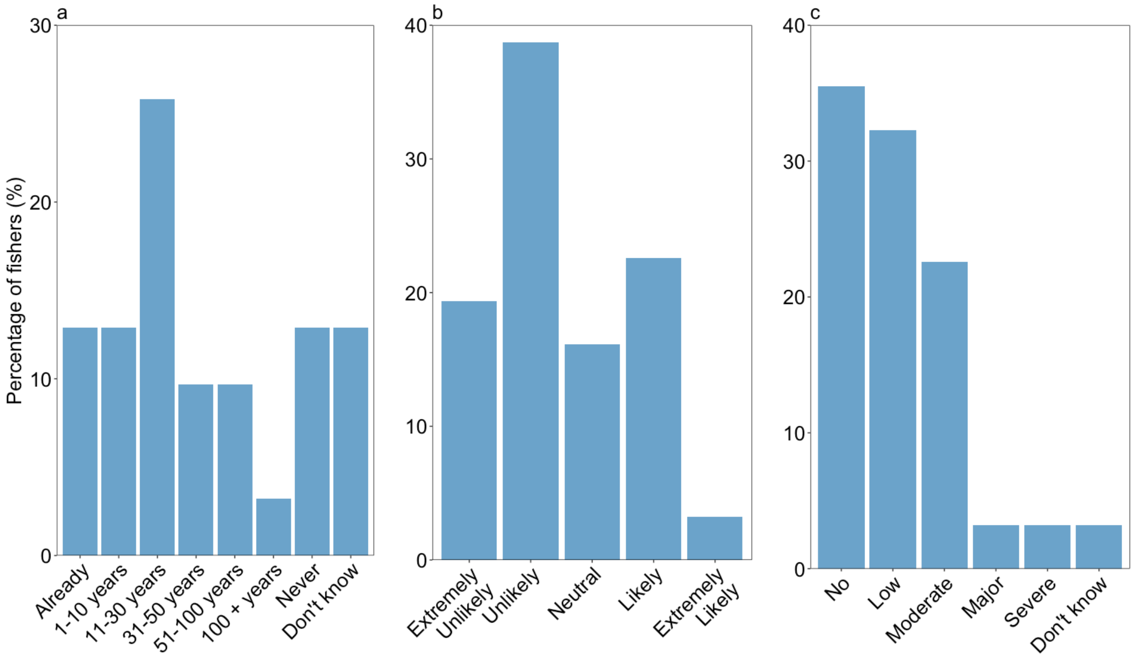


Figure 4.3. Percentage of fishers responding to questions and statements regarding a) how soon they think climate change will impact their fishing business; b) how likely they think it is that they will have to change their fishing practices as a result of climate change; c) how much of a risk climate change poses to the future of their fishing business.

Yet there were some fishers that felt climate change posed a moderate risk or even higher. As they explained:

> *"I think any fisherman should be worried, I think anyone that's not really isn't thinking properly. Why wouldn't you be worried, it's your business, it's your livelihood. I'd be worried."* and
>
> *"Things are happening and they're happening at an alarming rate."*

Regarding the five statements assessing different aspects of fishers' risk perceptions, most fishers tended to strongly disagree or disagree that they were concerned and worried about climate change, and that it made them feel uncertain when planning their future activities (Fig. 4.4). More fishers disagreed that '*climate change will affect other fishers more than me'* than agreed. Many fishers (51%) disagreed that climate change would have a negative impact on fish stocks.

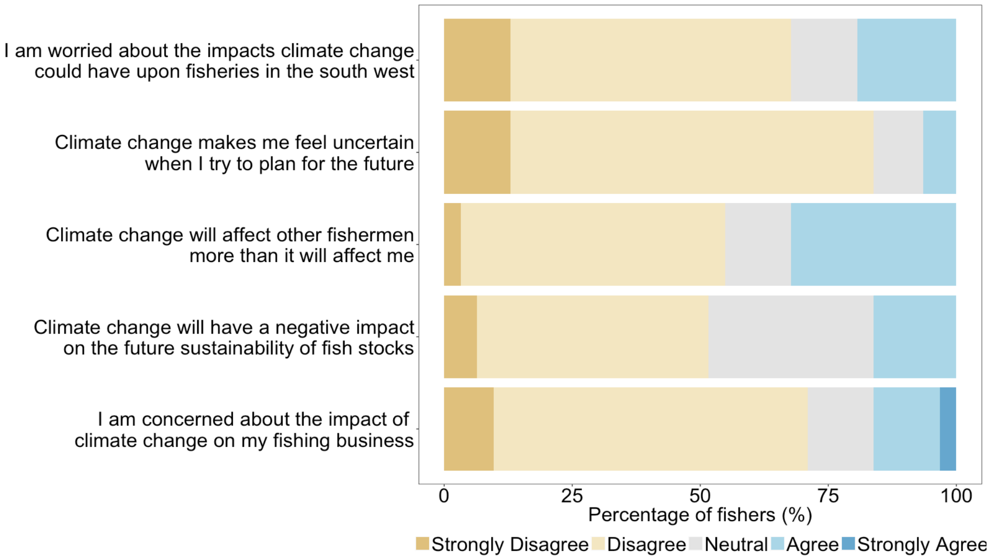


Figure 4.4. Fisher responses to likert scale statements of climate change risk perceptions.

This was explained by some due to the uncertainty they felt about the extent of impacts climate change may present, or that impacts may be in fact positive:

> *“The chances are if climate change does happen, will it make a difference? The whole thing we're talking about is hypothetical and we’re talking about a long-time frame.”* and
>
> *“But no one knows, will it change for the better, will we start seeing some of these tuna that start seeing off Spain coming down here. We'll all be going tuna fishing - that’d be really nice.”*

When asked how likely they felt that they would have to respond to climate change impacts, 58% of fishers answered very unlikely or unlikely (Fig. 4.3). There was a weak but significant positive correlation between fishers’ self risk assessment and how likely fishers felt it was that they would have to change their fishing practices, with increased risk perception linked to increased perceived likelihood of changing practices (Spearman’s rank *rho* = 0.43, S = 2815.4, *p* = 0.01). There was a range in how soon fishers felt they would feel the consequences of climate change—the most common answer was in 11–30 years—whilst similar amounts of fishers thought they would never feel the consequences or were already feeling the consequences (Fig. 4.3). There was a significant negative correlation between fishers’ self risk assessment and how soon they felt climate change would impact upon fishing businesses, with lower risk perceptions associated with impacts being perceived to occur further away in time (Spearman rank *rho* = -0.58, S = 5181.9, *p* <0.001).

PCA revealed patterns in the extent to which fishers perceived these climate risks. Two primary axes explained 60.3% (PC1) and 19.4% (PC2) of the variance amongst responses to the five risk perception statements (Fig. 4.5; Appendix C: Fig. A4.3). Four statements (worried, concerned, uncertain and negative) loaded strongly onto the first axis (Table 4.3), with a higher score on this axis representing a higher overall risk perception of climate change due to greater agreement with these statements. The statement ‘*climate change will affect other fishers more than me*’ strongly loaded onto the second axis (Table 4.3). This statement was reversed, so a higher score on this axis represented a higher individual risk perception.

Fishers were unevenly distributed along these axes, with cluster analysis identifying three main groups regarding how risks were perceived (Fig. 4.5). Group Three had the highest scores on PC1 reflecting higher risk perceptions, and Group One had the lowest, with significant differences found between all groups (Kruskal-Wallis test, $\chi^2 = 21.55$, df = 2, $p<0.0001$; Dunn multiple comparison test $p<0.01$ for all level comparisons).

Table 4.3. Loadings of five risk perception statements onto PCA axes

Risk statement	PC1 Axis	PC2 Axis
I am concerned about the impact of climate change on my fishing business	0.50	-0.04
Climate change makes me feel uncertain when I try to plan for the future	0.52	0.07
I am worried about the impacts climate change could have upon fisheries in the south-west	0.53	0.11
Climate change will have a negative impact on the future sustainability of fish stocks	0.40	0.07
Climate change will affect other fishermen more than it will affect me	-0.13	0.98

Groups one and three had similar PC2 scores, but Group Two had the lowest PC2 scores, reflecting lower individual risk perceptions compared to other fishers. There were significant differences between groups on PC2 except between groups one and three (Kruskal-Wallis test, $\chi^2=17.23$, df = 2, $p = 0.0001$; Dunn multiple comparison test $p<0.01$ for all level comparisons except 1 and 3*).*

Factors affecting risk perceptions

Six main factors were explored regarding their effects on risk perceptions (Table 4.1 and 4.2). Their relationship with PCA axes are visually shown in Appendix C: Fig. A4.4. Thematic analysis identified a further four themes influencing perceptions linked to the above factors: climate change being ‘out of mind’, adaptability of fishermen and the resource itself, extent of climate change as a driver; and age and stage of life.

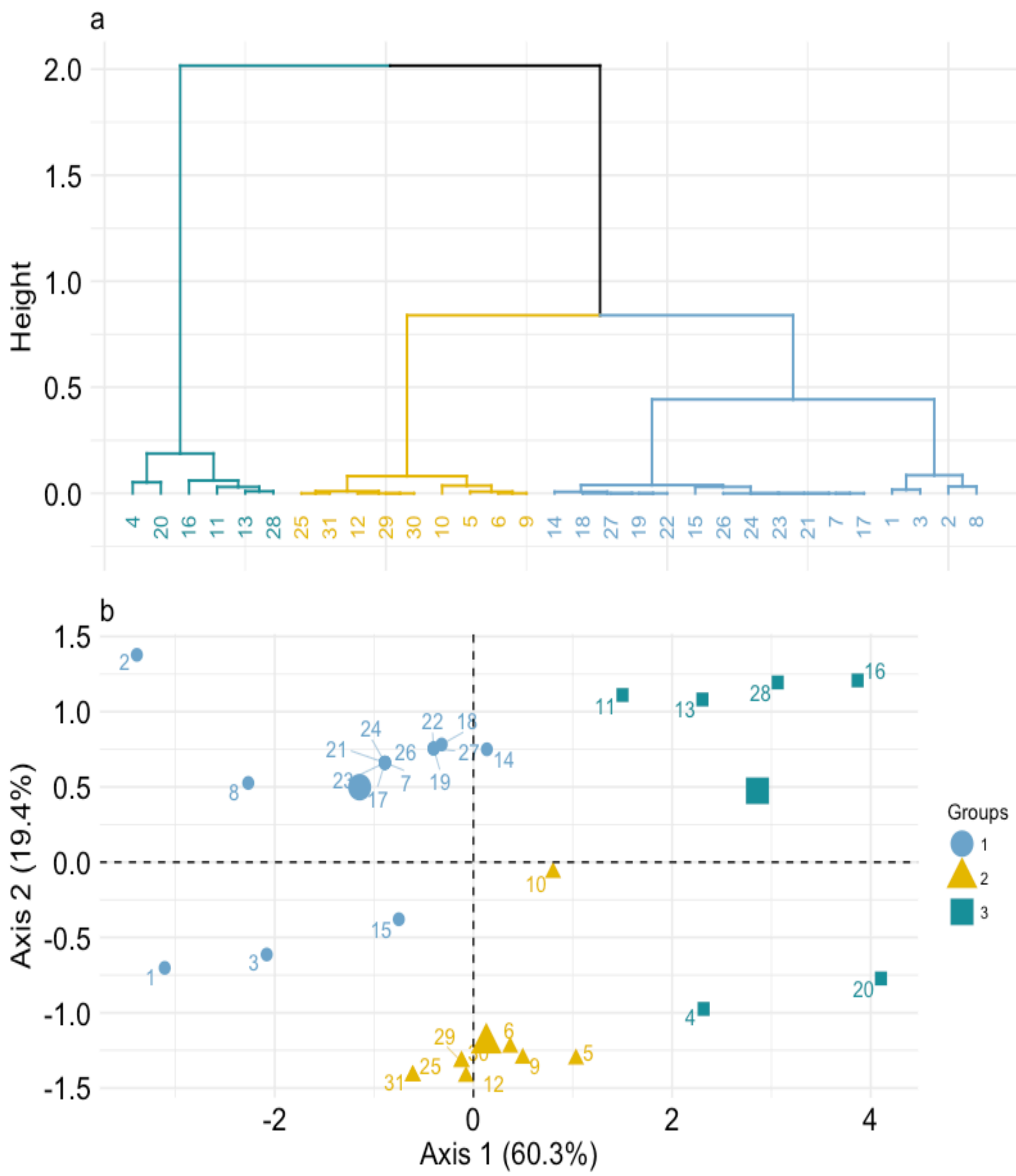


Figure 4.5. Results of PCA and HAC. a) Dendogram resulting from cluster analysis; b) individual fishers on the core PCA axes and coloured according to the groups from cluster analysis.

Scepticism

Fishers’ beliefs about climate change showed that many held sceptical views about it as a trend, its causes and its impacts (Table 4.4 and Fig. 4.6). Trend scepticism was apparent in a small number of fishers, mostly in Group One, some of whom also described themselves as sceptics and deniers.

Table 4.4. Factors influencing climate change risk perceptions identified through thematic analysis (number of fishers).

Factor	Description	Example
Scepticism (29)	Evidence scepticism – climate change as a trend. (5) Some fishers expressed scepticism regarding whether climate change was a trend leading to warming or saying that they simply didn't believe in it.	"I don't believe it." "I don't really believe in climate change." "I'm hanging in the wind as to whether it's real or. You know what I mean, I think we need more proof."
	Evidence scepticism – attribution of climate change. (13) While most fishers tended to agree that climate change was occurring there was scepticism over the extent to which humans were causing recent warming and whether instead it was just natural changes.	"I know ice caps and icebergs, I mean they break up all the time and they reform again but when you look at the overall cycle of planet earth, it does happen, all the time. It's like a big cycle, and it this part of that cycle? The earth warms up then it freezes over then it goes warm again. You know." "I'm just not seeing this climate change bit at the minute. I'm really not convinced that it's not just a natural cycle of the world." "Whether it's something to do with the planets and the rotation of the earth. But I would think that would have more effect on the climate than what human race is doing to it. You know how close the earth is to the sun over the centuries as we orbit the sun some centuries, some years might go a little bit closer and gets bit hotter and everyone goes oh isn't it lovely, isn't it barmy and then other centuries other years go a bit further off and everyone goes oh cold isn't it." "It's natural cycles and we have had these since time began. I mean we've had ice ages in this country, and that was before we were chucking stuff into the atmosphere and so you know do you say that that is a natural phenomenon?" "Well I think it will always happen I think it's going one way or another all the time, regardless of whether or not we're here."

	Evidence scepticism – impacts of climate change. (25) This was a common scepticism theme amongst fishers, expressing scepticism regarding the seriousness of impacts and whether it would have positive or negative effects. There was also discussion regarding wider uncertainty about what the impacts would be and how they would affect fisheries or themselves.	“I don't think we're gonna get any changes.” “I haven't seen any difference whatsoever in 30 year’s so I know everyone been going on about how much the ice caps are melting and so on and so forth, well it's made absolutely no difference as far as I can see.” “So far I don’t think it's a negative thing I think it's been a positive thing. I think the fish is better, the fishing is actually better now that what it was. Bring on climate change if that's the case!” “Something’s may improve and something’s may get worse. As I said squid and things like that. And some fish that don't like the warmer waters will move further north.” “I don’t think any of us really know what's going to happen. All a waiting game, we'll wait and see.” “Don't really worry about it. Good lord I've no idea. Such a big, how do you. Is it all just hypothetical, you don’t really know, you don’t really know exactly what's going to happen climate change wise.”
	Process scepticism – media exaggeration of climate change trends and impacts. (10) Many fishers felt that the media exaggerated and sensationalised climate change, making it into a bigger issue than it is or ‘scaremongering’ the public.	“It's just sensationalism by TV companies. Why do they need to stand somebody in the rain to tell someone what the weathers like. You know have a bad storm comes in so they send someone to the seafront with an umbrella. So everyone in London ‘Huh look at that’. 10 years ago they didn't send anyone down with an umbrella but we still had the same storms.” “They tend to lie I think, well maybe not lie, but blow things out of proportion. Blow things out of proportion I think, anything to make a story.” “There's just so much scaremongering with it all, you see it all before.”

	Process scepticism – how scientific research is generated. (8) For some fishers there was scepticism regarding the way research on climate change is conducted and how statistics are produced, the reliability of data and modelling methods generating information and the accuracy of this resulting information.	“I find climate change is just a bunch of smokey mirrors. They keep going on about it, but noone is coming out with anything in general. Sayin’ there's things that we're doing but how do they find out? Nobody tells us how they find out. Where the numbers are coming from. Are they just making them up?... I don't know, seems like conspiracy myself.” “How do you have one model that says this is this year and this is next or five years ago it was this and so this has changed.” “I know they have done tests but I don't think that the tests that they're doing or they've done go back far enough. They can't go back far enough. They couldn't measure it, everything right back to the old days to the minutest degree. And there's so many differences in the way they measure temperature and salinity and acidity and what not it fluctuates so much from one year to another I don't think it's been measured long enough or accurately enough to make big decisions on it, I really don't.”
	Process scepticism – lucrative industry and agenda pushing. (5) Fishers also discussed that there was a whole lucrative industry built upon climate change that therefore led to biased information. Others felt that environmental or political groups pushed the climate change agenda, pursuing their interests and not providing other sides of the argument (for why climate change may not be a human caused process).	“It’s a whole industry. Lets face it ok, however people are employed in the climate change industry, they're not going to turn around tomorrow and say that's just the way it is, cos they'd be all out of a job tomorrow. They have to, it's almost like a religion, they have to keep the faith, keep moving forward in the understanding that climate change is caused by humans. I mean it isn't.” “The information we get, who do you believe. You know, we're not educated enough to understand stuff that's often based on opinion most of the time. It's in most people's interests to say this, it's their job.” “I think there are too many people making a damn good living out of this climate change, so many people jumped on the band wagon, environmentalists so called, who have a vetted interest in pursuing it. And will ignore my side of the argument and the deniers and they will ignore the facts just to prove their argument.” “Anyone who stands up, not saying everyone, the spokespeople for climate change is normally the green party and they're delusional. I'd rather have someone who is impartial who hasn't got a political agenda on it to be more realistic than someone politically motivated…I find them delusional.”

		“They are all on this ego trip, it's a bit like my God's better than your God kinda thing. They're all trying to sort of ‘I'm right, you're not’ and I think that's wrong.’
	Response scepticism – individual level (5). There was some scepticism among fishers as to the extent to which their individual actions would help to address climate change.	‘Hard to see what unless you ditch the car, and get the paddles out on the boat what more, nothing else you can do.” “I can't change the environment no I can obviously whatever rubbish comes up in the trawl and put it in the bin or skip as it were but can’t change it in any major way no.”
	Response scepticism – social and political level (8). Some fishers expressed scepticism regarding the extent to which other countries or governments were acting to address climate change and whether such measures would have any effect on slowing climate change or mitigating its impacts.	“One country can do one thing and another country can do another thing. They all say oh we'll agree to do things for climate change but they don't. I think we're the only country that really sticks to its guns… They have all these meetings about climate change but they say one thing and don't do it.” “They have these summits, global summits where all countries get together and try sort out climate change, and Donald Trump has now come into power and said ‘F**k it, I'm going to start mining coal again and burning it.’ And he has, he's basically said ‘bugger this, climate change. We'll use coal.’ I disagree with that, the world's trying to go forward and he's come into power and don't care.” “I don’t believe that anything can be done about it. I think that the measures that have been taken about it are just p*****g in the ocean. I don’t think whatever this country does would make any difference, if climate change is mainly due to man I think it's the like of the Chinese and the Americans that need to change, the measures they've taken in this country have had no impact.”
‘Out of mind’ (8)	Climate change was an issue that many fishers described as being something that they simply didn’t tend to think about very much both generally and also in regards to its potential impacts on fishing.	“It's not something I've really thought about climate change impacts on the fishing, no.” “It's not something I look at, it's something we're all aware could be happening but it's not something I'm worried about.” “Don't pay attention to it.”

Extent of climate change as a driver of change (10)	For some fishers, climate change was seen as a key driver for affecting fish stocks. For others, it was not seen as an important factor in affecting fish stocks and instead other factors such as fishing effort or pollution were seen as a greater threat or having more impact on stocks.	“It's not the fishing fleet that's going to have any impact on it [fish stocks] cos it's dwindling away slowly as it is now. I think it's more to do with the climate side that will have the biggest effect on it.” “Climate change definitely changes fishing, like off of Shoreham when get first cold snaps the fishing goes really good so it's going to affect it if start doing that [warming].” “See I'm more worried about this plastic than I am to do with weather and climate change. Yeah, microbeads and plastic. That's a real concern.” “As a fisherman I see us affecting it faster than the global warming is, you know it's overfishing isn't it…. Like I say it's not so much climate change that effects, it's ourselves which you know, we're sort of catching the fish faster than the climate is changing to effect it if you know what I mean.” “I think the fishing effort on it will change the fish stocks far more than climate change ever will.”
Adaptability of the resource and of fishers (13)	The dynamic nature of fish stocks and the variability this presents for fishers meant that fishers often seemed unsure of how climate change would present new changes that fishers hadn’t had to cope with or adapt to before.	“They won't [feel the consequences of climate change] because fishermen will diversify if fish stocks go up or down. The fish stocks will stay the same they'll just migrate to where the water temperature is correct for them. Fishermen are always diverse.” “I believe one door closes another one opens, it's the way fishing is, we always seem to be able to find something, seasons change throughout the year but there's always something, some years are worse than others.” “I change my fishing practices all the time, down to different circumstances, wind, temp, different things happen all the every year, nothing stays the same. No two years are the same. No two years are the same.”

Personal observations and experiences (27)	Fishers recognised changes with weather and sea temperatures as well as changes in fish stocks, and some felt that they had been affected by climate change through personally experiencing it. Others expressed seeing no change, or that change occurred but wasn't attributable to climate change.	"I used to be a nay-sayer, you know, ah global warming it's, but it's been such a rapid thing that seen in the last 5 years even that I think no [it is happening]." "Sea is full of dolphins, and fish don't normally catch here, tuna and that in the English Channel. Lot of that, lot of things going 'whoah, what's happening here like?' It's all down to the warm water." "That's one thing I have noticed in last 5 years, when we get these storms now they seem to be a lot worse than they used to be. The weather pattern used to be more settled, now ones we're getting seem to be more intense." "Like I say I haven't seen no change since I've been fishing." "I don't recognise climate change. I don't see it, I haven't really experienced climate change, in all the years I've been fishing, I haven't experienced climate change." "I've seen no difference at all over past 30 years."
Age and lifespan (11)	Climate change is not seen as something to be concerned or worried about due to fishers being older, near to retirement age and therefore leaving the industry before impacts were perceived to be felt.	"I don't think it's going to happen in my lifetime, you know climate change is there but it's so gradual that this isn't an issue for my generation of people in their 50s. In 50 years time fishing will be completely different, it's not going to happen in the next 10 years, it's not going to happen in next 15 years, it's going to be the next 50 years it will change." "In my lifetime I don't think so. I'm a very old man."
Boat ownership (1)	One fisher mentioned that as he was not the owner of the boat he therefore wasn't really worried about the future.	"No never worried me cos at the end of the day I don't actually own the boat, I'm the skipper of a boat and always have been."

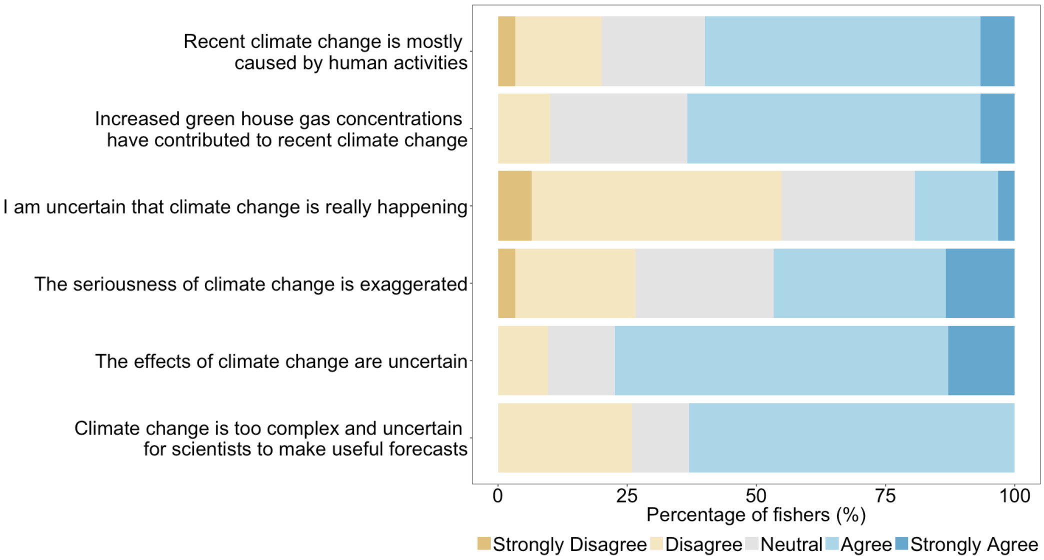


Figure 4.6. Fishers' responses to likert scale statements for determining climate scepticism regarding trend, attribution and impacts.

Some were sceptical about the attribution of climate change, but generally a greater proportion of fishers tended to agree that climate change was human caused and was occurring (Fig. 4.6). Generally, trend and attribution scepticism were less prevalent among fishers compared to impact scepticism and wider uncertainty regarding its impacts and the extent to which it would affect fish stocks, fishers or the industry (Table 4.4 and Fig. 4.6).

Thematic analysis also identified other aspects of scepticism (Table 4.4). Themes associated with process scepticism were discussed by 48% of fishers, including views that climate research was biased by a profitable industry and that the media exaggerated or sensationalised climate change and its impacts. Fishers (38%) also spoke about scepticism regarding the responses that individuals can play in addressing climate change as well as from a broader social and political perspective.

Scepticism views varied among the three groups, with a significant difference between groups one and three (Kruskall-Wallis test, $\chi^2 = 7.95$, df = 2, $p = 0.01$; Dunn multiple comparison test $p = 0.01$; Fig. 4.7). Group One had the highest scepticism scores, while Group Three had the lowest scepticism scores. Group Two had sceptical viewpoints but less so compared to those in Group One.

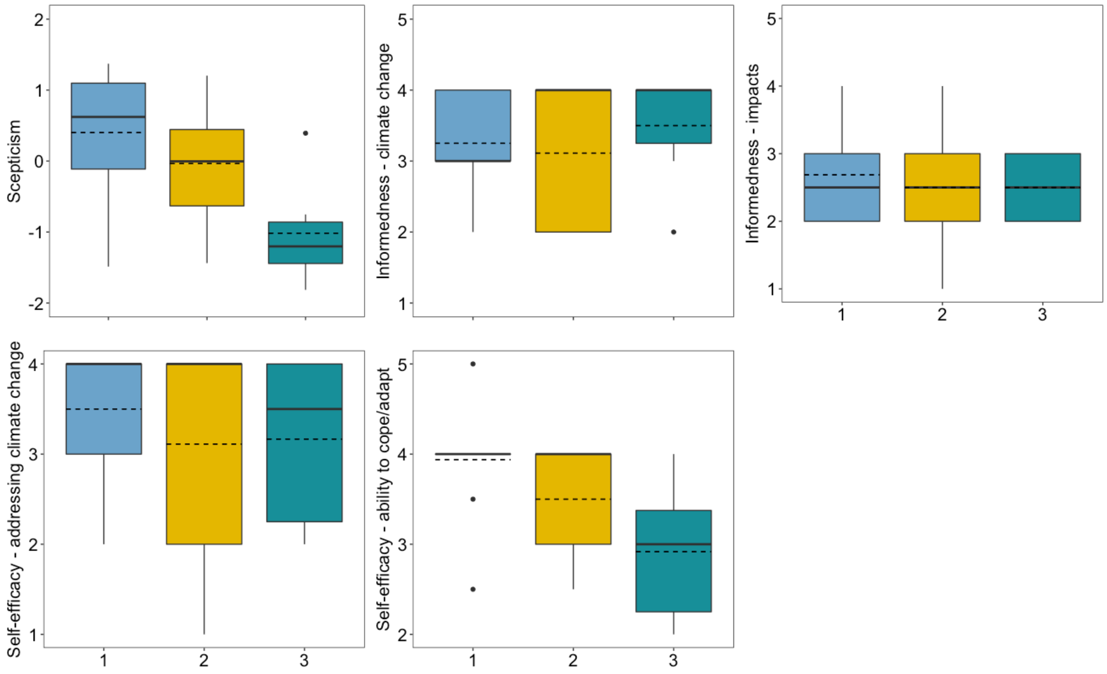


Figure 4.7. Differences between each measured factor and groups. From top left: scepticism, informedness about climate change in general, informedness about climate change impacts, self-efficacy (addressing climate change) and self-efficacy (ability to cope/adapt). Solid black line in boxes represent median; dashed black line represents mean.

Informedness and trust in information sources

Levels of self-reported informedness for both scales were similar across the three groups (Fig. 4.7). For informedness regarding climate change impacts on fisheries and their fishing business, all groups had lower agreement compared to the general informedness scale (Fig. 4.7). There were no correlations between these informedness scales and the two risk axes (Appendix C: Fig. A4.4). Thematic analysis found that 25% of fishers felt that climate change was not necessarily an important driver affecting fish stocks and that other factors had more of an impact, including fishing effort, pollution and plastic (Table 4.4). Most fishers with such views belonged to Group One. For other fishers, climate change was something that they simply didn’t tend to think about and was ‘out of mind’ (Table 4.4). Fishers tended to receive or access climate change information from news on the television (20 fishers) and newspapers (18). Other sources were general television programmes (9) and documentaries (4), online

(5), radio (2), news ‘apps’ (1), other fishers (1) and general ‘media’ (2). When asked generally how much fishers trusted these information sources, 34% stated they were very or somewhat untrustworthy, 31% they were neither trustworthy or untrustworthy and 34% they felt information was somewhat trustworthy. Trustworthiness in information had a weak negative relationship with overall scepticism (Spearman’s rank *rho* = -0.40, S = 2717.2, *p* = 0.02) with lower trustworthiness associated with higher scepticism.

Self-efficacy – addressing climate change

61% of fishers agreed that they could do something to address the negative impacts of climate change (Table 4.2). They often used other examples of how they had done things to help the marine environment, such as participating in the national ‘Fishing for Litter’ scheme as evidence that individuals can play their part in addressing environmental issues (http://www.fishingforlitter.org.uk/). This self-efficacy measure did not differ much between groups, although Group Two had the highest variability in answers (Fig. 4.7).

Self-efficacy – ability to cope/adapt to impacts

Some fishers talked about climate change and the impacts it could have as not being any different from the changes that fish stocks and they themselves have had to adapt to in the past or currently (Table 4.4). Linked to this was a sense that fishers were good at adapting to these changing resources, with thematic analysis identifying 35% of fishers as describing adaptability as being a strength of fishers and something that was a natural requirement of the occupation. Most fishers agreed with statements that they had the ability and skills to adapt to potential climate change impacts (Table 4.2). Perceived self-efficacy to adapt differed among groups (Kruskal-Wallis, $\chi^2 = 10.10$, df = 2, $p = 0.006$; Dunn multiple comparison tests $p = 0.005$ for groups 1–3, p>0.05 groups 1–2 and 2–3; Fig. 4.7). Group Three had the lowest perceived ability to cope or adapt while Group One had the highest; this links to earlier results showing Group Three having higher risk perceptions than Group One.

Personal observations and experiences

Fishers across all groups described personal observations of changes in weather, seas and fish stocks (Table 4.5). Five fishers noted there had been no change in weather patterns, while 19 fishers mentioned extreme weather events becoming more frequent or severe. Of these 19, 12 attributed such changes to climate change. One mentioned changes in seasons but did not attribute it to climate change. Ten fishers noted that sea temperatures were warming, and two stated that tides and currents were becoming stronger, which they attributed to climate change. Fishers described a number of changes in their target species, which they attributed to a range of factors, including climate change (Table 4.5). Linked to risks described earlier, overfishing was seen as driver of declines in many stocks. Other species were perceived to have increased in recent years. 14 fishers discussed seeing new species such as tuna, which 10 fishers attributed to warming waters. Five fishers spoke of changing abundance, distributions, seasons or general changes in fishing that they attributed to climate change. Lemon sole in particular was discussed by five fishers, saying that the season had become much later and that seas were not cold enough to ‘bring them on’. A further three mentioned they had seen no change in fish stocks.

87% of fishers felt that they had not been personally affected by climate change. Of the three fishers that said they had, the main impacts were attributed to the changing weather as opposed to changing fish stocks. One stated that they did not know whether they had been affected, linking it back to their scepticism regarding climate change as a factor affecting fisheries. Similar amounts of fishers answered that they had been affected by climate change and that fishers were already feeling the consequences of climate change (Fig. 4.3), although these were not the same people. Those who answered that fishers were already feeling the consequences of climate change but answered that they were not personally being affected by climate change commented that they were answering in a wider sense for other fishers, that they would be affected in the future but were not as yet, or that the impacts were not necessarily bad.

Table 4.5. Observed changes in species in fishing grounds in south west over last 10–15 years.
Green shading=increased abundance, red shading=declined abundance, blue shading=stable, grey shading=variable – no distinct trend.
* refer to particular sightings as opposed to overall consistent trends observed. E.g 'seen a few more Tuna'.

	Quota or management restrictions	Recovery scheme	Reduction in mesh size	Lowered fleet capacity/ fishing effort	Banning of certain gears e.g. French dredges	Change in fleet targeting behaviour	Reduction in landing size	Increased fishing effort	Warmer waters	Lack of prey availability	Increased prey availability	Natural variation	No attribution given
Dover sole	🟩	🟩	🟩	🟩				🟥					
Plaice				🟩					🟥	🟥			
Turbot and brill				🟩	🟩								
Lemon sole							Smaller sizes	🟥	Season starting later			▨	🟦
Sea bass	🟩										🟩		🟩
Cod, whiting, pollock, haddock								🟥					🟩
Anchovies, sprats and pilchards									🟩		🟩		
Herring								🟥					
Mackerel								🟥					
Anglerfish								🟥					
Rays	🟩												🟩🟥
Cuttlefish				🟩					🟩		🟩	▨	🟩🟥
Squid									🟩		🟩		🟩
Scallops								🟥				🟥	🟥
Tuna*									🟩		🟩	🟩	
Dolphins*									🟩		🟩		🟩
Sunfish*									🟩				🟩
Turtles*									🟩				
Whales*													🟩
All stocks	🟩		🟩	🟦		🟩		🟥				🟦	🟩▨🟦

Socio-demographics

There were few differences between the three groups regarding socio-demographic aspects of education, sector and boat ownership (Fig. 4.8). Mean age was similar across all groups (50.7; 51.5; 54.1). However, age was discussed in the context of climate change risk by 35% of fishers, across all groups (Table 4.4). The fact that many fishers were older, approaching retirement age or would be leaving the industry soon was often cited as an explanation for responses to interview questions and statements implying low levels of risk. For example:

> *“I don't think it's going to happen in my lifetime you know. Climate change is there but it's so gradual that this isn't an issue for my generation of people in their 50s. In 50 years’ time fishing will be completely different, it's not going to happen in the next 10 years, it's not going to happen in next 15 years, it's going to be the next 50 years it will change.”*

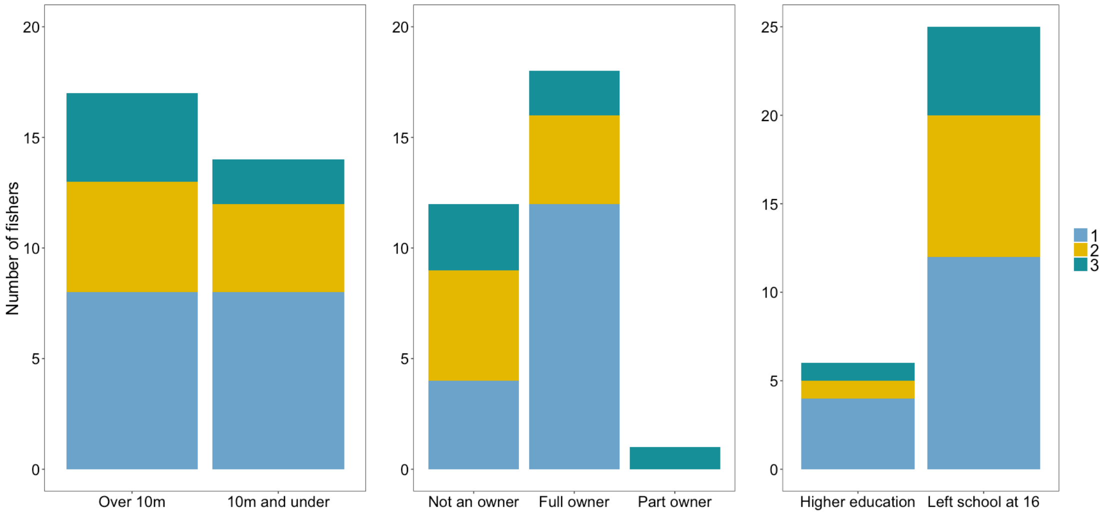


Figure 4.8. Differences between groups according to left: sector, middle: boat ownership, right: education.

Discussion

This study found that fishers perceived a range of risks to the future of fish stocks, fishing businesses and industry in the south-west UK, but that climate change is generally perceived as a low risk by most fishers. However, perceptions differed among fishers and were affected to different extents by a mixture of wider climate change beliefs (i.e. scepticism), perceived self-efficacy to adapt to future impacts, informedness, and personal observations or experiences.

Most risks identified by fishers centred upon environmental, socio-economic and governance aspects of fisheries. As has been observed in other studies of UK fishers (Tingley *et al.,* 2010; Nelson and Booth, 2014), overfishing was seen as the biggest environmental risk to the future sustainability of fish stocks, while concerns with management and policy were also important. These perceived risks arise from actors both within the fisheries system (e.g. fisheries managers, other fishers) and beyond (e.g. public and media). Climate change was infrequently discussed among fishers, highlighting that it was not such a pressing or prioritised risk in relation to other risks that were discussed. This was matched by feelings that climate change would not bring change that fishers had not had to cope with before, and that they felt it unlikely they would need to change fishing practices as a result of climate change. Similar findings have been reported in other fisheries contexts, including Tasmania (Nursey-Bray *et al.,* 2012), Norway (West and Hovelsrud, 2010) and the UK (Garrett *et al.,* 2015), with conclusions that fishers do not see climate change as a problem or that they are not vulnerable to its impacts.

Identifying patterns in fishers' risk perceptions provided the opportunity to explore how perceptions varied across individuals and what influenced these differences despite the relative similarities across fishers in terms of fishing practices and socio-demographics. Studies at an individual level are important for a number of reasons, primarily because responses to climate change require individual action and adaptation and as such depends on individual perspectives and circumstances (Grothmann and Patt, 2005; Stoll, Fuller and Croner, 2017). In order to support fishers in their responses and facilitate adaptation to climate change impacts, fisheries management and policy therefore needs to consider how perceptions can vary at these individual scales. For example, findings presented here show that fishers who were less sceptical about climate change and felt less able to cope or adapt to its impacts perceived higher levels of risk from climate change. This indicates that those fishers may not feel prepared to respond to future climate change and therefore may need greater assistance in their adaptation. Further research could explore how this relationship between lower perceived ability to cope and adapt, and higher risk perceptions interacts with fishers' sensitivity and adaptive capacity to climate change, and as such how they could be further supported in the face of future climate change. For other fishers who had lower risk perceptions and higher scepticism, greater attention may be needed to explore whether this could pose an issue for implementation of fisheries management or policy measures addressing climate change. Some have suggested that risk perceptions have the potential to create barriers to acceptance of climate change as an issue within fisheries contexts (Nursey-Bray *et al.,* 2012) and therefore this could affect support for changes in management or willingness to accept changes in management under such initiatives (Adger *et al.,* 2009; Tam and McDaniels, 2014; Máñez-Costa, Shreve and Carmona, 2017).

Lower risk perceptions were connected to higher climate change scepticism across fishers, and similar scepticism patterns among fishers have been documented elsewhere (Nursey-Bray *et al.,* 2012; Zhang, Fleming and Goericke, 2012). Sceptical viewpoints and their influence on lowering risk perceptions pose interesting questions if future management seeks to implement measures aimed at addressing climate change, for example reducing fishing effort on vulnerable stocks. If people are sceptical and have low risk perceptions, acceptance of climate change as an issue that management should address may be affected, leading to consequences on fishers' levels of support for such initiatives. Risk perceptions have been shown to affect levels of support for climate change policies and initiatives in other contexts (Zahran *et al.,* 2006; Tam and McDaniels, 2013; Taylor *et al.,* 2014; Mayer *et al.,* 2017). Additionally, many fishers identified changing management and the uncertainty that results from 'moving the goalposts' a risk to their business or the wider industry. It has been argued that fisheries management should become increasingly adaptive and flexible with climate change into the future (OECD, 2010), but this may conflict with fishers' views of wanting greater stability from fisheries management and thus leads to questions over how fishers would perceive management or policy changes particularly if they perceive climate change as low risk to begin with.

A common strategy for increasing individuals’ climate change awareness and concern is to improve communication, and therefore peoples’ knowledge, about its trends and impacts (Sundblad, Biel and Gärling, 2007; Hidalgo and Pisano, 2010; Lieske, Wade and Roness, 2014; Moser, 2014; Shi *et al.,* 2016). Fishers interviewed showed no clear differences regarding levels of informedness and risk perceptions, suggesting that there was a limited effect of these factors on risk perceptions. This does not suggest that informedness is not important, but that within this study other factors are likely to have had a greater role in shaping perceptions. However, all fishers felt they had lower levels of informedness regarding climate change impacts on fisheries or fishing businesses, and this may have contributed to the uncertainty that a large proportion of fishers felt about the extent and outcomes of climate change impacts upon them, and indirectly may have lowered risk perceptions. Such findings would indicate that more or improved communication regarding climate change effects could help improve fishers’ understanding and wider knowledge of how it may affect them and fisheries more widely.

The extent to which more communication and knowledge leads to heightened risk perceptions differs among studies (e.g. Kellstedt, Zahran and Vedlitz, 2009; Hidalgo and Pisano, 2010, Milfont, 2012; Shi *et al.,* 2016), and within this study this effect may be dampened by a number of factors. Fishers expressed views aligned with process scepticism, which has important links to how scientific research is produced, the biased nature of the ‘climate industry’ and that environmental groups push a climate agenda (van Rensburg, 2015). The media, where most fishers obtained information about climate change, was also criticised by fishers for exaggerating the importance of climate change or its effects, and sensationalising it as an issue, or its general untrustworthiness. Wider literature also documents levels of distrust fishers can feel towards scientists for other issues (Stanley and Rice, 2008). All these factors therefore have important potential consequences on the extent to which fishers would process, accept and listen to messages regarding climate change and its impacts (Lorenzoni, Nicholson-Cole and Whitmarsh, 2007; Leiserowitz *et al.,* 2013; Capstick *et al.,* 2015). Well-developed, targeted communication strategies that disseminate information using pre-identified trusted sources would likely be needed if fishers were to be approached to develop their climate knowledge and subsequent awareness and concern (Moser, 2010a).

Personal observations and experiences of climate change impacts have been shown to increase risk perceptions (Reser, Bradely and Ellul, 2014; van der Linden, 2015) but their effect on fishers' risk perceptions within this study appear to be limited and require more specific and targeted research. A number of fishers did observe changes in extreme weather events, citing examples such as storms affecting the south-west region in 2013–14 and more recently (Andrew and Read, 2014), and others noted changes in species that they attributed to warming waters. Some of these described changes reflect wider scientific literature; for example spawning of lemon sole has been found to occur later after warmer periods the previous year (Genner *et al.,* 2010). Observations of increases in anchovies and similar species with warming temperatures have also been documented (Beare *et al.,* 2004). Interestingly, despite their scepticism, in many cases fishers linked observed changes with climate change but this didn't result in them feeling that they had been personally affected. Full understanding of the complex relationship between personal observations, experience and risk perceptions was beyond the scope of this study, but some explanations are provided below.

Given that fishers are used to a variable and changing environment that is subject to shocks (Zhang *et al.,* 2011; Geetha *et al.,* 2014; van Putten *et al.,* 2015), even if they did attribute changes in weather or resources to climate change, fishers may feel this is something they are already used to. Findings indicated the important and likely combined effects of perceptions of an already dynamic system and the adaptability of fishers and as such their high perceived self-efficacy to cope and adapt. Additionally, many expressed scepticism and uncertainty regarding the severity and outcomes of climate change impacts, and whether it would pose impacts they hadn't dealt with before. Similar views have been shown in other studies (West and Hovelsrud, 2010; Nursey-Bray *et al.,* 2012; Garrett *et al.,* 2015). As such these factors may provide an explanation why despite observing change, fishers did not feel affected. These findings are consistent with wider literature that has reported mixed results regarding the extent of personal observations and experiences on risk perceptions (Whitmarsh, 2008; Marquart-Pyatt *et al.,* 2014; Hornsey *et al.,* 2016; van der Linden, 2017). Fishers' observations of weather changes were often discussed after introducing the topic of climate change, which may have influenced responses. To better understand how fishers attribute observed changes to climate change and how this links to their personal experience, scepticism and risk perceptions, future study should explore these aspects more fully (e.g. as seen in van Putten *et al.,* 2015a).

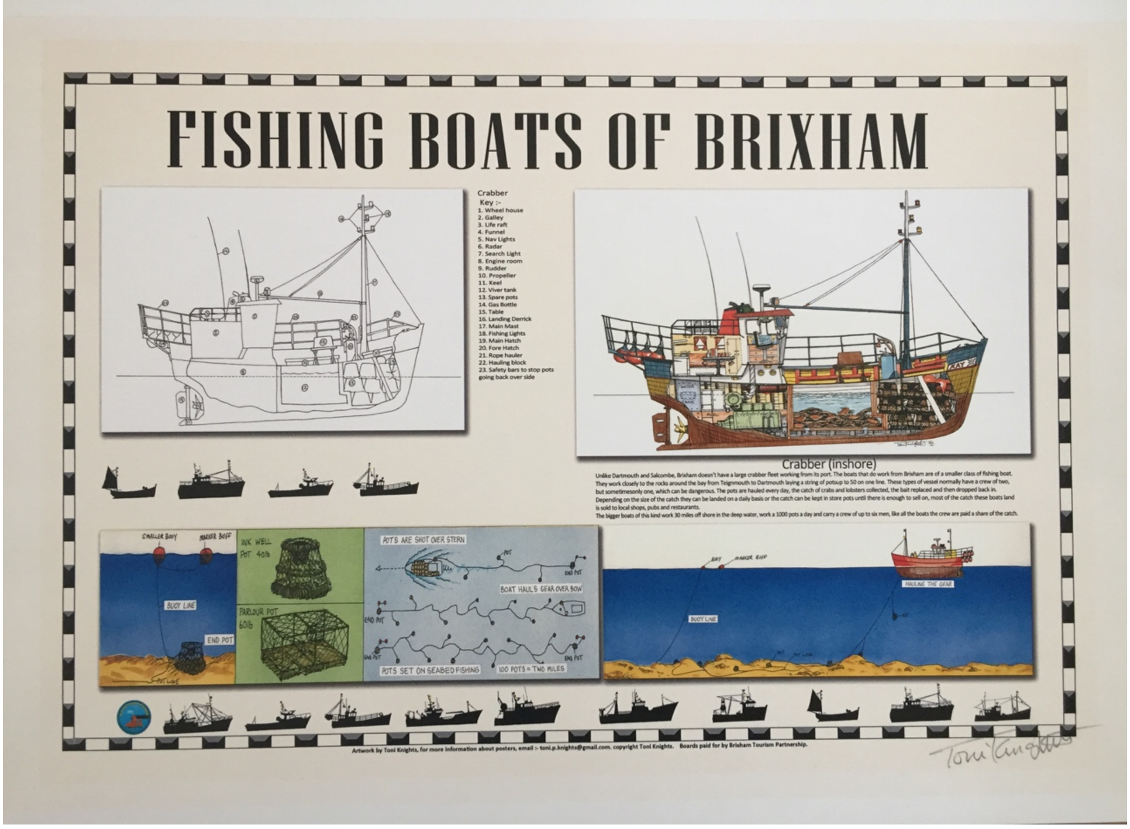
There were limited differences in fishers' perceptions according to sector, boat ownership and education. Whilst age did not appear to be important from PCA analysis results, and wider literature also suggests inconsistent or limited effects on risk perceptions or beliefs (Hornsey *et al.,* 2016; van der Linden, 2017), a number of fishers did discuss views of climate change in the context of their age and lifespan. Citing retirement or other age-related reasons such as health or having 'had enough of it' for their responses, there was some evidence that age might play a small role in lowering risk perceptions of some fishers. To further understand this relationship between fishers' age and risk perceptions, future study would need to engage with other fishers such as crew, who typically tend to be younger compared to skippers, to examine any differences.

This study does have inherent limitations. Increasing the sample size would allow for further quantitative analyses to be undertaken to understand the importance of factors in predicting risk perceptions and the strength of these relationships. More widely, the extent to which perceptions represent a single snap shot in time may be seen as an issue because they can change or be influenced by recent events (e.g. Tingley *et al.,* 2010), but here it is argued that understanding such perceptions has important implications from communication, management and policy perspectives (e.g. Nursey-Bray et al., 2012; Allison and Basset, 2015; Costa, Shreve and Carmona, 2017) and that such issues could be overcome through for example repeated surveys. This study is contextual in nature and as such limits the extent of comparisons that can be drawn at a more national level, yet given most impacts are felt at smaller scales such as the individual or community, such context is important to understand (Dolan and Walker, 2006; Adger *et al.,* 2009). Further work could include studies over a latitudinal gradient to explore the role of geographic location and personal observations and experiences in more detail, as well as interviewing other fishers with broader demographics, fishing practices and target species.

To conclude, this study has provided new understanding into how fishers within a UK fishing port perceive climate change and the factors associated with these perceptions. It highlights a complex set of other risks that fishers feel are important in affecting their future and therefore may also need to receive support in responding to in the future. While in general most fishers tended to have low climate change risk perceptions, further analysis indicated that there were three clear groups regarding these perceptions. Perceived self-efficacy regarding ability to cope/adapt and climate scepticism, particularly of its impacts, had important roles in influencing such perceptions. Through identifying differences in risk perceptions among individuals, this study provides important insights that can be used in decision making contexts regarding communication of climate change risks and impacts and understanding how people may support or respond to climate change policies or management measures due to these different perceptions.

Chapter 5

Perceptions and dimensions of fishers’ adaptive capacity to future climate change



Unlike Dartmouth and Salcombe, Brixham doesn't have a large crabber fleet working from its port. The boats that do work from Brixham are of a smaller class of fishing boat. They work closely to the rocks around the bay from Teignmouth to Dartmouth laying a string of potsup to 50 on one line. These types of vessel normally have a crew of two, but sometimesonly one, which can be dangerous. The pots are hauled every day, the catch of crabs and lobsters collected, the bait replaced and then dropped back in. Depending on the size of the catch they can be landed on a daily basis or the catch can be kept in store pots until there is enough to sell on, most of the catch these boats land is sold to local shops, pubs and restaurants.
The bigger boats of this kind work 30 miles off shore in the deep water, work a 1000 pots a day and carry a crew of up to six men, like all the boats the crew are paid a share of the catch.

Artwork by Toni Knights, for more information about posters, email :- toni.p.knights@gmail.com. copyright Toni Knights. Boards paid for by Brixham Tourism Partnership.

Drawing by Tony Knights

Abstract

Successful adaptation to future climate change is critical if fishers are to minimise the negative effects of future impacts and capitalise on new opportunities. Examining fishers' ability to adapt—so-called adaptive capacity—provides insights into what can enhance or constrain adaptation. Understanding perceptions of future impacts and constraints to adaptation alongside exploring the dimensions that contribute to adaptive capacity can provide new insights from individual perspectives. UK adaptive capacity assessments until now have focused on broad scale, national approaches and have neglected potential differences at the individual scale. This study focused on a UK fishing port, Brixham, to elicit fishers' perceptions of future climate change and explore how they anticipated responding to its impacts. Constraints to adaptation were also explored. Three core dimensions of adaptive capacity were examined to further understand fishers' adaptive capacity – their flexibility, social organisation and personal agency. Findings indicate that while fishers are aware of climate change and how it may impact the physical environment and fish stocks, many fishers did not anticipate having to change their practices with future climate change, likely due to a combination of psycho-social factors and perceived constraints. Three main groups of fishers were identified who, despite having similar fishing characteristics, differed in their adaptive capacity due to individual social factors, including their perceived ability to adapt. These insights provide information for management regarding potential implications of future adaptive behaviours and highlight constraints important to consider within development of adaptation strategies, which may have been overlooked using purely objective based methods. Extending UK adaptive capacity assessments beyond their current focus, and thus recognising the wider individual contextual factors, is important to help develop adaptation strategies that can effectively support fishers' adaptation by accounting for their needs.

Introduction

Climate change is increasingly affecting the marine environment, resulting in significant physical (e.g. storminess), ecological (e.g. shifting distributions) and socio-economic (e.g. resource availability) impacts at local, regional and global scales (Hollowed *et al.,* 2013; Poloczanska *et al.,* 2016; Cheung, 2018). Such impacts are expected to have particular effects upon resource dependent communities and sectors such as fisheries (Rijnsdorp *et al.,* 2009; Barange *et al.,* 2018; Sainsbury *et al.,* 2018). Fishers can have high financial dependency on marine resources, and often have high attachment to these specialised occupations and the areas in which they work and live, and may have few alternative occupations in which to diversify (Brookfield, Gray and Hatchard, 2005; Marshall and Marshall, 2007; Pita *et al.,* 2010; Seara, Clay and Colburn, 2016). For fishers to minimise negative consequences of climate change and benefit from potential future opportunities, successful adaptation will be crucial (Badjeck *et al.,* 2010; Perry *et al.,* 2010). Responding and adapting to climate change is dependent on fishers' ability to do so; their so-called adaptive capacity (Marshall *et al.,* 2010; Bennett *et al.,* 2014; Stoll, Fuller and Crona, 2017). This adaptive capacity forms an integral aspect of reducing fishers' vulnerability and heightening their resilience to future climate change impacts (Engle, 2011; Klein *et al.,* 2014).

Adaptive capacity is broadly considered to have a number of core dimensions which can act to support or constrain peoples' adaptation (Bennett *et al.,* 2014; Lockwood *et al.,* 2015; Whitney *et al.,* 2017; Cinner *et al.,* 2018). The first centres on flexibility and diversification. Fishers who can target other species or move to new fishing grounds can capitalise on new opportunities that climate change may present (Perry *et al.,* 2010; Stoll, Fuller and Crona, 2017). Those who are less attached to fishing or would be willing or able to change jobs or move to a new region are considered to have greater adaptive capacity (Daw *et al.,* 2009; Marshall *et al.,* 2010). Secondly, social organisation, such as having informal and formal networks with actors both within and outside the fishery, can help to support fishers during times of stress and enable cooperation and sharing of new information and technological innovations (Marshall *et al.,* 2010; Cinner *et al.,* 2018). Thirdly, having access to assets, such as finance or technology, can help during the adaptation process (Daw *et al.,* 2009; Cohen *et al.,* 2016). Fourthly, fishers who can learn new skills or develop their knowledge of climate change impacts and ways to adapt are thought to have greater adaptive capacity because they may be more prepared, know how to manage uncertainty and risks and have more awareness of potential impacts (Marshall *et al.,* 2010; Williams, Fenton and Huq, 2015; Whitney *et al.,* 2017; Cinner *et al.,* 2018). Finally, personal agency—peoples' belief in their ability to manage or respond to impacts—can also influence fishers' adaptive capacity by affecting the extent to which fishers may see the need or feel incentivised to adapt in the first place (Grothmann and Patt, 2005; Brown and Westaway, 2011; Cinner *et al.,* 2018).

Adaptive capacity can be explored through vulnerability assessments, which examine adaptive capacity according to a number of criteria reflecting some of the above dimensions (Cinner *et al.,* 2013; Metcalf *et al.,* 2015; Whitney *et al.,* 2017). Often these studies rank specified groups or nations according to the vulnerability of their fishery systems to climate change (Allison *et al.,* 2009; Blasiak *et al.,* 2017). Studies such as these generally find that tropical communities are more vulnerable and have lower adaptive capacity to climate change compared to those in temperate and/or developed nations (Allison *et al.,* 2009; Blasiak *et al.,* 2017). Other studies are focused on examining adaptive capacity dimensions in greater detail at individual, household or community scales (Coulthard, 2008; Cinner *et al.,* 2013; Cohen *et al.,* 2016; Stoll, Fuller and Crona, 2017). Indicator-based approaches have become an important and popular tool in measuring dimensions of adaptive capacity, which can use both objective and subjective measures within their assessments (Marshall and Marshall, 2007; Lockwood *et al.,* 2015; Seara, Clay and Colburn, 2016; Whitney *et al.,* 2017). Such insights are important in informing decision-making processes which may need to develop strategies to facilitate and assist fishers in their future adaptation to climate change impacts.

Subjective psycho-social aspects can have particular importance in influencing adaptive capacity, particularly at the individual scale (Adger *et al.,* 2009; Brown and Westaway, 2011; Johnson, Henry and Thompson, 2014; Evans *et al.,* 2016; Elrick-Barr *et al.,* 2017). These can be measured using indicators, or additionally through broader questioning to further explore the factors affecting peoples' adaptive capacity (Marshall and Marshall, 2007; Seara, Clay and Colburn, 2016; Grunblatt and Alessa, 2017). How people perceive both the risks that climate change may present as well as their ability to adapt can have important consequences including how individuals may manage future risk, their willingness to use information that can assist in the adaptation process and support for adaptation strategies (Adger *et al.,* 2009; Oppenheimer *et al.,* 2014; Metcalf *et al.,* 2015; Seara, Clay and Colbun, 2016; Cinner *et al.,* 2018). Within fisheries contexts there have been some studies exploring risk perceptions and perceived ability to adapt with climate change, but these tend to be broad in focus and centre on general perceptions of climate change (West and Hovelsrud, 2010; Nursey-Bray *et al.,* 2012; Dannevig and Hovelsrud, 2015; Seara, Clay and Colburn, 2016). Others have explored fishers' perceptions of historical and present climatic changes in the environment (Zhang*,* Fleming and Goericke, 2012; Jahan, Ahsan and Farque, 2017; Martins and Gasalla, 2018).

Few studies have explicitly examined fishers' perceptions of *what* future impacts they think they will have to adapt *to* and *how* they think they may have to adapt in the future. One exception looked at perceptions of future climate change impacts along a seafood supply chain in Australia, finding the harvest stage was aware of future impacts but that further up the supply chain there was less incentive for planning to adapt to its impacts (Fleming *et al.,* 2014). Yet, limited studies exist regarding fishers' perceptions of particular future impacts they think they may be exposed to, and how such impacts may affect them or require them to respond. Understanding these perceptions could provide a greater understanding of fishers' future behavioural and adaptive intentions, their preparedness for future impacts, and may also indicate levels of informedness regarding climate change among individuals (Grothmann and Patt, 2005; Seara, Clay and Colburn, 2016; Grunblatt and Alessa, 2017). Examining such perceptions also provides the opportunity to identify perceived constraints or limits to adaptation which may not be captured in more objective adaptive capacity assessments (Elrick-Barr *et al.,* 2017).

This study uses a UK fishing port, Brixham, as a case study to explore fishers' adaptive capacity to climate change. Within the UK there have been limited studies of fishers' adaptive capacity. Assessments have typically been part of wider global vulnerability research, ranking the UK with high adaptive capacity, but with limited specific insight into the role of different dimensions in influencing adaptive capacity at smaller geographic scales (Allison *et al.,* 2009; Blasiak *et al.,* 2017). These assessments used objective indicators using secondary data sources, focusing on healthy life expectancy, education, governance, size of economy (Allison *et al.,* 2009) and more recently the proportion of industrialised fishers in the fleet (Blasiak *et al.,* 2017). More focussed national assessments have emerged in recent years which have also identified high adaptive capacity among the UK fleet and wider industry due to it having 'strong commercial incentives to make the most of profitable opportunities' and assumed innate adaptive abilities of fishers to cope within a current changing environment (Defra, 2013; Garrett, Buckley and Brown, 2015). As part of their study, Garrett, Buckley and Brown (2015) consulted industry stakeholders to explore their perceptions of adaptation, who considered themselves to be highly adaptable to near term climate impacts and placed low priority on climate change adaptation due to other perceived risks. While these two assessments have provided insights at a national industry scale, less attention has been paid to individual actors within regional contexts or exploring their perceptions of future climate impacts and perceived constraints to their adaptation. Greater focus at these scales could provide a better understanding of the adaptive capacity of individuals within the wider fleet and the contextual factors that may influence their adaptation.

Using a mixed-methods approach this research explores individual fishers' adaptive capacity. The individual scale is examined because it is often at these levels at which people respond and adapt, and because individual differences, for example in fishing strategies, can potentially lead to differences in their adaptive capacity (Grothmann and Patt, 2005; Marshall *et al.,* 2013a; Stoll, Fuller and Croner, 2017). Three main aspects were examined: 1) the impacts fishers perceive for the future in terms of physical, ecological and fishery level impacts, 2) the constraints fishers perceive to their future adaptation to climate change, and 3) fishers' adaptive capacity to future impacts. Adaptive capacity was examined through the lens of their flexibility, social organisation and personal agency, considering how this differs among individuals.

Methods

Interviewing

Fishers from Brixham were identified and interviewed as outlined in Chapter 4. The fishers discussed within this Chapter are therefore the same as in Chapter 4. Information was collected regarding: 1) perceived future climate change impacts on the sea, resources and fishing practices; 2) perceived constraints or enablers of adapting to future climate change; and 3) aspects influencing fishers' adaptive capacity. Socio-demographic information was also collected (Chapter 4: Table 4.1).

- Perceived future impacts

To understand perceived future impacts, fishers were presented with a series of closed questions regarding different aspects of the sea and fishing practices that could be affected by climate change (Appendix B: interview section E and G). Importantly, such questioning was not designed to 'test' fishers' knowledge but rather understand how they perceived such aspects may change, if at all, in the future. Fishers were asked to firstly state whether they thought the aspect, for example sea temperature, could be affected, with a 'yes', 'no' or 'don't know'. If they answered 'yes' fishers were then asked with an open-ended question in what way they thought it could be affected. Questions on physical impacts included sea temperatures, sea levels, sea chemistry (e.g. oxygen levels and pH), sea nutrients (e.g. algal blooms), sea currents and storminess. Such physical impacts have been documented within the scientific literature as having been, or expected to be, affected by climate change (Collins *et al.,* 2013; Pörtner *et al.,* 2014).

Fishers were then asked how they thought fish stocks could be affected by climate change and what might drive those changes (e.g. warming waters). This was designed as an open-ended question to allow fishers to develop their own ideas with no influence from the interviewer. To understand perceived future impacts on fishing practices fishers were asked: '*If any, what aspects of your fishing activities do you think you may have to change as a result of climate* *change?*'. A list of pre-determined aspects was given: species targeted, gear used, vessel used, fishing locations, trip length and/or frequency and landing or home port. Similarly to when asked about physical aspects, fishers were firstly asked whether the aspect would change, answering 'yes', 'no' or 'don't know'. If fishers answered 'yes', they were asked in what way. Scientific literature also provides evidence that such aspects may be affected by future climate change (OECD, 2010; Perry *et al.,* 2010; Cheung *et al.,* 2010; Haynie and Pfeiffer, 2012; Hamon *et al.,* 2014). Reasons fishers gave for saying 'no' or 'don't know' were also recorded, but not all fishers gave reasons for these answers. Fishers were also given the opportunity to provide any other ideas of what practices might be affected or have to change.

- Perceived constraints to adaptation

Constraints to changing and adapting fishing practices were explored through direct questioning of what fishers felt could pose a constraint, or enhance, their ability to adapt to climate change impacts in the future (Appendix B: interview section M).

- Adaptive capacity

To understand fishers' adaptive capacity, a range of statements and questions were asked which are summarised in Table 5.1 (also see Appendix B: interview section O). There are a number of frameworks which have been developed to assess adaptive capacity and which typically highlight several main dimensions of adaptive capacity, as discussed in the introduction (Marshall *et al.,* 2010; Bennett *et al.,* 2014; Cinner *et al.,* 2018). Within this study three dimensions were examined: 'flexibility', 'organisation' and 'agency'. Flexibility was chosen because this dimension has particular relevance in the context of fishers given their resource dependency and its influence on their wider ability to change practices, adapt to new fish stocks or locations, or even their flexibility to change occupations (Marshall and Marshall, 2007; Badjeck *et al.,* 2010; Marshall *et al.,* 2010; Pita *et al.,* 2010; Bennett *et al.,* 2014). Flexibility was also relevant to other research questions in this study regarding perceived future changes to fishing practices and potential constraints, because these will in part be influenced by fishers' flexibility (or lack thereof). Organisation was explored to understand how connected fishers felt to different groups within the relatively tight-knit community of Brixham and how this could influence their adaptive capacity. Evidence shows that south-west fishers have drawn upon their social networks, such as the Fishermen's Mission, after storm events (Fishermen's Mission, 2014), thus highlighting the potential importance social networks may have in contributing to fishers' adaptive capacity in the future. Agency was chosen due to its importance in affecting other dimensions of adaptive capacity and to examine further findings within the literature that fishers have a perceived ability to cope with change because they have done so before (Nursey-Bray *et al.,* 2012; Johnson, Henry and Thompson, 2014; Seara, Clay and Colburn, 2016; Elrick-Barr *et al.,* 2017; Cinner *et al.,* 2018).

Using the frameworks as a guide (Marshall *et al.,* 2010; Bennett *et al.,* 2014; Cinner *et al.,* 2018), indicators, and the statements/questions used, were derived from reviewing the relevant literature regarding these three dimensions (Table 5.1). Some indicators were adapted into the context of fisheries and climate change.

Analysis

Quantitative analysis was undertaken in R and qualitative analysis was undertaken using NVivo V.11 and Microsoft Excel (R Core Team, 2018).

- Perceived future impacts

Answers to questions regarding physical and fishing impacts were firstly grouped into frequencies of 'yes', 'no' and 'don't know' as to how fishers expected that aspect to be affected. Explanations from fishers answering 'yes' were then categorised into groups and frequencies recorded e.g. number of fishers saying sea temperatures would increase, not sure on directionality, or decrease. Reasons fishers gave for answering 'no' as to whether they would change their fishing practices in the future were grouped into themes inductively as this was an exploratory aspect of the research. Answers to the open-ended question on ecological impacts on fish stocks were categorised based on similarity of answers and using the interviewer's own knowledge (based on literature reviewed in Chapter 1). Results were developed into a figure to illustrate the answers fishers gave and the connections and attributions they made between each aspect of the sea, fish stocks and fishing practices that could be affected.

- Perceived constraints to adaptation

Fishers' perceived constraints to changing and adapting fishing practices in the future were analysed through thematic analysis. In addition to analysing answers to direct questions as outlined above, the whole transcript was also analysed to capture other instances when fishers discussed any constraints and/or enablers to adaptation, such as when they described their answers to how their fishing practices may change in the future.

Responses were analysed in NVivo V.11 by coding answers into groups of similar constraints to adaptive capacity using the broad categories outlined by Klein *et al.* (2014). Within this IPCC report, eight main constraints were identified: 1) Knowledge, Awareness and Technology; 2) Physical; 3) Biological; 4) Economic; 5) Financial; 6) Human Resources; 7) Social and Cultural; and 8) Governance and Institutional (see Klein *et al.,* (2014) for descriptions). Constraints, also often referred to in the literature as barriers, are here defined as 'factors that make it harder to plan and implement adaptation actions' (Klein *et al.,* 2014). A lack of resources such as funding, or institutional constraints such as management rules are examples of constraints to peoples' adaptation (Klein *et al.,* 2014).

Table 5.1. Dimension of adaptive capacity, indicator used to measure the dimension and description of its link to adaptive capacity. Within the table adaptive capacity is referred to as AC.

Dimension of adaptive capacity	Indicator	Description	Statement*/ question	Information obtained	Source of indicator	Included in PCA (Yes/No)
Flexibility	Attachment to occupation	Having a greater sense of occupational attachment can indicate lower AC as people can develop strong identities associated with their occupations and therefore be more sensitive to changes in the resource (Marshall *et al.,* 2007; Marshall *et al.,* 2010; Bennett *et al.,* 2014)	I can't imagine doing any other job except fishing	Likert scale response	Adapted from Marshall *et al.,* 2007	Y
			Fishing to me is a lifestyle – it's not just my job	Likert scale response	Adapted from Marshall *et al.,* 2007	Y
			I have been tempted to leave fishing and find an alternative income/lifestyle elsewhere	Likert scale response	Marshall, 2011	Y
	Occupational mobility and flexibility	Less flexibility to work elsewhere or in another job indicates lower AC as there is higher reliance on the current occupation and gaining income from the resource-dependent job (Marshall *et al.,* 2007; Marshall *et al.,* 2010; Pita *et al.,* 2010)	I would be willing to leave this region if fishing opportunities were better elsewhere	Likert scale response	Novel: Influenced by Marshall *et al.,* 2010	Y
			I have other career options available to me if I decide to no longer be a fisherman	Likert scale response	Marshall and Marshall, 2007	Y
			Do you/ have you worked outside of the fishing industry, and what as?	Qualitative description	Novel: Influenced by Marshall *et al.,* 2010	N
	Business planning and approach	Peoples business skills can indicate their competitive advantage compared to others (Marshall *et al.,* 2010). Planning ahead can enable people to respond more proactively to risks, while larger businesses	I am often thinking of new and better ways to improve my fishing business	Likert scale response	Marshall and Marshall, 2007	Y (merged with below)
			I am interested in learning new skills to benefit my business	Likert scale response	Marshall and Marshall, 2007	Y (merged with above)
			How far into the future do you plan your fishing business activities?	Qualitative, consequently turned to	Novel: Influenced by Marshall *et al.,*	Y

		are considered to be able to buffer against future risks (Marshall *et al.*, 2010)		Likert scale (see main text)	2010	
			How many people do you employ?	Number of people	Novel: Influenced by Marshall *et al.*, 2010	Y
	Financial status and dependence on fishing	Greater dependence upon fishing and less diversity in income can lower AC due to greater reliance on the resource. Those with more debts or loans may have less financial flexibility (Marshall *et al.,* 2010; Bennett *et al.,* 2014; Islam *et al.,* 2014)	As a proportion (%), how much of your personal income comes from fishing?	Percentage proportions	Novel: Influenced by Marshall *et al.*, 2010	Y
			What proportion of your household income comes from fishing?	Percentage proportions		N
			Do you have any financial loans or debt? If so, what type?	Qualitative description	Marshall *et al.*, 2010	N
Organisation	Formal and informal social networks	Formal networks include connections with government agencies or managers. Informal networks can be with community members and friends. People who are less well connected are expected to have lower AC as they may have less support, access to new ideas and information and feel more isolated (Marshall *et al.,* 2010; Marshall and Stokes, 2014; Cinner *et al.,* 2018)	I have strong friendships within this community where I work	Likert scale response	Marshall, 2011	Y
			I have good networks with and feel connected to government agencies	Likert scale response	Adapted from Marshall and Stokes, 2014	Y
			I often discuss my fishing practices with other fishermen	Likert scale response	Adapted from Marshall and Stokes, 2014	Y
			Are you a member of a fishing association or producer organisation?	Qualitative description	Novel	N

Agency	Personal agency – self efficacy to cope/adapt to change	AC can be influenced by how people perceive themselves to be able to cope or adapt to future risks as this can affect behavioural intentions to act and willingness to use information in future adaptation (Grothmann and Patt, 2005; Seara, Clay and Colburn, 2016; Cinner *et al.,* 2018). In the second statement here, ability reflects personal feelings of being able to adapt but can also capture wider feelings of what may limit peoples' ability e.g. management rules	I have the necessary skills to adapt to any potential impacts of climate change on my fishing business	Likert scale response	Novel	Y (merged with below)
			I have the ability to adapt to any potential impacts of climate change on my fishing business	Likert scale response	Novel	Y (merged with above)

* Statements had five possible answers, ranging from strongly disagree (1) to neither agree nor disagree (3) to strongly agree (5).

- Adaptive capacity

A Principal Components Analysis (PCA) was undertaken to explore potential associations between dimensions of adaptive capacity and whether patterns emerged among fishers on the resulting axes. Analyses were performed using R software and the packages *FactoMineR* and *factoextra* (Lê, Josse and Husson, 2008; Kassambara and Mundt, 2017; R Core Team, 2018). Some indicators were modified before inclusion in the PCA. The two statements '*I am often thinking of new ways to improve my fishing business'* and '*I am interested in learning new skills to benefit my business*' were averaged into a single scale, as responses were strongly correlated. The two statements '*I have the necessary skills to adapt to any potential impacts of climate change on my fishing business*' and '*I have the ability to adapt to any potential impacts of climate change on my fishing business*' were averaged into a single scale for the same reasons. For the question '*How far into the future do you plan your fishing business activities?*', answers were grouped into very short term/short term/medium term/long term. Very short term ranged from planning at daily, weekly, monthly time scales to a maximum of one year ahead. Short term ranged from one year to five years. Medium term ranged from six to ten years ahead. Long term planning ranged over ten years ahead. For the question '*How many people do you employ?*' in instances where fishers didn't directly employ other fishers, number of crew was recorded to indicate the number of individuals dependent on that skipper.

Other indicators were excluded to avoid including too many variables within the analysis relative to the sample size and/or due to their unsuitability with assumptions of a PCA. The questions '*Are you in any financial loans or debt?*', '*Do you/ have you worked outside of the fishing industry?*' and '*Are you a member of any fishing associations or producer organisations?*' were excluded from analysis because binary Yes/No data were not suitable for inclusion within a PCA alongside other variables. Furthermore, converting fishers' answers into binary answers lost contextual information such as what types of loans they had or what association they were part of. Personal financial dependency upon fishing was included to maintain consistency with other variables that also measured adaptive capacity at the individual scale. Household financial dependency was excluded. The final list of indicators used within PCA are highlighted within Table 5.1, and all indicators were scaled within the analysis.

A parallel analysis was undertaken to determine the optimal number of components to retain within the PCA analysis. A parallel analysis is an empirical method which is more objective than the scree test (Horn, 1965). It builds upon the assumption to retain components with an eigenvalue greater than one (Kaiser, 1960) but instead uses simulation methods, using randomly generated data sets that have the same number of observations and variables as in the original data set, to generate adjusted eigenvalues (Horn, 1965; Hayton, Allen and Scarpello, 2004). 1000 iterations were undertaken.

Hierarchical Agglomerative Cluster analysis (HAC) using Euclidian distances and Ward’s algorithm (Ward, 1963; Husson, Lê and Pagès, 2017) was undertaken on the PCA scores to identify if individuals could be grouped based on aspects of their adaptive capacity. These groups were also examined to understand if they differed regarding fishers’ socio-demographics including fishers’ age, years of fishing experience, sector, ownership of vessel and education.

Results

Perceived future impacts

Fishers described a number of climate change impacts that could affect different aspects of fisheries in the future (Fig. 5.1). For impacts on the physical sea environment, fishers most frequently answered ‘yes’ that sea temperatures, sea levels and storminess could be affected in the future, with answers commonly stating that seas would warm:

> *“It will affect sea temperatures yeah, they'll go higher. You know they're talking that climate change is going warmer, temperatures are going up.”,*

sea levels would rise:

> *"If the polar caps melt the sea level will go up.",*

and storms would increase in number and/or severity, for example:

> *"Yeah I think you're going to get more, stronger storms and higher wind speeds."*

For some fishers, even though they felt the aspect such as sea levels or storminess would be affected, they were not sure on how it would be affected. There was also greater uncertainty regarding how sea chemistry, sea nutrient levels or sea currents could be affected. Fishers often said that they were not scientists to allow them to say if these aspects would be affected, for example:

> *"Oh I don't really understand that, I don't know. That's more scientific."*

and

> *"I don't know about that, I'm not a scientist. I don't know."*

Fishers described a range of future impacts of climate change on fish stocks, with changes in fish distributions including stocks shifting northwards and new species arriving being the most common answer.

As some fishers stated:

> *"I think depending on the, going back to the temperature, it only has to really go up a half a degree and it makes a lot of difference doesn't it. I think you might see, especially over here, you might see different sorts of species appearing in the waters, like the anchovies appearing cos they always sort of used to be Mediterranean and now it's a bit warmer. And I know down in Cornwall they did start having a few Tuna, and stuff like that really."*

and

> *“We could get more warm water species that we don't normally see... And it could diminish things like the cod stocks cos they're cold water fish. Any cold-water fish will go further north, well that's just pretty normal and assuming that climate change is correct.”*

Fishers also mentioned that climate change could affect the seasonality of stocks and/or the spawning cycles of fish. As one fisher stated:

> *“The only thing really, maybe, is the spawning seasons will change you know, different fish will come on and appear at different times of year.”*
> and
>
> *“It’ll speed the seasons up. The lemon sole used to come in December even before that but now we won't see them till at least February, so it seems like the seasons are getting later, and shorter.”*

Changing abundances including increases and decreases of stocks were also discussed. For example:

> *“If anything it might increase fish stocks.”* and
>
> *“A lot of fish depend on the temperature of the water to reproduce so I think on those grounds alone there will be a big decrease in stocks – it's a matter of survivability of things.”*

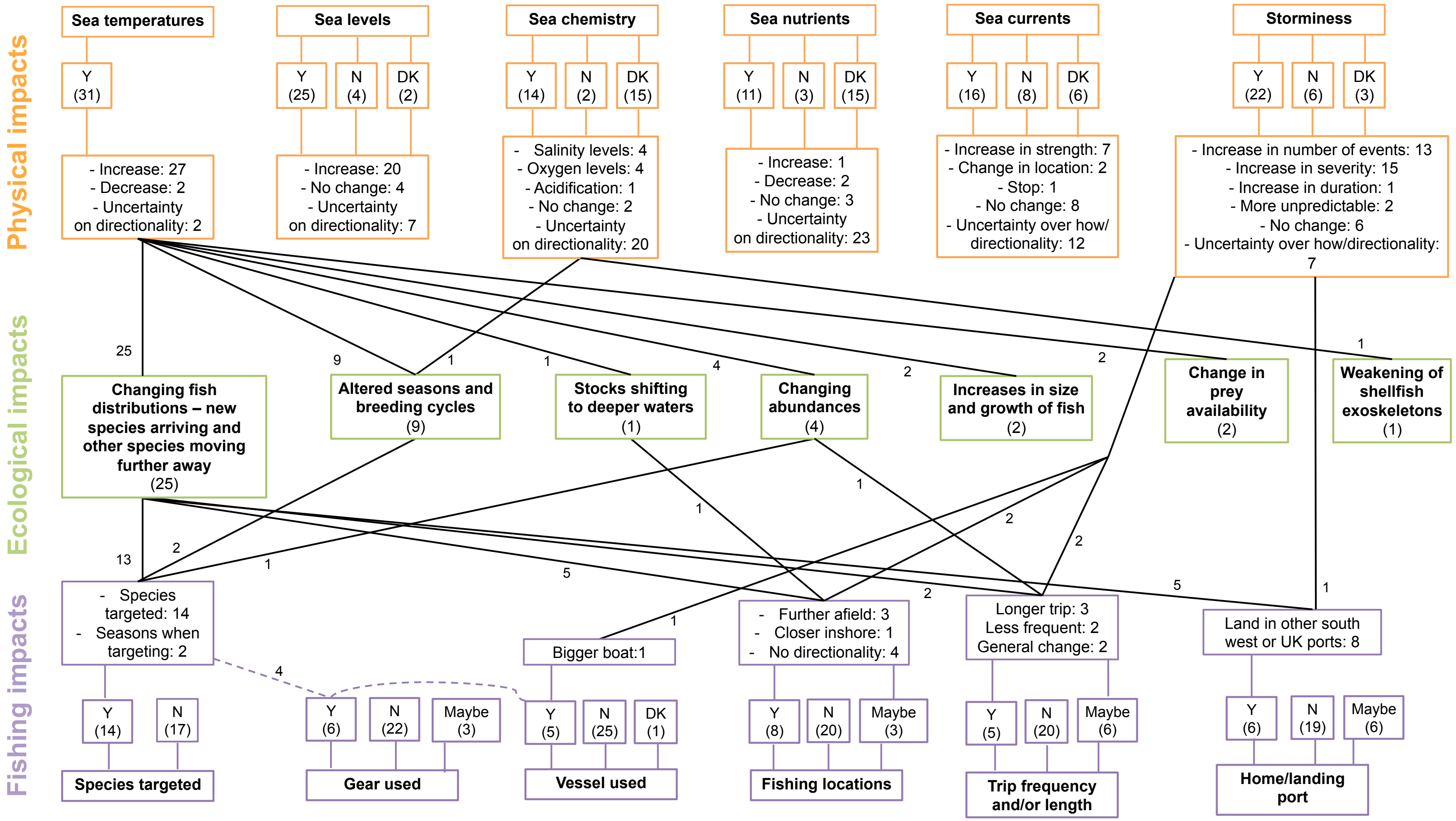


Figure 5.1. Relationships between perceived future impacts of climate change on fisheries by fishers. Numbers within boxes represent number of fishers answering 'Yes' (Y), 'No' (N) or 'Don't know' (DK). Lines between the three dimensions represent attributions fishers gave i.e. increasing temperature driving changing fish distributions and therefore changing species targeted. Numbers next to lines indicate the number of fishers that made direct attributions between the dimensions.

For those fishers that provided ideas of what would drive the changes in fish stocks (changing distributions, abundances, spawning, growth and altering the availability of prey), increasing sea temperature was commonly suggested as the main driver (Fig. 5.1).

Regarding future impacts on fishing practices and what fishers felt would have to change with climate change, the majority of fishers felt that they wouldn’t have to alter their practices in the future. The most common aspect that fishers did think would have to change was the species that they targeted (14 out of 31 fishers answering ‘Yes’; Fig. 5.1). Fishers felt this aspect would change because species may alter their distributions, change in their abundance or the seasonality of the targeted species would change into the future. As some discussed:

> *“I think less flatfish, that’ll ease off and we'll be targeting squid and cuttlefish more.”*

And

> *“Well probably, if the water warms up, probably won't see pollock, whiting and things like that what we do now. You know cod's not such a big fishery now but we used to see, used to make, used to be cod, but hardly see cod now and that may be due to temperatures of the water as it were and sends them off to deeper water as it were. Yeah I suppose we would have to change the species we target.”*

Smaller numbers of fishers felt that gears, vessels, fishing locations, trip length/frequency or landing/home port would have to change with climate change compared to those that did not (Fig. 5.1). For fishers that said aspects of their fishing practices would change, there were differences between them in how they would change. One fisher thought that they would need a bigger vessel to allow them to fish in more stormy conditions. Others noted that while they felt their vessel might have to change in the future it would depend on the species they would be targeting and gears used, and so they were not sure in what specific way it would change. Six fishers thought that fishing locations could change, moving further afield as stocks moved their distributions further north or to deeper waters. For example:

> *"Well that probably will change, I think we will have to go further afield. I think climate change could deplete stocks because what we catch here might move further north, so we might have to go further north."*

One fisher thought that storms could cause them to fish further inshore:

> *"Depending on what the weather's like might end up doing, like when you're mid water fishing, because if the weather's quite severe sometimes you might be doing a lot more fishing closer to land."*

Another felt storms could cause them to shift locations due to the effects it has on the softness of the ground and the ability of the gear to tow upon it. Four were unsure how fishing locations would be affected stating that it depended on other decisions, for example:

> *"Well, if you left the area to follow the fish it [fishing locations] would change, but if you adapted your boat to catch whatever species was coming into the area then location wouldn't change. It depends if you're going to catch the native species which isn't the native species anymore, or not."*

There were also differences in how fishers felt trip frequency or length of fishing trips could be affected. Three fishers thought that trips would become longer, often due to stocks shifting and moving further away, while two said that they would become less frequent due to poor weather:

> *"We're certainly getting less time, we're doing less sea time due to the bad weather cos the bad weather seems to go on for longer, the winters seem to be windier."*

Two were unsure and similarly to above stated that it depended on whether fishers would choose to move with the stock or stay and target another species.

Eight fishers also noted that climate change could require them to change their home or landing port, often in the context of fish stocks shifting in their distributions. For example:

> *"Generally you'd like to always land in your home port but depending on what the fishing is, you might have to go a little bit, say down Plymouth or something."* and
>
> *"If the species moved, particularly to the west of here, we wouldn't necessarily be able to catch it in that deep water... If you imagine a port like Brixham catching fish pretty much within 100 miles of here, you know. When we travel 100 miles, that's a long way for us, but if it moved 150 miles from us, that would change things quite a lot. You might be asking things about whether you'd need to base your boat somewhere else, perhaps in Newlyn."*

However, many fishers answered that they would not change certain aspects of their fishing practices in the future with climate change. This number differed depending on the fishing practice in question (Fig. 5.1), as fishers did not always answer 'no' to changing every aspect of their fishing practices – i.e. they could answer 'yes' to changing species targeted but 'no' to all other aspects (see Table. A5.1). Answers of 'no' were most common for changing vessel (25 out of 31 fishers saying 'no'), gear used (22), trip location (20), trip length/frequency (20) and home/landing port (19). Nine fishers answered 'no' to changing all aspects of their fishing practices.

Reasons fishers gave for answering 'no' to changing all or certain aspects of their fishing practices are displayed in Table 5.2, which were grouped into four main themes. Some fishers did not give reasons for their answers, simply stating 'no'. The first theme centred on personal reasons that fishers gave. Some described how they liked fishing from Brixham and would be unwilling to move elsewhere to fish, alluding to place attachment. For example:

> *“Oh no [change home port?]. I live here, and I don't have any plans of moving. If fishing goes down the pan then I’d have to go back to teaching.”*

Others mentioned their preference for the style of fishing they were undertaking and that they would not want to change to another method with different gear or vessel:

> *“In my case never, I mean I intend to stay trawling now. I've done the scalloping, I've done this, I've done that. To me the trawling, it's definitely the one with the least impact on the seabed.”*

Fishers also stated how they liked their ‘own bed at night’ and as such would not want to extend fishing trips or land their catch in other fishing ports. As one said:

> *“I don't venture very far, always fishing in the coast really. That's just simply me cos I want to be in my own bed at night.”*

Another theme discussed by nine fishers was regarding perceived ‘stability’ of fishing practices. Fishers discussed how fishing practices had stayed very similar during their fishing lifetime, particularly with regard to fishing grounds, and that they didn’t think this would need to change in the future. For example:

> *“In all the years I've been fishing I can go back to the same areas at certain times of the year and the same fish will be there. Different tides, same areas. You get the same areas on the same tide and usually you get the same fishing.”*

Within this theme two fishers felt that climate change would not impact them and therefore not require them to change their fishing practices.

Two stated that they answered ‘no’ because they were uncertain of how it could affect them (Table 5.2).

Fishers also answered ‘no’ to changing their fishing practices in the future using reasons that they would *not be able to* change, suggesting they were constrained in some way to change. These reasons are discussed in the following section ‘Perceived constraints to adaptation’.

Table 5.2. Reasons fishers gave for saying they would not change their fishing practices. Sample size: 31 fishers

Reasoning	Description	Example
Personal feelings and reasons (11)	Fishers had personal reasons as to why they may not change fishing practices, including personal attachment to fishing only from Brixham, preference for a particular style of fishing/vessel or being at a personal limit for how long they would want to fish for or where, or their age meaning they wouldn’t feel the effects of climate change and so wouldn’t alter their practices.	“I'm quite happy just to be out of Brixham. I don't venture very far, always in the coast really. That's just simply me cos I want to be in my own bed at night.” “Unless it gets to the point where I can't catch what I want to catch and then got to move onto somewhere else. If that happened I'd just sell up and do something else. I love it here.” “Don't want no bigger vessel than this, no bigger than this. I don't believe in all these tank ships, and you can make money with a 30m boat. 30m is plenty.” “Oh no I'm not spending any more time fishing.” “No, I don’t think so. I don’t think so in my time.”
Perceptions of stability (9)	Some fishers discussed how aspects of fishing, particularly fishing grounds, were similar from year to year and provided stability; thus shaping perceptions that fishing practices wouldn’t change or need to change as they had stayed similar in the past. Others felt there would simply be no changes that would require them to change fishing practices.	“Fishing locations have been pretty much the same ever since I started.” “No cos the fishing stocks still appear in the same places year after year after year.” “No, that's [fishing locations] been the same last 30 odd years.” “I just don’t think anything will happen.” “Nothing at all will be affected.”
Uncertainty of impacts (2)	Two fishers specifically said that they were unsure on the effects climate change would have upon their fishing practices and as such they said no.	“You know if it did change drastically I don't know how it would affect us, I've only been doing it three years this kind of fishing. I'm not sure, so I’ll say no [to changing fishing practices].” “No. It's the unknown isn't it – we’ll cross that bridge when we come to it.”
Impacts the same across the region (1)	One fisher felt that those fishing only in the south west region will experience similar weather conditions regardless of if they changed fishing practices and fished elsewhere, so they wouldn’t therefore feel benefit if they moved areas.	“Well if get a storm in the channel it’s going to be in all the channel, not like we're in Brixham and can nip up to Portland know what I mean, you know when get a strong south west gale it's going to affect the whole of the west country. Just stay where you are.”

Perceived constraints to adaptation

Three main constraints were identified through thematic analysis that could influence fishers' ability to change and adapt their fishing practices (Table 5.3). The most common theme centred upon UK management structures and measures, which fishers said constrained their flexibility to change practices. Some fishers stated that management limited where they could fish or what they could catch, and therefore restricted the options available to them (Table 5.3). As such even if fishers felt that changing fishing practices in the future may be needed, they felt that the way fisheries were currently managed would limit them from doing so. For example:

> *"It all depends on what they say, what happens with the government and what areas are shut off. Cos they're making it harder and harder for us."* and
>
> *"It's outside influences on the fishing industry itself. You know, fishing practices in general, we don't really, the only people we're controlled with is people outside the box, we go out, do what we need to do and then we come back in again. It's somebody else that tells us that can't fish there cos this has happened or can't fish there cos that's happened."* and
>
> *"No, because what I do to catch fish is all to do with regulation of the net size to catch the fish."*

Some said that fishers had been pushed into certain ways of fishing due to management restrictions on quotas or fishing grounds, therefore making fishers more specialised and as such harder for them to change to another mode of fishing.

As one said:

> *"You know I'd like to fish half the year and scallop half the year but they took that away from us now, I think. […] You know a lot of people have changed to an expensive way of fishing cos they're been pushed into it."*

As such, some fishers suggested that management could become more flexible:

> *“We need less restrictions with management and more flexibility.”* And
>
> *“Well, get the government to understand when the fish is here and when it isn’t here. Which is due to water temperature which I suppose is due to climate change. Fish come here autumn, winter, summer, so adapt the quotas accordingly.”*

Some alluded that relationships between the industry and management could be developed to help direct future management that was more appropriate for fishers needs and ‘listened to them’. For example:

> *“If someone could come down and speak to fishermen and not just say you need to do this, you need to do that, which is what happens. Ask the people themselves what they think should be done. People been doing this for 30,40 years like me have got more idea, and I'm not being nasty against you, sitting in an office or something like that, but they need to ask the people who are doing it. What do you think, what's a good way forward and that lot.”*

The second set of constraints identified by fishers centred upon their occupation and current fishing practices (Table 5.3). Numerous reasons were given and included the need to undertake shorter trips to preserve freshness of the catch (therefore limiting fishers in extending their trip if needed):

> *“We always try, we have tried to refrigerate, but to keep stuff fresh we don’t keep it for longer* [than necessary].”

Another said that because they fished alone and couldn’t take more crew on the boat, they couldn’t change to another mode of fishing because there was only so much one person could do (Table 5.3). Others said they were constrained by the hours they could fish for due to them operating on small boats and therefore they were restricted to daily trips.

Table 5.3. Perceived constraints fishers felt would affect their ability to change fishing practices in the future. Sample size: 31 fishers

Type of constraint or limitation	Constraint or limitation identified	Description	Example
Constraint – Institutional	Management constraints (18)	Changing fishing practices is constrained by what current management allows fishers to do, meaning that they may not be able to change even if they wanted or needed to.	“It's the influence from the MMO restrictions that cause people to change the species targeted, change the gears used, the vessel, fishing locations, trip frequency, change the home/landing port, that's all changes forced upon the fishermen from changes that the MMO make, and there's a history of that as well.” “That all depends [changing fishing locations] on whether we're allowed to go there cos of these conservation zones, and if they get their way they'll be conservation zones right round the coast line.” “The problem is we can't change it. This is what we catch and what we're allowed to catch isn't you know, I mean there's a lot of pelagic fish here but years ago everyone would go could go and catch that. But not allowed to catch this, not allowed to catch that, so we can't change. Got to keep flogging the dead horse if you know what I mean.”
Constraint – Social and Cultural (Occupation)	Current fishing practices (11)	Trip length or frequency limited due to need to preserve freshness of catch which in some vessels is stored on ice. (2)	“Part of what we do is take great care of what we catch, slowly icing it… so it comes out stiff and bright eyed. We try to keep the time at sea as short as possible purely for that reason.”
		Targeting of species is done on seasons not species (therefore can’t simply switch targeting to another species as limited to seasons). Others suggest gear is not selective in how it targets, meaning fishers couldn’t switch target species. (3)	“We can't target a particular species, it's seasons. Sometimes they're there, sometimes they're not. You know, it's not a specific species that we go for You know we can go lemoning and catch bass, can go cuttlefishing and get load of squid. You know, it's just previous years you've got a reference to it and you go well this time last year we were there and we'll try, sometimes it's not even there.” “Nothing will change cos our gear isn't selective in what it catches, it catches whatever is there at that time.”
		Crew limitations means can’t necessarily do other types of fishing or change if needed as limited by being on own. (1)	“You know I'm on my own so that's another thing, I can't afford to take a crew member you know, it's not all singing and dancing this fishing job, really isn't. You can only stay awake so long can't you.”
		Boat limited in how far can fish or what can	“You can only go to where your boat can take you. You know only limited as to

		catch. (1)	the size of your boat and its capacity. Can't really do any more than that. We haven't really got ocean going vessels, just little day boats like that. We're limited.”
		Skipper was not the owner, meaning decisions of changing practices out of their direct decision making. (1)	“That's up to the owner, that's not up to us. They could have us at sea 24/7. Boat never stops. Or could say can die it down a little bit but I mean that's their discretion… They tell us what species to catch and what not to catch.”
		General time limitations due to mode of fishing prevent moving fishing grounds, extending trip length or frequency. (2)	“No not for me, because we're running in day in day out, I ain't got the time to, not enough hours in the day to go.”
		Perceived limit to how could update or modify boat further. (2)	“I think like I say with the gear and vessels now I don’t think you could update them anymore. The technology in them now is as far as they could go I suppose unless they got robots on the deck doing it all for you.”
Constraint - Financial	Financial constraints (11)	Fishers discussed that changing fishing practices was restricted by the financial costs of purchasing new gears, modifying vessels and switching to a new way of fishing.	“Only thing is if I had to change the gear, the money side of it - it's so expensive [to buy].” “Just got the financial implication of changing things, that's the only thing that would limit me.” “Well the only thing that limits us is the financial costs of changing fishing practices.”

For example:

> *“No not for me, because we're running in day in day out, I ain't got the time to, not enough hours in the day to go fish somewhere else.”*

Others said that targeting of species was based around seasons and not direct species specific targeting, thus restricting their ability to target a new species that may appear due to shifting distributions. One fisher said that changing fishing practices was not within his own decision making, so he couldn’t change that unless the vessel owner felt that would need to change (Table 5.3).

The final constraint identified focused on financial constraints. These were discussed by 11 fishers as affecting their ability to modify or purchase new gear and adapt their vessel to accommodate different gears. As one stated:

> *“I think most of those things [constraints to adapting] are sort of financial, and if I had to raise a lot of money to go and fish somewhere else or make my boat massively different, I don't think I could easily do that.”*

Fishers mentioned that this could be overcome through grants or money being made available to them by the government, similar to grants that are currently made available to improve vessel safety. For example:

> *“If you had to change to do a different type of fishing, and obviously stuff costs money, it would be quite handy if they sort of gave you some sort of grant to do something else.”*

Adaptive capacity

Parallel analysis indicated that two components—axes—should be retained within the PCA (Appendix D Fig. A5.1). These axes collectively accounted for 37.9% of variance explained. The loadings for each variable onto the two axes are shown in Table 5.4 and their associations with the axes in Appendix D Fig. A5.2. For both axes, a higher perceived ability to adapt was associated with a higher score (Table 5.4). Variables loading strongly onto the first axis were associated with business approach, social networks and personal agency. The variable ‘*Fishing to me is a lifestyle, it’s not just my job*’, loaded positively onto this axis. One variable measuring occupation mobility—*'I would be willing to leave this region if fishing opportunities were better elsewhere’*— also loaded positively onto this axis.

Table 5.4. PCA loadings for each variable included within the analysis

Statement	PC1 Axis	PC2 Axis
I can't imagine doing any other job except fishing*	0.03	**-0.43**
Fishing to me is a lifestyle – it's not just my job*	**0.33**	-0.16
I have been tempted to leave fishing and find an alternative income/lifestyle elsewhere	-0.11	**0.52**
I would be willing to leave this region if fishing opportunities were better elsewhere	**0.30**	-0.16
I have other career options available to me if I decide to no longer be a fisherman	0.16	**0.36**
I am interested in learning new skills and am often thinking of new ways to improve my fishing business	**0.48**	0.07
I have strong friendships within this community where I work	**0.38**	-0.00
I have good networks with and feel connected to government agencies	**0.36**	0.11
I often discuss my fishing practices with other fishermen	-0.03	0.03
Self-efficacy to adapt scale	**0.31**	**0.34**
Number of people employ and/or crew	0.21	**-0.30**
Personal income from fishing	0.07	**-0.33**
Future planning of fishing activities	**0.31**	0.06

* Statements reversed, therefore agreement indicates higher adaptive capacity

Overall, higher scores on this axis indicated that fishers had a greater sense of connection within their social networks, a higher belief of being able to adapt, and a greater sense of planning and developing their business in the future. Fishers would be willing to leave the region if there were *fishing* opportunities elsewhere, and had higher sense of attachment to fishing because they saw it as more of a lifestyle than purely a job. This axis is termed 'Long term attachment to fishing'.

Variables contributing to the second axis were those measuring attachment to occupation (two of the three statements). One of these—'*I can't imagine doing any other job except fishing*'—loaded negatively onto this axis. The other—'*I have been tempted to leave fishing and find an alternative income/lifestyle elsewhere'*— loaded positively. The statement '*I have other career options available to me if I decide to no longer be a fisherman*' loaded positively onto the axis. Financial dependency and crew size loaded negatively onto the axis. Interestingly, personal agency loaded similarly onto this axis as the first. Therefore, fishers with a higher score on this axis had less attachment to their occupation and greater agreement that they had other career options available to them. They also had lower financial dependency on fishing, fewer crew to support and a high sense of being able to adapt to future change. Higher scores therefore infer higher adaptive capacity. This axis is termed ‘Occupational flexibility and mobility’.

Cluster analysis identified three main groups of fishers along these two PCA axes (Fig. 5.2), which are described in turn. Differences across groups are summarised in Table 5.5.

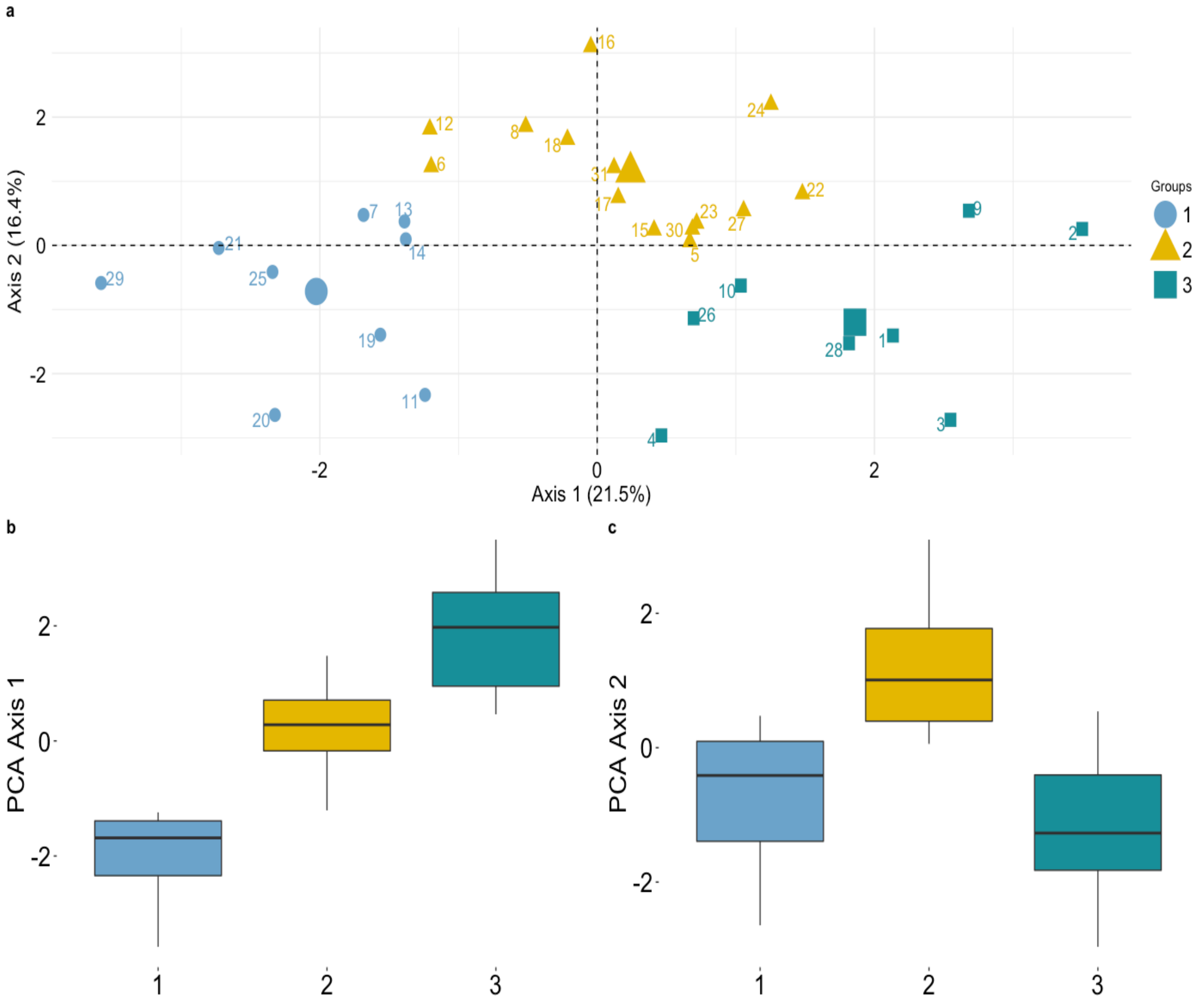


Figure 5.2. PCA results. A shows individuals on the two core PCA axes, coloured according to the results of the cluster analysis. B and C show differences between the groups on the two axes. Black line in box indicates median.

- Group One

Group One (29% of fishers) had low scores on both the ‘Long term attachment to fishing and ‘Occupational flexibility and mobility’ axes (Fig. 5.2). This indicates these fishers did not tend to learn new skills or think of new ways to improve their business, had a lower sense of connectedness within their social networks and felt less mobile in terms of moving to other regions to pursue fishing or changing occupation. These fishers had a lower sense of ability to adapt or cope with climate change compared to other groups of fishers given their low scores on both axes. This group had the highest average age and the most fishing experience (Table 5.5). Fishers tended to plan their future activities on very short-term time scales. Five of the nine fishers had previous experience of employment outside of fishing and jobs included working in a factory, as a fisheries inspector and within the navy. These fishers had high financial dependency upon fishing (Table 5.5). All fishers had left school before receiving any school qualifications. Numbers of fishers were similar within each sector, across vessel ownership and having/not having loans (Table 5.5). Six fishers were not members of a fishing association or organisation.

- Group Two

These fishers, representing 45.2% of fishers, clustered within the middle of the ‘Long term attachment to fishing’ axis and had the highest scores on the ‘Occupational flexibility and mobility’ axis compared to the other groups (Fig. 5.2). These fishers therefore showed flexibility regarding their occupation (but not necessarily willing to leave the region; Table 5.4) as well as interest in learning new skills or ways to improve their business and felt relatively well connected within their social networks. This group had beliefs that they would be able to adapt to future change. Most fishers had had previous employment in a range of other jobs including tug boat drivers, building and construction and factory work, despite most fishers in the group having left school with no qualifications (Table 5.5). There were similar numbers of fishers in each sector, but a large proportion of the group were not members of fishing associations (Table 5.5). Ten fishers were vessel owners and six were not. Although this group had moderately less financial dependence on fishing compared to the other groups, values still indicated high dependency on fishing (Table 5.5)

- Group Three

Group Three (25.8% of fishers) had the highest scores on the ‘Long term attachment to fishing’ axis of the three groups. However, similarly to Group One, it had lower scores on the ‘Occupational flexibility and mobility’ axis. Fishers within this group were more ‘invested’ in fishing as an occupation and way of life. They were more likely to want to develop skills and new ways to develop their business, more likely to plan ahead, felt connected within their social networks and had beliefs they could adapt to future change. Most fishers were owners or part owners of their vessels and seven were members of a fishing organisation. These fishers were similarly highly financially dependent on fishing as other groups and had larger crew sizes. Fishers within this group were younger and had less fishing experience compared to the other groups (Table 5.5). Six fishers within this group were on over ten metre vessels (Table 5.5). Three fishers had had employment in other jobs, each listing numerous different past occupations.

Perceptions across groups

Within Group One most fishers did not think that they would have to change most aspects of their fishing practices (Table 5.6), with similar numbers answering ‘no’ for each aspect. The aspect least commonly answered ‘no’ was species targeted. Three fishers within the group answered ‘no’ to changing all aspects of their fishing practices. Regarding the reasons identified through thematic analysis as to why fishers would not or could not change their fishing practices, no major trends within this group emerged, with similar numbers providing reasons for each theme (Table 5.6).

Roughly half of the fishers within Group Two answered ‘no’ for changing each aspect of their fishing practices (Table 5.6). The number of fishers providing reasons for ‘would not’ change were similar across the four themes. Management constraints were the most common constraint perceived by this group, followed by financial and current fishing practices constraints.

Table 5.5. Socio-demographic and occupation descriptions for each group. Numbers represent number of fishers unless otherwise stated.

Socio-demographic and occupation descriptions		Group 1	Group 2	Group 3
Number of individuals in group		9	14	8
Mean Age (Standard deviation)		57 (5.7)	49.8 (9.9)	48.7 (6.4)
Mean years of experience fishing		38.1	33.2	31.5
Number of fishers with previous employment in other sectors		5	13	3
Sector:	Over 10 m	4	7	6
	10 m and under	5	7	2
Vessel ownership	Yes	5	8	5
	Part			1
	Not an owner	4	6	2
Education	Left without qualifications	9	12	4
	Higher qualifications	0	2	4
Number of fishers who are members of fishing organisation	No	6	9	1
	Southwestern Fish PO (SWFPO)	3	4	5
	Scallop Association (SA)		1	
	SWFPO & SA			1
	Southwest Handline Fishermen’s Association			1
Mean personal income from fishing (%)		97.7	96.4	100
Mean household income from fishing (%)		86.1	82.1	89.3
Number of fishers with loan, debt or mortgage	No loan	4	7	2
	Mortgage	3	3	2
	Mortgage and vessel loan	2	2	3
	Mortgage and personal loan		1	
	Vessel and personal loans		1	
	Other unspecified loan			1

The majority of fishers within Group Three answered that they would not change their fishing practices in the future (Table 5.6). Five of these answered ‘no’ to changing all aspects of their fishing practices. The most common reason fishers gave for not altering their practices centred on personal reasons, which may also act to contribute to their high attachment to fishing as determined by the PCA axes. Fishers within this group commonly identified management as a constraint to their adaptation, followed by current fishing practices.

Table 5.6. Number and percentage of fishers within each group who answered ‘no’ to changing fishing practices with future climate change. Number and percentage of fishers providing reasons that they wouldn’t change practices or would be constrained in doing so are also presented.

Number answering ‘no’ to changing fishing practice	Group 1	Group 2	Group 3
Number of individuals in group	9	14	8
Species targeted	3 (33.3%)	8 (57.1%)	6 (75%)
Gear used	7 (77.7%)	7 (50%)	8 (100%)
Vessel used	8 (88.8%)	9 (64.2%)	8 (100%)
Fishing locations	6 (66.6%)	7 (50%)	7 (87.5%)
Trip frequency and length	7 (77.7%)	7 (50%)	6 (75%)
Home/landing port	6 (66.6%)	7 (50%)	6 (75%)
Number of fishers providing reasons for ‘would not change’	Group 1	Group 2	Group 3
Personal reasons	4 (44.4%)	2 (14.2%)	5 (62.5%)
Perceived stability	3 (33.3%)	1 (7.1%)	2 (25%)
Uncertainty of impacts		1 (7.1%)	1 (12.5%)
Changing practices little benefit		1 (7.1%)	
Number of fishers providing perceived constraints	Group 1	Group 2	Group 3
Management	3 (33.3%)	9 (64.2%)	6 (75%)
Current fishing practices	4 (44.4%)	4 (28.5%)	3 (37.5%)
Financial	3 (33.3%)	7 (50%)	1 (12.5%)

Discussion

This study finds that despite fishers perceiving future physical and ecological climate change impacts, most thought that they would not have to change their fishing practices in response. Reasons for this centred on fishers not perceiving a need or want to change, often due to personal preferences or perceived historical stability, and/or due to constraints they identified that affected their ability to change, such as inflexible management and lack of finances. Fishers' ability to adapt to future climate change was explored further through analysis of three dimensions of adaptive capacity: flexibility to adapt, their social organisation and their personal agency. Results indicated that fishers' differed according to two core axes and found three distinct groups who had different adaptive capacities and perceptions of their ability to adapt. Through exploring perceptions alongside assessing adaptive capacity a more detailed understanding of individuals' future adaptive responses and abilities could be gained.

Fishers discussed a range of physical and ecological impacts that they thought may occur with future climate change. These findings build upon other studies which have examined fishers' historical and present-day perceptions of climate variability, such as ocean temperatures and changing weather patterns, or observed alterations in fishery resources, and identify that fishers' observations link to those of the scientific community (Nursey-Bray *et al.,* 2012; Lima *et al.,* 2017; Blair and Momtaz, 2018; Martins and Gasalla, 2018). Furthermore, this research found that fishers' future perceptions can also reflect wider scientific projections. Fishers noted that increases in sea temperatures would lead to changes in species distributions, abundances and other aspects such as growth; changes that are expected and have been projected within UK seas and more widely (Cheung *et al.,* 2013; Jones *et al.,* 2013; Rutterford *et al.,* 2015; Pinnegar *et al.,* 2017). It is suggested here that individual local ecological knowledge, for example fishers' observations of patterns between species distributions and water temperatures, alongside external actors communicating information, such as the media, played a role in shaping these perceptions (Weber, 2010; Rudiak-Gould, 2014). These findings raise questions of whether awareness of impacts leads to individuals feeling subsequently inclined or motivated to respond to such impacts, which this study explored further.

Some fishers indicated that they would change their fishing practices in response to future climate change impacts, providing useful information from fisheries management and adaptation perspectives. A common response among fishers was that they would alter the species that they targeted in the future. Changing target species raises important questions as to what these other species would be, whether changing targeting could pose a threat to the sustainability of those species and how future fishing effort would need to be managed. Emerging species may not have management quotas associated with them, such as is the case for red mullet and anchovy which are increasing with warming in UK seas (Simpson *et al.,* 2011; EU Council, 2017; Pinnegar *et al.,* 2017). Absence of quotas would provide fishers with the flexibility to target emerging species if they wanted to take advantage of new opportunities. While in the short-term lack of regulation may be beneficial from an economic perspective—provided there are markets available and consumer demand—increasing effort on unmanaged stocks poses issues for long-term sustainability from both ecological and socio-economic perspectives, as the stock may be at risk of becoming overfished (Pauly, Watson and Alder, 2005). Through exploring perceptions of how fishers may think they will adapt, information can be gained on the potential implications of alterations in fishing practices as well as to how fishers may be supported in making those changes. For example, integrating fishers within decision-making processes may help develop future management approaches that allow greater flexibility for fishers targeting other species while also ensuring species are harvested sustainably (Cvitanovic *et al.,* 2018; Wilson *et al.,* 2018).

It was interesting to note that many fishers did not always think that they would alter their fishing practices in response to future climate change. This highlights that despite fishers' awareness of future climate change impacts, it may not be enough to influence their intentions to change their practices. This could be due to two, likely interacting, key reasons: 1) individuals' psychological processing and reasoning and 2) wider perceived constraints to adaptation.

The role of psychological factors in influencing behavioural intentions in the context of climate change has been well documented, with some suggesting they can even form barriers to future adaptation (e.g. Weber, 2010; Gifford, Kormos and McIntyre, 2011; Nursey-Bray *et al.,* 2012; van Putten *et al.,* 2015a, Bercht, 2017). Bercht (2017) argues that owing to fishers' strong occupational and identity attachments to fishing, fishers may unconsciously ignore new information, alter their beliefs or dismiss causal linkages of climate change despite viewing it as an issue, so that they downplay the need to adapt to climate change. Many fishers within this study showed attachment to living and fishing from Brixham and seeing fishing as a lifestyle and not just a job. While fishers were aware of climate change impacts, these reasons may have subconsciously led them to dismiss linkages between physical and ecological climate change impacts and effects upon them because the reality of needing to change practices would challenge what they valued (e.g. living and working in Brixham). Additionally, some fishers answered ‘no’ to changing their practices because of perceived historical stability regarding aspects of their fishing practices, such as fishing grounds. Fishers may have used this reasoning of perceived stability to further confirm their beliefs that climate change may not pose a serious threat or result in impacts beyond their current thresholds they are used to, and therefore not require them to change their practices (West and Hovelsrud, 2010; Bercht, 2017).

Wider literature suggests that fishers may not express a need for adaptation because they do not view climate change as a salient issue, while other studies highlight that fishers have low risk perceptions of climate change impacts or are sceptical of its effects, and as such may be less inclined to adapt because it is not seen as a threat (West and Hovelsrud, 2010; Nursey-Bray *et al.,* 2012; Dannevig and Hovelsrud, 2016). Within this study many fishers had a high perceived ability to adapt to future change which may have led them to underestimate the risks or impacts climate change would have upon them. This may have contributed to why some fishers did not feel a need to alter their fishing practices despite perceiving that they had the ability to adapt.

In addition to psychological factors contributing to fishers not feeling they would need to adapt, a number of perceived constraints to fishers’ adaptation were also identified within this study. These aspects may have otherwise been overlooked or not considered more deeply through a purely objective approach, as highlighted by others (Elrick-Barr *et al.,* 2017; Grunblatt and Alessa, 2017). Many of the perceived constraints could influence fishers’ flexibility in the future. For example, fishers identified institutional constraints through management restrictions and rules as affecting their ability to adapt in the future. Wider criticisms have been made that fisheries management may not be flexible or adaptive enough to manage climate change effects (Burden *et al.,* 2017; Ojea *et al.,* 2017; ABPmer, 2018; Pinsky *et al.,* 2018) and therefore greater attention may be needed to further identify what specific aspects of management constrain the flexibility of fishers. Other fishers highlighted that they were financially constrained. This could limit the extent to which fishers can update or modify their gear or vessel, or invest in technologies that may assist their adaptation (Marshall *et al.,* 2010; Marshall *et al.,* 2013a; Islam *et al.,* 2014). Many of the perceived constraints form the 'opposite' of factors that enhance adaptive capacity (e.g. lack of finance can restrict flexibility and also reflect a lack of assets), but through greater exploration of the reasons why these form constraints, more context and understanding of the specific factors influencing fishers' adaptive capacity can be gained (Johnson, Henry and Thompson, 2014; Elrick-Barr *et al.,* 2017).

The extent to which the perceived constraints interact or become firmer limits which are harder to overcome also deserves consideration (Dow *et al.,* 2013; Klein *et al.,* 2014; Barnett *et al.,* 2015). For example, the extent to which fishers could overcome constraints arising from their current fishing practices depends not only upon the trade-offs they personally may have to make (e.g. travelling further for perhaps increased catches at the risk of operating in stormier conditions) but also upon wider factors including their flexibility, fishing strategies and management restrictions (Coulthard, 2012; Stoll, Fuller and Crona, 2017; Cinner *et al.,* 2018). Further research could seek to determine potential thresholds that fishers would not think it possible to overcome and explore what factors would affect these decisions. Integrating perceptions within adaptive capacity assessments can therefore provide deeper and more detailed understanding of what constraints may exist than basing assessments purely on indicator-based approaches. Such information is useful to help develop strategies seeking to build adaptive capacity across individuals and communities by highlighting where particular issues may lie (Cinner *et al.,* 2018).

Despite the broad similarities across fishers regarding their fishing strategies and perception among many of them that they would not alter their fishing practices, this study identified three groups of fishers which differed in their adaptive capacity. Group One appeared to have the lowest adaptive capacity of all fishers due to low scores on both PCA axes. These findings support wider literature which describes how older fishers can have lower flexibility due to limits on their willingness to move into another occupation, their greater attachment to their job and even finding reorganising their practices in line with change as ‘exhausting’ (Marshall and Marshall, 2007; Pita *et al.,* 2010; Seara, Clay and Colburn, 2016). Importantly, this group also felt the least able to adapt to climate change compared to the other two groups and many fishers did not think they would need to alter their fishing practices with climate change. This group forms a potentially vulnerable part of the fishing community that adaptation strategies may seek to support. Building adaptive capacity would require targeted measures that are perhaps more sensitive to the life stage these fishers are at and their potential reluctance to diversify given their attachment to occupation and/or place (Pita *et al.,* 2010; Seara, Clay and Colburn, 2016). For example, such fishers may have less interest in learning and investing in whole new methods of fishing but could be provided with financial support to assist them in modifying their current gear or improving their current vessel (Marshall and Marshall, 2007).

Fishers within Group Two showed greater occupational flexibility and mobility, and similarly to Group Three, high perceived ability to adapt to future change. Occupational flexibility and/or mobility could provide an alternative adaptation strategy if climate change resulted in changes that fishers did not feel equipped or able to adapt to, or as indicated by perceptions of the group, felt constrained by management or access to financial capital. However, fishers may not necessarily want to leave the region, which could result in fishers being further constrained in the opportunities available to them. This is because, as with other fishing ports within the UK, Brixham is listed as being in a socio-economically deprived area and social mobility ‘coldspot’, meaning that fishers may have limited alternative options available to them in which to diversify (Corfe, 2017; SMC, 2017; Seafarers, 2018). As such, while fishers may feel they have other options available to them, the wider economic reality of the region may limit them. This may mean greater support is needed for these fishers which may be provided through schemes such as the EU European Maritime and Fisheries Fund that provide financial grants and support to assist fishers diversify and develop skills in other sectors (Pita *et al.,* 2010; EU Council

Regulation No. 508/2014). Additional research regarding the points at which fishers would exit the fishery (e.g. Daw *et al.,* 2012; Pascoe *et al.,* 2015) could also help to understand how fishers may anticipate responding to future climate change.

Group Three were particularly invested in fishing, which may make these fishers more sensitive to future climate changes given their dependency on fishing (Cinner *et al.,* 2013; Marshall *et al.,* 2013a). However, other attributes, such as membership of fishing organisations that can offer support and links to management agencies, as well as fishers showing a willingness to learn and develop knowledge to help them plan ahead, may compensate for this specialisation within fishing (Marshall *et al.,* 2010; Marshall *et al.,* 2013a; Williams, Fenton and Huq, 2015). For this group, further understanding of the institutional constraints, which many fishers' in the group perceived, as well as other constraints that may affect fishers' flexibility to change practices in the future may be of particular importance due to their increased reliance on fisheries for their livelihoods. Strategies that assist diversification within the fishing sector, as opposed to outside of it (see above), may also be more appropriate for this group if they have greater attachment to their occupation and show willingness to develop their businesses through learning new skills (Stoll, Fuller and Crona, 2017). Through identifying and defining these three groups the complexity of individual circumstances and viewpoints is highlighted and as such adaptation strategies may need to be developed to reflect the differing needs of individuals (Cinner *et al.,* 2015; Stoll, Fuller and Crona, 2017).

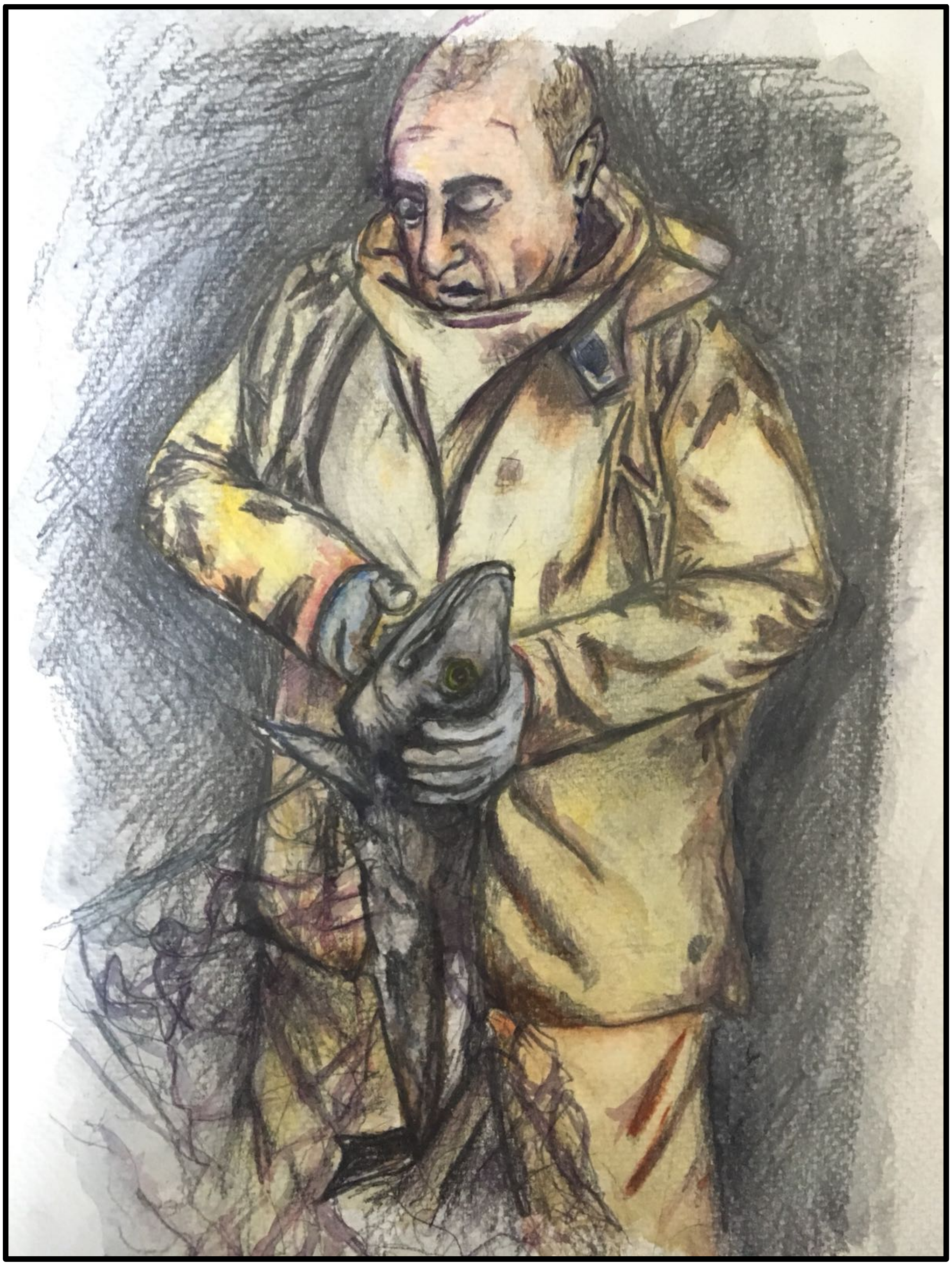
This study has revealed new and important insights but also has a number of limitations. The adaptive capacity assessment undertaken here only focused upon three of the main dimensions that affect adaptive capacity. This may mean that other aspects important in influencing fishers' adaptive capacity, such as access to new technologies and fishers' capacity to learn, process and share information regarding adaptation and climate change (Bennett *et al.,* 2014; Cinner *et al.,* 2018), may not have been fully explored. Future work should seek to undertake a more detailed assessment over these five dimensions for a more holistic understanding of fishers' adaptive capacity. This study also only interviewed demersal fishers because their catches form a substantial part of

Brixham's landings weight and volume (Chapter 1). However, understanding how perceptions and adaptive capacity may differ with other pelagic or shellfish fishers, and from other ports, would provide useful insights of into other segments of the UK fleet as wider work has highlighted the difference fishing strategies can have on adaptive capacity (Stoll, Fuller and Crona, 2017). A final limitation of this study is that adaptation was considered in the context of climate change impacts on fishery resources and practices. However, as members of coastal communities, these fishers may also be subject to other climate impacts such as rising sea levels and coastal erosion or flooding which they will also need to consider in future planning (Zsamboky *et al.,* 2011; Wong *et al.,* 2014). For a better, and perhaps more realistic understanding of fishers' adaptive capacity to climate change, future work could seek to consider adaptation in the context of these other impacts.

To conclude, this study highlights the importance of using an individual approach to exploring fishers' perceptions of future impacts and adaptation and examining adaptive capacity. Other work within the UK that has assessed adaptive capacity has taken a nationwide, industry approach, overlooking the subtler differences that may emerge among individuals. This research indicates that awareness of impacts does not necessarily translate to behavioural intentions to change and adapt to these impacts, and that individuals can differ within their adaptive capacity despite having similar overall fishing characteristics. Other factors including peoples' connections within their communities and with government agencies, their attachment to place and their occupation, and the opportunities that are (or not) available to them to diversity into influence fishers' adaptive capacity. This highlights that wider social and institutional factors influencing individuals within fishing communities need greater consideration within future UK fisheries adaptation assessment and planning. These insights are of particular use for decision-makers developing adaptation strategies that aim to support fishers adapt to future change by highlighting the importance of understanding individual differences and needs within regional contexts.

Chapter 6

General Discussion



Drawing by Amy Foreman, 2018

General Discussion

Climate change has had—and will continue having—significant impacts on the marine environment (Poloczanska *et al.,* 2016; Pecl *et al.,* 2017; Barange *et al.,* 2018). Fisheries can be affected by climate change in numerous ways including increased storminess and rising sea temperature affecting the availability and catchability of marine resources. This thesis contributes new knowledge to better understand climate change impacts on fisheries by applying an interdisciplinary perspective within an under-studied region of the UK. The research presented here developed a novel method for combining data from multiple surveys to allow larger-scale analyses to be undertaken. New projections of anticipated future changes in a number of key commercial fish stocks targeted by south-west UK fishermen were generated through the use of Generalised Additive Models. Fishers' perceptions were explored to examine how climate change was perceived among these resource dependent individuals, and how they thought it could impact them in the future. Finally, insights were gained into fishers' ability to adapt to future climate change through assessing dimensions of their adaptive capacity.

This chapter begins by summarising the findings of these research chapters within this thesis. These results are then drawn together to provide an overall understanding of the insights gained with particular focus on exploring the implications this research has for management and policy across a range of scales. The chapter concludes by providing priorities for future research aiming to further explore the future effects of climate change within the UK as well as more widely.

Key findings

Regional studies of climate change around the UK have been limited to focusing upon well studied regions such as the North Sea, resulting in less information about how climate change may affect other regions. One reason for this is due to ecological studies being limited by data availability and suitability. This thesis began by developing a methodology to standardise abundance data from scientific survey data and overcome some of the biases within survey data

(Chapter 2). This allowed research to be undertaken to explore the future impacts of climate change on the south-west UK in Chapter 3. Two methods—Bayesian PCA and Least Square Means—were used to generate standardised abundance estimates. Outputs were compared and results suggested that the Least Square Means methodology was most effective due to the strong associations between standardised and observed abundances for all species it was tested upon. This provided a new opportunity to combine multiple survey datasets and therefore allow further macro-ecological studies to take place within the region. Chapter 3 developed new insights into how eight commercial fish species may be affected by future climate change. Using Generalised Additive Models applied over 11 climate ensemble members, projections were generated of future abundances until 2090. Projections indicated that a number of cold-adapted species including anglerfish, Atlantic cod, European plaice and megrim could experience significant declines into the future due to warming sea temperatures. Warm-adapted species John dory and red mullet showed significant increases, while Dover sole and lemon sole showed less substantial changes. Distributional responses varied depending on species, with some expanding across their range while others shifted westerly towards deeper waters. Temperature and bathymetry had important roles in driving these changes. The associated uncertainty with using multiple climate ensemble-members was also highlighted, showing greater confidence in projections until at least 2040 across most species and greater uncertainty at later time frames.

Chapter 4 explored how climate change was perceived by fishers as a risk to the future of fish stocks, fishing businesses and the wider industry. Semi-structured interviews with fishers in Brixham found that for many fishers climate change was not seen as a risk, and that other issues including overfishing, changing regulations and Brexit were more commonly cited as bigger risks to the future of the industry than climate change. Further analysis found that these risk perceptions differed among individuals, identifying three main groups of fishers, and that several factors influenced the perceptions of these groups. Climate change scepticism and perceived ability to cope and adapt to future climate change were strongly associated with lower risk perceptions. Other factors such as levels of informedness of climate change and personal observations and experiences appeared to have less of an effect on fisher's risk perceptions.

Chapter 5 further examined fishers' perceptions of climate change to understand how fishers thought climate change would affect them in the future and how they would have to change their practices. Fishers discussed a range of future impacts, and these were generally consistent with scientific literature. Half of the fishers anticipated changing the species they targeted. Regarding other aspects of their fishing practices, such as gears used and fishing locations, the majority of fishers felt that they would not change these with future climate change. Reasons for this included personal reasons and perceptions of stability. Others identified constraints that would affect their ability to change fishing practices. Fishers' ability to adapt was further explored by assessing three dimensions of fishers' adaptive capacity – their flexibility, social organisation and personal agency. Three groups were identified that exhibited differences in their adaptive capacity. Group One was an older, more experienced group that was less connected within their social networks, had less flexibility and felt less able to adapt. Group Two had greater flexibility regarding pursuing other careers, while Group Three had less flexibility for leaving the industry but were more focused on learning new skills and planning longer term.

Value of a regional, interdisciplinary approach

Adopting an interdisciplinary approach for this research has provided new, broader insights and highlighted interesting links between research findings that may not have been uncovered if this project had been undertaken from a single discipline perspective. The value of interdisciplinary approaches is increasingly necessary to explore future challenges to fisheries systems and truly understand how these systems may respond and adapt in the future (Perry, Barange and Ommer, 2010; Christie, 2011; Berkes, 2012; Leenhardt *et al.,* 2015). By exploring the links and feedbacks between human and environmental parts of fishery systems, and how this can differ within and across scales, greater knowledge can be gained to inform policy and management aiming to address global challenges such as climate change (Liu *et al.,* 2007; Miller *et al.,* 2010a, Perry, Barange and Ommer, 2010; Berkes, 2012; Charles, 2012; Cvitanovic *et al.,* 2015; Alexander *et al.,* 2018). Within the UK, increasing efforts need to be undertaken to further these interdisciplinary approaches to gain more holistic understanding of climate change impacts on UK fisheries (Pinnegar *et al.,* 2017), and thus integrate this knowledge into future management and governance frameworks.

To date, regional studies of future climate change on fisheries within the UK have been limited in their geographic scale (Jones *et al.,* 2012; Rutterford *et al.,* 2015; Townhill *et al.,* 2017; Queirós *et al.,* 2018) and this research provides much needed new insights into an understudied region. Findings from this thesis are particularly useful because fisheries management in recent times has moved towards more regional based approaches. Within the European Union, fisheries management has become increasingly decentralised, with greater emphasis applied to regional approaches and advisory systems (European Parliament, 2018). Regional fisheries management approaches are also used in the UK, differing across the devolved administrations (Marine and Coastal Access Act, 2009; Pieraccini and Cardwell, 2016). For example, in England inshore fisheries are managed through 10 Inshore Fisheries Conservation Authorities (IFCAs) for waters out to six nautical miles (Defra, 2011). The remits of IFCAs extend from implementing and enforcing fisheries regulations, such as landing size restrictions, to wider marine conservation obligations such as the management of Marine Conservation Zones (Defra, 2011). In England, marine spatial plans are also being developed at regional levels, such as the 'South West Inshore and Offshore' marine plan, which seek to manage activities of multiple sectors within the marine environment on regional scales (MMO, 2013).

With fisheries and marine management and policy emphasising regional approaches, knowledge and evidence bases are increasingly needed at these scales to assist in decision-making. This is true not only for understanding current trends and status of the marine environment and fisheries, but also how these systems may change in the future (Perry and Ommer, 2003; Doney *et al.,* 2012). From adaptation policy perspectives, regional insights also form important knowledge bases to help understand the more resolved and contextual factors that can have important influence upon adaptive capacity of humans and/or the environment (Moser, 2010b; Charles, 2012). Scale and context are important to consider in regard to the process of adaptation, which is intimately linked to location and requires action from local government and communities in particular (Moser, 2010b; Barnett *et al.,* 2014; Mimura *et al.,* 2014). While an overarching National Adaptation Programme for climate change has been developed within the UK, these broad objectives and actions will need to be mobilised at smaller scales, and thus account for the needs of those within communities, sectors and other social groups (Defra, 2018). Research such as presented within this thesis therefore forms crucial additions to evidence bases that, when considered alongside broader scaled approaches, can be utilised in future decision-making from both management and adaptation perspectives.

Implications for fisheries management and climate adaptation strategies

In this next section the results from all main chapters of this thesis are presented and interpreted together. This provides new insights of how these findings contribute to wider knowledge bases and demonstrates their value from fisheries management and climate adaptation strategy perspectives.

Results from Chapter 3 clearly demonstrate that fisheries within the south-west UK will face changing abundances and distributions of many of the key commercial demersal fish species over the coming century. This creates both risks and opportunities for the fishing industry within the region. For fishers working from Brixham, many felt that they would need to change their targeting of species in the future as a result of shifting stocks (Chapter 5). However, as noted within interviews from Chapter 5, fishers identified a number of constraints to changing their fishing practices, including fisheries management. Fisheries management and wider governance will have a key role in influencing both the future of fishery resources as well as how fishers respond to such changes (Daw *et al.,* 2009; McIlgorm *et al.,* 2010; Miller *et al.,* 2010a; Charles, 2012; Cvitanovic *et al.,* 2018). Meeting ecological objectives that ensure fishery resources are harvested sustainably and consider the effects of climate change on these populations will need to be balanced alongside socio-economic objectives to enable new opportunities to be capitalised upon and support fishers' adaptation (Daw *et al.,* 2009; Miller *et al.,* 2010a; Melnychuk, Banobi and Hilborn, 2014; Ojea *et al.,* 2017). These ideas are explored in more depth below.

- Changing resources

A number of important commercial stocks such as anglerfish and Atlantic cod were projected to decline with future warming in the region (Chapter 3). Wider studies highlight that fish stocks can become more vulnerable to fishing with long term climate change (Jennings and Blanchard, 2004). Fishing can also increase the sensitivity of fish stocks to climate change through effects on stock structure, such as lowering ages and reducing sizes of fish (Ottersen, Hjermann and Stenseth, 2006; Rijnsdorp *et al.,* 2009). As such, lowering fishing effort and fishing mortality rates are a likely management response to attempt to further limit declines and reduce vulnerability to climate change (Brander, 2007; Rijnsdorp *et al.,* 2009; Thøgersen, Hoff and Frost, 2015). Reductions in fishing mortality rates will have consequential effects on the Total Allowable Catches (TACs) that are set for stocks (currently done at an EU level for the UK), and as such the quotas that are allocated to the UK and fishers would also likely be reduced. Other management restrictions may also be considered in the future to help relieve the pressure of climate change and fishing on stocks. This may include seasonal closures to reduce fishing pressure at key times in a species life cycle (e.g. during spawning) or spatial closures to protect and develop more 'robust' and resilient stocks (e.g. protecting larger individuals) (Melnychuk, Banobi and Hilborn, 2014; Roberts *et al.,* 2017).

Management restrictions such as those on fishing effort, while beneficial from ecological perspectives, would also impact fishers catching these species. Findings from Chapters 4 and 5 raise questions regarding the way quota reductions or restrictions in effort could be perceived if management uses climate change as a key argument for these decisions. Interviews highlighted that fishers felt management restricted their ability to alter their fishing practices currently, and in the future, and that restrictions posed a threat to the future of their businesses and the industry more widely. This could suggest that further management restrictions could be perceived negatively by fishers within Brixham. Importantly, climate change was generally perceived as a low risk and something to which fishers anticipated they would not have to change many of their practices to (Chapters 4 and 5). Additionally, many fishers' voiced scepticism of climate change and its impacts. How fishers would therefore perceive the legitimacy of management actions based on climate change goals, particularly if this could pose negative implications on them through reduced opportunities, are important questions to consider. Issues of legitimacy within other marine management contexts are relatively well researched, for example regarding marine protected areas, with evidence that lower perceived legitimacy can result in conflict between stakeholders (e.g. fishers and fisheries managers) and potential acceptance and compliance issues (Jentoft, 2000; Hard *et al.,* 2012; Kelly, Pecl and Fleming, 2017; Dehens and Fanning, 2018). Wider risk perception literature also documents that people who do not perceive climate change as a risk can have less willingness to support or act under strategies aiming to address climate change (Leiserowitz, 2006; Hidalgo and Pisano, 2010; Weber, 2010; Taylor, Dessai and Bruine de Bruin, 2014). The research presented here thus highlights potential issues that may emerge from future fisheries management seeking to address climate change, and which need greater consideration from both research and management perspectives. One way to address such issues could be to integrate fishers into decision making processes in order to facilitate dialogue and develop ways of managing resources that reflect both ecological needs and social viewpoints (Jentoft and McCay, 1995; Ostrom, 2010; Cvitanovic *et al.,* 2018).

Other species within Chapter 3 showed increases in abundance, including red mullet and John dory. These species could become increasingly targeted by fishers as indicated by findings from Chapter 5. Such findings from these projections and perceptions are therefore valuable to help prepare research and management for new fisheries that may emerge with climate change (Pinsky and Mantua, 2014; Pinsky *et al.,* 2018; Wilson *et al.,* 2018). For example, fishers within Brixham have shown their willingness and ability to capitalise on emerging species, as seen with cuttlefish (*Sepia* species) which have become increasingly abundant in European and UK waters (Xavier *et al.,* 2016; Pinnegar *et al.,* 2017) and are considered to be 'black gold' among fishers and now form large proportions of their catch (MMO, 2017a). Ability to target these species was particularly facilitated by the fact that these are non-quota species that currently have no management restrictions (ICES, 2017b). Currently, John dory and red mullet, alongside other species which have increased with warming in the region such as anchovies, are non-quota species, with limited management regulations (Simpson *et al.,* 2011; EU Council, 2017). While these alternative species are potentially promising for fishers to capitalise on if other stocks decline, there are also management implications regarding the sustainability of increasing fishing effort on these species. Often there is little known about their biology and ecology which can create uncertainty regarding how these species may respond to increasing fishing effort, climate change, and the interacting effects of both these stressors (ICES, 2012; ICES, 2013; Pinsky and Mantua, 2014). In these situations, arguments for more adaptive management systems become increasingly pertinent as they can allow management measures to account for uncertainties in stock status and be implemented and altered as and when new information and knowledge becomes available (Miller *et al.,* 2010a; Pinsky and Mantua, 2014; Cvitanovic *et al.,* 2015).

Projected alterations in abundances and distributions, such as shown in Chapter 3, will inevitably affect the composition of fishers' catches. Most south-west demersal fisheries are regarded as 'mixed fisheries', with many species caught within each tow. Stocks with low or zero TACs, and subsequently low quotas, pose issues for fishers because once the quota is reached, fishers may be unable to continue fishing due to difficulty in avoiding catching that species in future catches in that trip (Rihan, 2018, Seafish, 2018). In a climate change context these so called 'choke' species may arise from both stocks shifting and increasing in abundance beyond which fishers' have quota for, or from a declining stock having further quota restrictions applied and therefore fishers reaching their quota before they have managed to catch other species at their allowable limit (Rihon, 2018). Temperature driven alterations in species abundance and the repercussions of becoming a choke species have been seen in other mixed fisheries, such as northern European hake (*Merluccius merluccius* L.) in Scotland which has become more abundant in the region (Baudron and Fernandes 2015; Rihan, 2018). The implication these climate driven changes may have with current EU legislation, which seeks to prevent fishers from discarding unwanted catch and rather to land all catches (which thus counts towards their quota), adds further complexity (Seafish, 2018). Transferable quotas and catch shares are possible management measures that could be used to increase the flexibility for fishers to access and trade quota for when they need it (Reeves and Davie, 2017; Rihan, 2018).

- Flexible management approaches

It is increasingly advocated that fisheries management should become more flexible and adaptive in its approach to account for climate change effects and the associated uncertainty it can present (Grafton *et al.,* 2010; Miller *et al.,* 2010a; Pinsky and Mantua, 2014; Cvitanovic *et al.,* 2015, 2018; Pinsky *et al*., 2018). Adaptive fisheries management can take many forms but centres on the ability of the frameworks in place to review and respond to information as it becomes available and to alter accordingly, while achieving original objectives such as maintaining resilience of the system (Grafton *et al.,* 2010; Miller *et al.,* 2010a; Cvitanovic *et al.,* 2015, 2018). Achieving this requires fundamental shifts in governance structures, including greater participation from stakeholders and co-management approaches, and developing practical ways to allow flexibility such as through harvest control rules, tradeable quota systems and incentives to aid in livelihood diversification (McIlgorm *et al.,* 2010; Pinsky and Mantua, 2014; Cvitanovic *et al.,* 2015, 2018; Burden *et al.,* 2017; Ojea *et al.,* 2017; Pinsky *et al*., 2018). Calls for greater management flexibility were echoed by fishers in Chapter 5, who identified institutional constraints as a limitation to their ability to adapt and adjust their fishing practices and suggesting greater flexibility would help to reduce these constraints. This in some ways contradicts findings of Chapter 4, whereby fishers felt that changing regulations, rules and ‘moving the goals posts’ made them feel uncertain about what management would do next. Taken together these findings reflect the complex ways changing management measures can be perceived. This suggests that including fishers and their viewpoints within decision-making processes at all levels could enable greater transparency of how decisions are made and provide fishers with a greater sense of input into management and wider governance processes.

Flexibility in wider governance is also necessary. Findings from Chapter 3, alongside previous studies (Perry *et al.,* 2005; Cheung *et al.,* 2010; Pecl *et al.,* 2017), demonstrate that fish stocks will alter their distributions with future climate change.

The south-west UK is in a particularly multi-jurisdictional sea area, bordering with France, Ireland, Germany, the Netherlands and Belgium. Having governance mechanisms in place that will account for shifting stocks will be essential for future sustainable targeting of such species and to avoid potentially negative political tensions (ABPmer, 2018; Pinsky *et al.,* 2018). Tensions have been observed with other commercial stocks including anchovies and mackerel as a result of shifting distributions and increased abundance (Pinnegar *et al.,* 2013; Spijkers and Boonstra, 2017). Such cases will likely only become more common and important to consider as waters continue to warm (Pinsky *et al.,* 2018). This is particularly important from the perspective of the UK as it withdraws from the EU Common Fisheries Policy and seeks to establish new bilateral and trilateral agreements with European and non-European countries over access to stocks and fishing opportunities (Burden *et al.,* 2017; Appendix E: UK Fisheries Management POSTnote by Maltby and Wentworth, 2018). Incorporation of climate change within discussions and subsequent legal frameworks will be crucial to account for future shifts in stocks and facilitate adaptive management accordingly (Pinsky *et al.,* 2018).

- *Fishers' adaptation to climate change*

Fishers' responses to future climate change impacts, such as changes in resources as outlined in Chapter 3, are connected to their perceptions of climate change itself. Fishers were able to outline a number of future impacts that climate change may present into the future, yet did not necessarily feel they needed to alter their practices (Chapter 5). As such, despite having awareness of climate change impacts, the extent to which it was perceived to subsequently affect fishers and require them to alter their practices was a less linear relationship than perhaps would be expected. Chapters 4 and 5 provide insights into the complexity of factors that are likely to be contributing to this lack of perceived need to change fishing practices in the future, including low risk perceptions, scepticism, perceived ability to cope and adapt (Chapter 4), alongside wider perceived constraints and reasonings (Chapter 5).

These findings raise the question regarding the extent to which fishers in Brixham would, in the future, be ‘reacting to’ rather than ‘preparing for’ climate change risks and opportunities. Other studies have questioned whether fishers’ low risk perceptions and perceived low vulnerability to change could act as barriers to adaptation (e.g. West and Hovelsrud, 2010; Nursey-Bray *et al.,* 2012). Numerous psycho-social factors could have a role in shaping fishers’ perceptions of not needing to alter their fishing practices and adapt (Grothmann and Patt, 2005; Adger *et al.,* 2009; Weber, 2010; Gifford, Kormos and McIntyre, 2011; Bercht, 2017). Findings from this thesis suggest that fishers may be less inclined to act on new information that goes against their beliefs (Chapter 5), may be more sceptical and less trusting of information sources (Chapter 4) and may not always be willing to seek out new information that could help them to prepare for future changes (Chapter 5). Yet knowledge and learning new information have been argued as a key dimension of contributing to peoples’ adaptive capacity because it can help them to prepare and understand how to manage future risks (Bennett *et al.,* 2014; Williams, Fenton and Huq, 2015; Cohen *et al.,* 2016; Cinner *et al.,* 2018). As such, lower preparedness could result in fishers being negatively affected by climate change if other dimensions also contribute to a lower adaptive capacity (e.g. occupational flexibility and mobility, financial assets). This research therefore has implications for how climate change impacts, as well as adaptation options, can be communicated among fishers who may be less receptive to the information they are presented with. Tailoring communication to different groups is one way that this may be done, and demonstrates that research such as presented within this thesis, which identified different groups of fishers based on their risk perceptions, is particularly useful (Hine *et al.,* 2016). Framing messages differently, using trusted sources to communicate information and presenting information in ways that connect with people (such as local impacts and options as opposed to global messages) may be some of the ways to communicate risks more effectively (Moser 2010a, 2014; Hine *et al.,* 2016).

Strategies seeking to assist fishers to prepare for, and adapt to, climate change can also be informed through research that provides insights into what contributes to people’s adaptive capacity (Grafton, 2010; Marshall *et al.,* 2010; Cinner *et al.,* 2018). Chapter 5 presented findings of a number of perceived constraints to adaptation. This provided information that may not have been captured through more objective adaptive capacity assessments, and generated insights that decision-makers can use to further understand how fishers may be supported in the face of future climate change. For example, institutional constraints were listed by fishers as a factor affecting their ability to adapt in the future, and these issues may not have been raised through only using the indicators that were used within Chapter 5. Chapter 5 complemented current wider UK adaptive capacity assessments (Defra, 2013; Garrett, Buckley and Brown, 2015) by providing a more detailed approach to exploring how individuals within a fishing community may differ in their adaptive capacity, and highlighted the importance of wider socio-economic factors, such as occupational flexibility, age and personal preferences and perceptions. Results in Chapter 4 further highlighted the range of issues that fishers identified as posing a risk to their future livelihoods and wider industry and thus may also need consideration in future adaptation planning due to interacting effects. For instance, issues with rising fuel prices could affect the ability of fishers to travel further to catch target resources that have shifted due to climate change (Abernethy *et al.,* 2010; Pinsky and Mantua, 2014). Other issues of changing ownership, with vessels becoming owned by larger businesses and fishers becoming employed by these companies, could change the landscape of who is adapting to climate change and how adaptation is likely to transpire. Through adopting an interdisciplinary approach this thesis therefore highlights the need to consider a wider backdrop of social, economic, environmental and political factors during future decision-making regarding adaptation of fishers and fisheries to climate change.

As the findings from this thesis help to demonstrate, adapting fisheries to climate change is not just a focus for fisheries management itself but also for wider climate change adaptation strategies that focus on supporting coastal communities, which often rely on fishing, to cope and adapt to future change (Grafton, 2010; Perry, Barange and Ommer, 2010; Charles, 2012; Pinsky and Mantua, 2014; Khan, Charles and Armitage, 2018). While fisheries management can develop mechanisms to assist adaptation of fishery systems and promote resilience, some of the wider issues that can influence adaptation, particularly of fishers and the social sub-system, may extend beyond the traditional bounds and considerations of fisheries management (Pinsky and Mantua, 2014; Khan, Charles and Armitage, 2018). These may include implications of other climate change impacts such as sea level rise (Colburn *et al.,* 2016) or issues surrounding access to export markets (e.g. Fleming *et al.,* 2014). The process of adaptation takes place across multiple scales, from individuals in local areas through to the effect of governance at national and international scales, and as such supporting successful adaptation may need to extend beyond single scale, sector and disciplinary perspectives (Adger, Arnell and Tompkins, 2005; Charles, 2012; Bennett *et al.,* 2014; Mimura *et al.,* 2014). As such integration of fisheries management alongside wider strategies seeking to build adaptive capacity and facilitate adaptation requires broader approaches to help account for these issues of scale, sector and discipline (Charles, 2012; Pinsky and Mantua, 2014; Khan, Charles and Armitage, 2018). Potential ways to do this include building adaptive capacity through supply-chains, using ecosystem-based management approaches to fisheries management, and identifying 'entry points' to facilitate integration between different adaptation strategies (Fleming *et al.,* 2014; Heenan *et al.,* 2015; Khan and Amelie, 2015; Khan and Charles, 2018). Central to all of these approaches lies on the need for interdisciplinary research to help identify links and feedbacks within these systems, where issues may overlap or emerge and generate broader perspectives which can facilitate decision making (Miller *et al.,* 2010a; Perry, Barange and Ommer, 2010).

Future priorities

This thesis has produced a number of insights that offer areas for further research. Greater research efforts need to be paid to connecting the ecological responses of fishery resources to climate change with the effects and/or responses this will have upon fishers. This thesis helped to fill some of these knowledge gaps through qualitative interpretation, but there are numerous quantitative methods which could also be used to generate further understanding of the impacts of climate-driven alterations in resources on fishers. One such method would be to connect future species abundance and/or distribution projections with wider socio-economic variables or scenarios, such as revenues, profitability and employment. Examples of such work are becoming increasingly common (e.g. Lam *et al.,* 2016; Mullon *et al.,* 2016), yet within the UK efforts are limited (Jones *et al.,* 2015; Fernandes *et al.,* 2016). These studies would help to anticipate the wider socio-economic implications of climate change, enabling fishers and the wider sector and supply chain to be informed of and prepare for potential effects. The effects of different management scenarios can also be incorporated into such analyses to explore the effects of different management goals, for example fishing at Maximum Sustainable Yield, on resources under different scenarios of climate change (Thøgersen, Hoff and Frost, 2015; Serpetti *et al.,* 2017). This would subsequently help decision-makers explore which management approaches would be most effective. Generating these projections can use a variety of approaches (see Tittensor *et al.,* 2018 for a useful summary of relevant model approaches) and depends on the specific aims of the research but approaches include using bio-economic assessment models (e.g. Thøgersen, Hoff and Frost, 2015), ecosystem based models (e.g. Serpetti *et al.,* 2017) or connecting model outputs of projections in catches with different socio-economic metrics through various methods (e.g. cost-benefit analysis: Jones *et al.,* 2015; using multipliers: Fernandes *et al.,* 2016). Scaling these projections down to regional or local scales could provide even greater understanding of the more resolved effects upon economies and societies, but data to underpin these types of analyses could, in theory, be harder to obtain.

Another approach to more specifically explore the effects of resource changes on fishers' decision-making and behavioural responses could be through the use of fleet dynamic models. Humans are a key source of uncertainty for fisheries management and such uncertainty may increase as changing resources result in alterations in fleet and fisher behaviour in perhaps new and unexpected ways (Fulton *et al.,* 2011). No work has been done on exploring fisher and fleet behaviour under climate change within the UK, although more widely there have been some efforts (e.g. Hamon *et al.,* 2014). Yet, such approaches could provide useful understanding from management perspectives into where effort may be redistributed or what drivers would be important in influencing such change. Current methods that may have particular relevance in this context include those focusing on location choices (Hutton *et al*., 2004; Tidd *et al.,* 2012) and examining decisions to exit and enter into fisheries (Tidd *et al.,* 2011; Daw *et al.,* 2012). Importantly some of these methods are often focused on economic drivers of fishers' behaviour, and so may neglect other social factors that can influence targeting choice, such as habits, risk attitudes and social networks (van Putten *et al.,* 2012). As such, complementing these approaches with studies that can explore drivers and motivations of fishers' behaviour can help to determine what variables to include in these type of models as well as contextualise findings with fishers' own experiences and future expectations. Fishers' participation in these modelling exercises could also help to provide another avenue for communicating the risks and opportunities about climate change and promote further discussion on these topics.

Greater insight into fishers' perceptions of future changes and the barriers that may affect their adaptation are also needed. This thesis outlined that there could be important implications that result from fishers having low risk perceptions of climate change and not necessarily seeing the need to adapt, including effects on perceptions of legitimacy of future management, preparedness for climate change impacts and communication of future risks to these individuals. Yet, there is a dearth of literature within the UK that has examined fishers' perceptions and climate change. While this thesis has provided useful insights, questions still remain. For example, to what extent are the viewpoints of fishers within Brixham held among other UK fishers? Wider literature in other countries also suggests that fishers have low risk perceptions, do not see climate change as a salient issue, and have a perceived ability to cope and adapt to future change (West and Hovelsrud, 2010; Nursey-Bray *et al.,* 2012; Dannevig and Hovelsrud, 2015), but there is limited understanding as to how these perceptions vary across fishing groups and regions. Undertaking studies in other regions and communities in the UK, with fishers from a greater variety of fishing backgrounds and practices, could help to elucidate further how climate change is perceived and how fishers think they may have to adapt in the future. Importantly, drawing upon the links these perceptions may have with issues such as perceived legitimacy of future management, preparedness for impacts and willingness to support climate change strategies are important to examine further. Some of these questions could be explored using survey methods (e.g. to explore climate risk perceptions), but more understanding of the links between perceptions and effects on the aforementioned issues would require more in-depth interviewing or workshops. Bayesian Belief Networks are being used increasingly to incorporate qualitative information, such as attitudes and perceptions, alongside more quantitative ecological and economic information to assess the implications of management decisions upon ecological, economic and social outcomes (Levontin *et al.,* 2011; van Putten *et al.,* 2013; Hoshino *et al.,* 2016). These methods could therefore provide opportunity to integrate the information collected through surveys and interviewing to examine the outcomes of alternative fisheries management decisions made in light of climate change upon aspects such as stakeholder conflict and fisher compliance. These insights would contribute not only to the UK literature on these issues, but also more widely as such effects have had limited study within fisheries climate change contexts.

Finally, while the UK fishing fleet is considered to have high adaptive capacity to climate change (Allison *et al.,* 2009; Garrett, Buckley and Brown, 2015; Blasiak *et al.,* 2017), the findings in this thesis highlight that adaptive capacity can differ according to a range of factors and dimensions that have generally not been considered in sufficient depth within UK assessments. Greater emphasis is needed to understand the adaptive capacity of other fishers within the UK, extending beyond understanding differences according to fishing characteristics such as vessel size and sector, and looking at other dimensions of their adaptive capacity. This could also include a study to assess the adaptive capacity among key stages of the wider seafood supply chain, as has been seen in other countries such as Australia (Fleming *et al.,* 2014; Plagányi *et al.,* 2014). Additionally, greater exploration of the barriers, particularly institutional barriers, are also important to help guide future fisheries management and adaptation strategies to understand where adaptive capacity can be built among fishers. At a time when the UK will need to develop a new policy for fisheries management due to its withdrawal from the EU, the role of such information would be useful for exploring what mechanisms could be used to enable management to become more flexible and adaptive in its approach and thus facilitate adaptation of the fishing industry to climate change.

Conclusions

This thesis has provided a new, interdisciplinary insight into how fisheries within the south-west of the UK may be affected by future climate change. Through generating future projections and exploring fishers' perceptions, this research highlights complex ecological and social implications climate change will present. Through adaptive and integrated management and governance, fishery systems can be supported in their adaptation to help reduce negative impacts and allow emerging opportunities to be capitalised upon. Critically, such fundamental shifts in management and governance depend on interdisciplinary research that draws upon not only scientific expertise but also on the perceptions and knowledge of all fisheries stakeholders to inform decision-making. The time to act is now, and generating interdisciplinary evidence bases that are able to help address these future challenges are imperative to secure sustainable fisheries for future generations.

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Appendix A. Chapter 3 – Methods and Results

Methods

Fishing effort

Average decadal fishing effort (total hours yr^{-1}) by grid cell was calculated using data compiled by STECF (https://stecf.jrc.ec.europa.eu/reports/effort) and reported in the STECF 14-20 Evaluation of Fishing Effort Regimes data tables (effort_by_rectangle.xlsx), spanning from 2003–2013. Data were filtered to include only demersal trawl gears (beam trawls, bottom trawls and otter trawls):

- Beam trawls – STECF gear codes BEAM, BT1, BT2
- Bottom trawls – STECF gear codes 3A, BOTTOM TRAWL, TR1, TR2, TR3
- Otter trawls – STECF gear codes OTTER

Trawl gears accounted for the majority of landings (77–99%) of the species we considered and for which landings data were available (Table A3.1 and Fig. A3.1), and the available effort data are likely to have been a better indicator of fishing pressure on these species in the study region than effort data for set gears e.g. gill nets. Gear types listed as 'None' were excluded. Effort was summed across gears, countries and ICES rectangles for each year (total effort) and an average then taken for the whole decade. In the GAM projections fishing effort was kept constant across species and time periods to allow only temperature and salinity effects to vary and examine temperature and salinity effects.

Table A3.1. Total proportion of species landings caught using trawl gears (calculated using STECF 14-20 Landings_by_rectangle.xlsx data). NB. John dory and red mullet were not listed within landings data.

Species	% of landings caught with trawl gears
Anglerfish	87.7
Atlantic cod	77.4
Dover sole	83.6
European plaice	94.1
Lemon sole	98.6
Megrim	99.0

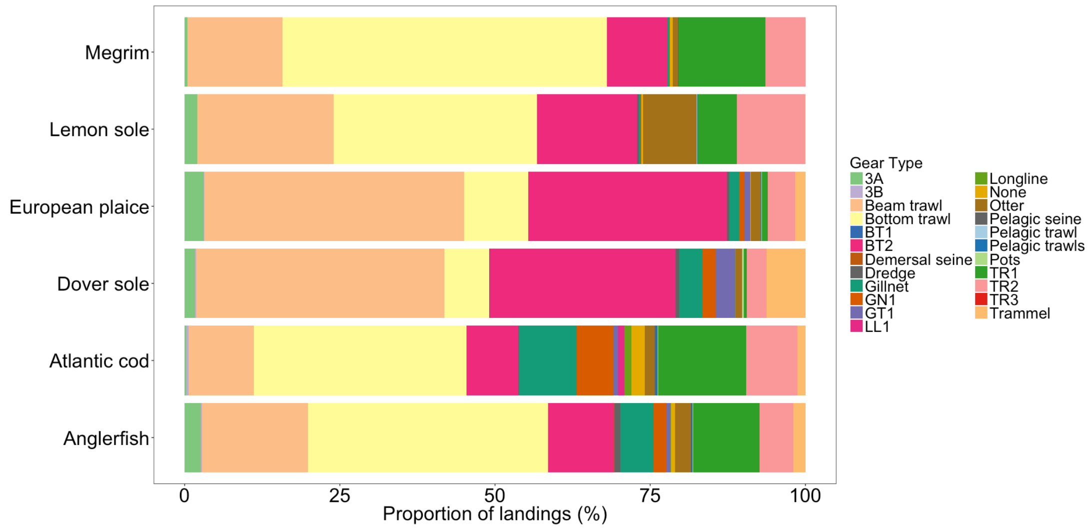


Figure A3.1. Proportion of species landings caught with different gear types (calculated using STECF 14-20 Landings_by_rectangle.xlsx data). Legend includes STECF gear codes: 3A beam trawl; 3B Gill net; BT1, BT2 Beam trawl; GN1 Gillnet; GT1 Trammel net; LL1 Longline; TR1,2,3 Bottom trawl. John dory and red mullet were not listed within landings data.

Habitat type assignment

Assignment of habitat types to grid cells was based upon EUSeaMap 2016 data obtained through EMODnet (http://www.emodnet-seabedhabitats.eu/). The habitat type for a grid cell was taken as any habitat which occupied >50% of the grid cell area. If no habitat type exceeded 50% of cell area, then the two most extensive habitats that together exceeded 50% of the area were recorded as the habitat type. Where no habitat data existed, cells were assigned no habitat type.

Standardisation of abundance data

Due to differences between survey designs, sampling coverage (temporal and spatial) and sampling methods (Table A3.2) we sought to standardise abundance data. Catch-per-unit-effort (CPUE) estimates were generated as outlined in the main methods. Decadal mean CPUE (per survey, where decade is defined as e.g. 2001–2010) was calculated to reduce the influence of inter-annual variability in the number of hauls and recruitment and distributions of fish and reveal longer-term trends. To ensure some consistency of coverage, a minimum of three hauls per grid cell per decade was taken as criterion for including a grid cell in the analysis.

A general linear model (GLM) was used to examine the effects of survey, decade and grid cell on CPUE (Table A3.3). Survey type had a significant effect on species' CPUE with Tukey tests revealing where differences occurred (Table A3.4). These differences were unsurprising given the range of different gears used on the surveys, and indicated that survey effect on CPUE should be standardised. This was achieved by generating least square mean estimates of CPUE (means generated having controlled for the covariates (Searle, Speed and Milliken, 1980). Least square means were calculated on a grid cell basis for the 2000s decade using the *lsmeans* package in R (Lenth, 2018). Outputs, as used in subsequent analysis, were single CPUE estimates for each grid cell. These CPUE estimates retain spatial heterogeneity and fit well within the distributional ranges of other survey CPUE estimates (Table A3.5. and Fig. A3.2).

Table A3.2. Survey attributes

Survey	Survey acronym	Survey data obtained	Season sampled*	Gear used	Total No. of hauls	No. of 1° grid cells sampled
Cefas Celtic Sea Groundfish	CELTIC	1987–2004	1	Portuguese High Headline Trawl	1136	36
IFREMER French Southern Atlantic Bottom Trawl	EVHOE	1997–2013	4	Grande Ouverture Vertical Trawl	2340	31
Cefas Eastern English Channel	EEC	1990–2012	3	4 m Beam Trawl	2445	18
IFREMER French Channel Groundfish	FRCGFS	1988–2013	4	Grande Ouverture Vertical Trawl	2307	10
Irish Marine Institute Irish Groundfish	IGFS	2003–2008	4	Grande Ouverture Vertical Trawl	997	23
Cefas South Western Beam Trawl	WESTERN	2006–2015	1	2 x 4 m Beam Trawl	792	16

* Season (quarter of year) sampled. 1=Jan–March; 3=July–Sept; 4=Oct–Dec

Table A3.3. GLM results for effect of survey, decade and grid cell on CPUE (CPUE ~ survey + decade + cell). Survey consistently had a significant effect on CPUE for all species.

Species	Variable	*F* value	df	*p* value
Anglerfish	Survey	205.70	5	<0.001
	Decade	1.26	3	0.28
	Cell	3.03	61	<0.001
Atlantic cod	Survey	32.97	5	<0.001
	Decade	2.14	3	0.09
	Cell	6.87	61	<0.001
Dover sole	Survey	179.06	5	<0.001
	Decade	2.87	3	0.03
	Cell	6.57	61	<0.001
European plaice	Survey	114.13	5	<0.001
	Decade	11.12	3	<0.001
	Cell	11.40	61	<0.001
John dory	Survey	47.84	5	<0.001
	Decade	6.70	3	<0.001
	Cell	4.84	61	<0.001
Lemon sole	Survey	9.70	5	<0.001
	Decade	0.46	3	0.70
	Cell	15.15	61	<0.001
Megrim	Survey	561.71	5	<0.001
	Decade	13.61	3	<0.001
	Cell	31.34	61	<0.001
Red mullet	Survey	76.64	5	<0.001
	Decade	4.29	3	0.005
	Cell	6.25	61	<0.001

Table A3.4. *P* values resulting from Tukey Test comparisons of differences between surveys. Bold text represents statistically significant differences (*p*<0.05).

ANGLERFISH	CELTIC	EEC	EVHOE	FRGF	IGFS	WESTERN
CELTIC	■					
EEC	**<0.001**	■				
EVHOE	**<0.001**	**<0.001**	■			
FRGF	**<0.001**	0.94	**<0.001**	■		
IGFS	**<0.001**	**<0.001**	0.99	**<0.001**	■	
WESTERN	**<0.001**	**<0.001**	0.78	**<0.001**	0.82	■

ATLANTIC COD	CELTIC	EEC	EVHOE	FRGF	IGFS	WESTERN
CELTIC						
EEC	0.10					
EVHOE	0.98	**0.02**				
FRGF	**<0.001**	**<0.001**	**<0.001**			
IGFS	0.43	**0.009**	0.69	**<0.001**		
WESTERN	**0.04**	0.98	**0.01**	**<0.001**	**0.003**	

DOVER SOLE	CELTIC	EEC	EVHOE	FRGF	IGFS	WESTERN
CELTIC						
EEC	**<0.001**					
EVHOE	**<0.001**	**<0.001**				
FRGF	**<0.001**	**<0.001**	**<0.001**			
IGFS	**<0.001**	**<0.001**	**<0.001**	**<0.001**		
WESTERN	**<0.001**	**<0.001**	**<0.001**	**0.04**	**<0.001**	

EUROPEAN PLAICE	CELTIC	EEC	EVHOE	FRGF	IGFS	WESTERN
CELTIC						
EEC	**<0.001**					
EVHOE	0.99	**<0.001**				
FRGF	**<0.001**	**0.01**	**<0.001**			
IGFS	**<0.001**	**0.01**	0.99	**<0.001**		
WESTERN	**<0.001**	**<0.001**	0.78	**<0.001**	0.38	

JOHN DORY	CELTIC	EEC	EVHOE	FRGF	IGFS	WESTERN
CELTIC						
EEC	**<0.001**					
EVHOE	**0.006**	**<0.001**				
FRGF	0.99	**<0.001**	0.10			
IGFS	**0.001**	**<0.001**	0.41	**0.007**		
WESTERN	**<0.001**	**0.001**	**<0.001**	**<0.001**	**<0.001**	

LEMON SOLE	CELTIC	EEC	EVHOE	FRGF	IGFS	WEST
CELTIC						
EEC	0.91					
EVHOE	1.00	0.93				
FRGF	0.95	0.62	0.95			
IGFS	**<0.001**	**<0.001**	**<0.001**	**<0.001**		
WESTERN	**0.34**	0.90	0.37	0.16	**0.001**	

MEGRIM	CELTIC	EEC	EVHOE	FRGF	IGFS	WESTERN
CELTIC						
EEC	**<0.001**					
EVHOE	**<0.001**	**<0.001**				
FRGF	**<0.001**	1.00	**<0.001**			
IGFS	0.99	**<0.001**	**<0.001**	**<0.001**		
WESTERN	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	

RED MULLET	CELTIC	EEC	EVHOE	FRGF	IGFS	WESTERN
CELTIC						
EEC	0.99					
EVHOE	0.99	0.99				
FRGF	**<0.001**	**<0.001**	**<0.001**			
IGFS	0.96	0.96	0.99	**<0.001**		
WESTERN	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.007**	

Table A3.5. Statistics for the correlation between decadal least square mean CPUE and decadal average 4th rooted CPUE abundance by grid cell (2000s only).

Species	Test	Correlation (r)	df	*P* value
Anglerfish	LS-Mean vs CELTIC	0.75	34	<0.001
	LS-Mean vs EEC	0.71	10	<0.001
	LS-Mean vs EVHOE	0.44	28	0.01
	LS-Mean vs FRGF	0.75	8	0.01
	LS-Mean vs IGFS	0.78	18	<0.001
	LS-Mean vs WESTERN	0.72	14	0.001
Atlantic cod	LS-Mean vs CELTIC	0.83	34	<0.001
	LS-Mean vs EEC	0.80	10	0.001
	LS-Mean vs EVHOE	0.91	28	<0.001
	LS-Mean vs FRGF	0.65	8	0.03
	LS-Mean vs IGFS	0.91	18	<0.001
	LS-Mean vs WESTERN	0.72	14	0.001
Dover sole	LS-Mean vs CELTIC	0.69	34	<0.001

	LS-Mean vs EEC	0.90	10	<0.001
	LS-Mean vs EVHOE	0.90	28	<0.001
	LS-Mean vs FRGF	0.87	8	<0.001
	LS-Mean vs IGFS	0.92	18	<0.001
	LS-Mean vs WESTERN	0.79	14	<0.001
European plaice	LS-Mean vs CELTIC	0.90	34	<0.001
	LS-Mean vs EEC	0.85	10	<0.001
	LS-Mean vs EVHOE	0.96	28	<0.001
	LS-Mean vs FRGF	0.89	8	<0.001
	LS-Mean vs IGFS	0.93	18	<0.001
	LS-Mean vs WESTERN	0.84	14	<0.001
John dory	LS-Mean vs CELTIC	0.81	34	<0.001
	LS-Mean vs EEC	0.78	10	0.002
	LS-Mean vs EVHOE	0.74	28	<0.001
	LS-Mean vs FRGF	0.87	8	<0.001
	LS-Mean vs IGFS	0.67	18	0.001
	LS-Mean vs WESTERN	0.72	14	<0.001
Lemon sole	LS-Mean vs CELTIC	0.89	34	<0.001
	LS-Mean vs EEC	0.86	10	<0.001
	LS-Mean vs EVHOE	0.95	28	<0.001
	LS-Mean vs FRGF	0.94	8	<0.001
	LS-Mean vs IGFS	0.92	18	<0.001
	LS-Mean vs WESTERN	0.94	14	<0.001
Megrim	LS-Mean vs CELTIC	0.92	34	<0.001
	LS-Mean vs EEC	NA*	NA	NA
	LS-Mean vs EVHOE	0.97	28	<0.001

	LS-Mean vs FRGF	NA*	NA	NA
	LS-Mean vs IGFS	0.97	18	<0.001
	LS-Mean vs WESTERN	0.97	14	<0.001
Red mullet	LS-Mean vs CELTIC	0.87	34	<0.001
	LS-Mean vs EEC	0.19	10	0.5
	LS-Mean vs EVHOE	0.89	28	<0.001
	LS-Mean vs FRGF	0.78	8	0.006
	LS-Mean vs IGFS	0.80	18	<0.001
	LS-Mean vs WESTERN	0.80	14	<0.001

* NA: Megrim not caught in EEC and FRGF surveys

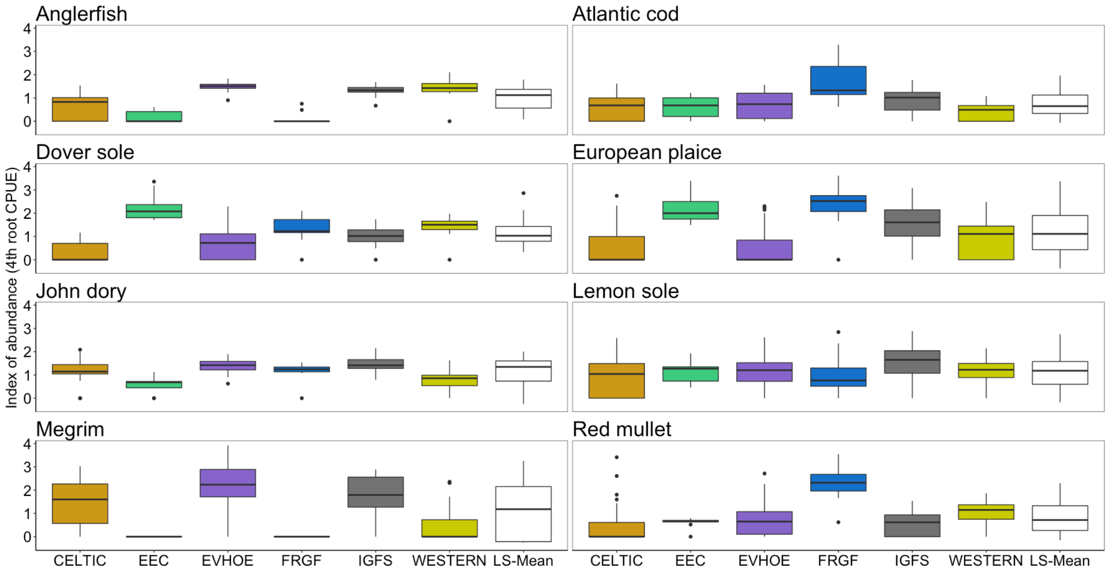


Figure A3.2. Decadal (2000s only) mean 4th rooted CPUE and decadal least square mean CPUE (labelled LS–Mean).

Table A3.6. Trialled GAMs for all species and ensemble-member combinations. *s*() denotes a smoothing term, SST= sea surface temperature, NBT= near bottom temperature, NBS= near bottom salinity, d=decadal, s=summer, w=winter.

	Model description	Formula
Model A	Full model with all predictors	Abundance ~ *s*(depth) + *s*(fishing_effort) + habitat_type + *s*(dSST) + *s*(dNBT) + *s*(dNBS) + *s*(sSST) + *s*(sNBT) + *s*(wSST) + *s*(wNBT)
Model B	Full model minus decadal temperatures	Abundance ~ *s*(depth) + *s*(fishing_effort) + habitat_type + *s*(dNBS) + *s*(sSST) + *s*(sNBT) + s(wSST) + *s*(wNBT)
Model C	Full model minus seasonal temperatures	Abundance ~ *s*(depth) + *s*(fishing_effort) + habitat_type + *s*(dSST) + *s*(dNBT) + *s*(dNBS)
Model D	Full model minus all temperatures	Abundance ~ *s*(depth) + *s*(fishing_effort) + habitat_type + *s*(dNBS)
Model E	Full model minus fishing effort	Abundance ~ *s*(depth) + habitat_type + *s*(dSST) + *s*(dNBT) + *s*(dNBS) + *s*(sSST) + *s*(sNBT) + *s*(wSST) + *s*(wNBT)
Model F	Full model minus salinity	Abundance ~ *s*(depth) + *s*(fishing_effort) + habitat_type + *s*(dSST) + *s*(dNBT) + *s*(sSST) + *s*(sNBT) + *s*(wSST) + *s*(wNBT)
Model G	Full model minus habitat type	Abundance ~ *s*(depth) + *s*(fishing_effort) + *s*(dSST) + *s*(dNBT) + *s*(dNBS) + *s*(sSST) + *s*(sNBT) + *s*(wSST) + *s*(wNBT)
Model H	Full model minus depth	Abundance ~ *s*(fishing_effort) + habitat_type + *s*(dSST) + *s*(dNBT) + *s*(dNBS) + *s*(sSST) + *s*(sNBT) + *s*(wSST) + *s*(wNBT)

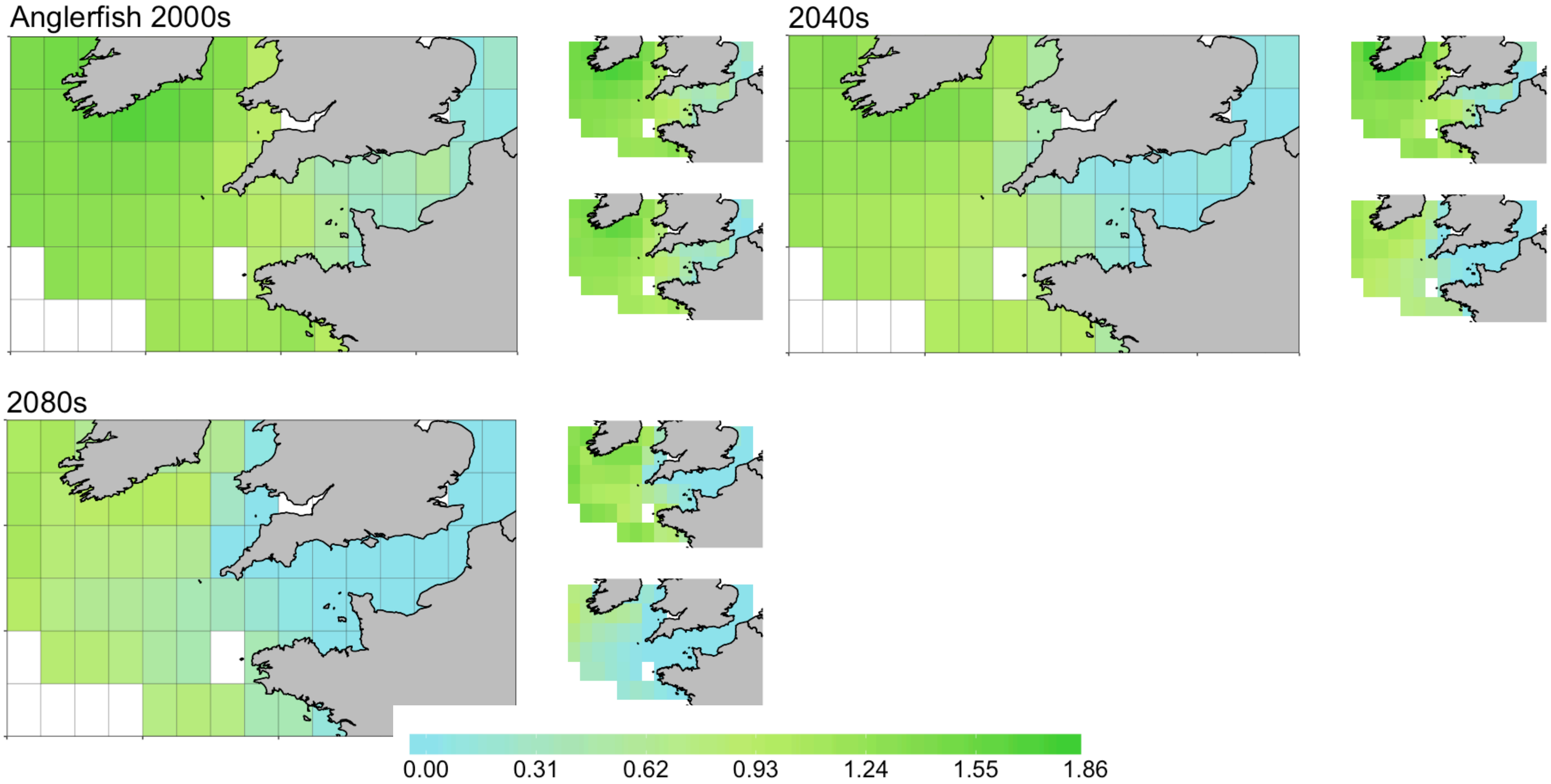


Figure A3.3a. Projected changes in index of abundance (4th rooted CPUE) for all species for time periods 2000s, 2040s and 2080s. White areas on maps represent grid cells with no survey data or projections. Main left panel: average CPUE across the region; top right panel upper 1.96 σ from the mean; bottom right panel shows lower 1.96 σ from the mean

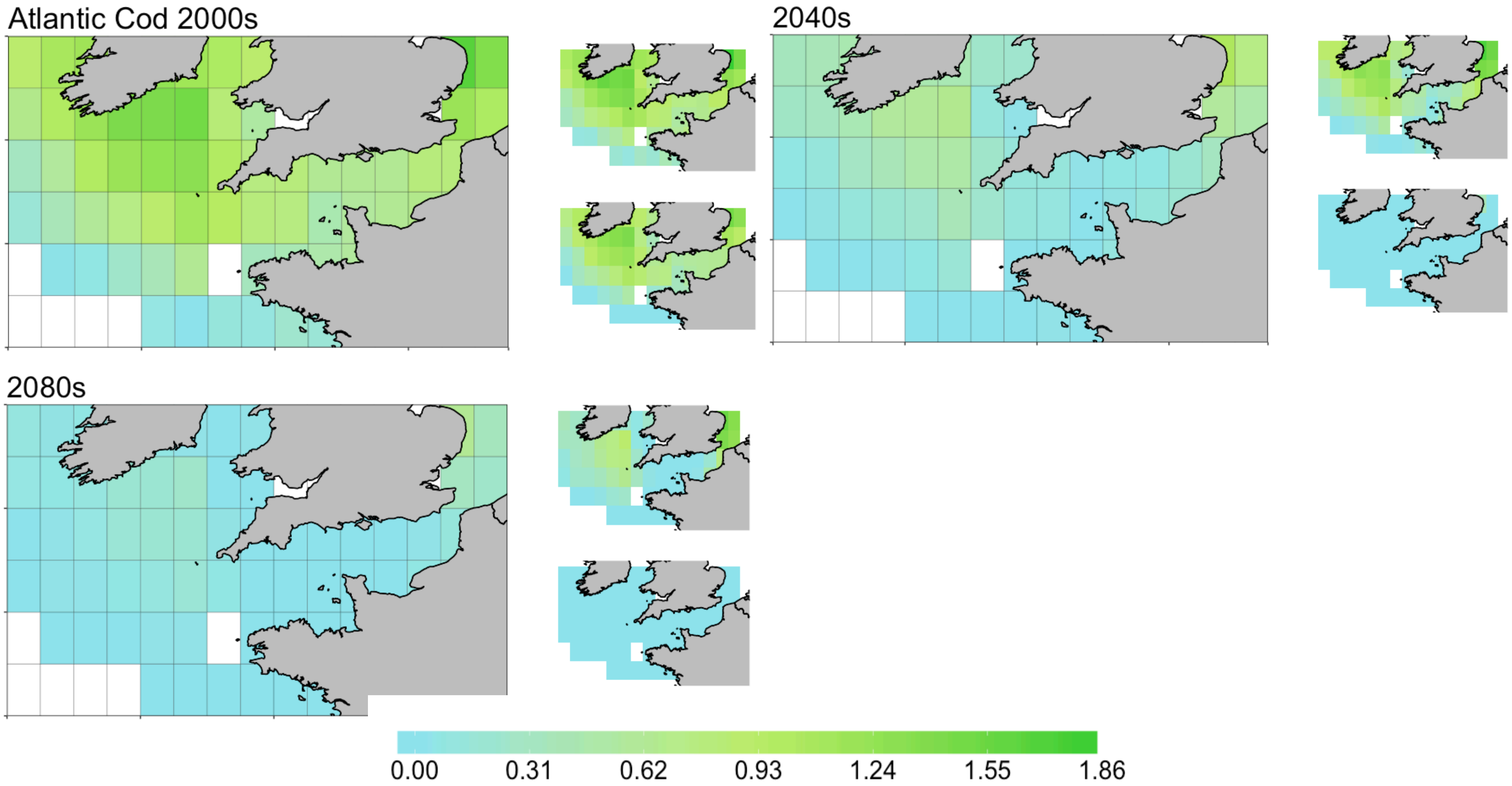


Figure A3.3b. Projected changes in index of abundance (4th rooted CPUE) for all species for time periods 2000s, 2040s and 2080s. White areas on maps represent grid cells with no survey data or projections. Main left panel: average CPUE across the region; top right panel upper 1.96 σ from the mean; bottom right panel shows lower 1.96 σ from the mean

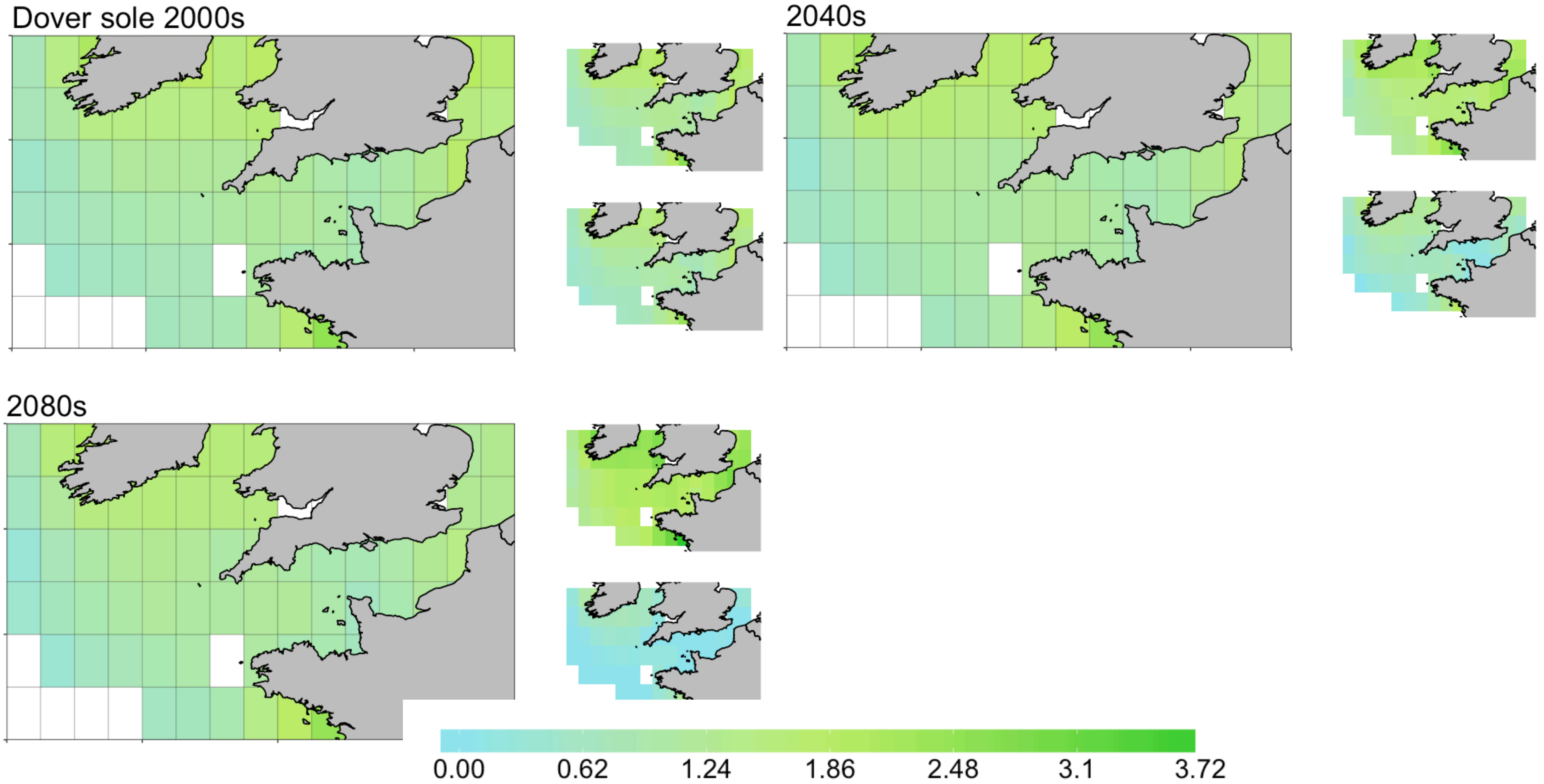


Figure A3.3c. Projected changes in index of abundance (4th rooted CPUE) for all species for time periods 2000s, 2040s and 2080s. White areas on maps represent grid cells with no survey data or projections. Main left panel: average CPUE across the region; top right panel upper 1.96 σ from the mean; bottom right panel shows lower 1.96 σ from the mean

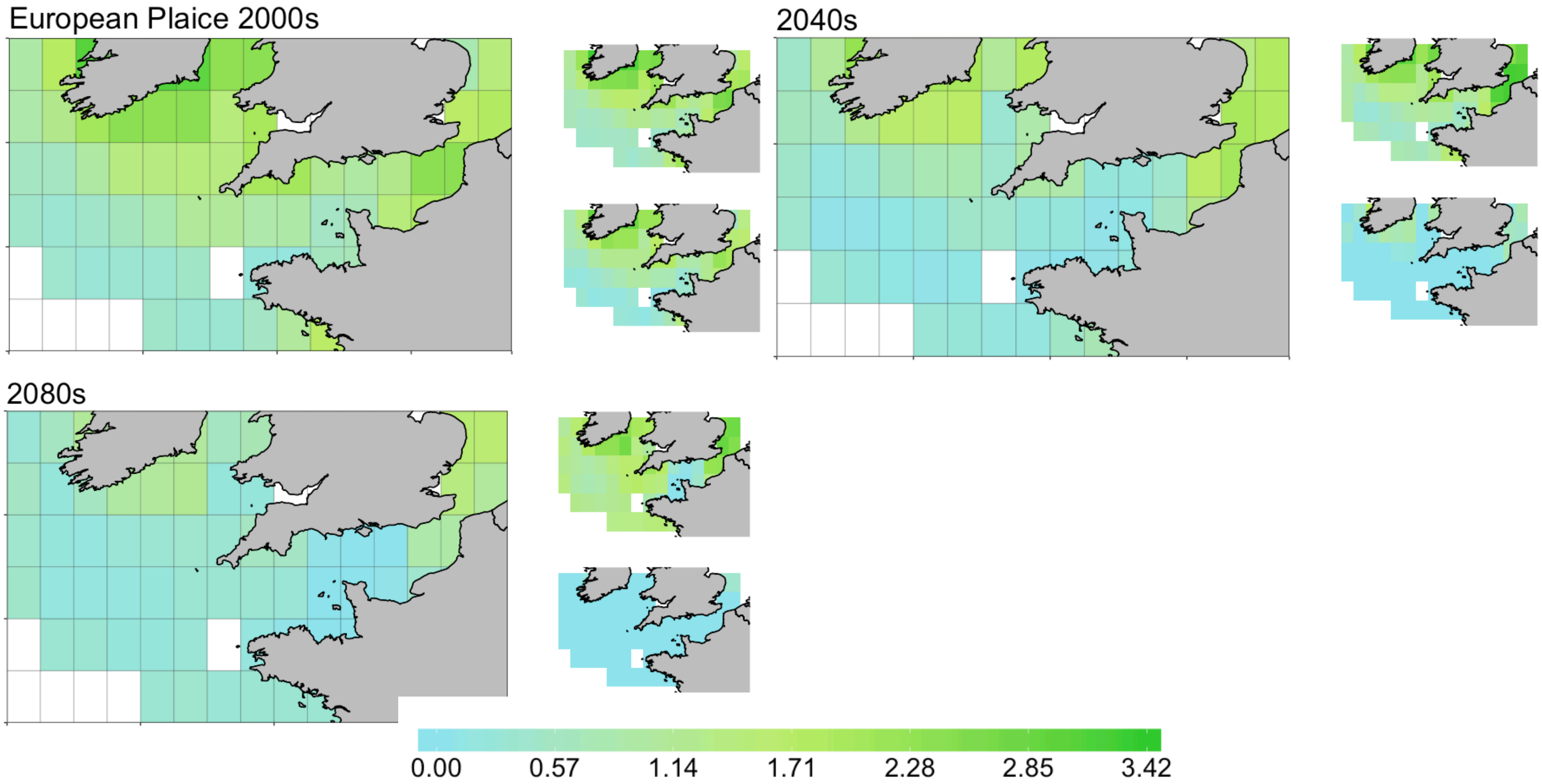


Figure A3.3d. Projected changes in index of abundance (4th rooted CPUE) for all species for time periods 2000s, 2040s and 2080s. White areas on maps represent grid cells with no survey data or projections. Main left panel: average CPUE across the region; top right panel upper 1.96 σ from the mean; bottom right panel shows lower 1.96 σ from the mean.

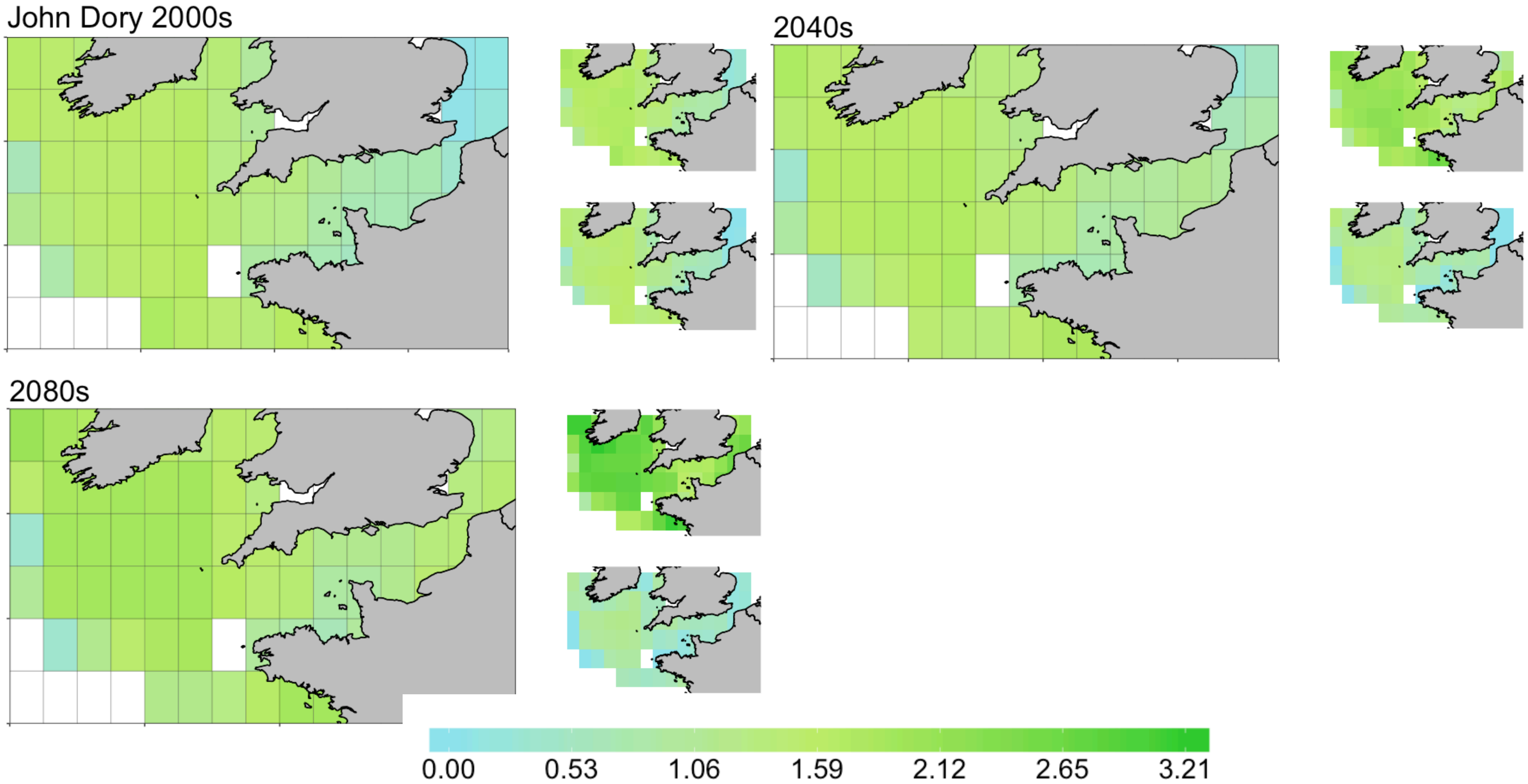
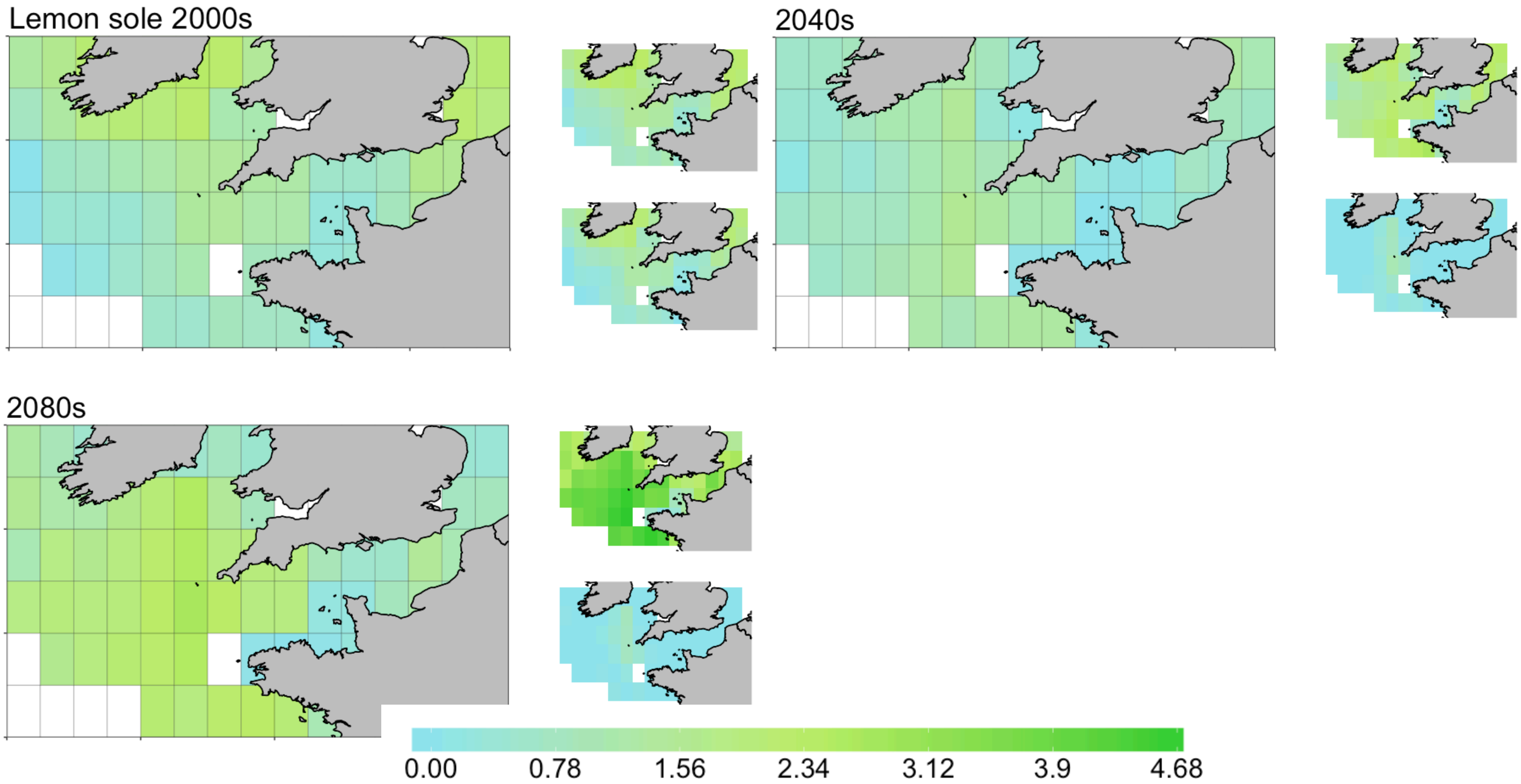


Figure A3.3e. Projected changes in index of abundance (4th rooted CPUE) for all species for time periods 2000s, 2040s and 2080s. White areas on maps represent grid cells with no survey data or projections. Main left panel: average CPUE across the region; top right panel upper 1.96 σ from the mean; bottom right panel shows lower 1.96 σ from the mean.


Lemon sole 2000s

2040s

2080s

Figure A3.3f. Projected changes in index of abundance (4th rooted CPUE) for all species for time periods 2000s, 2040s and 2080s. White areas on maps represent grid cells with no survey data or projections. Main left panel: average CPUE across the region; top right panel upper 1.96 σ from the mean; bottom right panel shows lower 1.96 σ from the mean

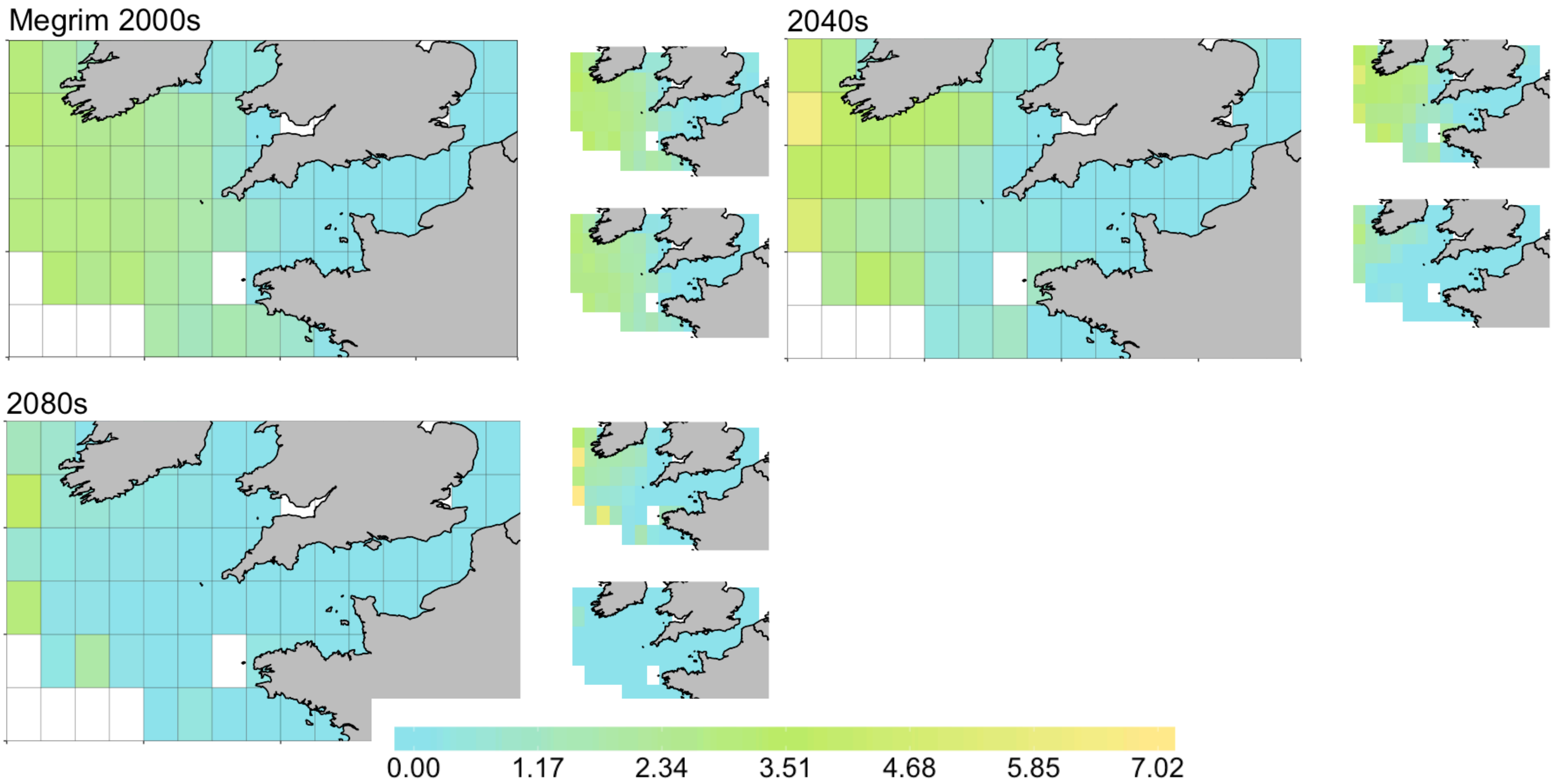


Figure A3.3g. Projected changes in index of abundance (4th rooted CPUE) for all species for time periods 2000s, 2040s and 2080s. White areas on maps represent grid cells with no survey data or projections. Main left panel: average CPUE across the region; top right panel upper 1.96 σ from the mean; bottom right panel shows lower 1.96 σ from the mean

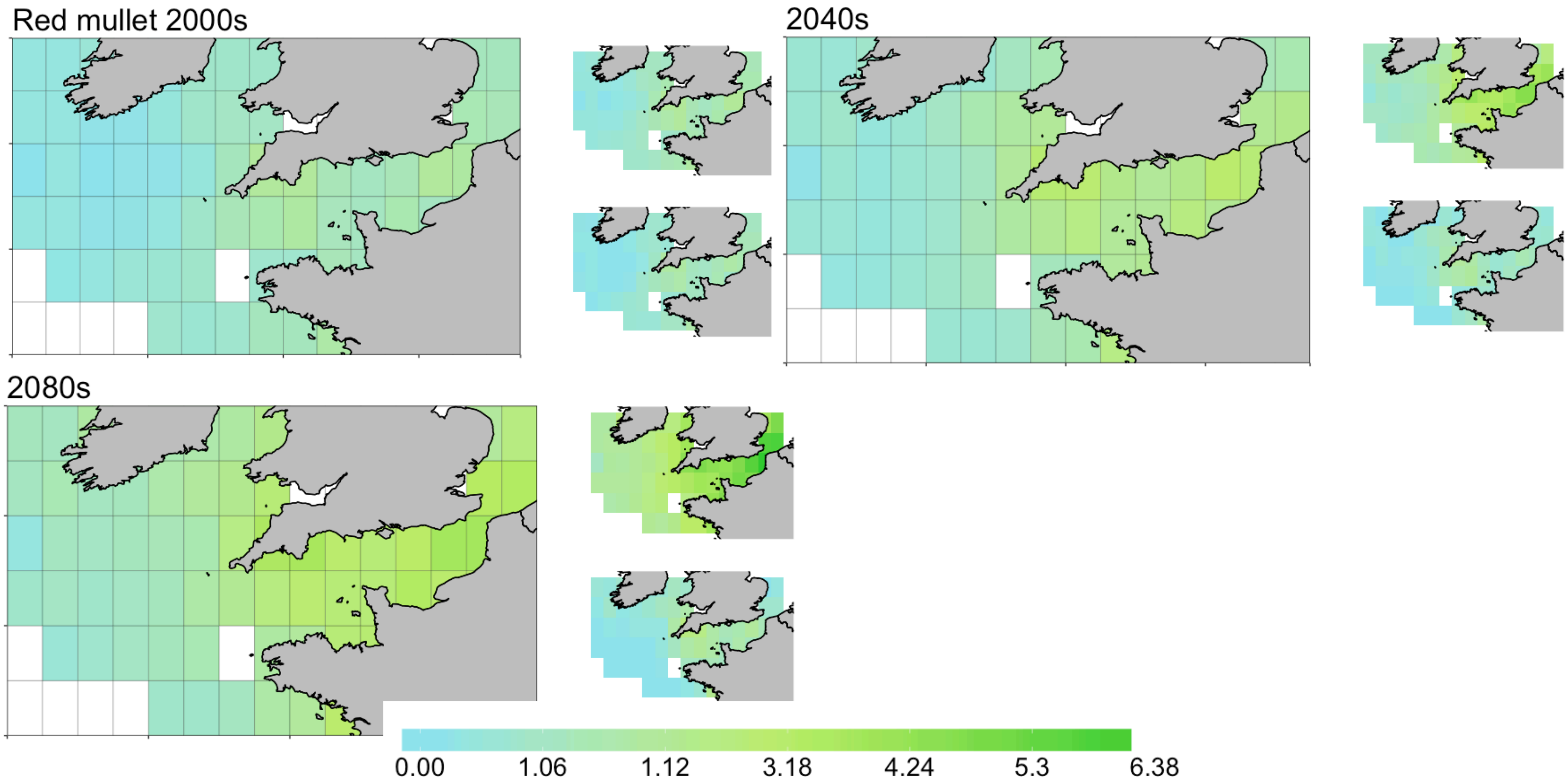


Figure A3.3h. Projected changes in index of abundance (4th rooted CPUE) for all species for time periods 2000s, 2040s and 2080s. White areas on maps represent grid cells with no survey data or projections. Main left panel: average CPUE across the region; top right panel upper 1.96 σ from the mean; bottom right panel shows lower 1.96 σ from the mean.

Table A3.7. Test statistics from GAM training for each species and ensemble-member combination. Grey shading signifies statistics for the optimal GAM selected. For details of models denoted A–H see Table A3.6.

Species	Climate ensemble-member	Test.Statistic	Model A	Model B	Model C	Model D	Model E	Model F	Model G	Model H
Anglerfish	ens_00	Adj R Sq	0.916	0.920	0.847	0.498	0.908	0.910	0.898	0.918
		AICc	-2.889	-13.609	22.819	77.960	-0.667	4.579	-20.598	-8.261
		Akaike Weight - AICc	0.000	0.029	0.000	0.000	0.000	0.000	0.968	0.002
		Correlation	0.974	0.974	0.949	0.793	0.972	0.973	0.962	0.974
		Delta AICc	17.708	6.988	43.416	98.557	19.930	25.177	0.000	12.337
		Deviance Explained	0.949	0.949	0.901	0.628	0.944	0.947	0.924	0.949
		GCV	0.035	0.032	0.059	0.170	0.038	0.038	0.035	0.034
Anglerfish	ens_01	Adj R Sq	0.935	0.928	0.835	0.567	0.911	0.930	0.922	0.936
		AICc	11.907	-9.201	32.009	67.381	3.269	3.422	-24.115	5.266
		Akaike Weight - AICc	0.000	0.001	0.000	0.000	0.000	0.000	0.999	0.000
		Correlation	0.983	0.979	0.947	0.821	0.973	0.981	0.974	0.983
		Delta AICc	36.022	14.914	56.124	91.496	27.384	27.537	0.000	29.381
		Deviance Explained	0.967	0.957	0.896	0.675	0.947	0.962	0.948	0.966
		GCV	0.032	0.031	0.066	0.145	0.038	0.032	0.029	0.031
Anglerfish	ens_02	Adj R Sq	0.928	0.924	0.870	0.614	0.908	0.931	0.921	0.932
		AICc	-1.124	-13.858	13.084	69.674	4.112	-5.838	-30.498	-5.143
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.980	0.976	0.957	0.856	0.972	0.980	0.972	0.981
		Delta AICc	29.374	16.639	43.581	100.172	34.609	24.660	0.000	25.354
		Deviance Explained	0.960	0.953	0.916	0.732	0.945	0.960	0.944	0.962
		GCV	0.032	0.031	0.051	0.139	0.039	0.030	0.028	0.030
Anglerfish	ens_03	Adj R Sq	0.933	0.932	0.848	0.536	0.916	0.916	0.904	0.934
		AICc	-0.721	-13.635	28.216	71.043	-1.675	1.885	-28.352	-7.406

		Akaike Weight - AICc	0.000	0.001	0.000	0.000	0.000	0.000	0.999	0.000
		Correlation	0.981	0.980	0.952	0.806	0.975	0.975	0.963	0.981
		Delta AICc	27.630	14.717	56.568	99.395	26.677	30.237	0.000	20.946
		Deviance Explained	0.963	0.960	0.905	0.650	0.950	0.951	0.927	0.962
		GCV	0.031	0.029	0.061	0.154	0.035	0.036	0.031	0.029
Anglerfish	ens_04	Adj R Sq	0.930	0.928	0.824	0.475	0.916	0.908	0.902	0.931
		AICc	6.339	-7.126	38.135	78.767	1.922	0.986	-22.992	-1.038
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.981	0.979	0.944	0.777	0.975	0.972	0.963	0.981
		Delta AICc	29.331	15.865	61.127	101.759	24.914	23.978	0.000	21.954
		Deviance Explained	0.962	0.958	0.891	0.604	0.951	0.944	0.928	0.962
		GCV	0.033	0.031	0.071	0.175	0.036	0.038	0.033	0.031
Anglerfish	ens_05	Adj R Sq	0.915	0.908	0.856	0.571	0.910	0.918	0.892	0.916
		AICc	8.864	-3.369	23.572	79.297	4.124	3.792	-12.855	5.464
		Akaike Weight - AICc	0.000	0.009	0.000	0.000	0.000	0.000	0.991	0.000
		Correlation	0.976	0.971	0.954	0.842	0.973	0.976	0.961	0.975
		Delta AICc	21.719	9.486	36.428	92.153	16.980	16.648	0.000	18.320
		Deviance Explained	0.952	0.943	0.910	0.708	0.947	0.953	0.922	0.951
		GCV	0.038	0.037	0.058	0.158	0.038	0.036	0.038	0.037
Anglerfish	ens_06	Adj R Sq	0.909	0.904	0.856	0.554	0.912	0.928	0.893	0.912
		AICc	8.938	-0.588	23.987	79.862	3.696	3.140	-16.033	3.373
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	0.999	0.000
		Correlation	0.973	0.970	0.954	0.832	0.974	0.980	0.960	0.974
		Delta AICc	24.970	15.445	40.020	95.895	19.729	19.173	0.000	19.406
		Deviance Explained	0.947	0.940	0.909	0.692	0.948	0.960	0.922	0.948
		GCV	0.039	0.039	0.058	0.162	0.037	0.033	0.037	0.038
Anglerfish	ens_07	Adj R Sq	0.930	0.930	0.849	0.502	0.919	0.913	0.902	0.932

		AICc	2.244	-10.608	40.002	75.382	-4.210	6.262	-24.278	-4.089
		Akaike Weight - AICc	0.000	0.001	0.000	0.000	0.000	0.000	0.999	0.000
		Correlation	0.981	0.979	0.956	0.790	0.975	0.975	0.962	0.981
		Delta AICc	26.521	13.670	64.280	99.660	20.068	30.539	0.000	20.188
		Deviance Explained	0.961	0.958	0.913	0.625	0.951	0.950	0.926	0.962
		GCV	0.032	0.030	0.065	0.166	0.034	0.038	0.033	0.030
Anglerfish	ens_08	Adj R Sq	0.930	0.930	0.829	0.503	0.920	0.913	0.907	0.931
		AICc	1.941	-9.915	37.577	75.260	-5.838	1.530	-26.055	-3.617
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.981	0.979	0.946	0.791	0.976	0.974	0.965	0.981
		Delta AICc	27.995	16.140	63.632	101.315	20.217	27.585	0.000	22.437
		Deviance Explained	0.962	0.959	0.895	0.626	0.952	0.948	0.932	0.961
		GCV	0.032	0.030	0.070	0.165	0.033	0.037	0.032	0.031
Anglerfish	ens_09	Adj R Sq	0.932	0.932	0.848	0.532	0.919	0.913	0.911	0.933
		AICc	2.361	-9.938	28.701	71.618	1.230	-0.193	-28.561	-4.226
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.981	0.980	0.952	0.804	0.976	0.973	0.967	0.981
		Delta AICc	30.922	18.623	57.263	100.179	29.791	28.368	0.000	24.335
		Deviance Explained	0.963	0.960	0.905	0.647	0.953	0.947	0.935	0.963
		GCV	0.031	0.029	0.062	0.156	0.035	0.037	0.030	0.030
Anglerfish	ens_10	Adj R Sq	0.925	0.923	0.804	0.463	0.924	0.900	0.896	0.927
		AICc	-1.901	-9.569	48.754	80.088	-5.864	7.175	-23.629	-8.369
		Akaike Weight - AICc	0.000	0.001	0.000	0.000	0.000	0.000	0.998	0.000
		Correlation	0.978	0.976	0.939	0.771	0.977	0.969	0.959	0.978
		Delta AICc	21.728	14.060	72.383	103.717	17.765	30.803	0.000	15.260
		Deviance Explained	0.957	0.953	0.882	0.595	0.955	0.939	0.921	0.957
		GCV	0.033	0.032	0.081	0.179	0.032	0.042	0.034	0.031

Atlantic Cod	ens_00	Adj R Sq	0.717	0.666	0.685	0.232	0.755	0.708	0.630	0.724
		AICc	65.430	69.613	56.331	105.214	67.014	63.025	51.374	60.112
		Akaike Weight - AICc	0.001	0.000	0.076	0.000	0.000	0.003	0.908	0.012
		Correlation	0.905	0.882	0.880	0.649	0.924	0.899	0.836	0.905
		Delta AICc	14.056	18.239	4.956	53.840	15.640	11.651	0.000	8.738
		Deviance Explained	0.819	0.778	0.774	0.421	0.853	0.808	0.699	0.819
		GCV	0.116	0.132	0.116	0.268	0.108	0.117	0.119	0.111
Atlantic Cod	ens_01	Adj R Sq	0.711	0.742	0.741	0.229	0.724	0.710	0.608	0.737
		AICc	63.026	70.003	53.093	110.667	62.610	59.771	53.442	64.184
		Akaike Weight - AICc	0.004	0.000	0.528	0.000	0.005	0.019	0.443	0.002
		Correlation	0.900	0.920	0.909	0.666	0.907	0.897	0.822	0.914
		Delta AICc	9.933	16.910	0.000	57.573	9.517	6.677	0.349	11.091
		Deviance Explained	0.811	0.846	0.827	0.443	0.822	0.805	0.675	0.835
		GCV	0.116	0.113	0.102	0.281	0.113	0.114	0.125	0.110
Atlantic Cod	ens_02	Adj R Sq	0.754	0.755	0.736	0.208	0.758	0.742	0.640	0.771
		AICc	60.105	65.222	47.122	107.092	54.747	52.358	50.517	60.657
		Akaike Weight - AICc	0.001	0.000	0.781	0.000	0.017	0.057	0.143	0.001
		Correlation	0.920	0.923	0.902	0.635	0.919	0.909	0.842	0.928
		Delta AICc	12.983	18.100	0.000	59.970	7.624	5.236	3.395	13.534
		Deviance Explained	0.846	0.852	0.814	0.403	0.844	0.827	0.709	0.861
		GCV	0.103	0.106	0.098	0.276	0.099	0.101	0.117	0.099
Atlantic Cod	ens_03	Adj R Sq	0.718	0.764	0.706	0.251	0.722	0.693	0.589	0.731
		AICc	68.876	74.496	54.421	109.160	64.604	63.372	59.166	66.603
		Akaike Weight - AICc	0.001	0.000	0.898	0.000	0.006	0.010	0.084	0.002
		Correlation	0.908	0.931	0.891	0.678	0.907	0.891	0.818	0.912
		Delta AICc	14.455	20.075	0.000	54.739	10.183	8.951	4.745	12.182
		Deviance Explained	0.824	0.866	0.793	0.460	0.822	0.794	0.669	0.832

		GCV	0.119	0.110	0.110	0.274	0.115	0.120	0.134	0.114
Atlantic Cod	ens_04	Adj R Sq	0.736	0.676	0.669	0.245	0.733	0.723	0.610	0.742
		AICc	70.083	68.190	61.482	104.168	63.215	69.111	52.630	66.245
		Akaike Weight - AICc	0.000	0.000	0.012	0.000	0.005	0.000	0.981	0.001
		Correlation	0.917	0.886	0.876	0.656	0.912	0.910	0.822	0.918
		Delta AICc	17.453	15.559	8.852	51.538	10.585	16.480	0.000	13.615
		Deviance Explained	0.840	0.784	0.767	0.430	0.831	0.828	0.676	0.842
		GCV	0.115	0.128	0.124	0.264	0.111	0.118	0.123	0.110
Atlantic Cod	ens_05	Adj R Sq	0.781	0.785	0.738	0.284	0.813	0.730	0.622	0.830
		AICc	67.680	59.139	57.123	100.890	62.511	60.567	52.694	66.140
		Akaike Weight - AICc	0.000	0.034	0.093	0.000	0.006	0.017	0.849	0.001
		Correlation	0.935	0.934	0.910	0.678	0.946	0.908	0.832	0.954
		Delta AICc	14.986	6.446	4.429	48.196	9.817	7.873	0.000	13.446
		Deviance Explained	0.874	0.872	0.828	0.460	0.896	0.825	0.691	0.909
		GCV	0.100	0.094	0.105	0.250	0.088	0.110	0.122	0.084
Atlantic Cod	ens_06	Adj R Sq	0.784	0.776	0.738	0.269	0.819	0.727	0.657	0.840
		AICc	67.721	63.350	59.689	102.156	62.533	64.137	51.581	64.378
		Akaike Weight - AICc	0.000	0.003	0.017	0.000	0.004	0.002	0.973	0.002
		Correlation	0.936	0.931	0.912	0.670	0.948	0.909	0.856	0.957
		Delta AICc	16.140	11.770	8.109	50.575	10.952	12.557	0.000	12.797
		Deviance Explained	0.876	0.867	0.831	0.449	0.899	0.827	0.732	0.915
		GCV	0.100	0.099	0.107	0.255	0.086	0.113	0.116	0.080
Atlantic Cod	ens_07	Adj R Sq	0.753	0.722	0.704	0.238	0.749	0.720	0.624	0.761
		AICc	71.709	76.091	67.460	104.737	62.164	66.935	53.191	66.896
		Akaike Weight - AICc	0.000	0.000	0.001	0.000	0.011	0.001	0.986	0.001
		Correlation	0.925	0.914	0.900	0.652	0.918	0.907	0.835	0.926
		Delta AICc	18.519	22.900	14.269	51.546	8.973	13.744	0.000	13.705

		Deviance Explained	0.856	0.835	0.810	0.425	0.843	0.823	0.696	0.858
		GCV	0.111	0.123	0.121	0.266	0.106	0.117	0.122	0.106
Atlantic Cod	ens_08	Adj R Sq	0.760	0.752	0.633	0.229	0.803	0.742	0.621	0.811
		AICc	66.410	70.268	68.521	105.431	63.616	66.582	54.713	63.331
		Akaike Weight - AICc	0.003	0.000	0.001	0.000	0.011	0.003	0.969	0.013
		Correlation	0.926	0.924	0.862	0.647	0.942	0.917	0.835	0.946
		Delta AICc	11.697	15.555	13.808	50.719	8.904	11.869	0.000	8.619
		Deviance Explained	0.857	0.854	0.742	0.419	0.888	0.842	0.697	0.895
		GCV	0.106	0.110	0.138	0.269	0.092	0.111	0.125	0.089
Atlantic Cod	ens_09	Adj R Sq	0.738	0.734	0.714	0.268	0.744	0.688	0.619	0.746
		AICc	66.483	64.714	52.526	108.893	61.460	64.646	58.536	62.429
		Akaike Weight - AICc	0.001	0.002	0.931	0.000	0.011	0.002	0.046	0.007
		Correlation	0.916	0.913	0.893	0.691	0.916	0.890	0.840	0.917
		Delta AICc	13.956	12.188	0.000	56.366	8.933	12.120	6.009	9.902
		Deviance Explained	0.838	0.833	0.798	0.478	0.839	0.791	0.704	0.841
		GCV	0.112	0.111	0.107	0.270	0.107	0.122	0.129	0.107
Atlantic Cod	ens_10	Adj R Sq	0.815	0.723	0.610	0.247	0.811	0.748	0.680	0.820
		AICc	68.253	75.603	71.739	103.938	60.470	65.074	47.798	61.228
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.002	0.000	0.997	0.001
		Correlation	0.949	0.914	0.852	0.658	0.945	0.920	0.867	0.949
		Delta AICc	20.454	27.804	23.941	56.140	12.671	17.276	0.000	13.429
		Deviance Explained	0.900	0.835	0.725	0.433	0.893	0.846	0.752	0.900
		GCV	0.090	0.122	0.146	0.263	0.087	0.108	0.109	0.085
Dover Sole	ens_00	Adj R Sq	0.739	0.698	0.562	0.496	0.710	0.661	0.749	0.740
		AICc	64.622	64.031	81.724	77.133	66.068	83.099	30.367	60.417
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.918	0.898	0.841	0.792	0.904	0.893	0.899	0.916

		Delta AICc	34.255	33.664	51.358	46.766	35.701	52.732	0.000	30.050
		Deviance Explained	0.842	0.805	0.707	0.627	0.818	0.797	0.808	0.838
		GCV	0.106	0.115	0.161	0.167	0.114	0.139	0.081	0.103
Dover Sole	ens_01	Adj R Sq	0.700	0.711	0.699	0.633	0.679	0.659	0.734	0.720
		AICc	75.899	65.943	65.638	69.357	75.801	74.811	35.888	73.814
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.906	0.905	0.899	0.867	0.896	0.886	0.895	0.914
		Delta AICc	40.011	30.055	29.751	33.470	39.913	38.924	0.000	37.926
		Deviance Explained	0.821	0.819	0.808	0.751	0.803	0.784	0.800	0.835
		GCV	0.123	0.114	0.116	0.134	0.129	0.133	0.087	0.117
Dover Sole	ens_02	Adj R Sq	0.722	0.728	0.711	0.632	0.699	0.683	0.732	0.717
		AICc	69.718	61.884	63.124	68.446	71.349	70.621	29.673	68.245
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.912	0.911	0.903	0.866	0.903	0.895	0.887	0.909
		Delta AICc	40.044	32.210	33.450	38.773	41.676	40.948	0.000	38.572
		Deviance Explained	0.832	0.829	0.816	0.749	0.815	0.800	0.787	0.826
		GCV	0.113	0.107	0.111	0.133	0.120	0.124	0.083	0.114
Dover Sole	ens_03	Adj R Sq	0.721	0.705	0.709	0.604	0.688	0.662	0.742	0.721
		AICc	81.465	68.184	74.265	72.080	78.766	83.283	33.879	75.629
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.918	0.904	0.910	0.854	0.903	0.894	0.898	0.915
		Delta AICc	47.586	34.305	40.386	38.201	44.887	49.404	0.000	41.750
		Deviance Explained	0.842	0.817	0.826	0.729	0.814	0.798	0.806	0.837
		GCV	0.122	0.116	0.120	0.142	0.129	0.139	0.085	0.118
Dover Sole	ens_04	Adj R Sq	0.706	0.694	0.709	0.591	0.697	0.601	0.748	0.713
		AICc	77.863	71.532	72.218	71.070	75.682	84.056	31.692	71.780
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000

		Correlation	0.910	0.901	0.908	0.845	0.905	0.865	0.900	0.910
		Delta AICc	46.171	39.840	40.527	39.379	43.990	52.364	0.000	40.088
		Deviance Explained	0.828	0.811	0.824	0.713	0.818	0.747	0.810	0.827
		GCV	0.123	0.122	0.119	0.144	0.124	0.155	0.082	0.117
Dover Sole	ens_05	Adj R Sq	0.727	0.713	0.719	0.663	0.711	0.658	0.729	0.732
		AICc	69.910	66.279	61.399	61.758	70.236	76.118	30.111	64.262
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.915	0.907	0.907	0.877	0.908	0.886	0.886	0.914
		Delta AICc	39.799	36.168	31.288	31.647	40.125	46.007	0.000	34.152
		Deviance Explained	0.837	0.821	0.821	0.768	0.824	0.785	0.784	0.835
		GCV	0.112	0.113	0.108	0.121	0.116	0.134	0.084	0.107
Dover Sole	ens_06	Adj R Sq	0.758	0.720	0.726	0.663	0.734	0.670	0.736	0.764
		AICc	64.063	64.480	57.145	61.699	64.657	75.748	28.852	58.604
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.926	0.909	0.907	0.877	0.915	0.892	0.890	0.926
		Delta AICc	35.211	35.628	28.292	32.846	35.804	46.896	0.000	29.751
		Deviance Explained	0.856	0.825	0.822	0.769	0.837	0.795	0.791	0.857
		GCV	0.100	0.110	0.104	0.120	0.107	0.131	0.082	0.096
Dover Sole	ens_07	Adj R Sq	0.737	0.703	0.688	0.608	0.703	0.674	0.759	0.743
		AICc	78.561	67.538	63.644	68.351	73.905	81.299	29.195	71.740
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.923	0.903	0.893	0.852	0.906	0.898	0.905	0.923
		Delta AICc	49.366	38.342	34.449	39.156	44.710	52.103	0.000	42.545
		Deviance Explained	0.852	0.814	0.796	0.725	0.821	0.805	0.818	0.851
		GCV	0.115	0.117	0.117	0.137	0.121	0.134	0.079	0.109
Dover Sole	ens_08	Adj R Sq	0.732	0.718	0.715	0.640	0.724	0.665	0.749	0.738
		AICc	69.722	64.450	58.708	65.527	69.529	73.988	31.747	64.177

		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.917	0.908	0.903	0.868	0.913	0.888	0.901	0.917
		Delta AICc	37.975	32.703	26.962	33.781	37.782	42.242	0.000	32.430
		Deviance Explained	0.840	0.823	0.814	0.752	0.833	0.789	0.810	0.841
		GCV	0.111	0.111	0.107	0.128	0.113	0.131	0.082	0.106
Dover Sole	ens_09	Adj R Sq	0.738	0.725	0.726	0.631	0.706	0.663	0.746	0.742
		AICc	66.386	64.142	58.245	67.809	67.150	80.645	30.575	60.664
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.918	0.911	0.908	0.865	0.904	0.892	0.898	0.917
		Delta AICc	35.811	33.568	27.670	37.235	36.575	50.070	0.000	30.089
		Deviance Explained	0.843	0.829	0.823	0.747	0.816	0.795	0.806	0.840
		GCV	0.107	0.109	0.105	0.132	0.116	0.137	0.082	0.102
Dover Sole	ens_10	Adj R Sq	0.731	0.709	0.706	0.646	0.728	0.639	0.742	0.735
		AICc	70.580	64.942	57.982	63.519	67.820	76.636	28.806	65.995
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.917	0.904	0.897	0.869	0.914	0.877	0.893	0.917
		Delta AICc	41.774	36.136	29.175	34.712	39.014	47.830	0.000	37.188
		Deviance Explained	0.841	0.816	0.805	0.754	0.835	0.769	0.797	0.839
		GCV	0.112	0.113	0.109	0.126	0.111	0.139	0.081	0.108
European plaice	ens_00	Adj R Sq	0.839	0.829	0.701	0.578	0.759	0.657	0.801	0.816
		AICc	141.971	126.343	133.379	144.700	134.585	152.633	96.549	124.126
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.958	0.951	0.896	0.836	0.924	0.888	0.926	0.945
		Delta AICc	45.422	29.795	36.830	48.151	38.036	56.084	0.000	27.577
		Deviance Explained	0.918	0.904	0.802	0.699	0.854	0.788	0.856	0.893
		GCV	0.256	0.248	0.366	0.480	0.324	0.451	0.224	0.256
European plaice	ens_01	Adj R Sq	0.846	0.842	0.613	0.433	0.825	0.667	0.770	0.850

		AICc	118.090	110.523	150.676	157.922	124.670	151.107	104.033	111.368
		Akaike Weight - AICc	0.001	0.037	0.000	0.000	0.000	0.000	0.939	0.024
		Correlation	0.955	0.952	0.864	0.761	0.949	0.892	0.912	0.955
		Delta AICc	14.058	6.490	46.643	53.889	20.637	47.074	0.000	7.335
		Deviance Explained	0.912	0.906	0.745	0.578	0.900	0.794	0.832	0.913
		GCV	0.221	0.215	0.478	0.619	0.249	0.438	0.255	0.209
European plaice	ens_02	Adj R Sq	0.865	0.858	0.639	0.461	0.851	0.722	0.791	0.868
		AICc	115.524	108.190	147.562	156.753	118.129	139.370	94.891	108.354
		Akaike Weight - AICc	0.000	0.001	0.000	0.000	0.000	0.000	0.997	0.001
		Correlation	0.962	0.958	0.875	0.778	0.958	0.910	0.918	0.962
		Delta AICc	20.633	13.299	52.671	61.861	23.238	44.479	0.000	13.463
		Deviance Explained	0.926	0.917	0.765	0.606	0.917	0.828	0.842	0.925
		GCV	0.200	0.198	0.450	0.598	0.216	0.364	0.226	0.189
European plaice	ens_03	Adj R Sq	0.869	0.851	0.644	0.443	0.855	0.647	0.795	0.869
		AICc	117.684	113.257	146.467	156.658	119.874	156.337	101.919	111.378
		Akaike Weight - AICc	0.000	0.003	0.000	0.000	0.000	0.000	0.987	0.009
		Correlation	0.964	0.956	0.876	0.765	0.959	0.886	0.925	0.963
		Delta AICc	15.765	11.338	44.547	54.739	17.955	54.418	0.000	9.458
		Deviance Explained	0.929	0.915	0.768	0.585	0.920	0.784	0.856	0.927
		GCV	0.198	0.210	0.443	0.608	0.214	0.469	0.237	0.191
European plaice	ens_04	Adj R Sq	0.872	0.860	0.688	0.537	0.867	0.675	0.790	0.870
		AICc	120.881	114.240	137.825	148.826	116.211	152.695	91.648	115.682
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.966	0.960	0.892	0.816	0.963	0.896	0.915	0.964
		Delta AICc	29.233	22.592	46.177	57.178	24.563	61.047	0.000	24.034
		Deviance Explained	0.932	0.922	0.796	0.665	0.928	0.803	0.837	0.929
		GCV	0.198	0.203	0.387	0.520	0.198	0.436	0.221	0.195

European plaice	ens_05	Adj R Sq	0.861	0.861	0.667	0.614	0.864	0.702	0.756	0.865
		AICc	110.531	96.331	139.840	139.776	107.341	140.884	101.053	105.153
		Akaike Weight - AICc	0.001	0.900	0.000	0.000	0.004	0.000	0.085	0.011
		Correlation	0.960	0.956	0.883	0.852	0.960	0.901	0.901	0.960
		Delta AICc	14.200	0.000	43.509	43.445	11.010	44.552	4.722	8.822
		Deviance Explained	0.921	0.914	0.779	0.726	0.921	0.812	0.811	0.921
		GCV	0.198	0.183	0.407	0.441	0.192	0.384	0.256	0.189
European plaice	ens_06	Adj R Sq	0.868	0.886	0.667	0.579	0.861	0.657	0.785	0.871
		AICc	115.273	101.463	140.663	145.042	103.428	152.372	94.758	108.351
		Akaike Weight - AICc	0.000	0.033	0.000	0.000	0.012	0.000	0.953	0.001
		Correlation	0.963	0.967	0.883	0.837	0.958	0.888	0.914	0.963
		Delta AICc	20.515	6.705	45.905	50.284	8.670	57.614	0.000	13.593
		Deviance Explained	0.928	0.936	0.780	0.700	0.917	0.787	0.836	0.927
		GCV	0.196	0.166	0.409	0.481	0.190	0.450	0.229	0.186
European plaice	ens_07	Adj R Sq	0.854	0.839	0.680	0.511	0.836	0.637	0.765	0.856
		AICc	126.651	117.758	140.806	153.471	126.315	157.938	98.209	119.551
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.961	0.953	0.890	0.806	0.953	0.882	0.904	0.960
		Delta AICc	28.442	19.549	42.597	55.262	28.107	59.730	0.000	21.342
		Deviance Explained	0.922	0.907	0.792	0.650	0.909	0.778	0.817	0.921
		GCV	0.222	0.227	0.401	0.555	0.241	0.482	0.246	0.213
European plaice	ens_08	Adj R Sq	0.860	0.852	0.649	0.483	0.845	0.633	0.746	0.862
		AICc	120.177	108.847	146.432	151.516	111.785	158.547	102.883	112.095
		Akaike Weight - AICc	0.000	0.047	0.000	0.000	0.011	0.000	0.932	0.009
		Correlation	0.961	0.956	0.879	0.783	0.953	0.881	0.896	0.960
		Delta AICc	17.294	5.963	43.549	48.633	8.901	55.664	0.000	9.211
		Deviance Explained	0.924	0.913	0.772	0.614	0.908	0.775	0.802	0.922

		GCV	0.210	0.204	0.439	0.561	0.214	0.488	0.265	0.199
European plaice	ens_09	Adj R Sq	0.879	0.879	0.619	0.447	0.869	0.664	0.789	0.880
		AICc	103.701	111.746	148.505	155.711	107.099	154.176	93.623	97.557
		Akaike Weight - AICc	0.006	0.000	0.000	0.000	0.001	0.000	0.871	0.122
		Correlation	0.965	0.967	0.865	0.766	0.962	0.892	0.916	0.964
		Delta AICc	10.078	18.123	54.883	62.088	13.476	60.553	0.000	3.934
		Deviance Explained	0.932	0.934	0.747	0.586	0.925	0.795	0.838	0.930
		GCV	0.174	0.182	0.467	0.601	0.187	0.449	0.225	0.167
European plaice	ens_10	Adj R Sq	0.863	0.860	0.683	0.506	0.840	0.633	0.772	0.864
		AICc	124.158	116.097	145.864	147.792	112.912	156.285	97.822	117.320
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.001	0.000	0.999	0.000
		Correlation	0.963	0.960	0.896	0.792	0.952	0.879	0.908	0.962
		Delta AICc	26.336	18.274	48.041	49.969	15.089	58.462	0.000	19.498
		Deviance Explained	0.927	0.922	0.802	0.627	0.905	0.772	0.825	0.926
		GCV	0.210	0.205	0.411	0.533	0.220	0.481	0.242	0.202
John Dory	ens_00	Adj R Sq	0.830	0.852	0.791	0.502	0.829	0.802	0.765	0.844
		AICc	48.554	41.862	55.340	92.261	44.236	57.381	28.507	48.830
		Akaike Weight - AICc	0.000	0.001	0.000	0.000	0.000	0.000	0.998	0.000
		Correlation	0.948	0.955	0.933	0.811	0.946	0.939	0.902	0.954
		Delta AICc	20.047	13.354	26.832	63.753	15.729	28.874	0.000	20.322
		Deviance Explained	0.899	0.913	0.871	0.657	0.896	0.882	0.813	0.910
		GCV	0.079	0.069	0.093	0.198	0.077	0.091	0.081	0.075
John Dory	ens_01	Adj R Sq	0.841	0.840	0.740	0.490	0.842	0.869	0.810	0.857
		AICc	55.314	44.730	66.363	82.591	52.478	64.405	22.728	58.249
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.954	0.951	0.915	0.785	0.954	0.966	0.927	0.961
		Delta AICc	32.586	22.003	43.635	59.863	29.751	41.678	0.000	35.521

		Deviance Explained	0.911	0.905	0.837	0.616	0.911	0.934	0.858	0.924
		GCV	0.078	0.074	0.114	0.186	0.077	0.072	0.070	0.074
John Dory	ens_02	Adj R Sq	0.882	0.846	0.755	0.493	0.869	0.879	0.862	0.883
		AICc	60.905	42.280	63.839	82.270	46.211	59.073	17.112	50.512
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.970	0.953	0.921	0.786	0.963	0.969	0.953	0.969
		Delta AICc	43.793	25.168	46.727	65.158	29.099	41.961	0.000	33.400
		Deviance Explained	0.941	0.909	0.848	0.618	0.928	0.939	0.908	0.939
		GCV	0.065	0.071	0.108	0.185	0.065	0.066	0.057	0.062
John Dory	ens_03	Adj R Sq	0.847	0.841	0.768	0.457	0.851	0.838	0.784	0.852
		AICc	55.503	46.211	58.350	86.483	52.717	60.249	26.456	50.299
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.957	0.952	0.924	0.769	0.958	0.955	0.913	0.958
		Delta AICc	29.046	19.755	31.893	60.027	26.261	33.792	0.000	23.843
		Deviance Explained	0.915	0.906	0.854	0.591	0.917	0.911	0.833	0.917
		GCV	0.076	0.074	0.101	0.198	0.074	0.081	0.077	0.072
John Dory	ens_04	Adj R Sq	0.852	0.845	0.754	0.455	0.853	0.826	0.786	0.854
		AICc	51.558	47.175	61.783	97.074	46.783	62.621	27.213	46.262
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.958	0.954	0.919	0.789	0.957	0.951	0.915	0.958
		Delta AICc	24.345	19.963	34.570	69.861	19.570	35.408	0.000	19.049
		Deviance Explained	0.918	0.910	0.845	0.622	0.916	0.904	0.837	0.917
		GCV	0.073	0.073	0.107	0.216	0.071	0.086	0.077	0.070
John Dory	ens_05	Adj R Sq	0.869	0.857	0.780	0.518	0.846	0.848	0.793	0.851
		AICc	58.139	49.575	57.044	92.323	53.068	55.066	30.357	57.097
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.966	0.960	0.929	0.820	0.956	0.957	0.921	0.959

		Delta AICc	27.783	19.219	26.687	61.966	22.711	24.709	0.000	26.740
		Deviance Explained	0.932	0.921	0.863	0.672	0.914	0.916	0.848	0.919
		GCV	0.069	0.071	0.097	0.195	0.076	0.076	0.078	0.076
John Dory	ens_06	Adj R Sq	0.861	0.851	0.779	0.507	0.840	0.833	0.821	0.848
		AICc	63.244	50.361	56.367	92.816	53.870	61.794	23.595	51.027
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.964	0.957	0.928	0.814	0.954	0.953	0.934	0.956
		Delta AICc	39.649	26.765	32.771	69.220	30.275	38.199	0.000	27.432
		Deviance Explained	0.928	0.916	0.862	0.662	0.910	0.908	0.872	0.915
		GCV	0.074	0.073	0.097	0.198	0.078	0.084	0.068	0.074
John Dory	ens_07	Adj R Sq	0.858	0.851	0.757	0.410	0.857	0.826	0.780	0.857
		AICc	54.065	45.965	60.694	91.841	44.439	63.429	28.435	46.653
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	0.999	0.000
		Correlation	0.961	0.956	0.920	0.746	0.958	0.951	0.912	0.959
		Delta AICc	25.630	17.530	32.259	63.406	16.004	34.994	0.000	18.218
		Deviance Explained	0.923	0.914	0.847	0.556	0.918	0.904	0.831	0.919
		GCV	0.072	0.071	0.106	0.216	0.069	0.087	0.079	0.070
John Dory	ens_08	Adj R Sq	0.857	0.854	0.752	0.410	0.858	0.815	0.815	0.854
		AICc	51.037	44.759	62.402	91.903	45.899	54.162	25.192	46.342
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.960	0.957	0.919	0.746	0.959	0.943	0.931	0.958
		Delta AICc	25.845	19.567	37.210	66.711	20.706	28.969	0.000	21.149
		Deviance Explained	0.921	0.916	0.844	0.556	0.920	0.890	0.867	0.917
		GCV	0.071	0.070	0.108	0.216	0.069	0.086	0.071	0.070
John Dory	ens_09	Adj R Sq	0.836	0.821	0.748	0.442	0.829	0.832	0.776	0.840
		AICc	63.620	53.575	63.675	88.291	59.026	61.345	31.667	56.515
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000

		Correlation	0.955	0.946	0.917	0.761	0.951	0.953	0.912	0.954
		Delta AICc	31.953	21.907	32.008	56.624	27.359	29.678	0.000	24.848
		Deviance Explained	0.911	0.895	0.841	0.580	0.904	0.907	0.831	0.911
		GCV	0.083	0.084	0.110	0.204	0.084	0.084	0.082	0.079
John Dory	ens_10	Adj R Sq	0.869	0.859	0.718	0.426	0.849	0.809	0.811	0.863
		AICc	56.770	52.101	68.290	100.067	49.298	56.079	20.999	49.853
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.965	0.961	0.906	0.776	0.956	0.942	0.926	0.962
		Delta AICc	35.771	31.102	47.291	79.069	28.300	35.080	0.000	28.854
		Deviance Explained	0.931	0.923	0.820	0.601	0.914	0.887	0.857	0.925
		GCV	0.069	0.071	0.121	0.227	0.073	0.088	0.069	0.069
Lemon Sole	ens_00	Adj R Sq	0.814	0.774	0.805	0.405	0.716	0.788	0.769	0.817
		AICc	110.219	103.375	91.990	134.884	119.624	115.325	84.435	104.065
		Akaike Weight - AICc	0.000	0.000	0.022	0.000	0.000	0.000	0.978	0.000
		Correlation	0.947	0.928	0.938	0.742	0.910	0.939	0.915	0.947
		Delta AICc	25.784	18.940	7.555	50.449	35.189	30.890	0.000	19.629
		Deviance Explained	0.897	0.861	0.879	0.551	0.828	0.881	0.836	0.896
		GCV	0.185	0.202	0.171	0.433	0.257	0.207	0.180	0.176
Lemon Sole	ens_01	Adj R Sq	0.778	0.731	0.780	0.353	0.725	0.774	0.745	0.783
		AICc	103.085	113.380	96.544	140.032	114.536	106.264	77.414	97.290
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.930	0.913	0.927	0.716	0.911	0.929	0.894	0.929
		Delta AICc	25.671	35.966	19.129	62.617	37.121	28.850	0.000	19.876
		Deviance Explained	0.864	0.834	0.860	0.512	0.830	0.863	0.799	0.864
		GCV	0.199	0.239	0.190	0.470	0.244	0.205	0.178	0.189
Lemon Sole	ens_02	Adj R Sq	0.809	0.754	0.798	0.375	0.748	0.824	0.787	0.813
		AICc	105.686	103.896	90.287	137.940	108.459	99.834	76.061	99.345

		Akaike Weight - AICc	0.000	0.000	0.001	0.000	0.000	0.000	0.999	0.000
		Correlation	0.944	0.919	0.933	0.727	0.919	0.948	0.920	0.944
		Delta AICc	29.625	27.835	14.226	61.879	32.398	23.773	0.000	23.283
		Deviance Explained	0.891	0.844	0.871	0.529	0.843	0.899	0.846	0.891
		GCV	0.184	0.213	0.173	0.454	0.222	0.168	0.161	0.174
Lemon Sole	ens_03	Adj R Sq	0.843	0.749	0.757	0.371	0.673	0.847	0.702	0.845
		AICc	123.602	106.021	101.325	138.325	125.017	130.424	92.249	115.802
		Akaike Weight - AICc	0.000	0.001	0.011	0.000	0.000	0.000	0.988	0.000
		Correlation	0.961	0.918	0.919	0.725	0.893	0.963	0.881	0.960
		Delta AICc	31.353	13.772	9.076	46.076	32.768	38.175	0.000	23.552
		Deviance Explained	0.923	0.842	0.845	0.526	0.798	0.927	0.776	0.921
		GCV	0.174	0.219	0.208	0.457	0.289	0.177	0.217	0.167
Lemon Sole	ens_04	Adj R Sq	0.812	0.768	0.792	0.422	0.766	0.839	0.779	0.817
		AICc	103.646	104.074	98.926	133.116	109.531	120.031	75.069	97.011
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.945	0.926	0.934	0.751	0.927	0.958	0.915	0.945
		Delta AICc	28.577	29.005	23.856	58.047	34.462	44.962	0.000	21.942
		Deviance Explained	0.892	0.857	0.873	0.564	0.860	0.919	0.836	0.892
		GCV	0.179	0.206	0.186	0.420	0.214	0.175	0.163	0.170
Lemon Sole	ens_05	Adj R Sq	0.788	0.781	0.780	0.543	0.724	0.804	0.760	0.791
		AICc	105.197	97.538	94.529	128.695	110.870	109.589	78.301	100.361
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.935	0.928	0.926	0.826	0.908	0.943	0.905	0.934
		Delta AICc	26.896	19.236	16.228	50.394	32.568	31.288	0.000	22.059
		Deviance Explained	0.874	0.862	0.858	0.682	0.825	0.889	0.818	0.873
		GCV	0.196	0.191	0.188	0.360	0.239	0.191	0.174	0.189
Lemon Sole	ens_06	Adj R Sq	0.818	0.793	0.795	0.449	0.775	0.818	0.785	0.820

		AICc	100.665	96.864	90.667	130.087	108.013	120.234	71.819	95.191
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.946	0.934	0.932	0.765	0.931	0.952	0.915	0.945
		Delta AICc	28.846	25.045	18.848	58.268	36.194	48.415	0.000	23.372
		Deviance Explained	0.895	0.872	0.868	0.585	0.866	0.905	0.838	0.893
		GCV	0.173	0.183	0.175	0.400	0.206	0.191	0.156	0.166
Lemon Sole	ens_07	Adj R Sq	0.799	0.762	0.782	0.413	0.757	0.810	0.765	0.805
		AICc	107.713	102.641	102.146	134.091	114.334	132.017	75.299	101.122
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.941	0.922	0.931	0.746	0.925	0.951	0.905	0.941
		Delta AICc	32.414	27.342	26.847	58.792	39.035	56.718	0.000	25.822
		Deviance Explained	0.885	0.850	0.867	0.557	0.856	0.905	0.820	0.885
		GCV	0.192	0.207	0.195	0.427	0.225	0.209	0.168	0.181
Lemon Sole	ens_08	Adj R Sq	0.787	0.744	0.700	0.412	0.746	0.722	0.737	0.791
		AICc	109.717	109.985	110.425	134.132	117.951	131.480	83.629	104.060
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.936	0.918	0.896	0.746	0.922	0.919	0.895	0.936
		Delta AICc	26.088	26.356	26.796	50.503	34.322	47.851	0.000	20.431
		Deviance Explained	0.877	0.842	0.802	0.557	0.851	0.843	0.801	0.875
		GCV	0.201	0.226	0.250	0.427	0.237	0.271	0.190	0.193
Lemon Sole	ens_09	Adj R Sq	0.806	0.763	0.806	0.376	0.754	0.844	0.775	0.810
		AICc	106.397	106.453	98.182	137.828	121.783	139.973	86.648	100.083
		Akaike Weight - AICc	0.000	0.000	0.003	0.000	0.000	0.000	0.996	0.001
		Correlation	0.943	0.924	0.940	0.728	0.928	0.964	0.920	0.943
		Delta AICc	19.748	19.805	11.534	51.180	35.134	53.325	0.000	13.435
		Deviance Explained	0.889	0.854	0.884	0.529	0.860	0.928	0.845	0.888
		GCV	0.186	0.212	0.177	0.454	0.237	0.186	0.180	0.177

Lemon Sole	ens_10	Adj R Sq	0.830	0.776	0.776	0.439	0.782	0.691	0.779	0.831
		AICc	101.424	100.496	97.524	131.226	108.727	130.255	73.385	95.274
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.951	0.927	0.926	0.760	0.934	0.905	0.913	0.950
		Delta AICc	28.039	27.111	24.139	57.841	35.342	56.870	0.000	21.889
		Deviance Explained	0.904	0.860	0.858	0.577	0.872	0.819	0.833	0.902
		GCV	0.166	0.197	0.193	0.408	0.204	0.288	0.161	0.160
Megrim Sole	ens_00	Adj R Sq	0.976	0.921	0.906	0.657	0.972	0.974	0.945	0.963
		AICc	116.094	112.945	103.133	145.566	84.466	108.422	52.039	108.899
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.995	0.980	0.973	0.877	0.994	0.995	0.982	0.992
		Delta AICc	64.055	60.907	51.094	93.527	32.427	56.383	0.000	56.860
		Deviance Explained	0.991	0.960	0.947	0.768	0.988	0.990	0.963	0.984
		GCV	0.086	0.215	0.229	0.700	0.086	0.088	0.114	0.120
Megrim Sole	ens_01	Adj R Sq	0.981	0.895	0.900	0.706	0.974	0.982	0.960	0.971
		AICc	108.404	126.642	114.615	137.778	83.955	98.380	36.389	92.432
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.997	0.973	0.973	0.895	0.994	0.997	0.987	0.994
		Delta AICc	72.015	90.253	78.227	101.389	47.566	61.991	0.000	56.043
		Deviance Explained	0.993	0.946	0.946	0.802	0.989	0.993	0.973	0.987
		GCV	0.068	0.284	0.257	0.601	0.081	0.063	0.083	0.091
Megrim Sole	ens_02	Adj R Sq	0.978	0.918	0.904	0.698	0.976	0.977	0.959	0.969
		AICc	98.411	117.875	106.772	139.367	76.298	96.173	63.921	94.700
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.002	0.000	0.998	0.000
		Correlation	0.996	0.979	0.973	0.892	0.995	0.995	0.988	0.993
		Delta AICc	34.489	53.954	42.851	75.446	12.377	32.252	0.000	30.778
		Deviance Explained	0.991	0.959	0.946	0.796	0.989	0.990	0.977	0.986

		GCV	0.076	0.227	0.238	0.619	0.074	0.079	0.103	0.098
Megrim Sole	ens_03	Adj R Sq	0.989	0.925	0.904	0.727	0.987	0.987	0.975	0.968
		AICc	74.126	119.087	106.746	137.657	43.419	83.318	49.158	140.994
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.946	0.000	0.054	0.000
		Correlation	0.998	0.982	0.973	0.906	0.997	0.997	0.993	0.994
		Delta AICc	30.706	75.668	63.326	94.238	0.000	39.898	5.739	97.575
		Deviance Explained	0.996	0.964	0.946	0.821	0.994	0.995	0.987	0.988
		GCV	0.039	0.213	0.238	0.575	0.039	0.047	0.067	0.118
Megrim Sole	ens_04	Adj R Sq	0.974	0.907	0.894	0.681	0.975	0.969	0.958	0.957
		AICc	114.196	131.623	115.251	143.550	107.552	104.287	45.132	97.903
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.995	0.977	0.971	0.887	0.995	0.993	0.987	0.990
		Delta AICc	69.064	86.492	70.119	98.418	62.420	59.156	0.000	52.771
		Deviance Explained	0.990	0.955	0.942	0.787	0.990	0.987	0.973	0.980
		GCV	0.091	0.266	0.267	0.660	0.086	0.101	0.092	0.126
Megrim Sole	ens_05	Adj R Sq	0.977	0.927	0.842	0.678	0.978	0.970	0.945	0.969
		AICc	125.294	112.403	121.701	150.584	110.535	97.994	51.526	111.559
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.996	0.982	0.952	0.892	0.996	0.994	0.981	0.994
		Delta AICc	73.768	60.877	70.175	99.059	59.009	46.468	0.000	60.033
		Deviance Explained	0.991	0.964	0.906	0.796	0.992	0.987	0.963	0.987
		GCV	0.086	0.201	0.364	0.701	0.079	0.095	0.113	0.105
Megrim Sole	ens_06	Adj R Sq	0.982	0.918	0.888	0.663	0.985	0.985	0.945	0.970
		AICc	101.588	118.797	115.052	146.619	117.755	117.518	54.386	89.078
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.997	0.979	0.968	0.881	0.997	0.997	0.982	0.993
		Delta AICc	47.203	64.412	60.667	92.233	63.369	63.132	0.000	34.693

		Deviance Explained	0.993	0.959	0.937	0.776	0.995	0.995	0.964	0.987
		GCV	0.064	0.228	0.278	0.699	0.060	0.060	0.116	0.093
Megrim Sole	ens_07	Adj R Sq	0.973	0.930	0.902	0.716	0.973	0.974	0.973	0.959
		AICc	96.985	114.074	117.411	142.305	80.408	100.872	27.894	82.237
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.994	0.983	0.974	0.904	0.994	0.995	0.992	0.990
		Delta AICc	69.091	86.180	89.517	114.411	52.514	72.978	0.000	54.343
		Deviance Explained	0.989	0.965	0.948	0.818	0.988	0.989	0.983	0.979
		GCV	0.087	0.199	0.257	0.610	0.082	0.086	0.062	0.114
Megrim Sole	ens_08	Adj R Sq	0.973	0.935	0.897	0.721	0.974	0.975	0.975	0.958
		AICc	94.357	100.267	120.263	141.275	80.163	103.146	43.690	88.627
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.994	0.983	0.973	0.906	0.994	0.995	0.993	0.990
		Delta AICc	50.668	56.577	76.573	97.586	36.474	59.456	0.000	44.937
		Deviance Explained	0.989	0.966	0.946	0.821	0.988	0.990	0.986	0.980
		GCV	0.087	0.175	0.269	0.599	0.080	0.086	0.065	0.119
Megrim Sole	ens_09	Adj R Sq	0.975	0.915	0.907	0.726	0.975	0.967	0.966	0.948
		AICc	107.314	120.864	107.028	135.782	92.878	88.782	48.918	88.292
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.995	0.979	0.974	0.904	0.995	0.993	0.990	0.987
		Delta AICc	58.396	71.945	58.110	86.863	43.960	39.864	0.000	39.374
		Deviance Explained	0.990	0.958	0.949	0.817	0.990	0.985	0.981	0.973
		GCV	0.087	0.235	0.233	0.568	0.081	0.099	0.082	0.138
Megrim Sole	ens_10	Adj R Sq	0.972	0.906	0.899	0.705	0.972	0.962	0.936	0.961
		AICc	152.039	118.329	115.727	140.297	140.396	112.189	61.351	110.700
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.995	0.975	0.972	0.897	0.995	0.992	0.979	0.992

		Delta AICc	90.687	56.978	54.376	78.945	79.045	50.838	0.000	49.349
		Deviance Explained	0.990	0.951	0.945	0.804	0.990	0.984	0.958	0.983
		GCV	0.111	0.251	0.260	0.615	0.106	0.123	0.134	0.125
Red Mullet	ens_00	Adj R Sq	0.661	0.634	0.663	0.546	0.587	0.665	0.688	0.670
		AICc	100.763	96.608	86.942	97.679	110.593	97.884	64.490	95.592
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.884	0.865	0.873	0.811	0.854	0.884	0.861	0.884
		Delta AICc	36.273	32.118	22.452	33.189	46.103	33.394	0.000	31.103
		Deviance Explained	0.782	0.749	0.762	0.658	0.729	0.781	0.742	0.782
		GCV	0.207	0.211	0.187	0.237	0.249	0.202	0.149	0.197
Red Mullet	ens_01	Adj R Sq	0.695	0.645	0.671	0.565	0.593	0.697	0.711	0.691
		AICc	94.437	93.906	85.332	94.916	113.010	91.529	59.606	92.019
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.896	0.869	0.875	0.820	0.860	0.895	0.873	0.893
		Delta AICc	34.830	34.300	25.725	35.310	53.404	31.923	0.000	32.412
		Deviance Explained	0.804	0.756	0.766	0.672	0.740	0.802	0.761	0.797
		GCV	0.187	0.203	0.183	0.227	0.251	0.183	0.138	0.185
Red Mullet	ens_02	Adj R Sq	0.680	0.654	0.693	0.557	0.605	0.677	0.688	0.680
		AICc	98.176	92.264	84.130	96.043	114.368	97.343	64.310	95.319
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.892	0.873	0.887	0.816	0.867	0.890	0.861	0.890
		Delta AICc	33.866	27.955	19.820	31.733	50.058	33.033	0.000	31.009
		Deviance Explained	0.795	0.762	0.787	0.666	0.752	0.791	0.742	0.792
		GCV	0.197	0.198	0.175	0.231	0.248	0.197	0.149	0.193
Red Mullet	ens_03	Adj R Sq	0.686	0.636	0.677	0.565	0.586	0.693	0.721	0.690
		AICc	97.157	95.552	86.028	95.039	110.607	93.597	62.108	93.097
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000

		Correlation	0.894	0.866	0.880	0.820	0.854	0.895	0.883	0.893
		Delta AICc	35.049	33.444	23.920	32.931	48.499	31.489	0.000	30.989
		Deviance Explained	0.800	0.749	0.774	0.672	0.729	0.801	0.779	0.798
		GCV	0.193	0.209	0.182	0.227	0.249	0.187	0.139	0.187
Red Mullet	ens_04	Adj R Sq	0.663	0.614	0.647	0.544	0.575	0.668	0.700	0.669
		AICc	100.509	100.429	89.902	97.966	110.098	96.655	62.741	95.508
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.885	0.859	0.866	0.810	0.847	0.885	0.869	0.884
		Delta AICc	37.769	37.688	27.162	35.226	47.357	33.914	0.000	32.767
		Deviance Explained	0.783	0.737	0.750	0.656	0.718	0.783	0.755	0.781
		GCV	0.206	0.223	0.197	0.238	0.252	0.199	0.144	0.198
Red Mullet	ens_05	Adj R Sq	0.700	0.631	0.654	0.551	0.630	0.702	0.742	0.705
		AICc	94.277	98.780	88.965	100.138	109.332	90.743	56.901	90.676
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.899	0.866	0.869	0.819	0.876	0.898	0.892	0.899
		Delta AICc	37.376	41.878	32.064	43.237	52.430	33.841	0.000	33.775
		Deviance Explained	0.808	0.750	0.755	0.671	0.767	0.806	0.796	0.808
		GCV	0.185	0.215	0.193	0.241	0.231	0.180	0.128	0.179
Red Mullet	ens_06	Adj R Sq	0.664	0.625	0.642	0.540	0.580	0.662	0.701	0.670
		AICc	103.109	99.777	90.585	98.409	110.580	98.242	65.580	99.026
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.888	0.864	0.864	0.808	0.851	0.882	0.873	0.887
		Delta AICc	37.530	34.197	25.005	32.829	45.000	32.662	0.000	33.446
		Deviance Explained	0.788	0.746	0.747	0.653	0.724	0.779	0.762	0.787
		GCV	0.209	0.218	0.199	0.240	0.251	0.204	0.148	0.202
Red Mullet	ens_07	Adj R Sq	0.665	0.600	0.642	0.548	0.539	0.672	0.723	0.658
		AICc	102.742	102.472	91.625	97.297	114.595	98.177	63.759	99.283

		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.888	0.853	0.865	0.812	0.832	0.888	0.886	0.881
		Delta AICc	38.982	38.712	27.866	33.538	50.836	34.418	0.000	35.523
		Deviance Explained	0.788	0.727	0.748	0.659	0.692	0.788	0.785	0.777
		GCV	0.209	0.231	0.201	0.236	0.272	0.200	0.141	0.207
Red Mullet	ens_08	Adj R Sq	0.665	0.603	0.632	0.547	0.564	0.674	0.765	0.670
		AICc	101.617	102.262	93.755	97.463	112.080	96.496	64.456	96.945
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.887	0.854	0.861	0.812	0.843	0.887	0.913	0.886
		Delta AICc	37.161	37.806	29.299	33.007	47.624	32.040	0.000	32.489
		Deviance Explained	0.787	0.729	0.742	0.659	0.711	0.787	0.833	0.785
		GCV	0.207	0.230	0.207	0.237	0.259	0.197	0.131	0.199
Red Mullet	ens_09	Adj R Sq	0.674	0.631	0.681	0.558	0.564	0.682	0.763	0.667
		AICc	99.855	96.520	86.465	95.997	113.471	95.825	72.393	96.328
		Akaike Weight - AICc	0.000	0.000	0.001	0.000	0.000	0.000	0.999	0.000
		Correlation	0.890	0.864	0.883	0.816	0.845	0.891	0.917	0.883
		Delta AICc	27.462	24.127	14.073	23.605	41.078	23.433	0.000	23.935
		Deviance Explained	0.792	0.747	0.779	0.667	0.714	0.794	0.841	0.780
		GCV	0.201	0.211	0.181	0.231	0.262	0.193	0.139	0.199
Red Mullet	ens_10	Adj R Sq	0.666	0.598	0.615	0.543	0.547	0.655	0.753	0.675
		AICc	106.978	104.530	95.305	97.998	113.289	99.397	68.756	101.564
		Akaike Weight - AICc	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
		Correlation	0.891	0.854	0.853	0.810	0.835	0.880	0.909	0.892
		Delta AICc	38.222	35.774	26.549	29.242	44.533	30.641	0.000	32.808
		Deviance Explained	0.794	0.729	0.727	0.656	0.698	0.774	0.827	0.795
		GCV	0.214	0.235	0.214	0.239	0.267	0.208	0.138	0.203

Appendix B. Interview used in Chapters 4 and 5

Declaration of participation

I agree to partake in this interview and agree to the results to be used in subsequent analyses.

I acknowledge that information will be anonymised and personal details kept confidential.

Signed -

Date

A. Easing in questions and scoping			Sources for statements and questions
1	**How long have you been fishing for?**		Novel
2	**How long have you been fishing from this port?**		Novel
3	**What are the main species that you target throughout the year and what gear do you use?**	Spring Summer Autumn Winter	Novel
B. Change in fisheries: observations of change			
4	**Have you seen any changes in your main target species over the past 10 years?** - **What do you think caused those changes?**	Change observed Driver Species	Novel
C. Future risk landscape: what risks do fishers identify for the future?			
5	**What do you think are the biggest risks to the future health and sustainability of fish stocks?**		Novel
6	**What do you consider to be the biggest risks to the future of your own fishing business?**		Novel
7	**Thinking about the wider fishing industry as a whole, are there any risks you think could affect it in the future?**		Novel
D. Climate change beliefs: scepticism statements			
8	**(Answering yes or no) have you heard about climate change?**		Novel

9	**The next few questions are statements which I'd like you to respond to using the following scale based on whether you: 1. Strongly disagree; 2. Disagree; 3. Neither agree nor disagree; 4. Agree; 5; Strongly agree**	a. Recent climate change is mostly caused by human activities b. Increased green house gas concentrations have contributed to recent climate change c. I am uncertain that climate change is really happening d. The seriousness of climate change is exaggerated e. The effects of climate change are uncertain	Taken or adapted from: a. Adapted from Poortinga *et al.,* 2011 b. Novel c. Poortinga *et al.,* 2011 d. Poortinga *et al.,* 2011 e. Poortinga *et al.,* 2011
E. Climate change: Understanding of impacts (in the context of fisheries) and observations of change			
10	**If any, what aspects of the sea do you think climate change could affect?** I will read the possible answers one by one. For each, I'd first like you to: - respond with whether you think it will or will not be affected by climate change with a yes or no - If you think yes, then could you state how you think it will be affected?	a. Sea temperature b. Sea level c. Sea chemistry e.g. oxygen levels, salinity d. Sea nutrient levels e. Sea Currents f. Storminess g. anything else that I haven't mentioned?	Novel Literature informing questions: Dye *et al.,* 2013 Rhein *et al.,* 2013 Pörtner *et al.,* 2014
11	**If any, what effects do you think climate change could have upon demersal fish stocks in the future?** **What do you think could drive these changes - any of the things we were discussing in the previous question?**		Novel

F. Risk perceptions of climate change: likelihood of need to respond to potential future impacts			
12	**Now answering with this scale, how likely do you think it is that you will have to change your fishing practices due to climate change?** 1. Extremely unlikely; 2. Unlikely; 3. Neutral; 4. Likely; 5. Extremely likely • **Why do you think this?**		Novel
G. Future responses to climate change			
13	**If any, what aspects of your fishing activities do you think you may have to change as a result of climate change?** I will read the possible answers one by one. For each, I'd like you to: - respond with yes or no as to whether you think you may have to alter this aspect of your activities - state in how you think it will be affected?	a. Species targeted b. Gear used c. Vessel used d. Fishing locations e. Trip frequency and time spent fishing f. Home or landing port g. Anything else you think could be affected that I haven't mentioned?	Novel Informed by literature including: OECD, 2010 Haynie and Pfeiffer, 2012 Defra, 2013
H. Personal experience of climate change			
14	Thinking about what we have been discussing so far, **Would you say that you and your fishing business have personally been affected by climate change?** • **How so?**		Novel
I. Factors that influence fishing practices currently and in the future			
15	**What factors would influence your decision to change the way you currently fish?**		Novel

J. Risk perceptions of climate change NB: a – e = 5 risk perception statements; f – g: Self-efficacy statements Q. 19 forms the 6th risk perception statement			
17	**How soon do you think fishers will feel the consequences of climate change on their fishing business?** Do you think…	1. Already 2. 1-10 years 3. 11-30 years 4. 31-50 years 5. 51-100 years 6. 100 + years 7. Never 8. Don't know	Novel
18	**I'd now like to read another list of statements which I'd like you to state whether you agree/disagree**	a. I am concerned about the impact of climate change on my fishing business b. Climate change will affect other fishermen more than it will affect me c. Climate change makes me feel uncertain when I try to plan for the future d. I am worried about the impacts climate change could have upon fisheries in the south west e. Climate change will have a negative impact on the future sustainability of fish stocks f. It is very difficult for someone like me to do	Taken or adapted from: a. Adapted from Leiserowitz, 2006 b. Developed based upon Spence, Poortinga and Pidgeon, 2012 c. Novel d. Adapted from Capstick *et al.,* 2015 e. Adapted from Brody *et al.,* 2008 f. Hidalgo and Pisano, 2010 g. Heath and Gifford, 2006

		something about the environment g. There are simple things I can do that would have a meaningful effect to alleviate the negative impacts of climate change	
19	**How much of a risk do you think that climate change poses to the future of your fishing business?**	a. No risk b. Low risk c. Moderate risk d. Major risk e. Severe risk	Novel
K. Factors affecting risk perceptions			
	Knowledge (self reported) and information		
20	**How informed do you feel about climate change…** Based on this scale ranging from 1. Very uninformed; 2. Uninformed; 3. Neutral; 4. Informed; 5; Very informed	a. in general b. in terms of its potential impact on fisheries c. in terms of its potential impact on you and your fishing business	Adapted from Kellstedt *et al.,* 2008
21	**Where do you find out information about climate change?**		Novel
22	**How much do you trust EACH OF THESE sources of information?** 1. Not at all trustworthy; 2. Somewhat untrustworthy; 3. Neutral; 4. Somewhat trustworthy; 5. Very trustworthy		Adapted from Milfont, 2012

L. Climate change belief – scepticism statement			
23	**Using the scale we've been using, do you disagree/agree that:**	Climate change is too complex and uncertain for scientists to make useful forecasts	Whitmarsh, 2011
M. Adaptation to climate change: Perceptions of self-efficacy and need for adaptation			
24	Answering with the scale we've been **please can you state whether you agree or disagree with the following statements**:	a. I have the necessary skills to adapt to any potential impacts of climate change on my fishing business b. I have the ability to adapt to any potential impacts of climate change on my fishing business	Novel Informed by literature: Grothmann and Patt, 2005 Kellstedt *et al,* 2008 Hidalgo and Pisano, 2010
25	**More generally, what do you think could enhance your ability to adapt your fishing activities and/or business to potential climate change impacts?**		Novel
26	And **do you think anything is or could limit your ability to adapt your fishing activities/wider fishing business to climate change?**		Novel

N. Risk attitudes			
27	I was wondering, **in general, how willing are you to take risks?** 1) Very willing; 2) Somewhat willing; 3) Neutral; 4) Somewhat unwilling; 5) Very unwilling		Dohmen *et al.* 2011
28	**How would you rate your willingness to take risks in the following areas**, using the same scale:	a. … while driving a car b. … in financial matters c. … during leisure and sport d. … with your health e. … in your occupation	Dohmen *et al.* 2011
O. Adaptation to climate change: resource dependency and adaptive capacity indicators			
	Attachment to occupation		
29	**Could you tell me if you agree/disagree with the following statements**	a. I can't imagine doing any other job except fishing b. Fishing to me is a lifestyle – it is not just my job c. I have been tempted to leave fishing and find an alternative income/lifestyle elsewhere	a. Adapted from Marshall *et al.* 2007 b. Adapted from Marshall *et al.* 2007 c. Marshall 2011
	Occupational mobility and flexibility		
30	* C and d are statements of business approach but put here for interview flow	a. I would be willing to leave this region if fishing opportunities were better elsewhere b. I have other career options available to me if I decide to no longer be a fisherman c. I am often thinking of new and better ways to improve my fishing business. d. I am interested in learning new skills to benefit my business	a. Novel: Influenced by Marshall *et al.,* 2010 b. Marshall and Marshall 2007 c. Marshall and Marshall 2007 d. Marshall and Marshall 2007

31	**Do you/ have you worked outside of the fishing industry?** - **if so, what as?**		Novel: Influenced by Marshall *et al.,* 2010
	Business size and approach		
32	**How many people do you employ?**		Novel
33	**How far into the future do you plan your fishing business activities?** **- Why do you plan in this way – why not shorter/longer?**		Novel: Influenced by Marshall *et al.,* 2010
34	**Are you a member of any fishing organisations/associations?** **a. If so, which ones?**		Novel
35	**Now could you tell me if you agree/disagree with the following statements**:	a. I have strong friendships within this community where I work b. I have good networks with and feel connected to government agencies c. I often discuss my fishing practices and decisions with other fishermen	a. Marshall 2011 b. Adapted from Marshall and Stokes 2014 c. Adapted from Marshall and Stokes 2014
	Financial capital		
36	**As a % proportion, how much of your personal income comes from fishing?**		Novel: Influenced by Marshall *et al.,* 2010
37	**What % proportion of your household income comes from fishing?**		Novel: Influenced by Marshall *et al.,* 2010
38	For this next question you can opt out of answering it, but **do you have any financial loans or debt?**		Novel
P.	Socio-demographics		
39	Gender		Novel
40	**How old are you?**		Novel
41	**How many more years do you plan to fish for?**		Novel

42	**Do any members of your family work in the fishing business with you?** **- what relation are they to you?**		Novel
43	**What qualifications do you have?**	a. None b. Secondary school (left at/ before 16) c. GCSEs/ O Levels d. A Levels e. University degree f. Sea Fishing Apprenticeship g. Basic Seamanship h. Other (please specify)	Novel
44	**Do you own the boat you skipper?**		Novel
45	**How big is the boat in m?**		Novel
Q. And finally, before we finish…			
46	**Have you thought about climate change in relation to your fishing business prior to this interview?**		Novel

Appendix C. Chapter 4 – Methods and Results

Methods

Generating an overall scepticism score

PCA was undertaken to develop an overall scepticism scale. A scree test (Fig. A4.1) indicated using two axes within the analysis. Most statements aligned and loaded onto PC1. Reliability tests using Cronbach alpha upon the statements revealed strong internal consistency (α 0.76), providing further confidence in reliability of this scale.

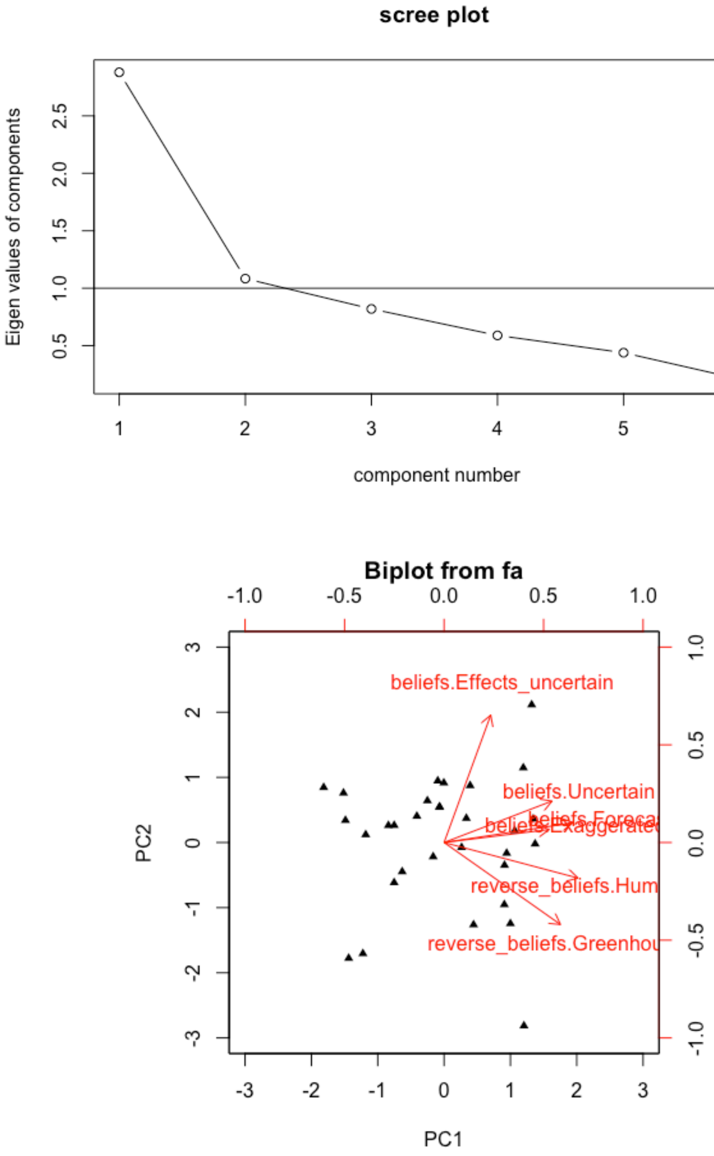


Figure A4.1. Scree plot (top) and biplot (bottom) from PCA of the six scepticism statements.

Table A4.1. PCA loadings for the six scepticism statements. PC1 was taken forward to use as an overall scepticism scale.

Scale and statement	PCA loadings	
	PC1	PC2
Scepticism[a]		
Recent climate change is mostly caused by human activities*	0.49	-0.23
Increased green house gas concentrations have contributed to recent climate change*	0.44	-0.50
I am uncertain that climate change is really happening	0.40	0.28
The seriousness of climate change is exaggerated	0.39	0.08
Climate change is too complex and uncertain for scientists to make useful forecasts	0.48	0.13
The effects of climate change are uncertain	0.17	0.81
Proportion variance explained	0.46	0.18

* reversed statements to ensure consistent directionality

a: likert scale 1: Strongly disagree, 5: Strongly Agree

Factors affecting risk perceptions

Informedness

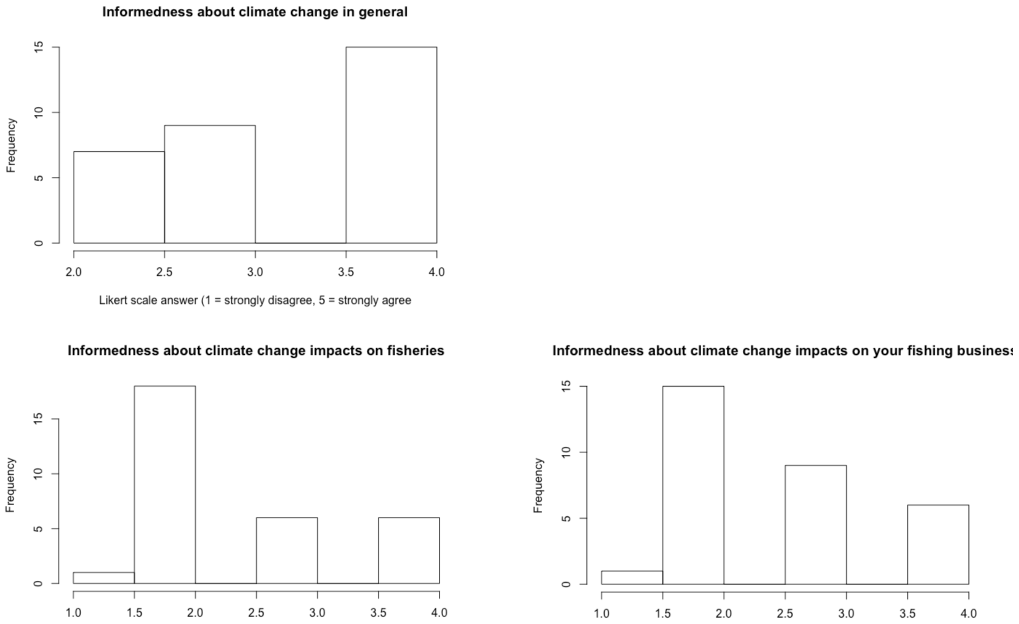


Figure A4.2. Frequency histograms of likert answers to three statements regarding informedness (1=strongly disagree, 5=strongly agree).

Results: Future risk landscape

Table A4.2. Risks identified by fishers

General theme (number of fishers)	Type of risk identified (number of fishers)	Description of risks	Example
Environmental (21)	Overfishing (20)	Future sustainability of fish stocks at risk due to overfishing from angling groups, spatial management restrictions re-distributing effort to other areas, non-Brixham based vessels and increasing effort from larger, powerful, more efficient vessels and gear types	“What is a threat to fish stocks is anglers… They’re on a charter boat catching as many as they want on any given day… More and more doing it now as well.” “The management that the MMO have done with the fleet, well mismanagement, by closing off all the area they done for scalloping, they’re directing more effort in fisheries that didn’t need the extra effort.” “Too many large, and when I say large I mean huge, fishing vessels from parts of the European union or whatever it is, coming into British waters and scrapping up.” “The size of the horsepower, it enables the boat then to tow a lot more gear so it’s more efficient and covering the ground quicker from A to B. And that’s a downfall.” “The increase in powerful vessels towing demersal trawls, especially twin rigs, that is putting incredible pressure on it for us here. People have put a lot of money into big twin rig boats and continue to do so and all the time that happens our living is just going to get worse and worse.”
	Weather and climate change (4)	Climate change may change fish stocks and fishing opportunities into future	“Whether climate change and warmer waters is going to, I suppose it will shift the fish around.” “So long as water temperatures and things, which seems to be the main thing affects fishing, water temperature and weather. So long as that stays similar I think there will always be a fishery. There’s talk or, the waters warming slowly from what we gather and there’s fish which never see in North Sea which is going up the channel. Whether different species... Who

			knows. So it could well be for the better rather than for the worse.” “Only way see it changing is the weather and climate changes. That’s the only reason the fishing is changing off of here not through any other reason.”
		Bad weather affecting catchability of fish and safety at sea	“The bad weather breaks up the shoals.” “It’ll be more dangerous to push more weather.”
	Plastic pollution (2)	Increasing plastic pollution affects health of fish stocks	“Microbeads and plastic. That’s a real concern.” “I think the biggest risk to the industry is pollution, all plastic.”
	Natural predators (1)	Increasing numbers of seals leading to catch being eaten from nets	“The inshore fleet that work gillnets have got a challenge with seals taking fish out of the nets…there’s a lot more seals around.”
Socio-economic (18)	Changing ownership (8)	Businesses buying vessels (and associated quota) within Brixham and other ports, leading to companies owning large majority of vessels and therefore having influence on the markets and port as a whole, and thus creating future uncertainty	“That’s our biggest threat at the moment is these companies. They’re owning all the quotas now and that is the biggest worry of the lot. They’re not fishermen. When they get bored of it, they’ll just throw it all away and they’ll just sell it on to the next big player like.” “It’s being bought now by, whereas before skippers were owners of boats, the owner would be the skipper of the boat... But now it’s all run by companies and it’s just a business now whereas it used to be more of a way of life.” “Because the big fleet is being bought by bigger companies there could be a chance of moving the fishing from here and basing it near the transport systems, so they can take the market auctions.”
	Recruitment (6)	Lack of people, particularly young people, coming into the industry, resulting in difficulties sourcing crew members and affecting the future of the industry as a whole	“It’s getting harder, not enough youngsters coming into it.” “I do think one of the biggest risks facing it [the industry] is going to be the crew side of it. There aren’t enough crews to go round there now.” “There’s no young skippers coming through at this game anymore, there’s nobody taking skippers tickets,

			none down there. And we're all getting older, well I am, there's going to be nobody in a minute to take these boats. It's worrying."
	Fuel prices (5)	Rising fuel prices could affect the profitability of vessels and wider industry in the future	"Only thing that could cripple the fishing industry is fuel prices. That is one of the biggest things if fuel keeps going up… Everyone come out the industry. Cos you don't get no help from the government as you're self-employed." "I think the only risk to the future of the fleet in Brixham are the fuel prices." "There's always fuel, that's the main risk for us."
	Environmental groups (5)	Groups perceived to have conflicting views with the industry over how fisheries should be managed. The way they portray fisheries and the industry isn't perceived as positive (by the industry itself)	"Greenies – true buggers. They talk about things they don't know nothing about." "They're trying to govern our fisheries, such as Greenpeace, Friends of the Earth. They had all these areas shut off in the English Channel." "Organisations like Greenpeace. Problem is they've got a very public persona and they don't give the full story to the public so they can generate scare stories."
	Media and public opinion (3)	Negative perceptions of the industry through media and the public	"All the publicity about the fishing industry since I can remember has been negative." "It's all become a bit trendy to become anti-fishermen."
Fisheries governance (18)	Changing regulations (9)	Unknown changes in domestic management rules and regulations into the future, not in the context of Brexit, creates uncertainty and may affect fishing opportunities, businesses and wider industry	"Yeah I'm worried about whatever they'll think of next, that's my concern of me surviving the fishing industry is what the government will think of next to change the system to what it is now." "I mean our biggest challenge is the government. What they want to do with the fishing industry itself. Do they want to keep it or do they want to get rid of it?" "Well you never know with the government and what they're going to do. They're the only people who will be a risk to the future of the fishing industry."

			"Biggest worry really is the rules and regulations side of it, cos they tend to keep changing the goal posts." "They chop and change the rules so much it's hard to keep up with it, there's stuff coming through all the time with changes, change to this, change to that."
	Quotas (5)	Quota system seen as an issue for the industry currently and in the future as it, for example, limits catching opportunities and non-UK based companies can buy quota	"It's about the quotas really… each species has got a quota on it. And over the past few years they've actually cut the quotas so it obviously limits what you're allowed to get." "Only thing I can see that's a challenge or a risk is our quota being tightened and tightened and tightened and given away." "What's happened is… I want some quota for the channel I can't get any cos it's all gone, owned by some Dutch company, Belgium, South African, French. Big companies are buying it up under a Flag of Convenience." "23% of the whole of the UK quota on just one boat, so that's the challenge we've got. And we've got a measly 30kg a sole, and they've been given a 23%, and they're not even belonging to this country!"
	Spatial area restrictions (5)	Closed areas being created currently and in the future reduce fishing opportunities and areas to fish in	"I think the IFCA is our biggest threat in the removal of fishing ground." "The way the government work is they split us all up and then they close it off to us as a trawler first… but then they stop the gillnetters then. They work their way down, get kicked out of that area then the next thing is they'll say they'll restrict the amount of pots in there and then before you know it it's a conservation area and no one's allowed to have anything in it. That's how they do it, divide and conquer." "They had all these areas shut off in the English Channel. And they've implemented a lot of these areas

			because they found a seahorse in one area and a bit of weed of interest in another.”
	Discards ban (3)	EU Discard ban creating uncertainty and potentially affecting fishing practices, health of stocks and/or wider aspects of fishing businesses	“Discard ban… They’re saying you’ve not quota for it, then you’re not allowed to go to sea. So essentially, we’re expected to land undersized fish and as soon as the quotas gone, don’t go to sea.” “We’ve got this discards business up and coming which I don’t fully understand.”
Political (10)	Brexit (10)	Withdrawal from the European Union creates uncertainty for the industry such as how fisheries will be managed and who will do so, concerns for future labour, future markets and general uncertainty over overall outcomes and its impact on fisheries	“It’s all to do with Brexit. Are we going to get more fish, are we going to get less fish, who’s going to govern... There’s a lot of questions to be asked and answered you know over what’s going to happen to the fishing industry.” “I would say that the immigration thing could be quite challenging, because some of us do use European labour... But I don’t know if the European fishermen would still want to work here even though we might have a facility that would allow them to work here – they might not want to because of the atmosphere perhaps.” “It is a bit of a worry lately over the Brexit thing. For instance on cuttlefish, it’s a huge thing in Brixham, the cuttle…. Our prices depend on exports… we get good prices on all our prime fish and the squid and cuttlefish which nearly all goes abroad. If we lost that export market through problems with Europe that would be a real worry here, it really would.”
Personal (6)	Safety (4)	General occupation poses risk to life and safety whilst at sea	“As soon as that boat goes out that is a risk right there.” “I’m single handed on here you know so there’s more risk of losing a life on here than if you’re on something else.” “We had an accident that happened the other week where the gear fell down, literally snapped and almost killed two people.”

	Prosecution (1)	Potential prosecution risks future viability of fishing business	“You know I'm in court for alleged fishing offences now, I haven't been found guilty yet and it's going to cost me £50,000 to take it to court... I've been treated like a criminal and they haven't actually, they don't know all the facts. Cos it's just disheartening for anyone. It's taken me years to get a boat and now two boats and now this has about crippled me before I've started.”
	Health (1)	Age and poor health poses risk to carrying out the job safely	“Well for me it’s my age. I’m at the end of it now… I’ve had a heart attack whilst I was on the boat. What you find with the fishing industry is that as you’re self-employed and all that, don’t get no sick pay. There’s no back up plan.”
Infrastructure (3)	Marine energy (2)	Windfarm development affects fish distributions and reduces areas to fish in	“What seems to happen when you put a wind farm on top of them [fish] is that they scatter and go to other places.” “It’s like the wind farms, you can’t fish in that… we’re shutting this area off for a wind farm.”
	Port/ harbour facilities (1)	Inadequate facilities such as landing staff and mooring facilities to accommodate increasing numbers of vessels	“The actual infrastructure because they’re inviting boats from around the country to land here and they haven’t got the facilities.”

Climate change risk perceptions: PCA

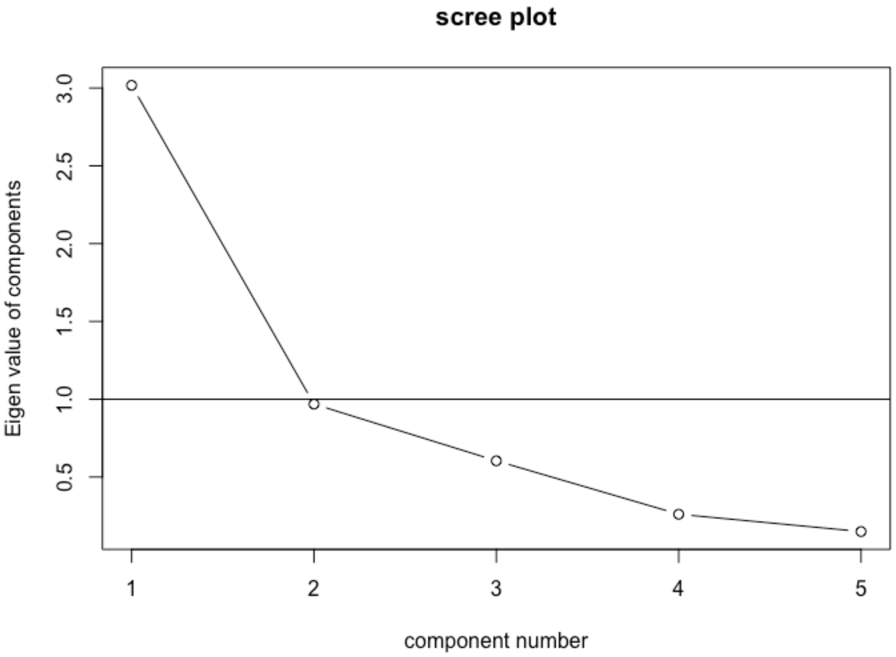


Figure A4.3. Scree plot for PCA

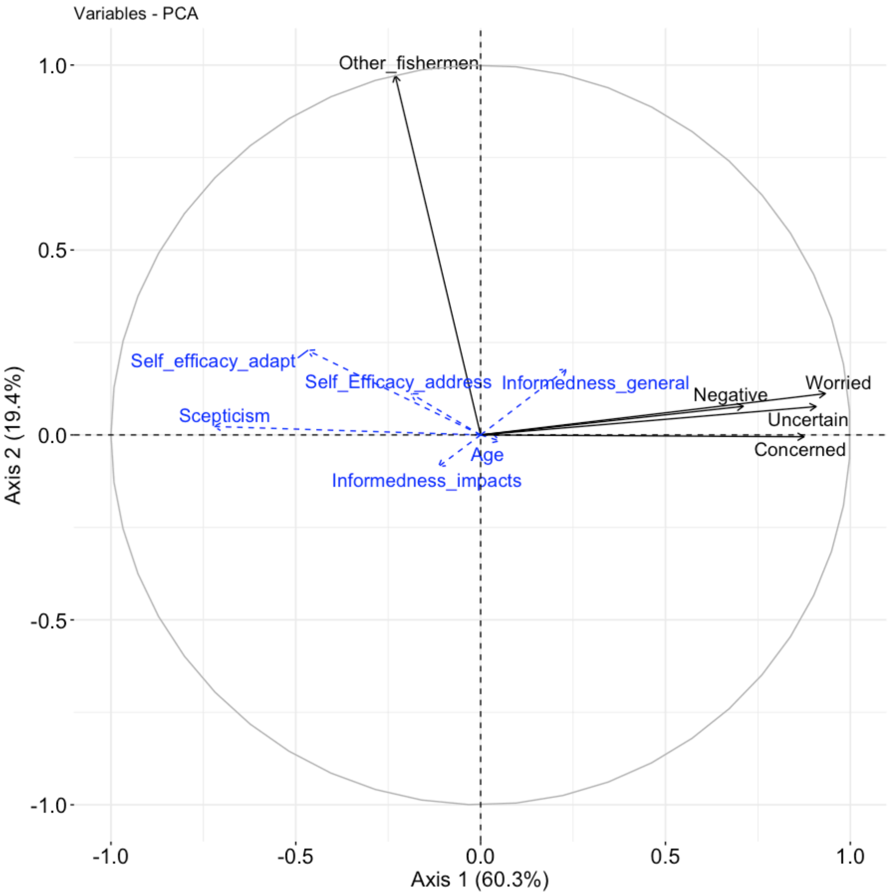


Figure A4.4. Relationship of variables with PCA dimensions. Black variables represent the five risk statements and blue variables represent the quantitative factors tested.

Appendix D. Chapter 5 – Results

Results

Table A5.1. Number of fishers answering ‘no’ to changing their fishing practices.

	Number of fishers
Said ‘no’ to changing all aspects of their fishing practices	9
Said ‘no’ to 5 out of 6 aspects	7
Said ‘no’ to 4 out of 6 aspects	3
Said ‘no’ to 3 out of 6 aspects	4
Said ‘no’ to 2 out of 6 aspects	4
Said ‘no’ to 1 out of 6 aspects	4

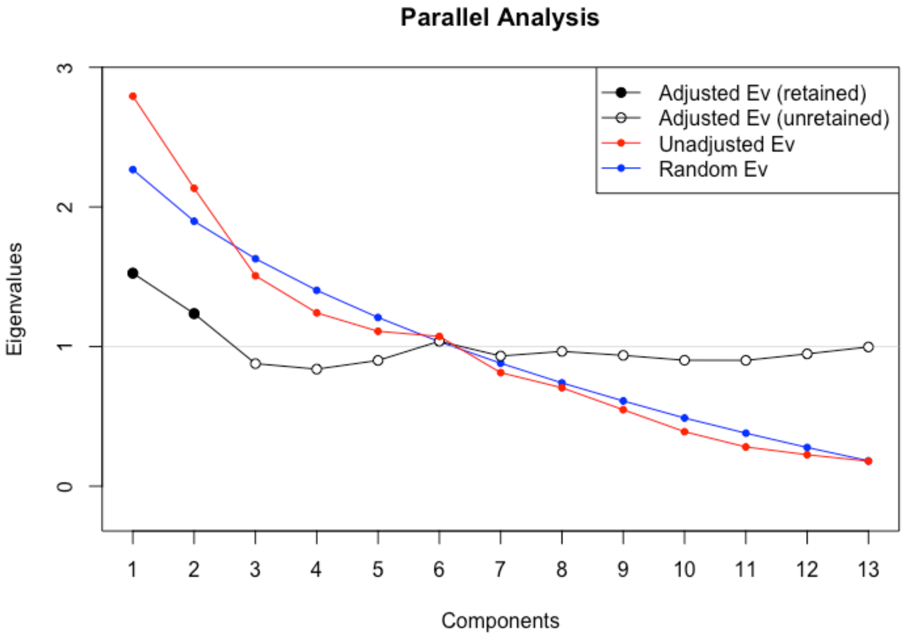


Figure A5.1. Parallel analysis results. Red line shows original ‘unadjusted’ eigenvalues from original dataset. Black line shows eigenvalues from the parallel analysis, ‘adjusted’ for the sample size. Blue line shows mean eigenvalues across the 1000 iterations. Following Horn (1965), components are retained when adjusted eigenvalues are greater than 1.

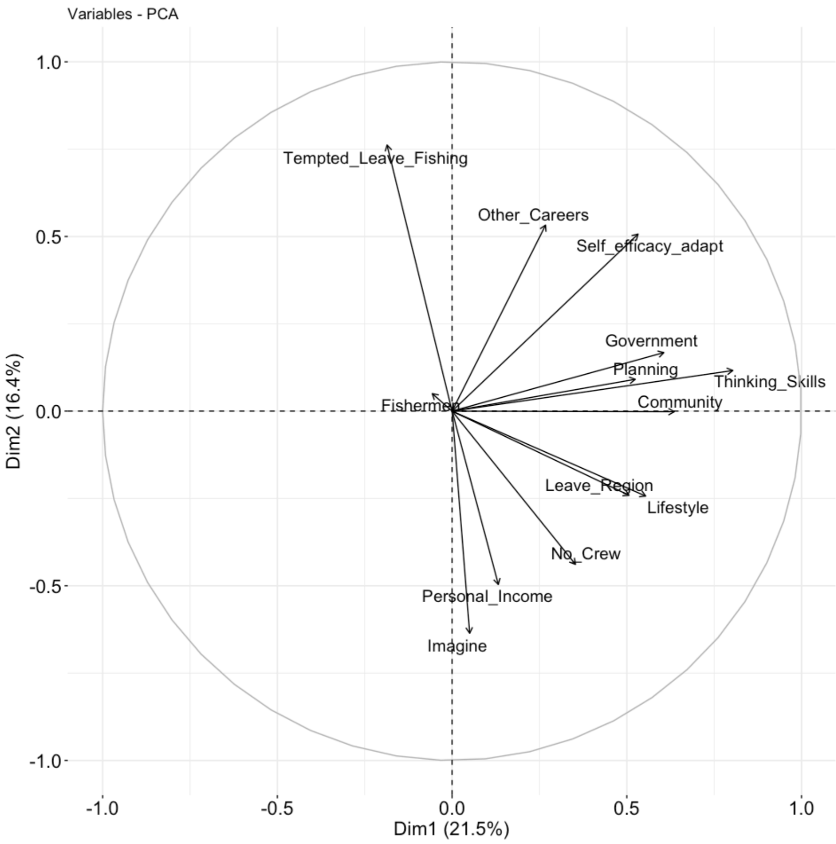


Figure A5.2. Association of variables with the two PCA dimensions.

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POSTNOTE

Number 572 February 2018

UK Fisheries Management

Following EU withdrawal the UK will have full responsibility for fisheries policy and management within its waters. This POSTnote summarises the science used to inform management, current approaches to EU fisheries, and challenges and opportunities for future UK fisheries management.

Overview

- The Government has stated that following EU withdrawal it intends to implement a new fisheries management system and will seek to restore and protect marine ecosystems.[1]
- The current EU Common Fisheries Policy requires that the size and status of fish stocks are assessed annually.
- These assessments form the basis for setting catch limits ('Total Allowable Catch' – TACs) that are then shared among states via quotas. Each state is responsible for distributing its quotas among its fishing fleet.
- Shared stocks with non-EU states are also assessed, and annual TACs negotiated.
- Future UK management will have to meet international legal requirements.
- A key future challenge will be managing fisheries in a changing environment while meeting other social and economic needs.

Background

The UK fishing industry was worth an estimated £1.4bn to the UK in 2016 and is part of a complex fisheries supply chain.[2,3] The focus of this note is on the capture of wild fish and shellfish (marine capture fisheries), but this wider industry estimate includes fish and shellfish aquaculture and processing.[2] In 2016, the UK commercial fishing fleet comprised 11,757 fishermen and 6,191 vessels.[4] These landed 701 thousand tonnes of fish and shellfish into the UK and abroad, valued at £936m.[4] The UK fishing fleet is regionally diverse with regulations varying depending on the size of the vessel (different regulations apply to boats under 10 metres compared to larger boats) and species caught.[4,5] In addition to their economic benefit, fisheries have social and cultural value for coastal communities and the public.[6,7]

UK waters can be classified depending on the distance from shore in nautical miles (nm) as follows:[5]

- 0-6nm – inshore waters largely fished by smaller vessels using diverse fishing methods to catch a variety of different species, particularly shellfish.[5,8]
- 0-12nm – UK territorial waters. In both territorial and inshore waters, other non-UK vessels are only permitted according to historic access and/or neighbourhood agreements.[5,9]
- 0-200nm – UK Exclusive Economic Zone (EEZ).[10,11] The EU Common Fisheries Policy (CFP) grants equal access for all member states to fish within the 12-200nm limit.[5,12]

The CFP is primarily concerned with the conservation of fish stocks, with Member States responsible for implementation of management measures.[13] In the UK, this responsibility for fisheries management is devolved.[5] This includes licencing vessels, managing quota and ensuring compliance with CFP and UK rules.[5] Upon EU withdrawal, the UK Government intends to develop new fisheries access and management arrangements, which will be set out in a Fisheries Bill and White Paper.[14] The following sections outline some key aspects of fisheries, describe how fish stocks are assessed and how fisheries are currently managed, and outlines some of the future challenges for UK fisheries management.

Understanding Fisheries

Marine fish can live and move over large areas irrespective of human jurisdictional boundaries. The lifecycles of fish and shellfish can be complex, with larvae, juveniles and adults sometimes occupying and breeding in different areas and habitats.[15,16,17] These species form part of, and interact with, the wider marine ecosystem and change over time. Fishing not only affects species numbers and interactions, but can also affect habitats and the seabed.[18,19,20] Conversely, changes in the marine ecosystem, such as alterations in habitat suitability or changes in wider food webs, can affect commercial species.[21,22] Other pressures including climate change can affect fisheries.[23,24] For example, warming sea temperatures have been shown to alter the distributions of commercial species.[23,25]

Some fisheries target specific species while others are mixed, catching several different species. Species caught can be grouped into three main categories:[4,26]

- Shellfish including langoustine (*Nephrops*), scallops, crabs and lobster. These are among the most valuable UK fisheries[4] and may be caught using pots, traps and dredges. [27]
- Pelagic fish that live in open water between the sea floor and surface.[28] They can form large shoals and are highly mobile or often migratory.[29,30] Examples include mackerel and herring that are caught using nets.[26]
- Demersal fish that live near or at the seabed such as cod and haddock, which are caught using trawls pulled along the seabed.[26,31] They are often caught together in ‘mixed fisheries’,[31] which can be more complex to manage (see below).[32] Many mixed fisheries occur in Scotland and the south-west of England.[4]

Species differ in their vulnerability to fishing because of factors such as growth rates, reproductive capacity and age of maturity.[33] Some species are more easily caught than others.[34,35] This can be because of their size, positioning in the water at different times of day, and behaviour regarding different fishing methods or gears.[34,35]

Assessing Fish Stocks

For assessment purposes, populations of fish and shellfish species are split into area based stocks, such as North Sea and Rockall Cod.[36] Assessments of stocks rely on data from different sources which include:[37]

- Internationally coordinated scientific surveys that collect biological information independently of fisheries.[38,39]
- Data provided by fisheries from fish landings, satellite data (from vessels over 12m) and observers aboard fishing vessels.[39]

Within the EU, data collection is undertaken by Member States’ government research bodies, which informs both national and international advice (Box 1).

Stock Assessment Methods

Such data are used in annual stock assessment models to determine past and current fish stock size and status and examine the effects of different fishing levels on stocks.[40,41] They also forecast future catches and Maximum Sustainable Yield (MSY, defined as the largest average catch that can be removed from a stock over time under existing environmental conditions without threatening future yields).[40,41] Managing stocks for MSY is a globally recognised objective for fisheries management.[42] MSY is affected and determined by different factors (Box 2). Stock assessments can examine fish stock status by using biological reference points (**RPs**).[43,44] **Limit RPs** define points at which a stock is in an undesirable state. **Target RPs** define the ideal state of the stock. **Trigger points** can be set between limits and target points to help prompt corrective management action.

Box 1. Data Collection for Stock Assessments

Within the UK, data are collected and assessed by the devolved administrations: Marine Scotland;[45] Welsh Government Marine & Fisheries Division;[46] Northern Ireland’s Agri-Food and Biosciences Institute[47] and the Centre for Environment, Fisheries and Aquaculture Science (CEFAS).[48] As a Defra executive agency, CEFAS also provides UK wide advice and assessments on certain issues.[49] These data inform national fisheries management and international advisory processes. The fishing industry can help improve stock assessments or fisheries data through involvement in schemes such as the Fisheries Science Partnerships,[50] which encourage knowledge exchange between industry and scientists. UK data collection for fisheries stock assessments is coordinated through the EU Data Collection Framework.[51] Upon EU withdrawal the UK will need to find ways to fund its future data collecting activities and wider fisheries management because funding for this will become a national responsibility. The New Economics Foundation have suggested that funding from other sources, such as the fishing industry, may be required to help cover some science and management costs.[52]

The International Council of the Exploration of the Seas (ICES) acts to provide scientific information and advice for management for over 200 fish stocks and some shellfish stocks occurring in the North-East Atlantic (Box 3).[36,40,53] The UK and other ICES member countries take part in expert working groups that undertake stock assessments and other scientific work to inform management.[54,55] The international nature of ICES helps to ensure balance and objectivity across individual countries interests. However, most advice and assessments for shellfisheries in national waters originate from national bodies (Box 1).

Variations in Assessment Approaches

There are variations in the types of stock assessment methods used. This can be due to differences in the type and availability of data.[56] For example, data issues can be common for new fisheries because of uncertainties about the stock’s biology, and in some shellfisheries because of inadequate sampling.[56,57,58] Methods may also differ depending on the information required for management purposes.[56] Many assessments are based on a single species to inform management, although this can create difficulties in accounting for species interactions or the nature of mixed fisheries.[59,60] There are also differences in the ways stocks can be analysed and modelled. [61] Fish assessments generally examine fishing effects on the stock using age or length based methods.[61] When data are

Box 2. Factors Affecting Fishing Yield

The yield of a fish stock depends on the stock size and status. This can be influenced by factors relating to the stock’s biology, the fishing pressure applied to it, as well as wider environmental and human factors. Stock assessments focus on determining a number of key aspects:[40,41,62]

- **Fishing mortality**: rate of removal of fish from the stock by fishing.
- **Natural mortality**: number of fish dying due to natural processes such as predation or disease.
- **Recruitment**: number of young fish entering the fishery each year.
- **Spawning Stock Biomass:** total weight of all sexually mature fish in the stock.

Box 3. ICES Advice on Shared Stocks

For stocks shared between EU Member States only, the European Commission develops management proposals using advice from ICES and the Scientific, Technical and Economic Committee for Fisheries (STECF) for EU Council.[63,64] For stocks shared between the EU and other countries, Regional Fisheries Management Organisations (RFMOs) have been established to coordinate management responsibilities and action.[65] Some RFMOs are only advisory, but most can set catch and fishing effort limits and other management measures. ICES provides advice to help inform their decisions.[66] The RFMOs of most relevance to the UK include:

- North-East Atlantic Fisheries Commission (NEAFC).[67]
- North Atlantic Salmon Conservation Organisation (NASCO).[68]
- International Commission for the Conservation of Atlantic Tunas (ICCAT).[69]

limited or more uncertain other approaches are often used to model trends in annual yield or population size.[56,61] Shellfish assessments use underwater TV surveys for langoustine; dredging surveys for scallops, cockles and mussels; and length based models for crab and lobster, which cannot be easily aged.[58,70] Wider environmental impacts, such as climate change effects on species distributions or recruitment, can also be hard to include in assessments due to uncertainty in projections.[71] The subsequent scientific advice is often precautionary to account for uncertainties arising from limitations of the data, modelling and the inherent complexities of fisheries.[40,72]

Current Fisheries Regulation

The CFP uses a number of different approaches to manage fish and shellfish stocks in EU waters. These are discussed in the following sections and include plans, catch limits, quotas, and technical measures.

Multi-Annual Plans and Catch Limits

Some fish stocks in European waters are managed through multi-annual plans and most have annual catch limits called Total Allowable Catches (TACs).[73,74] A multi-annual plan is a regionalised strategy to manage stocks on longer time frames and can include specific management objectives and measures.[74] Annual TACs are set using ICES advice after negotiations between the EU Council (for stocks shared by EU Member States only).[75] For stocks shared between EU and non-EU states, TACs are negotiated through bilateral and multi-lateral agreements (Box 4).[73,76,77] TACs are divided among states as quotas.[73] Multi-annual plans consider multiple stocks and the interactions between them, and set ranges within which future TACs and quotas should be set.[78] While ICES provides scientific advice, it is the responsibility of ministers to set TACs, which are often set higher than the advice suggests.[79,80] Not all stocks are managed using TACs and quotas (see below). These non-quota species include most commercial shellfish species.

Quotas

EU Member State quota shares are determined using an allocation method known as ‘relative stability’.[73] This is based on an historical reference period from the 1970s and was adopted into the CFP in 1983.[81,82] The relative shares remain constant to provide economic stability for fishing fleets.[81,83] However, it cannot easily account for changes in fishing patterns or stock distributions.[83]

UK Quota Allocation

Each Member State is responsible for allocating its quota share to its national fleet. In the UK, quota for each stock is split between devolved administrations according to the Concordat Agreement.[84] It is then divided among the fleet:[52,85]

- ‘The Sector’ – vessels over 10 metres that are members of one of the 23 UK Producer Organisations (POs), which allocate and manage quota for their members.[5,86]
- The ‘non-sector’ – over 10 metre vessels that are not PO members and hold licences mostly for non-quota species.[2]
- The 10 metres and under (‘Under 10 metres’) – these account for 78% of UK vessels.[4] Many of these inshore vessels target non-quota species, particularly shellfish.

Quota is allocated via Fixed Quota Allocation units. These are based on historic records and determine the proportions of quota for individuals or collective groups.[5,85] FQAs can be traded and this has led to increasing concentration of ownership in some cases.[52] An FQA register is publicly available listing owners of FQA units.[87] Quota can be leased across certain sectors as required and swapped between POs and with other EU Member States.[52,85] Governments of the devolved administrations allocate quota to the Under 10 metres and non-sector from a common pool.[5] In England, this is done monthly by the Marine Management Organisation (MMO).[85] Some stakeholders argue that insufficient quota is allocated to vessels in the Under 10 metres category across the UK.[88,89] Prior to the EU’s regulation of buyers and sellers,[90] these vessels were not required to declare landings.[52] This led to a poor record of landings and subsequently a small share of overall quota.[52,88]

Box 4. Negotiating Fishing with Non-EU States

Specific international agreements determine fishing opportunities, access and management measures for shared stocks.[75,76,77] Individual bilateral Northern Agreements exist for joint management of shared stocks between the EU and the Faroe Islands, Iceland and Norway.[76] Depending upon the stock, TACs are negotiated either through individual coastal state discussions or multi-laterally through the NEAFC (Box 2), prior to December EU Council meetings. However, these agreements do not have binding mechanisms to require states to reach a decision. This may result in unilateral TACs[30] that exceed ICES advice. For example, unilateral TACs were set in 2010 when mackerel abundances increased in the EEZs of Iceland and the Faroe Islands as no agreements could be reached between them, the EU and Norway.[30,83]

Norway-EU Negotiations

Norway and the EU use zonal attachment in some bilateral negotiations on certain stocks.[91,92] This allocates fishing opportunities using information on the spatial distributions of stocks over time and lifecycle.[93] This may be difficult because of complexity in species lifecycles or changes in their distributions due to factors such as climate change.[30,94,95] Selecting the criteria to use, such as biomass or abundance, in determining allocations is done on a political basis.[92] Although scientific evidence and advice can be provided to inform the political choice of criteria, there is also uncertainty over how objectively it can be used in decisions.[92] For example, differences in survey sampling between areas could weight criteria differently. Social and economic factors will also need to be considered in negotiations.[92,96]

Landing Obligation

Discarding is the practice of throwing back unwanted, often dead, fish to the sea because of management regulations or market conditions.[97] It was criticised by a public campaign.[98] The 2013 CFP reforms introduced a landing obligation (LO) to address discarding, to be implemented between 2015 and 2019, including on UK vessels.[99,100] The LO requires all catches of quota species on board to be landed and counted against quota.[100] The objective is to incentivise an increase in fishing selectivity, including by moving areas, and provide a better understanding of the total amounts of fish being caught through full documentation.[100] However, its implementation presents challenges,[101,102] including 'choke species'.[99] These are species with a low volume of quota, that when reached will cause fishing operations to halt, even if fishermen still have quota available for other species.[103] As the LO is still being implemented, it has yet to be evaluated for effectiveness.

Technical Measures and Effort Control

Fisheries managers also use technical measures and effort controls to manage both quota and non-quota stocks.[104] The many kinds of technical measures include minimum landing or conservation sizes, specifications on design and use of fishing gear, and closed areas or seasons.[104,105] They aim to improve selectivity in fisheries and reduce ecosystem impacts.[105] For quota species they can be used as an additional management measure. For example, some gears are better at selecting out species for which fishers have no quota.[106,107] Technical measures are often used as a main management tool for non-quota shellfish and can differ according to devolved, national and EU regulations.[58]

Fishing effort controls can be used on certain stocks to limit fishing capacity and vessel usage.[108] For example, limits to the number of days at sea apply to some vessels targeting the quota species Dover sole in the western Channel.[109]

Future UK Fisheries Management

After EU and CFP withdrawal, the UK will become an independent coastal state with sovereign rights to govern its 200 nautical mile EEZ under the United Nations Convention on the Law of the Sea (UNCLOS).[11,83] As such, the UK has certain responsibilities for its fisheries[110] according to international laws including UNCLOS and the UN Fish Stocks Agreement.[111,112] The UK will have to determine access agreements for foreign vessels into UK waters, as well as for UK vessels into non-UK waters.[113] New mechanisms for negotiating fishing access and TACs for shared stocks will also be needed and cooperation over management for regional seas.[110,113] The UK is not currently a member of NEAFC or NASCO, as it is currently represented by the EU.[112] As such the UK may wish to re-join independently (Box 3). Outcomes from these negotiations may impact on the wider fisheries supply chain.[114] Around two thirds of fish consumed in the UK currently comes from outside EU waters and the majority of what is caught by the UK fleet is currently exported to the EU.[115]

Technological Innovation in Fisheries

Technology is increasingly being used to generate data to inform management for compliance and enforcement and for scientific purposes.[116] Remote Electronic Monitoring (REM) can provide information on fishing activities to help allow real time management of a fishery as well as providing better understanding of fleet behaviour.[117,118] Vessel Monitoring Systems (VMS) are used on over 12 metre vessels in the UK fleet and an inshore VMS is now being implemented for the Under 10 metres.[119] Cameras can also be used as a tool to collect catch and discard information,[120,121] but there are some concerns regarding the processing of this information.[117,118,122] Mobile phone apps are increasingly used to record catch information.[123]

Managing Fisheries in a Changing Environment

The marine environment is increasingly being affected by climate change, pollution and ocean acidification.[23,124,125,126] Current domestic legislation and international commitments outline broader long term responsibilities for the UK government to protect the marine environment and its ecosystems.[127,128] These include adopting an Ecosystem Approach to marine management.[128,129,130] In the context of fisheries management, such an approach requires acknowledging fisheries form part of this wider, changing marine environment, and integrating and aligning fisheries with wider objectives, such as marine conservation or renewable energy (Box 5.).[131,132,133,134] The Government's 25 Year Environment Plan states this approach will 'account for and seek to minimise impacts on non-commercial species and the marine environment generally'.[1]

While management is often primarily focused upon managing fishery resources, the social, cultural and economic values of fisheries can be substantial.[6,7,135] UK fisheries management seeks to consider these factors,[127,136] but this can be a challenge. Fishery resources are a national, public asset and many sectors, such as recreational fishing and tourism also have an interest in their sustainable management.[137,138] For example, a 2012 survey estimated that there are 884,000 sea anglers in England alone, who caught around 10 million fish.[137]

Box 5. Marine Protected Areas in Marine Management

The European Marine Strategy Framework Directive[139], OSPAR Convention for the North-East Atlantic[128] and the International Convention on Biological Diversity[129] all outline obligations for an Ecosystem Approach for managing the marine environment. Marine Protected Areas (MPAs) are one of the many tools to help deliver this. The UK has 297 MPAs, including 56 Marine Conservation Zones (MCZs).[140,141] The Government's 25 Year Environment Plan has set out a new approach to MPA designation.[1, 142] Some suggest MPAs have the potential to benefit some fish stocks, through for example protecting nursery grounds or spillover effects, if areas are selected, designated and managed appropriately.[143,144,145] Consulting stakeholders such as the fishing industry in the planning of MPAs helps ascertain potential wider social and economic implications and outcomes.[141,146] However, some academic commentators argue that the current MPA network around the UK is not adequately protecting the marine environment from fishing activities.[147]

POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of policy issues that have a basis in science and technology. POST is grateful to Katherine Maltby for researching this briefing, to the British Ecological Society for funding her parliamentary fellowship, and to all contributors and reviewers. For further information on this subject, please contact the co-author, Dr Jonathan Wentworth.

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