Fishers' behavioural responses to severe weather events: implications for the vulnerability of fisheries to changing storminess

Submitted by Nigel Christopher Sainsbury to the University of Exeter as a thesis for the degree of Doctor of Philosophy in Geography, November 2020.

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other university.

(Signature) …………………………………………………………………………………

What cost to us, the fishermen,
The toilers of the sea,
To dare old Mother Nature,
And bring home fish to thee.
“The price of fish,”
“The cost of fish,”
A housewife to me discerned
Well, weigh your cost with the children
Whose fathers never returned.

Mark Curtis
Newlyn skipper

Abstract

Growing evidence suggests that climate change is altering storm frequency and intensity over the world's oceans. Uniquely among fisheries climate risks, changing storminess poses risks over short temporal scales and direct social risks to fishers. However, little is known about fisher decision-making in the context of short-term weather-related risks and consequently their vulnerability to climate change. Improving our understanding of this climate threat is critical because fish provide livelihoods, food security, and cultural identity to billions of people globally. It is estimated that 38 million people directly harvest fish; 12% of the population (approximately 900 million) make their livelihoods in the fisheries supply chain; and 3.1 billion people rely on fish for 20% of their animal protein (FAO, 2016). The United Kingdom commercial marine capture fishery, particularly the fleet in Cornwall in southwest England, provides a useful case example for changing storminess and fisheries research. The UK is exposed to the North Atlantic storm track and the fishery is highly varied in terms of target species, fishing methods, and vessel characteristics, thereby offering wider insights at a global scale. By focusing on fishers' short-term behavioural responses to storm-related weather conditions, this thesis seeks to improve understanding of fisheries climate vulnerability. The thesis findings can help inform the inclusion of changing storminess in fisheries climate vulnerability assessments and adaptation action.

In this thesis I draw on qualitative and quantitative research approaches to provide global, UK-wide and local insights relating to the risk posed by changing storminess to marine capture fisheries. First, a global review of changing storminess and the ecological and social effects of storms on fisheries was carried out to inform a research roadmap for this novel field. Second, skippers in Newlyn, Cornwall were interviewed to provide a rich, qualitative description of how weather conditions feature in fishers' short-term fishing decisions. Third, a stated choice experiment was carried out with 80 skippers fishing in Cornwall to empirically estimate their preferences for weather conditions, fish price and catch, and to identify how they trade off physical risk and economic rewards in their daily trip decisions. Fourth, a novel fine spatial-temporal resolution dataset describing a decade of UK fisheries landings and weather conditions was

analysed to describe the influence of weather conditions on fisheries productivity for vessels choosing to be at sea. Finally, the extent to which Newlyn skippers manage physical risk was assessed using semi-structured interview data by comparing their approach to the ISO 31000 risk management process.

The global review of changing storminess and capture fisheries found this field is in its infancy. Globally, the evidence suggests that the ecological and socio-economic impacts of storms on fisheries are extensive and potentially catastrophic. Existing research suggests that changing storminess is spatially heterogeneous within and between ocean basins. A research roadmap was proposed that included improving climate modelling of storms, exploring fishers' behavioural response to storms, identifying the mechanisms by which storms affect fish and their habitat, investigating social-ecological linkages, and developing adaptation actions and assessments of the fisheries vulnerability to changing storminess.

Semi-structured interviews revealed that a complex interaction of meteorological and oceanographic variables affect the elements of fishers' trade-offs. Newlyn skippers were found to have a binary perspective on safety. When skippers judged conditions to be unsafe, they generally chose not to be at sea. When conditions were considered safe, fishers were found to trade off physical risk, discomfort, and economic reward in their short-term fishing decisions. Fishers' trade-offs were influenced by a number of individual fisher differences and social processes, such as economic need and fear of missing out. Working with crew was also important, due to a desire to protect their crew's safety and comfort, but also because of the effect of crew capability on physical risk. Fishing methods and vessel characteristics were found to influence the effect of adverse weather on physical risk and trip profitability. For instance, purse seines were described as highly sensitive to large waves due to reduced vessel stability during net hauling, and bottom trawl skippers explained that larger waves reduce their catch due to reduced gear efficacy.

The stated choice experiment revealed that fishers operating in Cornwall have non-linear preferences for weather conditions. They initially preferred higher wind speed and wave height, before their preferences fell at an accelerating rate. Fishing gear, vessel length, presence of crew, vessel ownership, age, recent fishing success and reliance on fishing income all influenced the skippers' decisions to go to sea. Skippers of larger boats and those that owned their boat were more likely to go to sea in worse weather conditions than those of smaller boats or those that did not own their boat. Skippers with greater economic need were more likely to take greater physical risk. Trade-offs also differed by fishing methods. Hand lining skippers were less averse to wind speed and wave height than those using other gears, purse seine skippers preferred small waves more than skippers using other gear types, but their aversion to wave height fell more rapidly.

Analysis of the novel national scale landings and weather data revealed that landings varied with wind speed and wave height in non-linear ways, differentiated by gear type. Landings either increased with, or were unaffected by, increasing wind speed and wave height with the exception of pots and traps, for which landings decreased with both weather variables. Midwater trawls and gillnets and entangling nets showed the most biologically significant increase in landings as wind speed and wave height increased. For the most economically important UK fishing method, bottom trawls, the effect of weather variables on landings on varied slightly with the smallest boats seeing a greater fall in landing at extreme weather levels and the second largest vessels experiencing no reduction in catch. Mean daily landings did not always increase with vessel size within gear type. For instance, the largest vessel length category for pots and traps, seines, and hooks and lines did not have the largest mean catch.

Comparing Newlyn skippers' approach to risk management process theory demonstrated that they informally carried out each step of the ISO 31000 risk management process. As such, they were determined to be experts at managing risk. The skippers described their risk context, how they identify hazards, the way that they analyse the likelihood and consequence of the risks, evaluating these risks against their context, before treating the risk, predominantly using risk avoidance, risk reduction, and risk acceptance strategies. The analysis of risk likelihood of at-sea hazards using weather data, including digital forecasts, real time data, visual observation, and testing the conditions was central to their management of risk.

By taking a bottom-up approach, this thesis has revealed the importance of individual fisher behaviour in climate vulnerability. The findings provide insights for the concept of fishers' sensitivity to climate risks, a key tenet in the concept of climate vulnerability, because fishers choose the risks they are sensitive to through the way they make trade-offs in their short-term decisions. The effect of weather conditions on landings indicates that UK skippers who take the physical risk of going to sea will not be sensitive to reduced catches, unless they use pots and traps or bottom trawls in the most extreme conditions. This provides insights into fishers' trip catch expectations, and therefore how economic reward features in their decision trade-offs. The expertise shown by skippers in their approach to risk management may make them safer by mitigating the physical risks they face from storms when at sea and reducing the likelihood of accepting greater risk than intended. The findings in this thesis have implications for the design of fisheries vulnerability assessments. Designers of fisheries vulnerability assessments should seek to include exposure, sensitivity, and adaptive capacity to changing storminess, with particular attention to individual heterogeneity in physical and economic risk sensitivity. Individual fisher heterogeneity should also be reflected in the way that changing storminess adaption policies, such as climate risk insurance instruments, are designed. The new knowledge presented in this thesis represents the first focused research efforts in the field of changing storminess and fisheries. It is hoped that by informing vulnerability assessments and adaptation actions, this thesis will contribute to improving the wellbeing of fishers and coastal communities in the UK and further afield as the climate changes.

Acknowledgements

Funding enabled me to carry out this PhD. As well as a stipend, my research and training were generously funded by the UK Natural Environment Research Council (NERC; GW4+ studentships NE/L002434/1), Centre for Environment, Fisheries and Aquaculture Science and Willis Research Network. Looking further back, I would like to thank the Ruby and George Will Trust for helping to fund my MSc, which provided the pathway to this PhD.

I was extremely lucky to have a wonderful group of supervisors: Rachel, Steve, Martin, John, Geoff, Clare, Pete, Gaetano and Adam. In an ever-demanding world, you were always available when I needed support, guidance, and advice. Thank you all. I must particularly thank Rachel, for giving me the freedom to find my academic feet but always deftly keeping me on course.

I worked with many people across a variety of organisations during my research, all of whom helped me along the way. Thanks to Roi Martinez at Cefas for helping me understand fisheries data, Kevin Williamson and Simon Dixon at the MMO for extracting data for me and helping out with data definitions and issues, Dan Fairweather at Willis Towers Watson for his continued interest in my research, and Andy Saulter at the Met Office for support with WaveWatch III data.

It was a rare privilege to spend time with the Cornish fishing community. My thanks go to Laurence Hartwell, Andy Wheeler, Sam Davis, and Pete Bromley, for helping me understand the fishery and realities of fishing in the waters around Cornwall at the outset. I would also like to thank Peter Haddock and Mike Ridgeway for their support engaging with fishers at Hayle and Newquay. Meeting and spending time with skippers in Cornwall was a fantastic experience and I doubt I will ever again meet a more genuine group of people. I am very grateful to all the skippers who participated for giving up their precious time for my research. In a job that places such great physical and mental demand on those who go to sea and, in many cases, for little gain, the fishers I met were faultlessly generous. I would particularly like to thank Andy Pascoe, Johnny Murt, David Warwick and Jonathon Fletcher for connecting me with other skippers and helping me improve the design of my fieldwork research.

My PhD experience has been rich and varied. I have a passion for teaching and received lots of support to pursue this. Thanks to Rachel Turner, Tomas Chaigneau, Kate Leyshon, and Dave Hodgson for the chance to give lectures and teach on fieldtrips in Kenya and California. I am also very grateful to Tim Marwood and Kelly Moyes for the encouragement and developmental support.

Most of all, I am grateful to my family for the love and support that has sustained me and carried me here. In particular, to mum and dad, thank you for giving me the deep-seated belief that I can take a crack at anything, and make a decent shot of it. To Ruth and Paul, for taking care of the pups whilst we went off teaching in different corners of the world. To Chucho, for never giving in and always leading the way. To Barbie for the endless supply of cuddles and the daily pep talks, at least, that's what I assumed you were saying. To Diego for bringing us light in the darkness and being generally awesome. Finally, to Katie, for your advice, positivity, and unwavering, unconditional love. I couldn't have done it without you. To paraphrase one of the 20th century's most iconic athletes, "Yo Katie, I did it!"

Contents

Tables and Figures

Authors declaration for co-authored manuscripts

I conceived and developed the ideas for chapters 2, 3, 4, 5, and 6. I designed the research method and analytical approach for the studies in chapters 2, 3, 4, 5, and 6 with the support of Rachel Turner (RT) (chapters 2–6), Martin Genner (MG) (chapters 2 and 5), John Pinnegar (JP) (chapter 2), Steve Simpson (SS) (Chapter 2 and 5), Pete Schuhmann (PS) (chapter 4), Gaetano Grilli (GG) (chapter 4) and Adam Leonard-Williams (chapter 5).

I carried out the review of the literature for chapter 2. I carried out the fieldwork for chapters 3 and 6. Sam Gill collected four surveys from one port in Cornwall for chapter 4. Transcription of 24 of 26 interviews was outsourced. I defined the data requirements for chapter 5 and negotiated their release with the Marine Management Organisation and UK Meteorological Office. Clare O'Neill (CON) extracted the weather data and Kevin Williamson extracted the landings data. I performed the analysis for chapters 3, 4, 5, 6 with guidance from RT (chapters 3–6), MG (chapter 5), SS (chapter 5), PS (chapter 4), and GG (chapter 4). I conceived the three figures in chapter 2 and Emma M. Wood provided design services to produce them. I created all other figures in this thesis.

Chapters 2–6 have been published (chapter 2) or written as co-authored academic papers for publication (chapters 3–6). I wrote chapters 1–7 and revised them based on comments and advice from RT (chapters 1–7), MG (chapters 1–7), JP (chapters 2–4 and 6), GS (chapters 2, 5, and 6), SS (chapters 2, 4, and 5), CON (chapters 2 and 5), PS (chapter 4), and GG (chapter 4). I conceived the idea, carried out the research, and wrote the manuscript for Appendix A. Comments were provided on the manuscript by RT, JP, Bryony Townwill, and Stephen Mangi.

Chapter 1

Introduction

Chapter 1: Introduction

Context

Anthropogenic climate change represents one of the greatest existential threats to humanity (Allen et al., 2019). Climate change is driving alterations to the Earth system and oceans are affected by climate change in several ways. Land ice loss and thermal expansion of the oceans is driving sea level rise (Solomon et al., 2009). Oceans are warming, becoming more acidic and holding less oxygen due to the absorption of additional heat and carbon dioxide from the atmosphere (Bopp et al., 2013). Evidence is growing that climate change will alter the frequency and intensity of cyclonic storms (Hartmann et al., 2013; Murakami et al., 2013, 2017; Feser et al., 2015; Mölter et al., 2016; Kossin et al., 2020).

Marine capture fisheries (fisheries from hereon) present an excellent case study to explore social responses to environmental change in socio-ecological systems because they comprise a large number of identifiable individuals engaged in harvesting natural resources in a highly dynamic environmental, ecological, social and economic context. Marine and inland commercial capture fisheries are a major contributor to food security, health, livelihoods and culture. Millions of individuals make their livelihoods directly from harvesting fish or as part of the fisheries value chain (FAO, 2016). Fisheries are heterogeneous in nature, involving different practices and targeting different species across scales (Pauly et al., 2002).

Marine life harvested for human consumption, henceforth referred to as ‘fish’, provides three billion people with 20% of their animal protein (FAO, 2016). Fish are also a vital source of micro-nutrients, particularly for children and pregnant women in the tropics, and an estimated 845 million people are at risk of receiving insufficient levels of these nutrients if fish stocks were to reduce (Golden et al., 2016). Fish are an important part of the global economy, particularly for developing countries. The global fish trade accounts for 9% of global agricultural exports and involves over 200 countries (FAO, 2016). Capture fisheries also represent an important source of cultural capital in many coastal and island communities (Urquhart and Acott, 2014; Leeney and

Poncelet, 2015). It is therefore of great social and environmental concern that global capture fisheries face a period of uncertainty and change.

Fisheries have faced the challenge of sustainably extracting marine life from global oceans since at least the Second World War, following the explosion in the world population and accelerated industrialisation (Pauly et al., 2002). Although part of this increased demand has been met by aquaculture sources, which now account for half of global fish production, capture fisheries remain vital for subsistence and trade (FAO, 2016). A growing demand for fish places greater pressure on a social-ecological system that is failing to harvest natural resources at sustainable levels (Pauly and Zeller, 2017). Fisheries must not only respond to the challenge of sustainable development, but also adapt to climate change (Brander, 2007).

Due to the potential impact of climate change on the social and ecological aspects of marine systems, the fisheries that rely on them face a number of climate-related risks. Ocean warming is causing species distribution shifts (Cheung et al., 2013; Poloczanska et al., 2013). Ocean acidification changes seawater biochemistry, negatively affecting fish physiology and the formation of calcium carbonate skeletal structures (Fabry et al., 2008; Riebesell and Gattuso, 2015). Ocean deoxygenation reduces the oxygen available for fish to function healthily (Keeling et al., 2010; Stramma et al., 2010). Although these climate risks are ecological in nature, they have consequences for fishers through social-economic linkages. For instance, the productivity and distribution of target species may change, reducing catch potential for fisheries that have traditionally exploited them (Cheung et al., 2013). Other fisheries climate risks have the potential to cause direct socio-economic impacts. Rising sea levels threaten the coastal infrastructure upon which fisheries depend, including near-shore habitats, beaches, harbours, buildings and transportation infrastructure (Daw et al., 2009; Ashoka Deepananda and Macusi, 2012). However, the most profound risk of climate change on fisheries may result from the impact of changes in global storminess. Changing storminess is unique among fisheries climate risks because it presents a direct risk to the social and ecological aspects of the system with the potential for sudden shocks as well as sustained impacts. As such, human dimensions of changing storminess and fisheries are of particular interest.

Fishers are socio-economic agents operating in one of the most dangerous livelihoods on Earth (FAO, 2016) and weather is one of the greatest risks to their personal safety and economic security (Norrish and Cryer, 1990; Jin and Thunberg, 2005; Smith and Wilen, 2005; Wu et al., 2009; Emery et al., 2014; Rezaee et al., 2016b; Thiery et al., 2016; Marvasti and Dakhlia, 2017; Marvasti, 2019). Future changes in the frequency and intensity of storms may increase the physical risk to fishers and disrupt fishing activities. As such, fishers' short-term fishing decisions may be important in the nature of the risk that changing storminess poses to fisheries. It might also be possible that changes in storminess affect fisher decisions over longer temporal scales, such as base location, target species, gear selection, vessel investment, or even participation in the livelihood. It is therefore necessary to understand fishers' behavioural response to storms in order to study the socio-economic vulnerability of fisheries to storms and to inform adaptive action.

The risk to fisheries of climate-driven changes in storminess is a function of their vulnerability. Vulnerability in a climate change context is defined in its most established form as "a function of the character, magnitude, and rate of climate variation to which a system is exposed, the system's sensitivity and its adaptive capacity" (McCarthy et al., 2001). Exposure to changing storminess is therefore the extent to which storm frequency and intensity will alter for a particular fishery. Climate sensitivity is, "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli" (McCarthy et al., 2001). Climate sensitivity can be ecological (the degree to which fish and habitats are perturbed by a climate stressor) or social (the degree to which a community depends on fishing) (Cinner et al., 2013). Adaptive capacity describes the ability of a community to adapt to or exploit opportunities from changes (Cinner et al., 2018). Vulnerability may be differentiated by country (Allison et al., 2009) and between communities and individuals (Cinner et al., 2018). Attempts to assess the global vulnerability of national fisheries have shown that small island state and least developed country fisheries are amongst the world's most vulnerable to climate change (Allison et al., 2009; Blasiak et al., 2017; Monnereau et al., 2017). However, despite growing recognition that climate change is driving changes in global storminess (Hartmann et al., 2013; Murakami et al., 2013, 2017; Feser et al., 2015; Mölter et al., 2016; Kossin et al., 2020), we know little of the vulnerability of global fisheries to this environmental change nor the adaptations required to minimise its effect on human well-being.

The Thesis

In this thesis I report work that broadly aims to identify ways in which fisheries are vulnerable to changing storminess by focusing on the effect of wind and waves on fishers' short-term behaviour and their catches, and fishers' capacity to manage risks associated with changing storminess. Drawing on the most established conceptualisation of climate vulnerability as, "a function of the character, magnitude, and rate of climate variation to which a system is exposed, the system's sensitivity and its adaptive capacity" (IPCC, 2014), the research in this thesis focuses on the sensitivity of fisheries to changing storminess and their adaptive capacity. The aim is for the knowledge reported in this thesis to contribute to the conceptualisation of climate vulnerability, to the inclusion of changing storminess in fisheries vulnerability assessments, and to adaptation solutions and policies. Collaborating with Willis Research Network has provided a direct route to informing the development of parametric insurance instruments, which represent a promising avenue for fisheries adaptation to changing storminess.

The effect of climate change on storms is conceived in this thesis as a shift in the frequency of all severities of cyclonic storm events. A small shift in mean storm intensity or frequency would lead to a very large relative change in extreme storms (Trenberth, 2012), but also a smaller relative change in all levels of storm frequency and intensity. Consequently, my aim has been to reveal how fishers' behaviour, and fishing success, are affected across the full range of wind and wave conditions.

Changing storminess is a new area of research in the field of fisheries climate risk, and investigating all aspects of the problem is beyond the scope of the thesis. For example, this research does not address challenges in climate modelling, the effect of storms on marine habitats, or long-term social dynamics. The studies in this thesis predominantly sought to identify social and economic aspects of fishers' behavioural response to storms. However, given that fisheries are social-ecological systems and there are intimate connections between fishers and the fish they hunt, with wind events affecting both, marine ecology plays an important role in two chapters of this thesis. Understanding the effect of wind events on capture fisheries requires consideration of meteorology and oceanography, and these disciplines feature throughout the thesis.

Thesis study system

The UK, and the southwest of England in particular, has been selected as a case study because it is a large fishery with a range of fishing methods and vessel characteristics exposed to a range of weather conditions. Despite its relatively small geographic size, the UK is the 24th largest capture fish producer in the world with an output of 701,749 tonnes in 2016 (FAO, 2018). Despite only contributing less than 1% of the UK's GDP (Ares et al., 2017), local fishing communities are highly dependent on fishing from a cultural, social and economic perspective, including in Cornwall (Abernethy et al., 2010; Urquhart and Acott, 2013; 2014). Cornwall, located in the far southwest of England, is an excellent location for fieldwork because it is home to England's largest port by landed weight (Newlyn). In addition, Cornwall's fishery is diverse across vessel sizes, fishing gears and fish species, providing ample opportunity to sample fishers to explore individual behavioural heterogeneity that would not be possible in a single species fishery. The UK and Cornwall's waters are exposed to a range of weather conditions, from calm inshore waters to some of the most extreme sea states observed on earth (World Meteorological Organization, 2016; UK Meteorological Office, 2020). UK fishers are therefore experienced at fishing in a range of meteorological conditions providing them with rich perspectives on weather-related decisions. Finally, UK fisheries are data rich and offer the potential for high resolution observed analysis of fisher behaviour.

Thesis aims and objectives

This thesis employs a mixed-methods interdisciplinary bottom-up approach (Conway et al., 2019) to investigate the role of short-term human behaviour in the vulnerability of resource users to changing storminess in a social-ecological system. There were five aims. First, to review the field of changing storminess and fisheries and identify key areas of future research. Second, to describe how weather features in fishers' short-term fishing decisions. Third, to identify how wind and waves disrupt decisions to go to sea. Fourth, to determine how fishing success varies in different weather conditions when fishers choose to go to sea.

Fifth, to identify how fishers manage the risks associated with adverse weather. To achieve the aims, five research objectives were pursued using a case study of the United Kingdom (UK) commercial marine fishery, with a particular focus on Cornwall in southwest England:

1. Review the available evidence relating to changing storminess and global capture fisheries to draw the topic to the attention of the research community.

2. Describe the factors that affect fishers' short-term weather-related fishing decisions using the fishery at Newlyn, UK, as a case study.

3. Explain how fishers based at ports in Cornwall, UK, trade off physical risk and economic reward in daily participation decisions and reveal factors affecting individual differences.

4. Identify how weather conditions affect landings of UK vessels fishing in the UK Exclusive Economic Zone.

5. Assess how fishers working from Newlyn, UK manage the physical risks of working at sea and the degree to which this reflects risk management theory.

Thesis structure

After this introduction, I present five original research chapters in the form of individual research papers, followed by an overall concluding discussion. A brief essay on the challenges of adopting climate risk insurance as an adaption to changing storminess in fisheries, published in *Nature Climate Change* as a letter, is appended to the thesis (Appendix A).

Chapter 2 reviews the literature on changing storminess and global capture fisheries, drawing on a range of disciplines to emphasise the criticality of the issue. I present evidence for the global heterogeneity in projected changes in storminess and demonstrate how storms can ecologically and socio-economically impact fisheries. I present a detailed research roadmap including elements of climate modelling, human behaviour, ecological impacts, and climate vulnerability and adaptation. This chapter was published by *Nature Climate Change* in 2018 (Sainsbury et al., 2018).

In Chapter 3, I present a qualitative study based on 26 semi-structured in-depth interviews carried out with fishers at Newlyn, UK. I explore how weather conditions feature in fishers' short-term decisions. I focus on fishers' decisions to go to sea and to return to port. The study describes how fishers perceive physical risk and how they balance safety and economic rewards in their decisions. I explain how technical fishing factors, such as fishing method and boat size, and economic need affect the way that fishers choose to trade off physical risk and economic reward.

Chapter 4 documents a quantitative stated choice experiment carried out with fishers working at Cornish ports. The experiment asked skippers to make a number of choices between hypothetical fishing trips defined by different weather conditions and anticipated trip catch levels and fish prices. Econometric modelling reveals the value that respondents place on weather features and the factors governing trip rewards. The findings also demonstrate how fishers trade physical risk off with economic rewards. This chapter has been published in *Global Environmental Change*.

In Chapter 5, I analyse how levels of landed catch vary with weather conditions for individual UK registered vessels fishing in the UK Exclusive Economic Zone (excluding overseas territories and crown dependencies) over a decade from 2008–17. Using data sourced from the Marine Management Organisation and the UK Meteorological Office, and generalised additive models, I elucidate differences in the impact of wind speed and wave height on the eight most economically important fishing methods in UK waters. I discuss the potential oceanographic, ecological, technical and human dynamics that may explain the findings.

Chapter 6 details a study of fishers' risk management practices at the port of Newlyn, UK. Based on semi-structured interviews focusing on the risks generated by weather conditions, I present the way that fishers informally identify, analyse, evaluate, and treat risks. I compare fishers' risk management practices to risk management theory to assess the degree of expertise they demonstrate. I conclude by discussing the implications for the physical vulnerability of fishers to increased storminess.

This thesis concludes with Chapter 7, in which I discuss how my research contributes to the concept of fisheries climate vulnerability, the insights provided for the vulnerability of UK and global fisheries to changing storminess, and the implications for fisheries adaption to changing storminess. I also consider the future research that is required to support policymakers and fisheries managers in minimising the human cost of changing storminess to global fisheries.

Chapter 2

“Changing storminess and global capture fisheries”

Chapter 2: Changing storminess and global capture fisheries

This chapter has been published as:

Sainsbury, N.C., Genner, M.J., Saville, G.R., Pinnegar, J.K., O'Neill, C.K., Simpson, S.D., Turner, R.A. (2018) Changing storminess and global capture fisheries. *Nature Climate Change* **8**, 655–659.

Climate change-driven alterations in storminess pose a significant threat to global capture fisheries. Understanding how storms interact with fishery social-ecological systems can inform adaptive action and help reduce the vulnerability of those dependent on fisheries for life and livelihood.

Fisheries are an important source of food, nutrition, livelihoods and cultural identity on a global scale. Fish provide 3.1 billion people with close to 20% of their animal protein (FAO, 2016), and are relied upon for vital micro-nutrients, which are particularly critical to the health of children and pregnant women (Golden et al., 2016). Capture fisheries and aquaculture are estimated to support the livelihoods of 12% of the global population and 38 million fishers regularly risk their lives in one of the most dangerous jobs on Earth (FAO, 2016). Despite its dangers, fishing is an important source of cultural identity and well-being for fishing communities around the world (Coulthard et al., 2011).

In addition to ocean warming and acidification, changing storminess is a climate stressor that affects marine life and habitats (Fig. 2.1a), with potential negative consequences for fish catch and the well-being of coastal communities. Changing storminess also poses a direct risk to fisheries. Storms directly affect fishing effort, posing a physical threat to fishers, their vessels and gear, as well as to fishing communities and their infrastructure. Whilst ocean warming may alter potential fish catch over the next 50 to 100 years (Cheung et al., 2010), changing storminess has the potential to cause more immediate and catastrophic impacts. The 21st century has already witnessed many tropical, extra-tropical storms and thunderstorms that have claimed thousands of fishers' lives, destroyed fishery-dependent livelihoods and assets, and disrupted the production of commercial inland and marine capture fisheries (Fig. 2.1b).

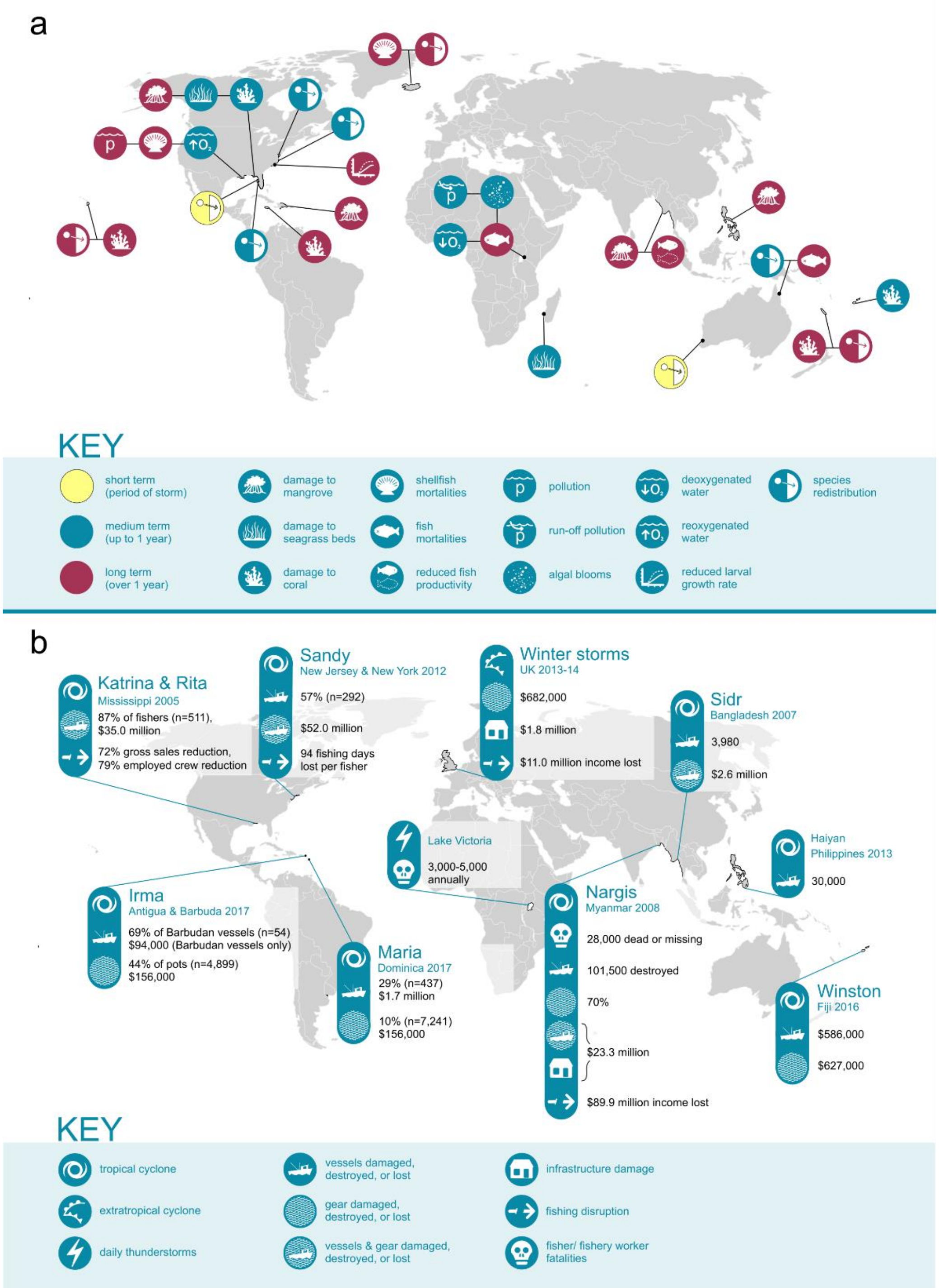

Figure 2.1. Ecological, social and economic impacts of storms on fisheries. (a) Examples of storm-induced marine ecosystem disturbances. (b) Examples of social and economic impact case studies from the 21st century. Case studies were selected based on scale of impact, global geographic spread and availability of data. For further detail see Appendix B.

Storminess reanalysis and projection studies are growing in number and geographic scope (Fig. 2.2). However, uncertainty in past and future storminess from global and regional climate models remains high as a result of widespread variation in analytical methods, poor historic observational data and the challenge of distinguishing externally forced climate changes from natural internal climate variability (Hartmann et al., 2013). Attribution of particular extreme weather events to anthropogenic climate forcing is problematic, and especially so for storms (Bindoff et al., 2013). Thus, extreme weather event attribution is an expanding area of research and examples for storm events are beginning to emerge (Trenberth et al., 2015).

Despite the challenges of modelling the location, frequency and intensity of storms, there is sufficient certainty for the IPCC to conclude for the North Atlantic basin, where fisheries productivity is high and historic storm data is particularly rich, that the frequency of the most intense tropical storms has increased since the 1970s (Hartmann et al., 2013). A recent review of future winter storminess studies in Europe, ranging over periods spanning 2020–2190, predicts increases in storm frequency and intensity in Western and Central Europe, and decreasing storminess over the North Atlantic north of 60° and in Southern Europe (Mölter et al., 2016). Evidence of changing storminess from a growing number of studies outside the North Atlantic includes a northward shift in Western North Pacific tropical cyclone exposure towards the East China Sea (Kossin et al., 2016) and increased post-Monsoon storminess in the Arabian Sea (Murakami et al., 2017). However, substantial uncertainties in storminess projections remain, and represent a real barrier to effective assessment of global fishery vulnerability.

The uncertainty surrounding the changing nature of storm hazards is paralleled by a lack of knowledge about how storm events directly interact with social and economic variables to influence the behaviour of fishers. In addition, the impacts of storms on marine ecosystems and the linkages by which these cause indirect social and economic perturbations to fisheries are little understood. An interdisciplinary research effort is now required to clarify the climatic, social and ecological dimensions of changing storminess to support the assessment of fishery vulnerability and inform adaptive action.

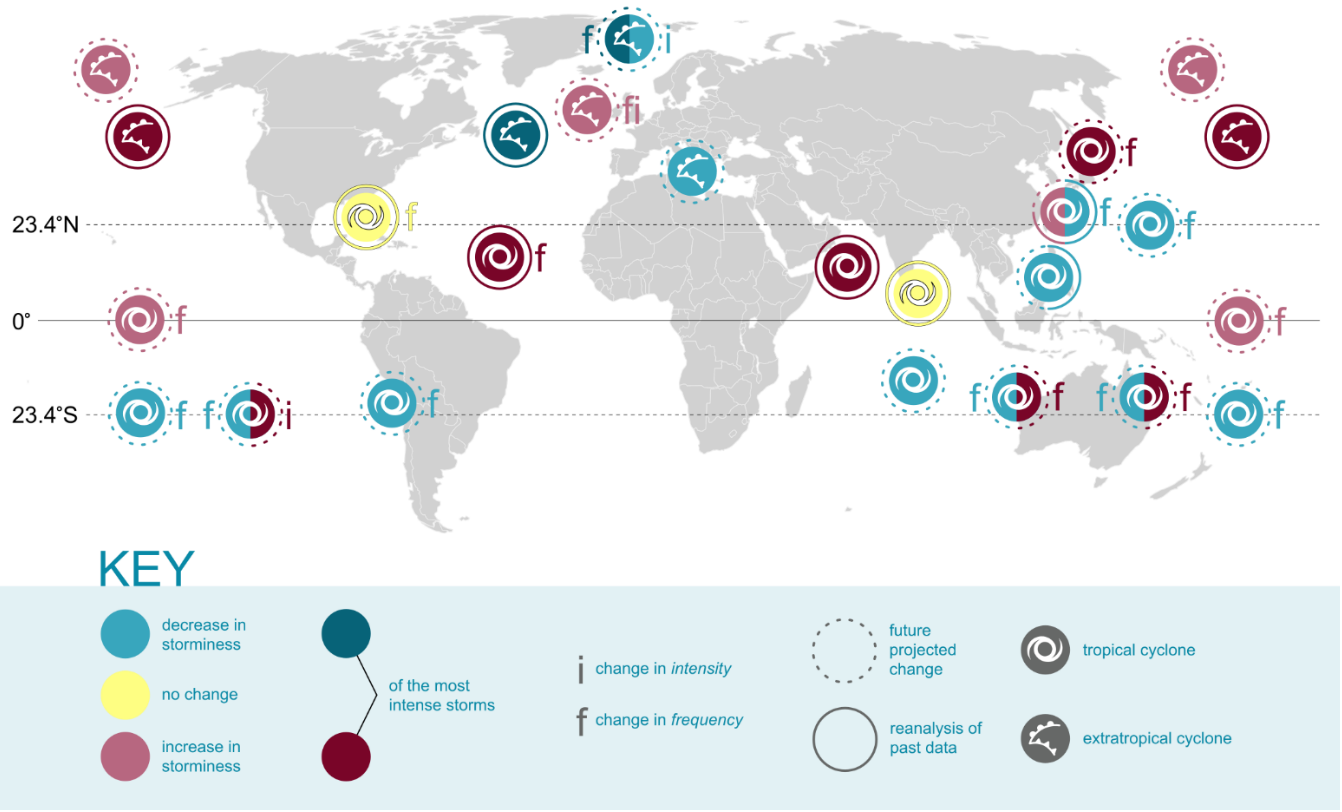

Figure 2.2. A selection of reanalysis and projection studies of storminess from across the world demonstrating the spatially heterogeneous nature of changing global storminess. The selection of studies is not systematic but is designed to reflect a range of studies carried out for the Atlantic, Pacific and Indian Oceans, which account for the majority of global fish catch. Darker colours represent changes in the most intense storms. Letters next to symbols indicate changes in frequency (F) or Intensity (I). For further detail see Appendix B.

Plotting the course ahead

We advocate a roadmap drawing on climate science, environmental social science, psychology, economics, and ecology, and based on four interlinked research areas (Fig. 2.3): 1) developing climate modelling to better understand changing storm hazards; 2) understanding fishers' behavioural response to storms; 3) examining the effects of storms on coastal marine ecosystems and socio-economic linkages; and, 4) assessing fisheries vulnerability and adaptation strategies for changing storminess.

Modelling changing storm frequency and severity

Identifying the risk to fisheries of changes in storminess requires climate models that provide a reliable spatial and temporal view of past and future tropical, extra-tropical and thunder storm frequency and intensity. To achieve this, improvements are required in the explicit representation of the sub-grid scale physical processes by which the most intense storms form and develop, such as convection. Advances in ocean-atmosphere coupled models are also necessary to capture the boundary layer processes that drive storms. Progress is being made in these areas, for instance in developing climate models that better represent the coupled ocean-atmosphere processes in tropical cyclones (Scoccimarro et al., 2017).

Improving the characterisation of storms in climate models demands finer spatial resolutions and a shortening of time steps, which will intensify the trade-off between resolution and simulation timescale resulting from limited computing resources. Supported by greater computing power, enhanced representation of storms in climate models will improve both reanalysis and predictions of storminess and strengthen our understanding of the influence of climate variability at seasonal to decadal timeframes on storm events.

Fishers' behavioural response to storms

The effect of storms on fisheries is in part a function of fishers' behavioural response to meteorological conditions. The heterogeneity of fisher daily participation and spatial effort decisions in adverse weather conditions for different fishery types, vessel characteristics and social and cultural contexts

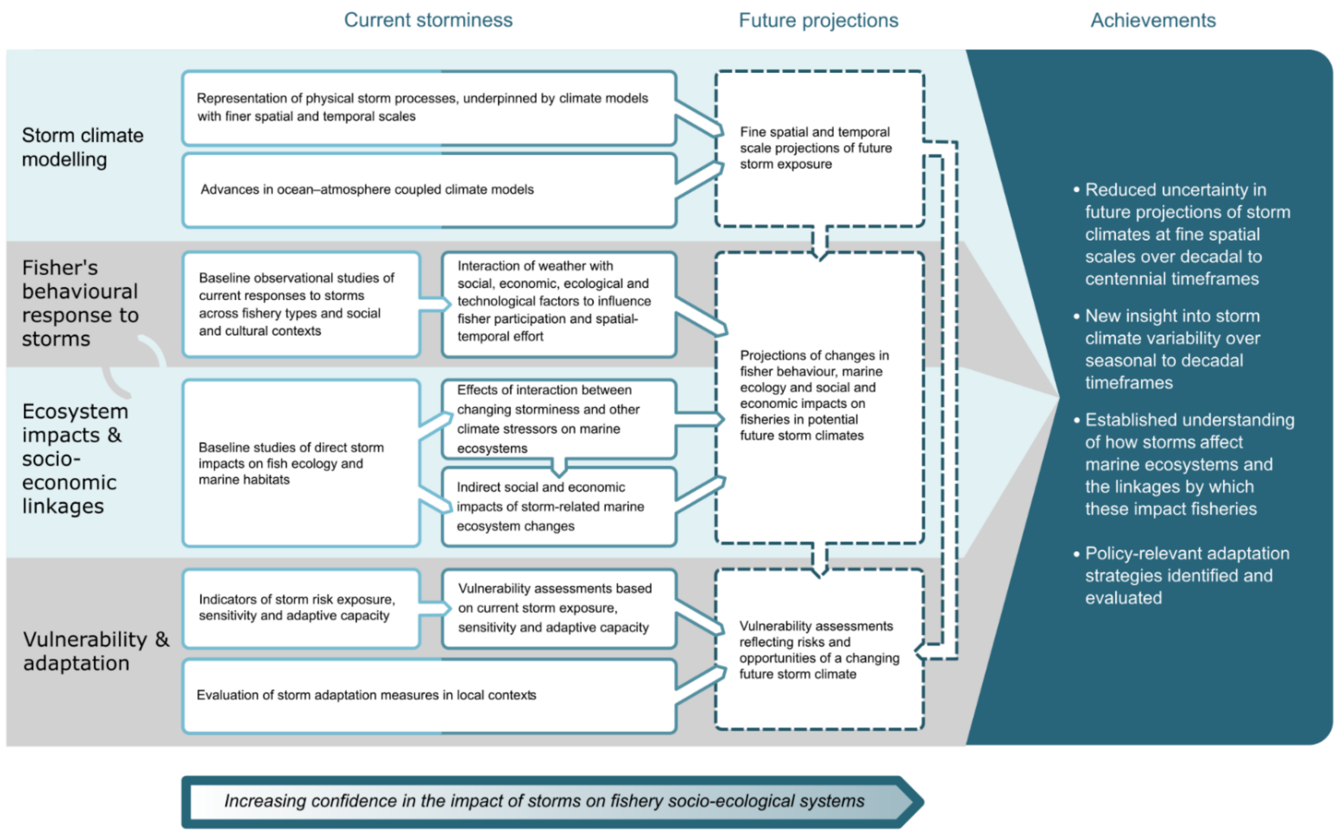

Figure 2.3. Schematic of a research roadmap to understand the impact of changing storminess on fisheries. Straight arrows between boxes demonstrate the dependencies within and between research streams. Curved arrows represent the feedback loop in which changes in fisher behaviour affect the ecosystem and changes to the ecosystem affect fisher behaviour. Collaboration will be required between research streams. The order of research streams does not represent importance or priority. The detail of the achievements listed as the outcomes of the roadmap will only be known once the research described is well developed.

around the world should be explored. Fishers' decisions on where and when to fish are known to be affected by a complex array of socio-economic factors (van Putten et al., 2012). However, the way in which fishers make weather-related decisions is poorly understood. We do not know how projected weather information is used or if it is accessible to fishers. It will be important to understand fisher decisions to go to sea, or stay at sea, during storms, how weather conditions affect the distribution of fishing activity, the performance of different gears in adverse weather, and the interaction of physical and economic risk perceptions in decision making.

Explaining the behavioural response of fishers to storms will require the involvement of psychologists, sociologists, anthropologists and economists employing research methods across the epistemological spectrum. Qualitative approaches can unravel the complexity of factors, motivations and processes underpinning decision making. Experimental methods, such as economic choice experiments, offer the potential to reveal how decisions are made where observational data are not readily available, as is the case in many tropical fisheries. The increasing availability of on-board satellite vessel tracking technology and wind and wave hindcast modelled data is creating the potential to model fisher behavioural response to weather conditions at unprecedented fine temporal and spatial resolutions. In addition, the emerging application of agent-based modelling approaches to fisheries could reveal the weather-related behaviour of fleets based on the decisions and interactions of individual fishers.

Coastal marine ecosystems and socio-economic linkages

Storms have the capacity to cause extensive disturbance to marine ecosystems and habitats that support productive fisheries. Several areas require investigation to improve our knowledge in this area. Little is known about the manner in which fish lifecycle events, including spawning migrations, larval growth and dispersal during the planktonic larval phase, and the use of shallow nursery ground habitats, are influenced by storm disturbance. There is some evidence that fish may evacuate storm areas or be redistributed by storm waves and currents (Fig. 2.1a), but this requires further exploration. Storm-induced fish mortality events, such as the death of 400,000 fish in the Nyanza Gulf of Lake Victoria following post-storm deoxygenation and turbidity in 1984 (Ochumba, 1990), are poorly understood. Finally, the way that changing storminess interacts with other marine climate change impacts, including ocean warming, acidification and deoxygenation, to affect marine ecosystems remains unexplored.

Interdisciplinary efforts are required to uncover how direct marine ecosystem impacts link to indirect social and economic impacts on fisheries. Whilst there are examples of storm damage to key habitats, we know little of how this flows through to abundance or catchability of targeted fish species. We lack knowledge of how storm-induced fish distribution changes affect fishery catches, but fishers' logbooks may offer a rich source of data to address this gap.

Vulnerability and adaptation strategies

Assessing the vulnerability of fisheries to changing storminess is essential for prioritising limited adaptation resources and informing adaptation strategies. The exposure of fisheries will vary spatially with projected changes in storm risk, target fish species, the resilience of infrastructure, and the extent of natural and man-made storm defences. It is probable that the impact of changing storminess on fisheries will be socially differentiated, with severe impacts more likely to affect small-scale fisheries. The vulnerability of fisheries to changes in storminess is currently unclear. Fishery vulnerability assessments developed over the last decade have acknowledged, but not reflected, changing storminess (Allison et al., 2009), largely because of the gaps in knowledge outlined here. These assessments can be enhanced by incorporating appropriate measures of exposure, sensitivity and adaptive capacity to storms.

Fishery adaptation measures will require evaluation in local contexts. Possibilities include technological advances, improvements in the accuracy and communication of weather forecasts, and innovative financial solutions. In Kerala, India, a weather forecast service called 'Radio Monsoon' (Radio Monsoon, 2020) provides daily information over loudspeaker in harbours and through social media. Insurance schemes triggered by environmental indexes are growing in popularity in terrestrial agriculture (Surminski et al., 2016) and could increase fishery resilience to increased storminess. Modifications of this concept would have to reflect the nature of daily harvesting activity and the dynamic nature of marine resources. Some fishers may also have opportunities to adapt to take advantage of reduced storminess, which may exacerbate existing challenges to sustainable natural resource use.

Conclusion

Greater attention to the research priorities outlined here could help inform adaptation and protect the well-being of billions of people worldwide. Although scientists are actively working in some of these areas, research gaps remain, and existing knowledge is yet to be applied to this social-ecological climate issue. The potentially catastrophic impacts of changing storminess for global fisheries across relatively short timescales mean that enhanced integration across disciplines is urgently needed to address this challenge.

Chapter 3

“Pushing the weather”:

factors affecting fishers’ short term decisions

Chapter 3: "Pushing the weather": factors affecting fishers' short term decisions

Introduction

Changing storminess (Hartmann et al., 2013; Feser et al., 2015; Murakami and Sugi, 2013; Mölter et al., 2016; Kossin et al., 2020) threatens global capture fisheries, which are pivotal to the wellbeing of billions of people around the world through their contribution to livelihoods and food security (FAO, 2018). At risk are fishing activities, coastal fish habitats, fishing assets, and the safety of fishers in what is already one of the most dangerous occupations on Earth (Petursdottir et al., 2001; Roberts, 2010; Sainsbury et al., 2018). Establishing the vulnerability of fisheries to climate change is a prerequisite for identifying appropriate adaptations (Metcalf et al., 2015) and is critical for reducing the socio-economic impacts of climate change on fishery-reliant coastal communities (Allison et al., 2005, 2009).

Risks from changing storminess to fisheries differ in their nature to those from other climate stressors, potentially requiring a different approach to fisheries climate vulnerability. The risks posed by storms to fisheries occur on a shorter temporal scale compared to other fisheries climate stressors, such as ocean warming, acidification, and deoxygenation (Plagányi, 2019). Storms also pose direct physical and economic risks to fishers as they go about their daily work, which other climate stressors do not. Furthermore, there may be trade-offs between direct physical and financial risks. Consequently, fishers decisions influence which risk they are exposed to. This means that short-term behaviour has more relevance to changing storminess than other climate stressors. The sensitivity dimension of climate vulnerability, which is defined as "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli" (McCarthy et al., 2001), is interpreted in a social context as the reliance of a community on fisheries for such things as livelihoods, food security, and culture (Allison et al., 2009; Colburn et al., 2016). The direct physical and financial risks that fishers face at sea may mean that fishers' daily trip decisions, and the factors affecting them, should be considered as an additional dimension of fisheries climate sensitivity. Given the fine temporal-spatial scale of fishers' short-term decisions, a bottom up approach, in which people's past responses to environmental change are studied (Conway et al., 2019), offers a useful route to understanding fisheries' vulnerability to changing storminess.

Wind and waves conditions influence fishers' decisions to be at sea. Observational studies have shown that weather conditions directly affect fishers' daily participation decisions, i.e. whether or not fishers go to or stay at sea. Wind speed predicts the probability of fishers taking a trip (Jin and Thunberg, 2005; Christensen and Raakjær, 2006; Kahui and Alexander, 2008), but its effect reduces for longer vessels (Laevastu and Hayes, 1982; Rezaee et al., 2016b). Increasing wave height influences the probability of fishers going to sea (Lopes and Begossi, 2011; Murray et al., 2011; Emery et al., 2014; Shepperson et al., 2016; Stobart et al., 2016). The severity of storm warnings also affects fishers' trip decisions (Pfeiffer, 2020). A focus on wind speed and wave height has ignored the potential role of a wider range of weather factors and interactions with oceanographic processes (e.g. wind direction, wave direction, wave types, and tides). Understanding the full range of environmental factors affecting fishers' decisions is important, as it will determine the links between changing storminess at local levels and fishers' decisions.

Whilst observational studies have provided insight into fishers' behaviour in response to faster winds and larger waves, they have not explored why these weather factors influence participation. Little is known about the mechanisms by which weather factors influence, and interact with, non-environmental decision dimensions, such as economic incentives and physical risk. Crucially, few studies have explored how fishers trade off trip profitability and physical risk in their short-term decisions (see Smith and Wilen, 2005; Emery et al., 2014). Revealing skippers' perspectives in these areas would help to refine the assumption of profit-driven rationality in fishers' short-term decisions (van Putten et al., 2012) and provide a novel insight into how fishers' behavioural response to storms mediates sensitivity to changing storminess.

Adverse weather is known to alter trip profitability in several ways. Firstly, fish prices tend to increase during adverse weather as the supply of fish is reduced by fewer boats going to sea (Abernethy et al., 2010). This may motivate fishers to go to sea if they expect increased prices to lead to greater trip revenues (Jin and Thunberg, 2005; Christensen and Raakjær, 2006; Emery et al., 2014), but that is only the case if other negative factors do not outweigh increased prices. Second, adverse weather can have a positive or negatively effect on catch levels. However, evidence is limited to lobsters (Drinkwater and Tremblay, 2006; Feenstra et al., 2014) and bottom trawls (Harden Jones and Scholes, 1980; Ehrich and Stransky, 1999; Wieland et al., 2011) over short timescales. Finally, higher wind speeds and wave heights elevate fuel costs (Abernethy et al., 2010) and increase the risk of costly damage to fishing gear (Holland, 2008; Morel et al., 2008). The evidence for how weather conditions affect trip profitability is restricted to a small number of observational studies, fishing methods and locations. It would therefore be beneficial to identify how weather impacts on elements of trip profitability differ by fishing methods.

Based on the extreme dangers involved in fishing (Roberts, 2010), it might be expected that physical risk would play a role in fishers' short-term decisions. Fishers face risks of injury and death every time they go to sea, with risks particularly high for single-handed skippers and those working on smaller boats (Bye and Lamvik, 2007; Laursen et al., 2008; UK Marine and coastguard agency, 2015, 2020). Despite the risks they take, fishers have been shown to be averse to physical risk (Emery et al., 2014; Smith and Wilen, 2005). They cope with the dangers of their profession through ritual behaviours (Poggie et al., 1976) and adaptive psycho-cultural traits such as fatalism and denial (Poggie et al., 1995). Research also suggests that fishers underrate and have a dismissive macho attitude towards physical risk (Binkley, 1995a; Davis, 2012). Their perceptions of physical risk have been shown to change with age, level of experience, type of fishing and whether they own their vessel (Poggie et al., 1996). Although these insights demonstrate how fishers perceive physical risk, it remains unclear how physical risk manifests in fishers' short-term decisions and how this varies across fishing methods and vessel characteristics. This is important in the context of the wide variety of fishing methods and vessels used in global fisheries.

Given the presence of poverty in global small-scale fisheries (Allison and Ellis, 2001), the role of economic need in fishers' trade-offs between physical risk and economic reward is of interest. A small number of studies have shown that increased economic need results in fishers accepting greater physical risk in pursuit of trip profits. The collapse of North-west Atlantic cod stock in 1993, and the resultant fall in fishers' incomes, led to Nova Scotian skippers taking greater physical risk by fishing during storms (Binkley, 1995b). Similarly, reductions in fishing income caused by extreme weather, which can increase economic need for financially vulnerable fishers, were shown to increase physical risk taking (Huchim-Lara et al., 2016). Furthermore, higher debt levels or pressure from lenders can have a similar effect (Stead et al., 2007). Empirical studies of fishers' behaviour seldom include individual social, economic or psychological variables because fisheries datasets lack these variables (van Putten et al., 2012). Whilst these studies provide evidence that economic need leads to greater physical risk taking, it remains unclear whether this is universal to all fishers and how fishers trade off physical risk with trip profits.

Understanding how fisher behaviour mediates the sensitivity of fisheries to changing storminess requires deeper insight into the specific weather variables that affect individual fishers' decisions and how fishers respond to the physical risks and economic incentives generated by adverse weather. By placing weather conditions at the centre of a qualitative investigation of fishers' short term decisions, this study aimed to provide a rich analysis of the weather-related short-term decision making of individual fishers. a qualitative inductive approach was employed in which respondents had the freedom to share their thoughts in areas unknown to existing knowledge in the field. In this way, the study objective was to reveal unknown unknowns about fishers' perspectives on weather-related decision making in their own words, which a quantitative approach could not achieve. A quantitative approach would have suited a research objective seeking to generalise or empirically test or add to an existing theory. The study used a case study of Newlyn, a large mixed fishery in southwest England, which provided a wide range of fishing methods and vessel characteristics and a large population of fishers from which to sample. The specific aims of the study were to: (1) identify the specific weather factors involved in fishers' decisions; (2) explain how fishers trade off physical risk and economic rewards in short-term decisions; and (3) identify how economic need, vessel characteristics, and fishing methods affects fishers' physical risk and economic reward trade-offs.

Methods

Study area

Cornwall, the south westerly peninsula of England, has a centuries old tradition of fishing (McWilliams, 2014). In addition to many small fishing villages, Cornwall has a large modern harbour, Newlyn (Fig. 3.1). Newlyn was chosen for this study because of its economic importance, its exposure to the prevailing southwest weather systems approaching the UK from the Atlantic, and the presence of a wide variety of vessel sizes, designs and gear types. The Newlyn fleet consists predominantly of small boats under ten metres in length (72% of 195) (MMO, 2019b) using a mix of nets, pots and hand lines to catch shellfish and whitefish in inshore waters. There are 55 (28%) fishing boats over ten metres in length with Newlyn registered as their home port (MMO, 2019b). These larger boats use a wide range of gears, including static nets (gill, tangle and trammel nets), purse seines (locally referred to as “ring nets”), otter board and beam trawls, dredges and pots. These larger boats fish up to 200 miles from the coast and catch over 60 species (Cornwall Wildlife Trust, 2020). The majority of the fish caught by the Cornish fleet is sold at auction, although some skippers (particularly those targeting shellfish) sell direct to wholesalers and restaurants. Newlyn is directly exposed to south-westerly weather systems and as such regularly experiences winter storms and oceanic swells originating from the Atlantic Ocean. Storminess is predicted to increase around the United Kingdom over the remainder of the 20th century (Feser et al., 2015; Mölter et al., 2016).

Data collection and sampling approach

In-depth semi-structured interviews were carried out with skippers who fished permanently or on a seasonal basis from the port of Newlyn. Some skippers were based at Mevagissey, a smaller harbour on the south coast of Cornwall, but fished from Newlyn during the summer. Key informant interviews carried out at Newlyn aided the design of the interview guide (Appendix C). Two pilot interviews were carried out in other Cornish ports to refine the guide. Data collected from these pilot interviews was of high quality and so retained for analysis. A semi-structured interview methodology (Bryman, 2012) was selected because it provided flexibility to cover key areas of interest, and to pursue interesting and relevant new avenues raised by respondents. As a result, the chosen methodology provided greater inductive power than more rigid qualitative approaches, such as surveys and structured interviews (Bryman, 2012).

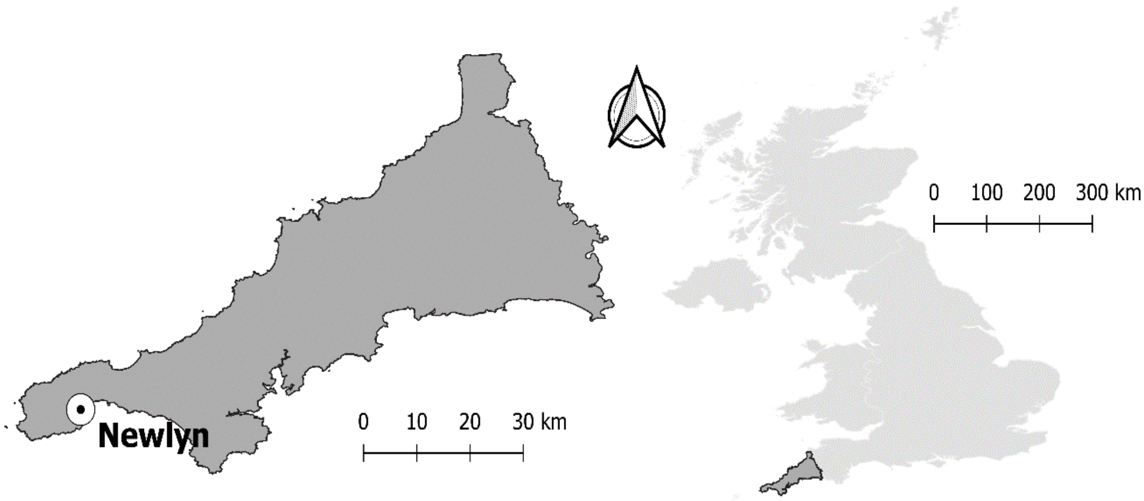

Figure 3.1. Cornwall and the port of Newlyn and its location in the United Kingdom

A stratified opportunistic and snowball sampling approach was employed to ensure an even distribution of gear types and vessel lengths within the sample. Time was spent in and around the quayside at Newlyn opportunistically approaching skippers to participate in the study. The time of day spent at the harbour varied to encounter skippers using different gear types who follow different schedules. Skippers that participated were asked to recommend other skippers to participate. This process continued until the sample was balanced by gear type and vessel length and no new themes were emerging from the interviews, which was considered theoretical saturation (Ando et al., 2014). In total 26 skippers were interviewed. Their boats ranged from five to 35 metres in length. Nine skippers' vessels were under 10 metres in length, seven were between 10 and 15 metres long and nine were over 15 metres long. The sample consisted of four beam trawls, five static netters, five otter board trawlers, five potters, four purse seiners (three of which also used static nets out of the purse seine season), two using pots and nets, and one hand liner. The single hand lining skipper was included to boost the sample size of the smallest vessels. Further skippers using hand lines were unavailable during the study period. Interviews were transcribed verbatim and thematically coded in Nvivo 12 (QSR International Pty Ltd, 2018). Coding was performed inductively beginning with detailed codes and then grouping these into themes. The study received ethics approval from the University of Exeter Ethics committee, reference eCORN000055.

Results

In this section, I first describe how and why different aspects of the weather and ocean environment impact decisions. I then describe the themes that emerged regarding trade-offs, physical risk and trip profitability. The theme of discomfort, which emerged inductively from the study, is also described. Themes relating to factors affecting trade-offs are then then set out, notably economic need and the social dynamics of fear of missing out and working with crew. The role of vessel characteristics and fishing methods in the way that weather conditions affect physical risk and trip profitability is described throughout.

Weather conditions

Newlyn skippers highlighted six meteorological and oceanographic variables (weather variables from hereon) that feature in their short-term decisions: wind speed; wind direction; swell waves; wind waves; daily tides; and, lunar tidal cycles (Fig. 3.2). Skippers frequently cited wind speed and direction as the most important factors, because of the central role they play in defining ocean conditions and the way they interact with other weather variables. Skippers reported that the main effect of wind in isolation was making it difficult to position their boat. Wind was described as creating two types of waves, “wind sea” and “ground sea” (swell waves). Skippers characterised “wind sea” as shorter, steeper waves caused by local winds with energy predominantly isolated to the sea’s surface. “Ground sea” was described as being high energy, long wavelength waves originating from strong winds over a long fetch in a distant location. Skippers explained that swell wave energy penetrates deeper in the ocean than wind waves and can disturb the seabed.

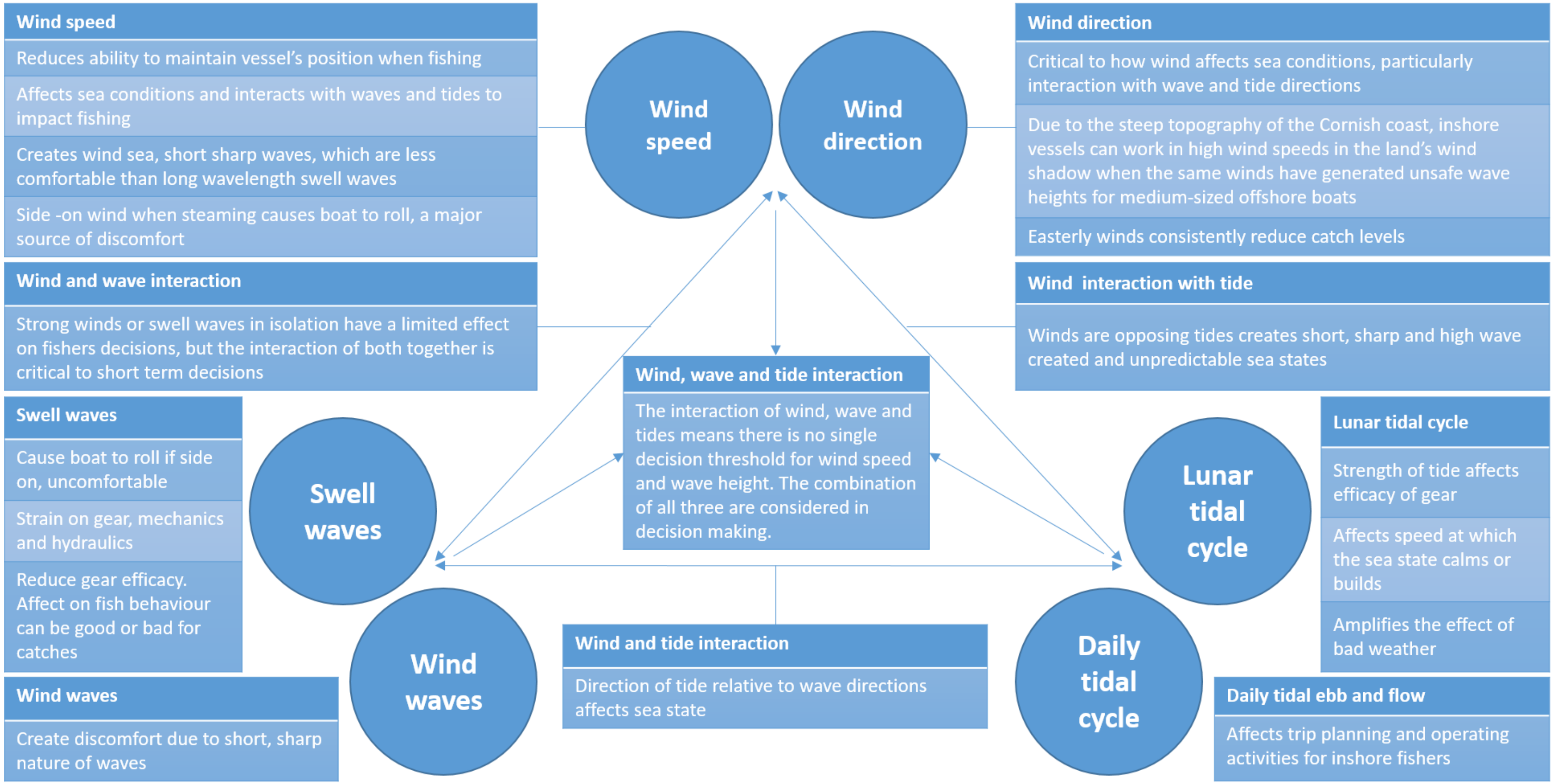

Figure 3.2. The impact of specific meteorological and oceanographic factors on short term fishing decisions

Wind seas were discussed by skippers as affecting their degree of discomfort. Most skippers explained that swell waves influence catch levels, reduce fish quality, and damage and reduce the life of gear, mechanics and hydraulic systems. However, the hand line skipper, operating with a small inshore boat, reported that large swells with little wind can be “one of the finest ways of being at sea”. This difference stems from variations in the way that fishing methods interact with particular elements of weather and ocean conditions.

> *“Sometimes I can be out on my boat and my boat's that small, it just goes up and down the wave and you don't feel like there's any weather at all.”*

Skippers’ descriptions of the interconnectedness of weather variables revealed that it is the interaction of tides, wind and waves that influence the physical risk and discomfort of the sea state (Fig. 3.2). Tides are key mediators of how wind and waves influence trip decisions. Several skippers explained that waves change shape and increase in size when wind or wave direction are against the tide, generating rougher seas. Skippers observed that a swell wave system accompanied by strong winds is more dangerous to work in than swell in isolation. If the wind is perpendicular to the swell, skippers discussed being unable to direct the boat to avoid side-on forces, which destabilise the boat and cause it to roll. Similarly, wind sea waves generated by wind blowing across the direction of swell waves creates a “confused sea state”, which can be unpredictable and more dangerous. Wind sea waves and swell waves can also be additive when moving in the same direction.

> *“We had this majestic swell, but on top of it was this bitch of a southerly sea. All of a sudden instead of being on a six-meter wave, you're on something that's maybe akin to seven or eight or nine metres”.*

The direction of wind relative to the land was frequently described by small boat skippers as determining safety levels in inshore waters. Wind blowing from the land creates a wind shadow that provides shelter for vessels. Weather conditions can therefore affect not only whether fishers choose to be at sea, but also where they choose to fish.

> *“Sometimes you can have a northerly wind blowing off the land. You can tuck in little places and fish away in what would seem to be abhorrent conditions to somebody looking [from] shore-side.”*

Trading off physical risk, discomfort and profit

Skippers described weather conditions creating a short-term decision trade-off between expected higher profits and the risks of physical harm, and discomfort. Trading off increased physical risk and discomfort with higher catch expectations or prices was described by skippers as “pushing the weather”. Skippers repeatedly emphasised that you can “only push what is safe”. Some skippers were adamant that they ignore prices in their decision-making and never accept higher physical risk for better prices. For some gear types, higher prices from deteriorating weather conditions do not necessarily equate to higher potential profits. Some trawler skippers explained that higher prices are offset by lower catches in adverse weather. They described continually evaluating whether they are making sufficient profit to justify the discomfort and risk they are taking at the end of every tow.

> *“You’re thinking, “I’ve got to take a cut on the fishing because there's lovely big fish here, but it's going to be shit weather and I can’t get at it.” It's so frustrating, but you've got to weigh up how safe it's going to be to stay here, how safe is going to be to go [to sea], and you got to weigh up the cost. That's a big word: "cost, at what cost". Thinking that things that could go wrong, for what? Play safe, look at the things that can go right or you might not have such a big trip, but at least you'd be safe. You will come home with that. Then what you think about is the jingle in your pocket or the jangle in your head.”*

Skippers explained that their willingness to suffer discomfort is relative to the rewards they expect to receive from a trip. Many fishers described the disappointment of fishing in poor conditions, suffering every moment of the trip, and catching little. When considering a potential trip with low catch expectations and uncomfortable conditions, skippers explained that their alternative option is to spend a productive and comfortable day working shore-side on gear and vessel maintenance. Conversely, if the expected rewards are high, they were generally willing to accept an uncomfortable trip. However, some skippers were not willing to trade discomfort for high expected profits.

> *“If the fishing is really good, you will be inclined to work in a bit worse weather, not to the point of being dangerous obviously, but there's some days when you could quite happily go to sea, the weather's bad but it's not that bad but if fishing is shit you just say, "I don't want to go and roll around there all day for next to nothing." So you don't.”*

Skippers described the challenges of making decisions based on several stochastic, uncertain factors. Uncertainty exists in the information skippers use to make decisions (weather forecasts, catch predictions, and market prices when selling at auction), but also over the optimum trade-off to make in any given scenario. Skippers reported that incorrect forecasts or unexpected catch levels, led to them being “caught out” in adverse weather or conversely, having “missed out” on safe weather and good fishing. Uncertainty is clearly a pervasive aspect of weather-related decision-making.

> *“The weather is number one. Then as a skipper, you have to go like, "Can we tow there? Can we make it comfortable for the crew and the boat? The area we're working? If we stop in this weather, is it going to be safe? Is the fishing good enough to warrant pushing it?”*

Physical conditions at sea

Physical risk

Above all other considerations, maintaining physical risk below levels that they consider to be unsafe was the most important factor to skippers in their short-term decisions.

> *“This job is not about heroics, it’s about being sensible and doing it in such a way that gets you a good living without taking too many risks.”*

Skippers accepted that they take weather-generated physical risks at sea, but described continually evaluating their risk exposure to decide whether it is safe to be at sea. “Safety” was a term used by skippers in a binary way: they explained that conditions are either safe or unsafe, and conditions judged to be unsafe represent an upper threshold that they generally do not consciously cross.

> *“[Safety] takes overall priority. If it's not safe, whether you're catching shitloads of fish or whether you're not, if it's not safe, you've got to fucking leave [to return to port].”*

Skippers explained that there is no single wind speed or wave height that defines this safety threshold because the risk they face is generated by a complex interaction of weather variables. Skippers described using their expertise to interpret weather forecasts and prevailing weather conditions to judge levels of risk, which they explained becomes more challenging as weather conditions approach their safety threshold. In these circumstances, fishers described making mistakes, and being caught at sea in conditions beyond their safety threshold.

> *"Sometimes it's easy because the weather and the time what have you, you just look at and go, 'no fucking way. Too much, I'm not going to deal with that'. Simple, clear-cut. The worst ones I hate is the iffy ones, 'Maybe we might be able to...,' those are the ones I fucking hate. When I'm coming to sea I either like to see a fine forecast for the whole trip or I'd like to see a gale of wind for the whole trip and that's that and we're back home again."*

Skippers discussed facing a multitude of physical risks at sea, which are exacerbated by adverse weather conditions. They explained that large waves make it difficult to balance, operate machinery and increase the risk of slip and trip hazards, man overboard, and entanglement in a rope as gear is shot. Static gear skippers described the increased risk of gear damage and injury to fishers from extreme forces exerted on vessel hydraulics, ropes and chains when hauling and shooting gear in large swell waves (Table 3.1). Some skippers explained that large waves can cause objects to move around on deck if not adequately fixed in place, and risk trapping or crushing fishers. Several skippers explained that they invested in larger vessels with more robust construction, for instance the introduction of shelter decks, so they can remain safer in more extreme weather.

> *"The motion of the boat is so much, it's like being on the waltzers permanently at the fair. Round and round and up and down…You've got a job to fucking stand up. There's losing men, there's things jamming, the weather affects everything. Men's fingers you got to think about, and hands. There's a lot to consider in bad weather."*

Table 3.1. The way in which weather considerations affect skippers' decisions by gear type

Gear type	Effect category	Effect
Beam trawl	Safety	Work carried out on deck without shelter. Water on deck and movement of boat makes operating large heavy gear hazardous in poor weather.
	Economic	Large swell waves move boat reducing beam trawl efficacy by pulling beams off sea bottom negatively effecting catch.
		Damage to beams.
		Catch levels greater in winter on average.
Otter board trawl	Safety	Trawl net caught on sea ground feature is more dangerous to boat in large swell waves.
	Economic	Large swell waves move boat breaks contact between trawl and sea bottom negatively effecting catch.
		Swell waves stir up sea bottom reducing visibility of otter board sand clouds that herd fish into net.
		Fine weather reduces catch.
		Swell forces trawl net to move back and forth reducing the quality and value of fish in the cod end of the net.
		Strong winds and large waves increase fuel consumption.
	Comfort	Boat rolled by wind blowing side on when trawling.
Pots	Safety	Risk of getting caught in the pot string rope and pulled into sea greater in rough sea states.
		If pot gets hitched to a seabed feature while hauling, boat is at greater risk of wave inundation.
		Pots on deck move around in rough sea states endangering fishers.
	Economic	Bad weather reduces operating efficiency so less pots can be worked in one day, reducing catch.
		Catch reduced by swell or spring tides pulling buoys that mark the end of pot strings under water so they take longer to find.
		Large swell waves can move pots over miles of sea, bury pots in the sea ground and lodge them between rocks causing financial loss of gear and interrupting fishing operations.
		Crabs and lobsters bury in the sand in February and March, providing pot fishers the opportunity to perform boat and gear maintenance and missing two bad weather months.
		The forces created by large swell waves place pressure on hydraulics used to haul pots.
		If a pot hitches on the seabed when being hauled, the power of swell waves can cause the rope between pots and boat to break, interrupting fishing as the pot string is searched for.
		Calm days with no wind or waves reduce crab movement but moderate swell waves cause crabs to move increasing catch.
		Pots fish less effectively in heavy swell reducing catch.
		Lobster pots, which are more likely to be placed nearer to shore on rocky ground, are at risk of damage from swell waves.

Table 3.1 (continued). The way in which weather considerations affect skippers' decisions by gear type

Gear type	Effect category	Effect
Static nets	Safety	For the largest boats with enclosed "shelter" decks, all but the most extreme weather is safe for crew to work on deck. The winch door can be closed when dodging, a practice in which the boat faces into oncoming wind and waves to ride out a storm.
		Shooting nets is safer and more comfortable than hauling nets in poor weather conditions.
		Risk to the boat and to gear from "coming fast" on hard ground when hauling becomes more severe in adverse weather.
		Greater risk of crew getting entangled with gear when shooting nets.
	Economic	Lunar tide inhibits fishing two weeks in every four and spatial variation in tide strength affects where skippers choose to fish.
		Lunar spring tides are more powerful tides that collapse gillnets, rendering them ineffective. During spring tides, gillnet skippers do not go to sea, creating natural "closed periods". This may lead to skippers pushing the weather more during neap (weak) tides.
		Large netters can carry different net types providing flexibility to improve catch potential in adverse weather.
		Catch improves with swell.
		Swell risks damage to, or loss of, nets shot in shallow water or on wrecks.
		Shot nets keep fishing whilst the boat is dodging (facing into oncoming wind and waves to ride out a storm), so no opportunity cost.
		Short term trip planning must account for period nets are left out fishing, which varies by net type.
		On-deck operating efficiency reduces as the weather deteriorates.
		Sustained fine weather is bad for catch levels.
		Incentive not to lose fish caught in nets, and to reset nets to fish again, drives skippers to push the weather to haul the nets.
Purse seine nets	Safety	This fishing method involves holding up to 20 tonnes of fish in a concentrated mass on one side of the boat whilst it is brailled (emptied) by pump or basket onto the boat. This causes a stability risk that limits the size of waves skippers can work in safely.
		Whilst brailling a catch, the boat needs to hold its position. Strong winds and tides can drift the boat out into worse conditions or in towards the shore.
	Comfort	Purse seine netting for sardines at Newlyn is generally comfortable due to limitations of the fishing method in pushing the weather beyond moderate conditions.
	Economic	Fishing near to shore allows the exploitation of brief windows of acceptable weather during periods of adverse weather.
		In waves over two metres, the forces of a heavy catch are working against the boat as it rises and falls in large waves, creating a risk of the net splitting and generating maintenance costs.
		Fine weather reduces catch, as sardines can better see and avoid the net.
		Prices stable across season, so price plays a minimal role in short-term decisions during a season.
		Strong winds make it difficult to control position of boat relative to sardine shoal.

As well as increasing physical risks, strong winds and large waves also amplify general fishing risks that are easily resolved in fine weather, but can be catastrophic when a vessel is near its safe weather limits. A common example provided by skippers was “coming fast”, whereby a net or pot becomes fixed to the sea bottom when trawled or hauled. Skippers explained that the consequence of coming fast in strong winds and large waves escalates dramatically because the forces at work are orders of magnitude greater. Trawler skippers explained that because they use very strong warps (metal wires) between the boat and net, the risk of their boat being pulled under is far greater than for other vessels that use rope.

> *“When something happens you soon get in the shit, soon escalates. Poor weather, engine stops or you come fast in a wreck or something, its calm weather, you deal with it. You're out there now, 30 or 40 miles an hour wind and come fast, doesn't bear thinking about. Soon turns into a dangerous situation.”*

Discomfort

An emergent theme in the analysis was that skippers perceived discomfort as distinct from safety concerns and that it played an active role in their trade-off decisions with physical risk and trip profit. Skippers described a range of weather conditions where they judge the conditions to be safe, but increasingly uncomfortable as the weather deteriorates. Skippers who reported suffering from seasickness or disabilities, described the discomfort as being particularly severe. According to skippers, such discomfort is affected by a variety of weather variables. For instance, swell waves or wind moving perpendicular to the direction of a vessel cause it to roll, which skippers described as being uncomfortable whether working on deck, in the wheelhouse, or trying to sleep in their bunks. One skipper depicted barely being able to stay in his captain’s chair whilst working in large waves and strong winds. Skippers reported wind sea and the interaction of tide against swell or wind being particularly uncomfortable. They explained that steaming is more uncomfortable than fishing because the boat is moving at higher speeds. Skippers discussed that discomfort featured more prominently in their decisions as they grew older. Many older skippers attributed this to the toll that fishing had taken on their bodies over time. A few older skippers still working on deck described being unable to cope with working more than one day in adverse weather. One skipper described having to factor this in his trip planning, because after one day in rough conditions he has to rest the following day.

> *"[It is] physically hard just to hold on for all that length of time and it wears you out. You don't have to put yourself through that [working in adverse weather]. Wait a couple days for the weather to get better or whatever. Physically I can't do it any more, to be honest with you."*

Economic reward

Skippers described weather conditions affecting revenue through catch levels, fish prices and costs.

Catch levels

When considering a fishing trip, skippers explained that they form their expectations of catch levels based on recent fishing success and of how weather conditions have affected catch levels at the same time in previous years. They explained that their catch levels are impacted by the weather's effect on 'fishability' (fishing effort and operational efficiency) and 'catchability' (availability of fish to gear and fish behaviour). Many skippers reported catch levels being lower during calm weather. Skippers explained that a period of fine weather "kills the fishing" and described fish as being "lethargic" during calm weather. Skippers consistently talked of catch levels only improving in the aftermath of a "stir up", a period of strong winds and swell waves, which they argued elevates nutrients from the seabed causing fish to move in order to feed. However, several skippers described easterly winds as "cutting the fishing in half".

Differences were apparent across gear types in the way that skippers described the effect of weather on fish catchability via fish behaviour. Skippers of large static net boats reported that their catch levels improved with stronger winds and larger waves. Skippers using purse seines explained that swell-induced turbidity increases their catch levels because the sardines *Sardina pilchardus* they target are less likely to evade the net if their visual acuity is reduced. Skippers targeting crabs with pots described catch levels increasing before a storm. One skipper explained that crabs sense a storm approaching and feed whilst they are able. A skipper of a large trawler reported opposing effects on monkfish *Lophius piscatorius* and soles (various species of the family *Soleidae*) during the sustained period of storms in early 2014.

> *"We lost the monk fishing in Jan to March, because they couldn't fish themselves. Monk uses a lure above its head…to catch fish. They moved 150 mile south. I've never seen anything like it. It had a huge effect on the fishing…We caught a lot of sole that winter. Soles were so relaxed, if you like, it was so murky. They were going round hunting the food that they were so easy to catch. We ran out of sole quota that year. I've never run out of sole quota in my life."*

The effect of deteriorating catchability due to reduced gear efficacy (i.e. how effective the gear is at catching fish) was described by skippers of all gear types. However, the thresholds at which gear efficacy reduced varied across gears. One otter board trawl skipper explained that turbidity created by large swell waves obscures the sand clouds generated by the trawl doors reducing the catchability of the trawl. Several trawl skippers attributed lower catch levels to the vertical and horizontal movement of trawl nets in the water column caused by large waves. Furthermore, trawl skippers explained that large waves cause a boat to move at inconsistent speeds, reducing the ability of the trawl net to outrun the target fish into the net. Conversely, skippers of static gear explained that their gears' efficacy is only reduced by the most extreme swell waves, which can physically relocate and roll up nets and pots, leading to loss or damage.

All skippers reported experiencing reduced operational efficiency as weather deteriorates, because it reduces the amount of work that can be done on a trip in any given period of time. Skippers using pots described the time wasted searching for buoys marking the end of pot strings, which are frequently pulled under water by large waves. Skippers using static gear highlighted the challenge of "staying on their gear" in strong winds and large waves, which is necessary for the safe and efficient handling of gear. Other skippers described the movement of a boat in strong winds and large waves slowing operations on deck. They explained that fishers deliberately slow the pace of work as a way of reducing risk of injury. Furthermore, skippers recounted the constant fight to retain their balance and avoid moving objects on deck, which prevents them working as fast as in fine weather.

> *"You think it will be twice as hard but I think it is probably 10 times. It's crazy. Everything, every job you've got to do, just gut a fish, it's not going to stay where you put it. Everything like that, it's just constant."*

Fish prices

Some skippers, primarily those using pots and purse seines, explained that the prices they receive for their catch are fixed with wholesalers for a season. These skippers explained that their decisions were almost never affected by price. Skippers reported the price of fish sold at auction is primarily dictated by how prevailing weather conditions affect the supply of fish. Skippers described the incentive they feel to go to sea during a storm or to get out as early as possible as a storm recedes in order to achieve an elevated price before supply increases. According to some skippers, whilst storms may reduce the quality of their fish, it often does not affect price as buyers must still meet their customer commitments.

> *"I've pushed it certainly after a week or 10 days when it's been really bad and not many boats have been to sea. I've pushed it then maybe a day earlier than I would have done just to get that fish in the market first. It's financially good. You're talking double or triple sometimes."*

Operating Costs

According to some skippers, adverse weather conditions affect their trip costs in several ways, and they are conscious of these when making short term decisions. Fuel costs may increase in adverse weather, but for some fishing methods more than others. Skippers using passive gears, such as static nets and pots, explained that their decisions are not affected by the negligible increase in fuel consumption resulting from having to drive their engines harder to reach their fishing grounds. Conversely, skippers using active gears, such as otter trawls and beam trawls, described the significantly higher fuel consumption required to tow heavy gear through deep water in adverse weather. Trawl skippers spoke of knowing exactly how much fuel they are burning in any given weather conditions and the fuel cost they are incurring. As one otter board trawl skipper explained, "If you're burning more fuel than what's coming aboard, you're going backward".

A small number of skippers factor the acceleration of fishing asset depreciation in their short-term decisions. They described adverse weather causing greater wear and tear to the engine and gearbox, the hydraulics, winch, and the hull of the boat. They explained that this expedites maintenance costs, large capital expenditure, and income disruption whilst repairs are carried out. Skippers of all gear types described the increased risk of gear damage in adverse weather acting as a trip disincentive. Otter board trawl skippers were concerned about the higher risk to their nets and boat when coming fast. Beam trawl skippers explained that large waves increase the risk of damage to the large steel beams that run along the seabed. Alternatively, for skippers using static nets, the risk of gear loss was described as a powerful incentive to go to (or remain at) sea to retrieve gear in the face of adverse weather conditions. They explained that whilst gear is their second biggest asset (after their boat), insurance is not available for it. These skippers said they would not choose to shoot their nets if adverse weather is forecast. However, they described leaving their nets to fish for up to three days based on a favourable forecast only for a storm to develop during that time. They explained that if conditions were worse than forecast on the third day, they would push the weather towards the upper limits of their safety thresholds to retrieve their nets and avoid significant financial loss.

Losing fish caught in nets or pots was as an additional incentive for static gear skippers to haul their gear during adverse conditions. Skippers explained that if left too long, crabs may escape pots and whitefish may spoil or be eaten by other fish whist in the net. They explained that if they choose not to haul their gear in adverse weather, not only will the fish be lost, but the opportunity to shoot their gear again is also foregone. Consequently, skippers perceived a decision not to haul their gear in adverse weather not as one lost catch, but two.

Factors affecting trade-offs

Economic need was frequently raised by skippers as a reason for having taken elevated physical risk during their careers. Skippers remembered periods of sustained adverse weather or prolonged vessel maintenance preventing them going to sea and periods of general hardship in the industry reducing their incomes. Often they were driven to sea by the need to pay bills and put food on their table. One skipper described a time when economic need drove him to sea in conditions that he knew to be above his safety threshold, *"It [the weather] was beyond the capabilities of the boat, I didn't want to. I knew it was too dangerous but you had to get something. We had bills to pay. We had no choice".*

Some skippers strongly resisted the notion that economic need drives them to take additional weather-related risk. One skipper explained, *"I wouldn't let a debt or a bill coming in drive me to sea. That's fatal*". Some skippers described prudent financial planning as being critical to avoiding financially-driven risk taking. Servicing business debts was not described by skippers as a reason to fish beyond safety thresholds, but they did refer to it increasing their motivation to push the weather.

"When I was 24 I had a boat built. I got quite a big bank loan around my neck. That makes you even keener. If you're coming up to the end of the month you got to make your payment. We never got to the stage where it's like, 'no we have to go or else. That's Deadliest Catch. It's all down to the last haul or else there will be financial ruin'. It's never been like that."

For some skippers, the decisions of others play an important role in their motivation to 'push the weather'. These skippers explained that when they judge conditions to be safe but high risk, their daily participation decisions may be influenced by the decisions of other skippers because they fear missing out on a successful trip. Skippers described seeing others return from sea with a good catch and regretting their decision to stay ashore. To these skippers, missing out in this way was considered not only as lost income, but also as evidence of their own poor decision-making.

"If one boat goes, you'd think, 'He's going to be out there making a good day's work and we will be in there doing nothing.' If it's just sort of half and half morning and you are all toying to go, it only takes one to go and then everyone follows."

Skippers reported that the level of trust they have in their crew's ability to work safely and effectively alone and with other crew in adverse weather governs the levels of physical risk they are prepared to take. Some skippers working with crew described feeling responsible for their financial and physical wellbeing of the crew. The need to earn a good wage for their crew was mentioned as a strong incentive to "push the weather". In contrast, skippers also discussed tempering their risk taking to protect crew safety.

> *"It's not just your risk, you're putting them in the firing line too. And the worst thing there can be is to lose one of your crew and then have to go back and explain to his family why he's not coming back. And that's more of a consideration than for yourself."*

Some skippers also reported a desire to avoid exposing crew to excessive weather-driven discomfort, for example by choosing to fish in less exposed areas of sea even if they expect to catch less fish. Mindful of their wellbeing and the need to maintain morale, some skippers reported protecting crew from protracted periods of discomfort by only working one extreme weather day followed by a day without fishing. However, other skippers denied that their decisions were ever affected by consideration for their crew.

Discussion

To improve understanding of the vulnerability of fisheries to changing storminess, this study provides a novel qualitative exploration of the role that weather plays at the heart of fishers' short-term decisions. The findings reveal that a complex interaction of meteorological and oceanographic variables affect physical risk, discomfort, and economic reward, which govern Newlyn skippers' short-term decisions. I have shown that Newlyn skippers trade off physical risk, discomfort, and economic reward and that these trade-offs depend on individual differences and social processes. As such, I have found evidence supporting the notion that fishers may not always be rational economic actors seeking to optimise profit, but act as satisficers seeking an acceptable balance between physical risk, discomfort and trip profit. By taking a bottom-up approach to investigating climate vulnerability (Conway et al., 2019), I have shown that individual fishers can be differentially sensitive to changing storminess and that through their short-term decisions, influence their sensitivity to physical and socio-economic risk.

When skippers judge conditions to be safe, they trade off physical risk and discomfort with expected fishing rewards in what I conceptualise as a "zone of uncertainty" (Fig. 3.3). The zone contains a curve representing the likelihood of a skipper choosing to be at sea in any given weather conditions. The zone's boundaries are defined by meteorological and oceanographic parameter values. At the lower end, the zone is bounded by conditions that begin to meaningfully affect physical risk, discomfort and profitability. The upper boundary of the zone is defined by a skipper's safety threshold. The boundaries, and shape and position of the curve are influenced by individual risk perceptions, economic need, vessel characteristics, fishing methods and response to social dynamics.

Conceptually, the zone of uncertainty helps us understand that the sensitivity of fishers to changing storminess is complex, and that fishers must choose whether they are sensitive to physical risk or economic risk. Furthermore, the concept demonstrates that the sensitivity of fishers to changing storminess is differentiated by individual and vessel characteristics, fishing methods and responses to social dynamics. Skippers that choose to respond to increasing storminess by pushing the weather further, closer to and possibly beyond their safety threshold, are less vulnerable to economic risks, but more vulnerable to fatalities, injuries, disability and discomfort. They may also be vulnerable to a degree of economic risk from the variability of catch levels inherent in fishing and the risk of damaged or lost fishing assets. Adapting to increasing storminess in this way to retain a viable fishing livelihood may require skippers to make trade-offs with their wellbeing, for instance their health and feelings of safety (Coulthard and Britton, 2015). Conversely, if fishers choose to adapt to increased storminess by avoiding increased physical risk, they may suffer greater economic risk, but they will be safer. Skippers' adaptation decisions may also affect wellbeing at the household and community level, with fishers' families and people working in the fisheries value chain impacted by their choice of physical or economic risk sensitivity.

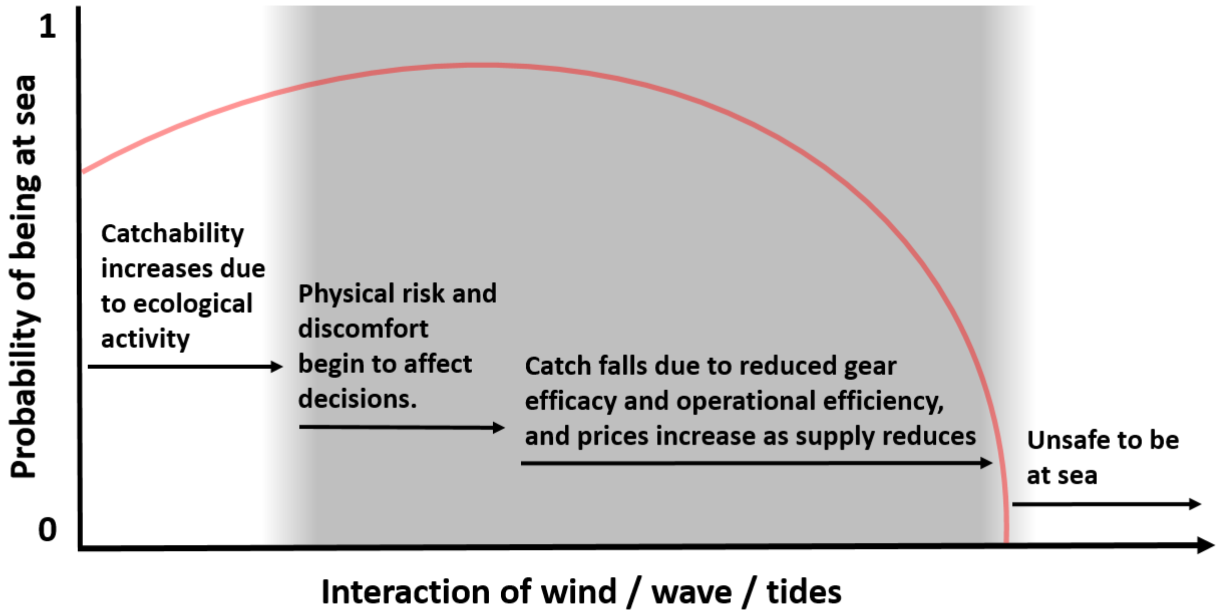

Figure 3.3. The zone of uncertainty conceptual framework. The grey zone represents the zone of uncertainty, in which fishers trade off increasing physical risk and discomfort with economic rewards under great uncertainty. The fuzzy edges of the zone of uncertainty represent the uncertainty of weather forecasts. To the left of the zone of uncertainty, weather and ocean conditions do not reduce safety. Skippers judge the weather and ocean conditions to the right of the zone of uncertainty to be unsafe. The red line represents the probability of a skipper choosing to be at sea in any given wind, wave and tide conditions. The position of the boundaries of the zone of uncertainty vary by vessel size and gear type. The shape and position of the at-sea probability curve varies with fishing method and individual skipper social and socio-economic contexts.

Skippers make safety their top priority in their trip decisions and will generally choose to be ashore when conditions are above their safety threshold, which reflects previous evidence that fishers refuse to risk their lives in adverse weather (Lopes and Begossi, 2011). Our findings suggest that skippers neither completely ignore physical risk nor do they have a limitless acceptance of danger. When the weather is fine, physical risk does not factor in skippers' decision-making. Fishers' aversion to physical risk (Smith and Wilen, 2005; Emery et al., 2014) explains their conscious intention not to be at sea beyond their safety threshold. However, their under-estimation of risk (Davis, 2012), their competitive nature (Acheson, 1981; Gustavsson and Riley, 2020), and a desire to be seen as a skilful skipper who makes the right decisions (Gustavsson and Riley, 2020), may explain why some fishers unintentionally find themselves at sea in conditions beyond their upper threshold.

The weather and ocean conditions that defined physical risk levels and safety thresholds varied with vessel characteristics and fishing methods. The safety threshold of small boats was defined by relatively low weather parameter values. As a result, skippers using these boats only have a narrow range of conditions in which they trade off increasing physical risk, discomfort and economic reward. Consequently, they are highly sensitive to increasing storminess. For these skippers, lower safety thresholds create a form of natural fisheries management, because weather conditions restrict the number of days they can safely spend at sea. Fisheries managers should consider the high sensitivity of small boats, because restrictive management regimes for small inshore boats could compound social-economic harm for arguably the most sustainable segment of the fishing fleet. For instance, the allocation of quota to vessels in quota management systems should reflect vessel size so that small boats have quota available during the restricted number of days they are able to fish safely. Conversely, the larger a vessel is, the more resilient they are to adverse weather and the more their zone of uncertainty shifts to the right, which reflects previous evidence that larger boats are safer (Pollnac et al., 1998; Jin et al., 2002; Rezaee et al., 2016b). Shelter decks and the robust seaworthiness of large static net vessels means that physical risk only enters these skippers' decisions shortly before they reach their upper threshold. Consequently, decisions made by these skippers in the zone of uncertainty are dominated by economic reward, reflecting decisions of large French trawler skippers (Morel et al., 2008). Skippers of these boats demonstrated low sensitivity to physical risk and economic risk. However, through the decisions of skippers of larger boats to be at sea in adverse weather whilst smaller boats are ashore, fishers working on these larger vessels appear to have higher sensitivity to discomfort and disability from increasing storminess than fishers working on smaller boats that have stayed ashore.

Although several economic studies have investigated fishers' decisions based on the expected utility (satisfaction) of a trip, which could be considered to include levels of discomfort, and vessel comfort is important for retaining crew (Christensen and Raakjær, 2006), the role of discomfort in short-term decisions has not been overtly identified. Skippers' feelings of discomfort, and how they trade this off with trip rewards, can be conceptualised as influencing the shape of the trip probability curve within the zone of uncertainty. Skippers with less propensity to accept discomfort will have a lower probability of being at sea in any given weather conditions. Older skippers' lower propensity to accept discomfort, due to accumulated work-related injuries, is unlikely to be unique to Newlyn, because fishing has one of the highest disability rates in the UK (Turner et al., 2019).

The benefit of increased catch levels from an initial deterioration in conditions suggests that calm weather may not be the conditions for optimum fish catches. The negative effect of increasing wave height on otter board trawl catchability reflects previous studies and may be the result of wave-induced turbidity effecting fish behaviour and gear efficacy (Harden Jones and Scholes, 1980; Scholes, 1982; Ehrich and Stransky, 1999; Poulard and Trenkel, 2007; Wieland et al., 2011; Secor et al., 2019). Therefore, the likelihood of an otter board trawl skipper being at sea may fall more quickly than skippers using other gears. As a result, these skippers may choose to return to port before they reach their safety threshold. The catchability of other gear types seems to increase with larger wave heights. For gears that rely on not being seen by fish, such as static nets and purse seines, increased turbidity may be responsible for increased catch levels (Murphy, 1959; Laevastu and Hayes, 1982; Olin et al., 2004; Gabriel et al., 2005). These results provide evidence that sensitivity to lower at-sea productivity from changing storminess is differentiated by fishing method.

The greater desire shown by some fishers to go to sea when prices are driven higher by adverse weather conditions echoes previous findings (Abernethy et al., 2010). However, contrary to this there was also evidence that some skippers refused to be influenced by economic reward. In addition, I revealed that there is little inflationary price effect from adverse weather if prices are fixed for the season (e.g. crabs, sardines). Skippers targeting fixed-price species are less likely to be incentivised to be at sea in adverse weather. The role of market processes in weather-related price changes are Newlyn demonstrates that this dynamic is more complex than previously thought.

Fuel costs did not factor in the decisions of skippers using static nets, pots and lines, but did for trawlers, which reflects evidence from previous studies (Abernethy et al., 2010; Andersen et al., 2012). This suggests that when in the zone of uncertainty, the probability of being at sea would be lower for trawl skippers than for static gear skippers due to lower trip profits. Our finding that the higher risk of gear damage dis-incentivises fishing in adverse weather reflects previous evidence (Holland, 2008). However, I also found new evidence that static gear skippers feel an incentive to take greater physical risk in order to avoid uninsurable loss of gear and caught fish.

Increased economic need appears to drive skippers to take greater physical risk and endure greater discomfort in pursuit of economic reward. This finding reflects previous fisheries evidence (Brennan, 2008) and risk sensitivity theory (Mishra and Fiddick, 2012), which states that individuals take greater risk when the low risk option does not meet their needs and so a high risk option that may meet their needs is chosen. Increased economic need can be conceptualised as shifting a skipper's trip probability curve to the right, reflecting the potential for a skipper to choose to be at sea beyond their safety threshold. The effect of economic need on decisions may decline with age. Skippers in the latter stages of their career had mostly paid off their home mortgage and business debts, and felt less need to pursue economic gain. Conversely, a small number of older fishers had made one last big investment in a large boat, and this debt increased their need to push the weather.

Applications

The findings suggest policymakers should consider who is more vulnerable to physical and economic risks from storms when choosing approaches to adaptation and fisheries management. For instance, UK fishers, particularly small-scale fishers, are currently facing economic need from financial hardship and insecurity (Jones, 2020), which may make them more vulnerable to storms now and to future changing storminess. In a mixed fishery like Newlyn, with a variety of gear types and target species, policymakers could incentivise a move to less vulnerable gears types or more resilient vessels. This might include helping skippers meet the costs of acquiring a new vessel or gear, for instance through grant funding, subsidies or increasing access to credit. However, switching gear types and increasing vessel resilience may be maladaptive if it leads to fishing effort becoming concentrated on fewer fish stocks, or leads to more days spent fishing because of an increase in new vessels' higher safety thresholds. When fisheries managers create new policies, they should consider that fishers are not profit maximisers, but satisfice based on trade-offs of trip physical conditions and profits. By doing so they may be less surprised by fishers' behavioural responses (Fulton et al., 2011).

Climate risk insurance in the form of index-linked policies may offer an adaptation that removes the need for skippers to take physical risk beyond their safety threshold and mitigates the socio-economic impacts of disrupted fishing activities. Index-linked insurance instruments pay out to national governments or individual fishers when an environmental parameter (such as wind speed or wave height) passes a pre-defined threshold. They are considered a potential adaptation for fisheries to changing storminess (Sainsbury et al., 2019). The zone of uncertainty concept suggests that index-linked parameter thresholds should be set relative to fishers' safety thresholds. I have shown that these safety thresholds are not uniform within a fishery, but vary by individual skipper based on a complex mix of technical fishing and individual fisher variables and social dynamics. Whilst simplicity is a key feature of index-linked instruments, our findings suggest that their design should include flexible parameter thresholds that vary based on an individual fishers' fishing vessel and gear, or at least a fleet level aggregate of individual vessels and gear. Furthermore, our findings suggest that the design of index-linked instruments should be based on a detailed understanding of the specific weather variables that affect local skippers' decisions, including interactions between variables. Effective index-linked instruments should trigger payments to reduce skippers' need to push the weather when thresholds are reached, thereby reducing the economic need for greater physical risk taking.

Concluding remarks

This study provides a novel insight into the central role of weather in fishers' behaviour in the mixed fishing fleet at Newlyn, UK. I found that Newlyn fishers trade off physical risk, discomfort and economic reward when deciding whether to be at sea. The findings suggest that the vulnerability of the Newlyn fishery to changing storminess is heterogeneous across skippers and is influenced by fishing method, vessel size, economic need, and social dynamics with crew and other skippers. Whether skippers decide to take additional physical risk and endure greater discomfort to retain the number of fishing days if storminess increases will determine whether they are sensitive to injury and loss of life or reduced income. Fine resolution fisheries catch and meteorological data may be available in developed world industrial fisheries to test the effect of weather conditions on catch levels (for example see Chapter 5). In addition, quantitatively specifying how fishers trade off physical risk and reward in different weather conditions across gear types and vessel and individual characteristics would provide an empirical perspective of how individual heterogeneity affects the sensitivity of fisheries to changing storminess (for example see Chapter 4). The zone of uncertainty concept I have developed in this paper provides a way to understand and further examine the complexity of fishers' weather-related decisions and fisheries' vulnerability to changing storminess.

Chapter 4

"Trade-offs between physical risk and economic reward affect fisher's vulnerability to changing storminess"

Chapter 4: Trade-offs between physical risk and economic reward affect fisher’s vulnerability to changing storminess

This chapter was published in March 2021 as:

Sainsbury, N.C., Schuhmann, P.W., Turner, R.A., Grilli, G., Pinnegar, J.P., Genner, M. J., Simpson, S.D. (in press) Trade-offs between physical risk and economic reward affect fisher’s vulnerability to changing storminess. *Global Environmental Change*.

Introduction

Social-ecological systems, such as fisheries, involve complex connections between people, the natural resources they seek to exploit, and the governance institutions that shape the management of the system (Ostrom, 2009). Climate change is disrupting social-ecological systems at a global scale. Changes in the frequency and intensity of extreme weather events, such as storms, are some of the most conspicuous signs that our climate is changing (Hartmann et al., 2013; Feser et al., 2015; Murakami et al., 2017; Kossin et al., 2020). The potential impact of climate change on a social-ecological system can be explained by the system’s climate vulnerability, which is defined as a function of its exposure and sensitivity to environmental change, and the adaptive capacity of the system (McCarthy et al., 2001; Adger, 2006). Assessment of climate vulnerability can enable policymakers to reduce climate change impacts by providing insights into adaptation actions (Marshall et al., 2013; Metcalf et al., 2015) and prioritising adaptation resources within and between systems (Monnereau et al., 2017).

Global fisheries are already experiencing the effects of climate change (Plagányi, 2019). Effects of climate stressors are expected to become more severe in future climate pathways (Adger et al., 2005), threatening the wellbeing of billions of people who rely on fisheries for livelihoods, food security and nutrition (FAO, 2016; Golden, 2016). There is a growing body of research suggesting that changes in future storminess will vary spatially, with increases in storm frequency and intensity in some regions, and reductions in storminess in others (Sainsbury et al., 2018). Already facing threats from ocean warming (Cheung et al., 2013), acidification

(Ekstrom et al., 2015) and deoxygenation (Keeling et al., 2010), global fisheries must now also contend with changing storminess. Storms have the potential to disrupt fishing activities and cause extensive loss of assets, infrastructure and lives (Adger et al., 2005; Sainsbury et al., 2018). Attempts to assess the vulnerability of fisheries to climate stressors (for example, Allison et al., 2009; Monnereau et al., 2017) have only recently started to reflect the risk exposure of changing storminess (Pinnegar et al., 2019). The decisions that fishers make in different weather conditions are key social mediators of fisheries' vulnerability to changing storminess.

Studies that explore fishers' short-term decisions have thus far focused on biological and economic dimensions of fleet-level spatial behaviour (van Putten et al., 2012). Weather affects daily participation decisions (Huchim-Lara et al., 2016; Stobart et al., 2016), the fishing effort deployed at sea (Lopes and Begossi, 2011), how far fishers travel from shore (Macusi et al., 2015; Shepperson et al., 2016) and the depth of water fishers operate within (Naranjo-Madrigal et al., 2015). Fishers' expectations of trip catch, price and costs play a role in their individual short-term spatial effort decisions (Mistiaen and Strand, 2002). The unit price fishers expect to receive for their catch has a close connection to the weather. Adverse weather disrupts fishing effort. Such disruptions may reduce the supply of fish, driving up market prices, creating an economic incentive for fishers to go to sea in more extreme weather conditions (Abernethy et al., 2010). For example, decisions by skippers of large (20–24-m long) French trawlers in the face of worsening weather are predominantly price-driven (Morel et al., 2008). Despite the evidence of how fishers' decisions are affected by the weather, relatively little empirical evidence exists to explain fishers' daily participation decisions (whether or not to go to sea) in relation to weather and ocean conditions.

Fishing remains one of the most dangerous livelihoods on Earth (Roberts, 2010; Jensen et al., 2014; Fulmer et al., 2019). Given that fishers face great physical risks at sea yet must fish to meet their income requirements, their trip choices often involve trade-offs between physical risk and economic reward in conditions of great financial and environmental uncertainty (Smith and Wilen, 2005). Studies have explored fishers' financial risk appetite, with the majority finding fishers to be risk averse (Bockstael and Opaluch, 1983; Mistiaen and Strand, 2002; Smith and Wilen, 2005). Fishers' willingness to trade off financial returns for the risk of mortality has been calculated using fleet-level landings and fatality data for Alaskan crab fishers (Schnier et al., 2009). Yet few studies have sought to understand individual fishers' physical risk preferences, how they are traded off with economic reward, or the factors that affect these trade-offs (exceptions being Smith and Wilen, 2005; Emery et al., 2014).

Stated choice experiments are a particularly useful empirical economic methodology to understand individual preferences when observational data are not available, as is commonly the case in fisheries (van Putten et al., 2012). In the context of this study, preferences mirror the utility (satisfaction) derived from a feature of a fishing trip. Stated choice experiments require respondents to make choices between hypothetical alternatives defined by a set of attributes that take a range of discrete values (Johnston et al., 2017), and in doing so reveal individuals' relative preference for attributes and the trade-offs that they are willing to make between those attributes (Louviere, 2000). Stated choice experiments have been used extensively in health economics (de Bekker-Grob et al., 2012; Clark et al., 2014), environmental economics (Hoyos, 2010) and transport economics (Greene and Hensher, 2003; Hensher and Greene, 2003). For example, stated choice experiments are commonly used to explore how individuals trade off the health benefits and side effect risks of treatment options (van Houtven et al., 2011; Brett Hauber et al., 2013; Mühlbacher and Johnson, 2016; Husni, 2017) and have also been used to identify how tourists trade off hurricane risks with holiday rewards (Forster et al., 2012). Studies to understand fishers' trip preferences have most commonly employed revealed choice methods (for example, Smith and Wilen, 2005), which use observations of real choices to elicit preferences. Choice experiments have been used to assess risk preferences, but to our knowledge not in trade-offs between environmental risk and economic reward. We are only aware of one stated choice experiment that has been used to study commercial fishers' choice preferences (Eggert and Lokina, 2007) and it did not feature weather-related risks.

Previous studies have analysed a narrow range of species, gear types and vessel characteristics with very little comparison across these technical fishing dimensions or individual socio-economic factors. We address these research gaps using a stated choice experiment to reveal fishers' willingness to trade-off weather-related risk and rewards. Further, we identify the role that vessel characteristics, gear type, and socio-economic factors play in shaping differences in individual preferences for catch, fish prices, wind speed and wave height in daily participation decisions. This study employed a stated choice experiment with skippers fishing from the temperate mixed fisheries in Cornwall, United Kingdom. The specific aims of the study were to: (1) empirically estimate preferences for wind speed, wave height, expected fish catch and expected fish price; (2) identify how preferences for weather conditions and economic reward differed relative to a number of individual-level technical fishing factors (e.g. vessel length and gear type); and (3) estimate how social and economic factors influence physical risk and economic reward trade-offs. The effect of higher wind speed and wave height on the likelihood of a fisher taking a trip was hypothesised to be negative, whilst higher fish catch levels and price were expected to increase the likelihood of a trip (Table 1). Based on key informant interviews and the literature, it was also expected that technical fishing and individual fisher factors would influence the role of weather variables in trip likelihood (Table 2). For instance, increasing age was predicted to increase aversion to wind speed and wave height, whereas increasing vessel length was expected to have the opposite effect.

Methods

Study area

The county of Cornwall forms the tip of the England's south-west peninsula. It has a centuries-old fishing industry, and its coast is dotted with small fishing villages and larger, more modern harbours, including Newlyn, which is England's second largest fishing port (McWilliams, 2014). A total catch of 18,790 tonnes with a value of £48,148,000 was landed in Cornwall in 2018 (MMO, 2019a). As of 1 September 2019, 526 fishing vessels were registered to a home port in Cornwall and the Isles of Scilly, of which 446 were under 10 metres in length and 80 were 10 metres or more, with a range of 3.9 metres to 34.8 m (MMO, 2019b). There are several vessel types in the Cornwall and Isles of Scilly fleet, ranging from small wooden punts using mixed gears through to large steel hull netters and trawlers. As of 2011 there were 1,300 people working in fishing and aquaculture in Cornwall and the Isles of Scilly (ONS, 2017), the majority of whom work in the fishing supply chain as Cornwall has a limited aquaculture industry. Cornwall has a mixed-species fishery with 36 species landed into Cornish ports in 2018, of which 22 were demersal, 10 were shellfish, and four were pelagic (MMO, 2019a). Fishing gear types used in Cornwall include crab and lobster pots, otter board trawls, beam trawls, ring nets (purse seines), gill nets, tangle nets and trammel nets, hand lines and dredges (McWilliams, 2014). Ring nets are classed as European Purse Seines (FAO, 2019) and target species that aggregate near the surface, most commonly European sardine *Sardina pilchardus*. Cornwall's harbours are exposed to prevailing south west winds and powerful swell waves from the North Atlantic, particularly to the west of Lizard Point, which provides protection to fleets operating further east in the English Channel (Fig. 4.1; van Nieuwkoop et al., 2013). Future storminess is projected to increase in Western Europe over the remainder of this century (Feser et al., 2015; Mölter et al., 2016).

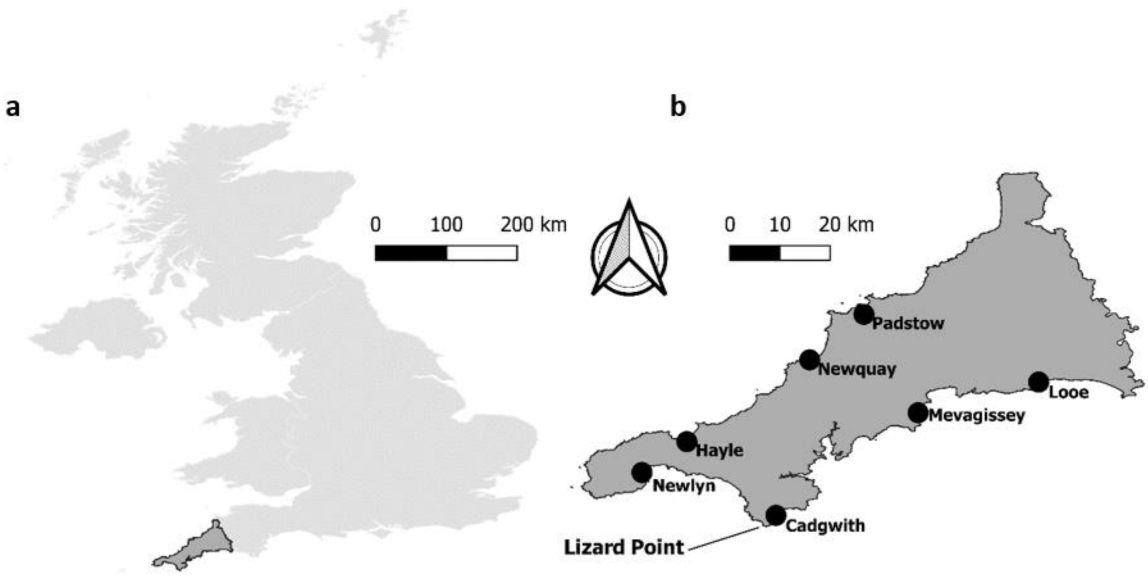

Figure 4.1. The study area. (a) United Kingdom highlighting location of Cornwall. (b) Cornwall showing the locations of the seven ports used for data collection. Lizard Point, used to categorise ports as north or south coast, is also shown.

Sampling and data collection

Stated choice surveys were administered face-to-face with commercial fishing skippers at seven harbours in Cornwall (Fig. 4.1) between May and July 2019. The sample was restricted to skippers, because even if a boat has crew and the skipper listens to their views, the skipper will make the final decision (Acheson, 1981). Locations were selected based on known size of the registered fleet so as to maximise the sample frame and to achieve a balance between gear types, vessel lengths and port locations on the north and south coasts of Cornwall. Fishers are a difficult group to access due to their time at sea and small population distributed among harbours separated by large geographic distances. As a result, a combination of convenience, stratified and snowball sampling was used (Faugier and Sargeant, 1997; Bryman, 2012). Skippers using otter board trawl, purse seines, passive nets (gill, tangle and trammel) nets, hand lines and pots were included within the sample. Pre-interviews with skippers revealed that few boats in Cornwall use beam trawls and dredges. As such these fishing methods were excluded from the study because the population of skippers was insufficient to provide a large enough sample for these gear types. Harbours were visited at different times of day and fishers who were present on the quayside were approached opportunistically. Through snowball sampling, skippers who completed the survey were asked to provide contacts with other skippers. Although the snowball approach can be effective for sampling difficult-to-reach populations, including some fishers, the method does bring the risk of introducing bias towards people with greater social networks (Griffiths et al., 1993). As data were collected, a cumulative record was kept of respondents' technical fishing and socio-economic characteristics across the whole sample. As data collection progressed, characteristics with lower counts or limited ranges were increasingly targeted across all ports to maximise the statistical power of each variable.

Survey structure and facilitation

Data were collected through a survey comprising five sections: (1) questions about fishing practices including home port, the gear in use at the time of the survey, prior experience with impacts of extreme weather; (2) average landed catch weight and unit price by species; (3) trip choice questions to elicit preferences for wind speed, wave height, expected catch, expected price (Table 4.1); (4) reflections on the realism of the choice questions; and (5) technical fishing elements such as vessel length and power, socio-economic questions such as debt and household reliance on fishing income and age (Table 4.2).

Table 4.1. Choice attribute details. Description of choice attributes varying across alternatives within choice sets including attribute levels with hypothesized effects shown for all variables.

Attribute	Description	Hypothesized direction of effect on trip likelihood	Hypothesis rationale	Attribute levels	Justification for inclusion
Wind speed	Wind speed in a favourable direction (mph)	Negative	Stronger winds and larger waves increase discomfort, create operating challenges and reduce safety.	10, 20, 30, 40, 50 mph	Christensen and Raakjær (2006) Gianelli et al. (2019) Interviews
Wave height	Wave height (metres)	Negative	Bigger waves increase discomfort, reduce the efficacy of some gear and reduce safety. Larger waves, particularly swells, may increase fishing success.	1, 2, 3, 4, 5 m	Emery et al. (2014) Interviews
Expected catch weight	Weight of landings a skipper expects to catch.	Positive	Trip decisions are influenced by the previous days' fishing. In adverse weather conditions, low catch expectations may reduce the likelihood of a skipper taking a trip.	Average – 50% Average Average +50%	Lopes and Begossi (2011) McDonald and Kucera (2007) Interviews
Expected unit price	Market price the skipper expects to receive for their catch	Positive	Generally, as weather conditions deteriorate, supply of fish reduces driving up prices. Higher prices incentivise skippers to take greater physical risks.	Average – 50% Average Average +50%	Morel et al. (2008) Abernethy et al. (2010) Interviews

Table 4.2. Socio-economic and technical fishing factors to explain choice preference heterogeneity. Description of socio-economic and technical fishing variables fixed across choices but varying across individuals with hypothesized effects shown for all variables

Attribute	**Description**	**Hypothesized direction of effect on trip likelihood**	**Hypothesis rationale**	**Data type**	**Justification for inclusion**
Vessel length *(effect on wind/wave)*	Registered length of vessel (m)	Positive for wind and wave	The longer the vessel, the greater its capacity to retain stability in adverse weather conditions	Continuous	Christensen and Raakjær (2006) Interviews
Gear type *(effect on wind/wave)*	Fishing gear used at time of survey	Mix of positive and negative, differing by wind and wave	Different gears are affected positively and negatively by weather conditions in different ways	Categorical	Christensen and Raakjær (2006) Rezaee et al. (2016b) Binkley (1991) Interviews
Power *(effect on wind/wave)*	Power of vessel engine in bhp	Positive for wind and wave	Increased power provides greater vessel control and capability to move in extreme sea states	Continuous	Interviews
Port location	Location of port on north or south coast of Cornwall	Positive (for north relative to south) for wind and wave	The north coast (defined as being the west of Lizard Point) is more exposed to swell waves from the Atlantic Ocean. It is hypothesised that fishers will be more accustomed to, and therefore be less averse to, higher waves.	Binary categorical	Poggie et al. (1996) Interviews
Crew *(effect on wind/wave/ catch/price)*	Whether respondent regularly has one more crew onboard (yes/no)	Positive for price and catch, negative for wind and wave (for crew relative to no crew)	With crew there is a greater need to achieve higher income levels to ensure there is enough for all vessel employees.	Binary categorical	Eggert and Lokina (2007) Interviews
Age (*effect on wind/wave*)	Age of respondent	Negative for wind and wave	In general risk theory are people become older they become more risk averse.	Continuous (years)	Roalf et al. (2012) Interviews

Table 4.2 (continued). Socio-economic and technical fishing factors to explain choice preference heterogeneity. Description of socio-economic and technical fishing variables fixed across choices but varying across individuals with hypothesized effects shown for all variables.

Attribute	Description	Hypothesized direction of effect on trip likelihood	Hypothesis rationale	Data type	Justification for inclusion
Children under 18 (*effect on wind/wave*)	Whether respondent has children under the age of 18	Positive for wind and wave (for having children)	Having children creates greater financial need.	Binary categorical	Interviews
Boat owner or employee skipper *(effect on wind/wave/ catch/price)*	Whether the respondent owns the boat or not	Positive for wind, wave, catch and price (for owners relative to employee skippers)	Whilst the catch share is the same for a skipper whether they own the boat or not, an owner skipper is hypothesised to have a greater motivation because of the need to cover the vessel's fixed costs, which it is standard to take from vessel revenue before catch shares are calculated.	Binary categorical (yes/no)	Poggie et al. (1996) Binkley (1995) Interviews
Reliance on fishing income *(effect on wind/wave/ catch/price)*	Whether fishing is main source of household income	Positive for wind, wave, catch and price (for fishing being main household income source)	Greater reliance on fishing income creates greater financial need.	Binary categorical (yes/no)	Eggert and Lokina (2007) McDonald and Kucera (2007) Interviews
Debt *(effect on wind/wave)*	Total household and business debt liabilities relative to annual gross income	Positive for wind and wave	Greater debt relative to income creates greater financial need	Continuous (ratio)	Interviews
Fishing success in preceding month *(effect on wind/wave/ catch/price)*	Rating of 1–5 based on combination of catch and price (1 = very poor, 5 = very good)	Increasingly positive as success decreases for wind, wave, catch and price	The level of fishing success (catch and price) in the previous month affects the financial need of the skipper.	Continuous (interval scale assumed to map to linear continuous variable)	Interviews

To increase choice realism and reduce hypothetical bias, average trip catch and price data collected in survey section (2) were used to provide real respondent-specific values in the choice set in survey section (3) (Rose et al., 2008). Hypothetical bias exists when choices made by respondents differ between real and hypothetical decisions. Choice attributes and the first choice were explained to respondents to ensure their understanding of the structure of the choice sets. Skippers were asked to explain each of their choices to reduce the risk of respondents using non-compensatory decision processes, in which individuals do not consider the relative utility of all choice attributes across alternatives (Hensher et al., 2005; Hensher, 2006). Skippers were asked to make their choices based on the gear they were using, the species they were targeting, and the harbour they were fishing from at the time the survey was completed. Data collected in survey section (4) were sought to provide validity to the experiment by testing for hypothetical bias (Hensher, 2010). Show cards were given to respondents for questions relating to finances (Flizik, 2011) in survey section (5). The cards allocated a series of unique letters to monetary ranges for income and debt questions and were used to encourage responses to sensitive questions. Data from Section 5 were collected to test potential sources of preference heterogeneity.

Stated choice experiments typically assume that respondents have perfect cognition and use all the information available when making decisions (Puckett and Hensher, 2008). However, according to cumulative prospect theory (Kahneman and Tversky, 1992), humans have bounded rationality. When making decisions, individuals may use non-compensatory decision processes or heuristic coping strategies (Hensher et al., 2005; Hensher, 2006), such as attribute non-attendance, where only a subset of attributes are considered (Hensher, 2006). To mitigate the risk of attribute non-attendance introducing bias to coefficient estimates, respondents were asked after every choice which of the attributes they used in their decisions so this could be accounted for *ex-post* in the modelling process (Scarpa et al., 2013).

Choice experiment design

Choices, attributes and alternatives

The number of choices, alternatives and attributes were selected to reflect the expected sample size of 70 – 90 respondents (Orme, 2010) and to mitigate the risks of respondent fatigue, cognitive burden and non-compensatory decision processes (DeShazo and Fermo, 2002; Hensher, 2006; Hoyos, 2010). A blocked design (Hoyos, 2010) was adopted consisting of 20 choices in two blocks of ten. The two blocks of choices were presented to respondents alternately. Face-to-face administration of the survey provided the opportunity to retain respondents' engagement in the choice-making process. To reduce hypothetical bias (Reed Johnson et al., 2013), a literature review and qualitative interviews (Chapter 3) were used to identify realistic attributes and levels (Kløjgaard et al., 2012). Four attributes were selected for inclusion in the design (Table 4.1). Wind speed and wave height were chosen to reflect physical risk and given units most commonly used by local fishers (mph and m respectively). Expected fish catch weight (kg) and price (£/kg) were selected as measures of fishing reward. Respondents were instructed to assume that other attributes that might affect trip decisions were constant across all the choices: favourable wind direction and stage of lunar tidal cycle; forecasted continuation of wind speed and wave height attribute levels for the week ahead; passive gear is at sea and needs to be hauled; and quota is available to land whatever target species are caught.

Five discrete levels were chosen for wind speed and wave height and three levels for expected catch weight and expected price. Attribute values were selected based on interviews and chosen to reflect all but the most extreme conditions for the vessel sizes and gear types within the sample frame (Table 4.1). To ensure relevance to every respondent, expected catch and price attribute levels pivoted around each respondent's average value (pivoted values: average, average minus 50%, average plus 50%). The display of expected fish price and catch weight attributes within choice sets included both the pivoted value and the real respondent-specific values based on their declaration of average daily catch and price by species (Fig. 4.2). Following Eggert and Lokina (2007), the design included three unlabeled alternatives (trip

1, trip 2, no trip). Although three alternatives placed a greater cognitive burden on participants than two alternatives, a design using three was chosen to maximize the statistical information provided by each choice decision (Fig. 4.2). Maximising statistical information from each choice was important because of the known sample limitation of the fishing community in Cornwall. The 'no trip' alternative was included to avoid the bias associated with forcing respondents to choose between alternatives when they would prefer neither (Hanley et al., 2002). This was particularly important for making the choice sets realistic given the nature of fishing trip decisions.

CHOICE 1 — PLEASE CHOOSE ONE OF THE THREE OPTIONS: TRIP 1, TRIP 2, OR NEITHER

	TRIP 1	TRIP 2	
Wind speed	20 Mph *equivalent to 17 knots*	40 Mph *equivalent to 35 knots*	
Wave height	3 Metres *equivalent to 10 foot*	3 Metres *equivalent to 10 foot*	
Expected fishing success (weight)	Average - 50% *Based on the average catch you supplied, this would be:* *75 Kg*	Average + 50% *Based on the average market price you supplied, this would be:* *225 Kg*	
Fish price (£/kg)	Average - 50% *Based on the average market price you supplied, this would be:* Monk £5.00 Ray £1.75 Turbot £6.50 Brill £5.00 Spider crab £0.75	Average *Based on the average market price you supplied, this would be:* Monk £10.00 Ray £3.50 Turbot £13.00 Brill £10.00 Spider crab £1.50	
1. Which trip would you choose?	TRIP 1 — 1	TRIP 2	I WOULD CHOOSE NEITHER TRIP

Figure 4.2. Choice experiment presentation. An example choice set with pivoted expected catch and expected fish price values shown for an example individual respondent.

Pilot and Bayesian d-efficient design

A pilot was carried out with three fishers, who each employed different gear types and were based at different harbours. This pilot helped to refine the framing of the experiment and the choice attributes and levels. Limitations of cognitive burden and respondent fatigue prevent the use of fully orthogonal choice experimental designs, necessitating efficient designs that maximize statistical power within acceptable levels of experiment complexity (Scarpa and Rose, 2008; Bliemer and Rose, 2011). The experimental design was carried out using a Bayesian d-efficient approach (Bliemer and Rose, 2011) in Ngene software (Choicemetrics, 2018). In the d-efficient approach, the determinant of the variance-covariance matrix is calculated based on different combinations of choice attribute values and the design with the lowest determinant is selected. The pursuit of the lowest determinant of the variance-covariance matrix ensure that the standard errors on the model coefficients are as low as possible. Design rules were used to prevent dominant choice alternatives and unrealistic choice scenarios (Crabbe and Vandebroek, 2012). The Bayesian d-error of the final design was 0.0194.

Data preparation

Discrete and continuous versions of wind speed and wave height variables were created so that models could be estimated with discrete variables first to check for non-linear relationships. The expected price attribute levels presented to respondents (average, average plus 50%, and average minus 50%) were converted to mean fish prices (in £/kg) for each individual using a weighted-mean calculation based on their real species catch composition values. Individual harbours were coded into a new binary north or south coast categorical variable based on their position relative to Lizard Point (Fig. 4.1). To preserve the ordinal information provided by fishing success in the preceding month, this independent variable was treated as a continuous linear variable. Categorical covariates were effects coded (Hensher et al., 2015a) to avoid confounding with the null-coded opt-out “no trip” choice alternative (Daly et al., 2016). Attribute levels in choice tasks where the respondent stated they did not use the attribute in their decision-making process were coded using NLOGIT 6 (Econometrics Software Inc., 2019) so that they were not used in the model estimation, so that the associated attribute(s) did not influence model coefficients, thereby removing bias caused by attribute non-attendance. Checks for multi-collinearity between covariates were carried out through mixed factor analysis in R (R CoreTeam, 2019) using the *FactoMineR* package (Lê et al., 2008) and by checking the stability of model coefficient estimates after removal of potentially multi-collinear variables. Vessel power and length were found to be collinear. As a result vessel power was removed from the analysis. Some respondents did not respond to the income and debt questions, and so these variables were removed from the analysis due to missing values.

Analytical approach

Each of the 30 observations generated by each respondent (ten choices, three alternatives) contained data describing the levels of the four attributes for each alternative within a choice (or zeros in the case of the third, ‘no trip’ option within each choice set), individual-specific socio-demographic and technical fishing covariates, and a binary response variable indicating the chosen alternative. Respondents inferred the negative risks (e.g. physical danger, personal discomfort and threat to fishing assets) from the wind and wave levels of the choice attributes but were given specific trip rewards (fish catch and price) resulting from each trip alternative. Conditional logit (CL) and random parameter logit (RPL) models were estimated in NLOGIT 6 (Econometrics Software Inc., 2019). The models are specified in the Appendix D. Quadratic terms were included for wind speed and wave height based on evidence from a conditional logit model with discrete versions of these variables. The inclusion of quadratic terms in the specification of the utility function for choice experiments allows the estimation of the diminishing marginal utility of an attribute *(van der Pol* et al., 2010). CL and RPL models were selected using stepwise deletion on models containing all choice attribute variables and interactions between choice attribute variables and technical fishing or socio-demographic variables with the objective of parsimony. The procedure involved the iterative removal of the least statistically significant continuous predictor variable or level of a categorical variable with a p-value over 0.05, until the models contained only variables statistically significant at the 95% level. Minimum adequate models were compared to null models using likelihood ratio tests. The minimum adequate CL model was used as the maximal RPL model before stepwise deletion. The magnitude and sign of coefficients on omitted (reference) levels of effects-coded covariate interactions were derived by taking the negative sum of the coefficients on the remaining attribute levels from the minimum adequate CL model (except gear type, for which the full CL model before stepwise deletion was used) (Bech and Gyrd-Hansen, 2005).

Results

Respondent characteristics

In total, 80 skippers fishing in Cornwall responded to the survey, of which 78 had their registered home port in Cornwall and the remaining two fished seasonally from Newlyn but were registered elsewhere. Newlyn and Mevagissey contributed 32 and 27 responses respectively, with the remainder obtained from smaller ports. Of the total sample, 47 (59%) of respondents fished from the north coast of Cornwall and 34 (41%) fished from the south coast. Vessel lengths ranged from 4.8 m to 22 m, with a mean length of 10.7 m (±0.46 SE). The most frequently sampled gear type was passive nets (n = 29), followed by pots (n = 21), otter board trawl (n = 17), hand lines (n = 9) and purse seine (n = 4).

The 78 respondents registered in Cornwall represented 15% of all vessels with registered home ports in Cornwall, and by vessel length category represented 9% of the under 10 m vessels and 52% of the 10 m and over vessels. The mean age of respondents was 49 years (±1.4 SE) and ranged from 22 to 77 years. The mean fishing success rating over the month preceding survey completion was 2.85 (±0.15 SE) with a minimum of 1 and maximum of 5 (on a scale from one to five, where 1 was very poor and 5 was very good). Fishing was the main household income for 76% of respondents, 45% of respondents had children under 18 years of age, 84% of respondents owned their vessel, 64% fished with one or more crew members regularly, and all respondents were male. All respondents completed all choice sets. The sampling strategy was not random and therefore precluded generalisation of the Cornish fleet. However, the sample size and resultant number of choices made was sufficiently large to provide the statistical power required to analyse how physical risk and fishing rewards affect fisher trip decisions across individual-level covariate factors.

Modelling results

Linear and quadratic terms for wind speed and wave height were found to be statistically significant in both models (Table 4.3). The negative quadratic coefficients for wind speed and wave height showed that the utility skippers derive from wind speed increases, peaks, and then decreases as wind speed and wave height increase (Fig. 4.3; Fig. 4.4). The magnitude of the quadratic coefficients determine the shape of the curve and the linear coefficient determines the position of the curve. The greater the negative quadrative coefficient of a variable, the faster aversion to that variable falls after the peak. An increase in the positive linear coefficient shifts the curve up and to the right, decreasing aversion at any given wave height or wind speed. Both models had several statistically significant interaction terms between covariates and main attributes, providing strong evidence of heterogeneity in attribute preferences across individuals (Table 4.3).

Aversion to weather attributes varied across all gear types (Table 4.3; Fig. 4.3; Fig. 4.4). Skippers using purse seines were less averse to wind speed (linear term in CL model) and more averse to wave height (quadratic term in both models) than the mean aversion to wind speed. Skippers using passive nets were less averse to wave height (quadratic term in both models) than the mean aversion to wave height. In both models those using hand lines were less averse to wind speed (quadratic term in both models) and wave height (quadratic term CL model), whilst skippers using pots were more averse to wind speed (linear term in CL model). Using the negative sum of the coefficients on the other gear types in the full CL model, skippers using otter board trawls were found to be more averse to wave height (linear and quadratic terms), less averse to wind speed (linear term) and more averse to wind speed (quadratic term). Respondents with longer vessels were less averse to wave height (quadratic term in CL model) and wind speed (quadratic terms in both models).

Social and economic factors interacted with the main choice attributes in both final models (Table 4.3; Fig. 4.3; Fig. 4.4). Respondents who worked single-handed were less averse to wind speed (quadratic term in CL model) and placed less value on expected catch in their trip decisions than those working with crew. Use of crew did not feature in the final RPL model. Skippers who were not the main income provider in their household were more averse to wind speed (quadratic term in both models) and placed a higher value on catch (linear term in both models) in their decisions. Respondents who did not own their boat placed lower value on expected catch than those who did own their boat in both models. Similarly, respondents with better fishing success over the month preceding the survey were found to place less value on expected catch in their trip decisions in both models. Older respondents were more averse to larger waves (quadratic term in CL model) but less averse to increasing wind speed than younger skippers (quadratic term in both models).

Table 4.3. Choice experiment modelling results. Model coefficient estimates for models explaining the effect of choice attributes and their covariate interactions on trip decisions. Statistical significance at the 99% level is denoted by * and at the 95% level by **. In the random parameter logit model, all attributes are random effects except wave height, which was treated as a fixed parameter. Coefficient estimates and confidence intervals are in logits. Reference levels for categorical covariates are otter board trawl gear, skipper works with crew, skipper is main household income provider, and skipper owns vessel. Full model results can be found in the Supplementary materials.**

	Conditional Logit				Random Parameter Logit			
Variable	**Coefficient estimate**		**2.5% CI**	**97.5% CI**	**Coefficient estimate**		**2.5% CI**	**97.5% CI**
Choice Attributes								
Wind speed	0.09344	***	0.04401	0.14286	0.12772	***	0.06448	0.19096
Wave height	1.16763	***	0.72327	1.61198	1.31883	***	0.73907	1.89859
Expected catch weight	0.00306	***	0.00203	0.00408	0.00329	***	0.00192	0.00465
Expected price	0.18274	***	0.13789	0.22759	0.57539	***	0.38247	0.76831
Wave height^2	-0.25956	***	-0.37097	-0.14816	-0.32861	***	-0.43770	-0.21951
Wind speed^2	-0.00674	***	-0.00848	-0.00500	-0.01129	***	- 0.01474	-0.00784
Fishing interactions								
Gear type								
Wave height^2*purse seine	-0.18776	***	-0.25183	-0.12369	-0.19321	***	-0.28333	-0.10310
Wind speed*purse seine	0.06417	***	0.02807	0.10028	-		-	-
Wave height^2*passive nets	0.08239	***	0.05347	0.11131	0.1475	***	0.09019	0.20481
Wave height^2*hand line	0.08048	***	0.03441	0.12655	-		-	-
Wind speed^2*hand line	0.00074	**	0.00010	0.00137	0.0021	***	0.00119	0.00301
Wind speed*pots	-0.03121	**	-0.05040	-0.01203	-		-	-

Table 4.3 (continued). Choice experiment modelling results. Model coefficient estimates for models explaining the effect of choice attributes and their covariate interactions on trip decisions. Statistical significance at the 99% level is denoted by * and at the 95% level by **. In the random parameter logit model, all attributes are random effects except wave height, which was treated as a fixed parameter. Coefficient estimates and confidence intervals are in logits. Reference levels for categorical covariates are otter board trawl gear, skipper works with crew, skipper is main household income provider, and skipper owns vessel. Full model results can be found in the Supplementary materials**

	Conditional Logit				Random Parameter Logit			
Variable	**Coefficient estimate**		**2.5% CI**	**97.5% CI**	**Coefficient estimate**		**2.5% CI**	**97.5% CI**
Choice Attributes								
Vessel length								
Wave height^2*vessel length	0.01060	***	0.00575	0.01545	-		-	-
Wind speed^2*vessel length	0.00010	***	0.00004	0.00016	0.00017	**	0.00006	0.00027
Social and economic interactions								
Regular presence of crew								
Wind speed^2*no crew	0.00050	***	0.00023	0.00077	-		-	-
Expected price*no crew	-0.06142	***	-0.10351	-0.01934	-		-	-
Reliance on fishing income								
Wind speed ^{2}*skipper not main household income provider	-0.00108	***	-0.00144	-0.00072	-0.00129	***	-0.00195	-0.00063
Expected catch weight*skipper not main household income provider	0.00195	***	0.00097	0.00292	0.00163	**	0.00034	0.00292
Vessel ownership								
Expected catch*vessel not owned by skipper	-0.00070	***	-0.00098	-0.00041	-0.00101	***	-0.00142	-0.00060

Table 4.3 (continued). Choice experiment modelling results. Model coefficient estimates for models explaining the effect of choice attributes and their covariate interactions on trip decisions. Statistical significance at the 99% level is denoted by * and at the 95% level by **. In the random parameter logit model, all attributes are random effects except wave height, which was treated as a fixed parameter. Coefficient estimates and confidence intervals are in logits. Reference levels for categorical covariates are otter board trawl gear, skipper works with crew, skipper is main household income provider, and skipper owns vessel. Full model results can be found in the Supplementary materials**

	Conditional Logit				Random Parameter Logit			
Variable	**Coefficient estimate**		**2.5% CI**	**97.5% CI**	**Coefficient estimate**		**2.5% CI**	**97.5% CI**
Choice Attributes								
Fishing success								
Expected catch*fishing success in preceding month	-0.00011	***	-0.00017	-0.00004	-0.00015	***	-0.00024	-0.00006
Age								
Wave height^2*age	-0.00235	***	-0.00370	-0.00101	-		-	-
Wind speed^2*age	0.00003	***	0.00001	0.00005	0.00004	**	0.00001	0.00008
Choice specific constants								
ASC: Trip 1	-0.06850		-0.81120	0.67420	-0.19624		-1.10694	0.71446
ASC: Trip 2	0.18626		-0.54742	0.91994	0.06111		-0.83538	0.95759
Distribution of random parameter (standard deviations)								
Wind speed	-		-	-	0.04690	***	0.01966	0.07415
Wind speed^2	-		-	-	0.00092	**	0.00020	0.00164
Wave height^2	-		-	-	0.08787	***	0.05156	0.12418
Expected catch	-		-	-	0.00000		-0.00009	0.00009
Expected price	-		-	-	0.36954	***	0.22011	0.51897
Key model metrics								
AIC	961.8				927.9			
Pseudo R^2	0.4525				0.4971			
Log-likelihood	-456.89				-441.96			

Respondents who were not the main household income provider were more averse to wind speed (quadratic term in both models) and placed a higher value on expected catch than those who were the main income provider (both models). Having children under the age of 18 and port location on the north or south coast were not found to statistically significantly affect preferences for any of the main attributes the CL model and therefore did not feature in the RPL modelling process.

Discussion

By taking a human behavioural perspective, this study provides a unique contribution to understanding how changing storminess can impact fisheries. We employed a stated choice experiment, an established experimental methodology, in a novel context to identify for the first time how fishers value and trade off physical risk and fishing rewards in their daily participation decisions. We have shown that fishers' trade-offs of physical risk and fishing rewards are influenced by technical fishing, social and economic factors. This study can help inform how fisheries vulnerability to changing storminess is considered and assessed, and provides insights for policymakers regarding potential adaptation actions.

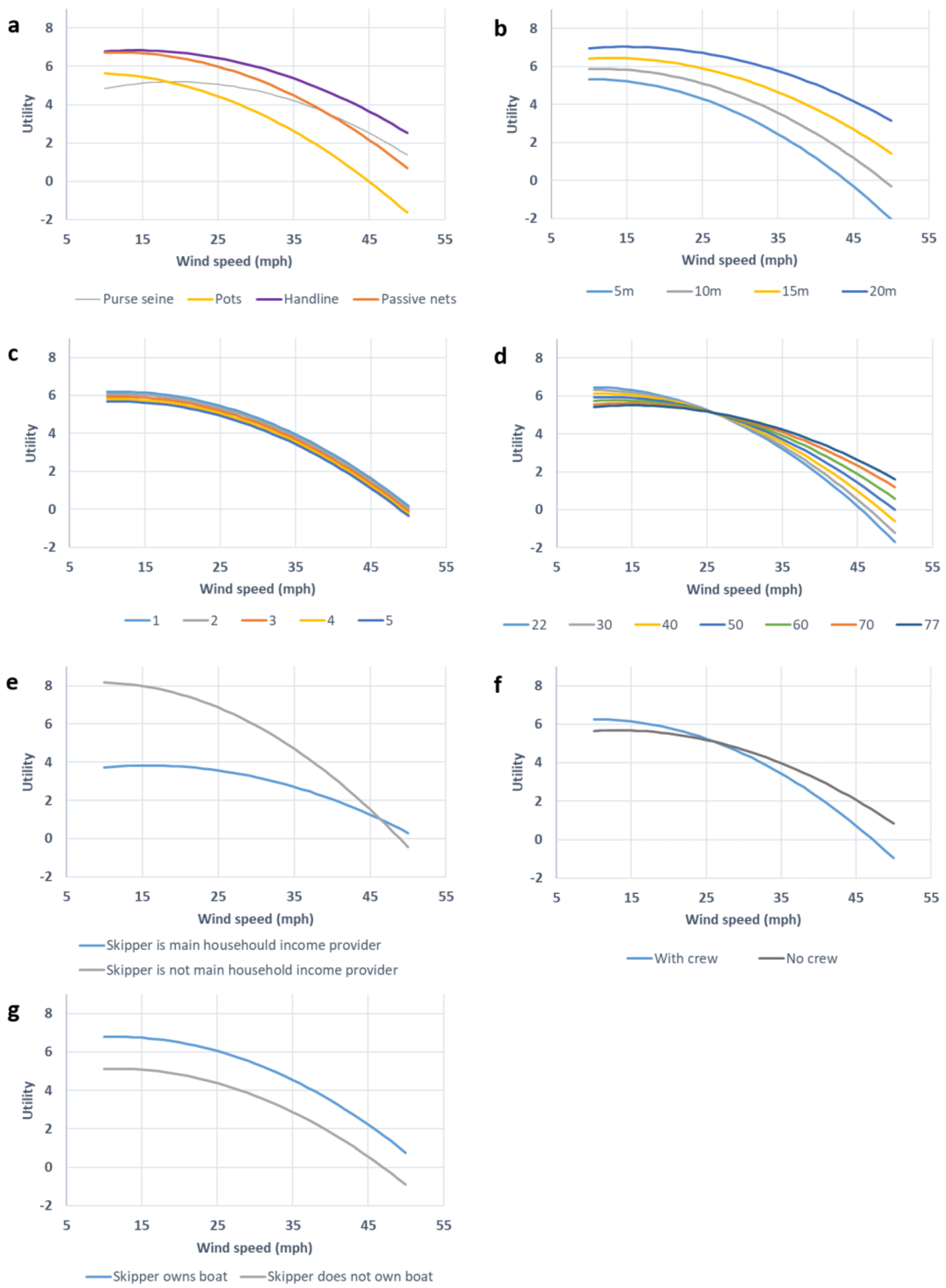

Figure 4.3. Utility curves for wind speed (utility can be considered akin to satisfaction). Utility is in logits. Plots showing conditional logit model predictions of how the aversion to wind speed varies with (a) gear type, (b) vessel length, (c) fishing success in preceding month, (d) age, (e) reliance on fishing income, (f) use of crew, (g) vessel ownership. Except for the variable highlighted in each graph and wind speed, variables are held constant at their mean.

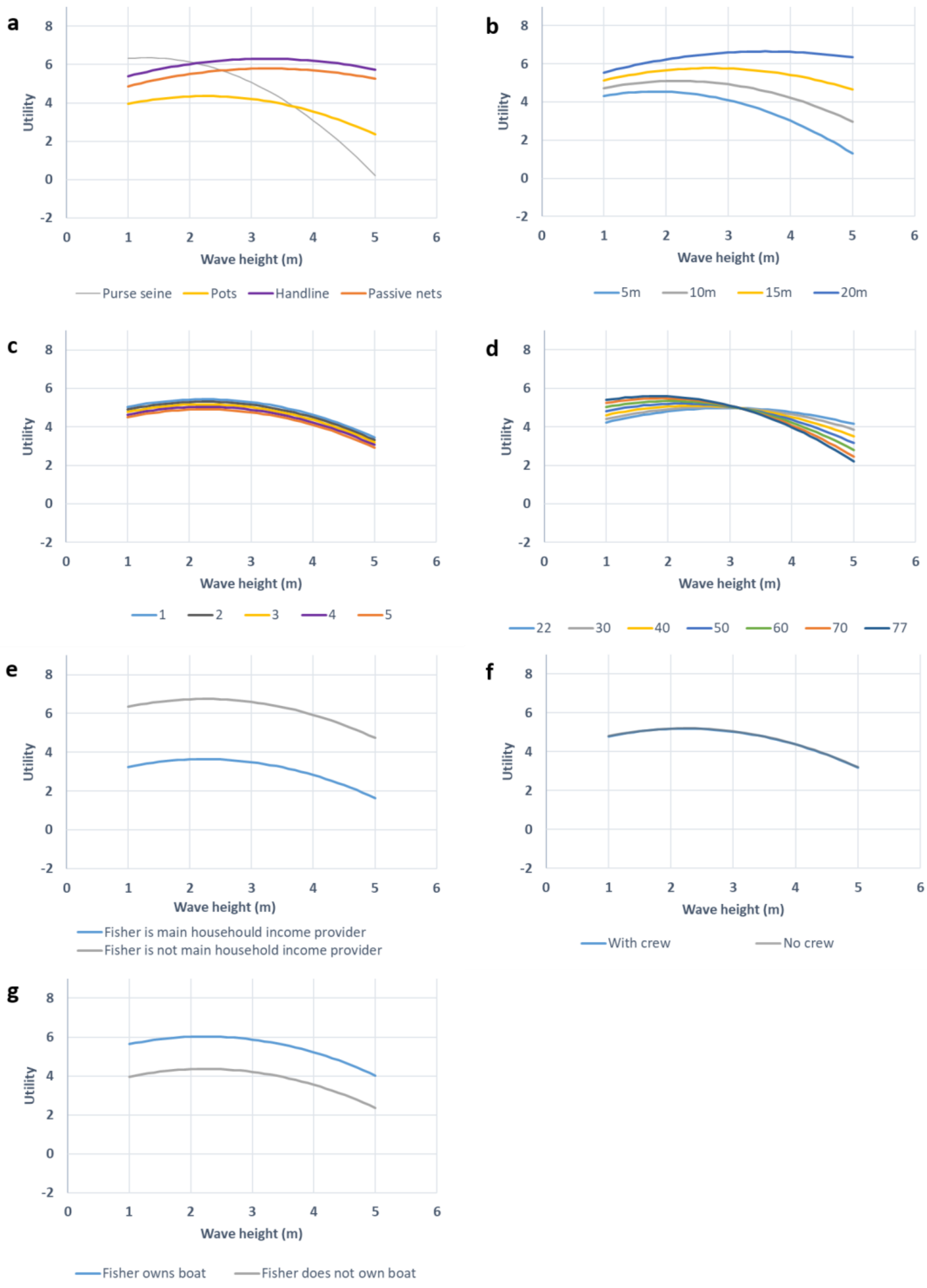

Figure 4.4. Utility curves for wave height (utility can be considered akin to satisfaction). Utility is in logits. Plots showing conditional logit model predictions of how the aversion to wave height varies with (a) gear type, (b) vessel length, (c) fishing success in preceding month, (d) age, (e) reliance on fishing income, (f) use of crew, (g) vessel ownership. Except for the variable highlighted in each graph and wave height, variables are held constant at their mean.

The role of weather, expected catch and expected price in fishers' trip decisions

Fishers are more likely to take a fishing trip when they expect to catch more fish and achieve a higher price for the fish, but this preference can be overridden when weather-related risks become too great. Skippers' showed a preference for increasing wind speed and wave height up to a threshold, above which they became increasingly averse to them. Previous findings have shown that fishers have a simple aversion to higher wind speeds and larger waves (Smith and Wilen, 2005; Christensen and Raakjær, 2006; Emery et al., 2014; Gianelli et al., 2019). The initial increase in preference for wave height was stronger than for wind speed, suggesting that there are benefits of fishing in perturbed sea states. Previous work has shown that catches change during and after perturbed sea states (Ehrich and Stransky, 1999). The underlying reasons are not clear, but may relate to changes in turbidity promoting active feeding by target fish, reducing target fish visual acuity, and causing temporary evacuation from the area.

Fishers' aversion to higher wind speed may result from the role it plays in elevating the risk of at-sea vessel accidents (Jin et al., 2005; Rezaee et al., 2016a; Lincoln and Lucas, 2017), escalating physical risks (Smith and Wilen, 2005), and increasing fuel costs (Abernethy et al., 2010; Bastardie et al., 2013). The reduction in fisher utility after preferences for wave height peak reflects existing evidence that fishers are averse to higher wave heights (Emery et al., 2014). Aversion to larger waves may be explained by higher wave heights predicting more severe (Wu et al., 2005) and more frequent (Wu et al., 2009) vessel accidents, increased the risk to boats and fishers (Niclasen et al., 2010), reduced gear efficacy and therefore catch (Stewart et al., 2010), and increased risk of gear damage (Holland, 2008).

Individual fisher preference heterogeneity

Technical fishing factors

Variations in fishers' preferences for wind speed, wave height, expected catch and expected price are linked to technical aspects of gear operation and the ecology of target species. Skippers using passive net gears below average aversion to wave height. Although passive net fishing efficacy is only adversely affected by the most extreme weather, large waves increase the risk of gear loss. Passive net skippers' lower aversion to wave height may reflect an incentive to avoid losing valuable net assets damaged and relocated by large waves and to haul the fish aboard rather than allow them to spoil whilst they wait out the storm. Increased turbidity in shallower demersal zones caused by large swell waves may also play a role in making otter board trawl skippers more averse to wave height. The efficacy of otter board trawls for capture of round fish is diminished by turbidity as this reduces the ability of target fish to see the sand clouds stirred up by trawl doors and bridles, which herd fish into the net (Main and Sangster, 1981; Dickson, 1993). Conversely, turbidity can increase the catchability of gill nets (Murphy, 1959; Olin et al., 2004), as fish are less likely to see and avoid them. Trawl efficacy for round fish relies on a consistent trawl towing speed, which is reduced by adverse weather (Weinberg and Kotwicki, 2015). Furthermore, the catchability of flat fish by otter board trawls in large waves may be reduced by inconsistent contact between trawl bridles and the sea bottom (Somerton, 2003) and decreased trawl net spread (Queirolo et al., 2015).

Strong winds make it difficult for a skipper to maintain a vessel's position to safely haul pots, which may explain the above average aversion to wind speed shown by skippers using pots. As with passive nets, the incentive for pot skippers to rescue their gear and its catch may reduce their aversion to wind speed, although shellfish tend to take longer to spoil than whitefish. However, if crabs and lobsters are left too long in pots there is the risk of escape (Muir et al., 1984; Zhou and Shirley, 1997), damage from fighting and, in the case of lobsters, cannibalism (Jacklin and Combes, 2007).

Users of purse seines were found to have above average aversion to wave height and below average aversion to wind speed. The greater aversion to wave height may be associated with the destabilising nature of the fishing method. Catching upwards of ten tonnes in one net, the catch is held on one side of the vessel whilst it is transferred onto the boat. This creates a stability risk to the vessel that is exacerbated by large waves (Ben-Yami, 1987). Purse seine skippers' greater preference for wind speed may reflect the inshore location of their fishing grounds, and echoes evidence that tuna purse seine fishers in the Seychelles avoid fishing locations with either very low or very high wind speed (Davies et al., 2014). Hand line skippers also tend to fish inshore, which may explain why they are less averse to high wind speed and wave height than the mean of all gears, as all choices were based on an assumption of a favourable wind direction, which would allow them to fish comfortably in lee of the land. Furthermore, the efficacy of hand lines is not known to be negatively affected by wind or waves in the same way as some other gears, such as trawls.

Vessel length is an important factor in the safety of vessels at sea because vessel stability is in part a function of the vessel length to wavelength ratio (Niclasen et al., 2010). Smaller vessels are more likely to be involved in accidents at sea caused by wind (Jin and Thunberg, 2005). Our findings of the influence of vessel length on wave height aversion do not support those of Emery et al. (2014), who found that vessel length did not interact with wave height in decisions to go to sea. The lack of evidence for port location affecting wind speed and wave height preferences suggests that the differences in swell conditions between the north and south coasts of Cornwall does not affect the role of wind speed or wave height in skippers' short-term decisions.

Social factors

The increased aversion to wind speed that skippers had when working with crew may result from the close relationship between crew and skipper (Urquhart et al., 2011). Skippers feel a sense of responsibility to ensure the safety of their crew and to avoid the discomfort of extreme weather, especially if expected trip revenue is low. The labour market for crew in Cornwall has a shortage of people with the requisite skills (Cornwall Rural Community Charity, 2016), which may create competition between skippers for the best crew and cause skippers to be more empathetic to crew's wind speed preferences. The greater preference for a trip with higher expected fish prices shown by skippers working with crew compared to those working single-handed may reflect social and economic aspects of the relationship between skipper and crew. Skippers need to earn a greater income when working with crew in order to provide them with sufficient catch share income, and are motivated by the responsibility they feel for the welfare of their crew when revenues are low (Holland, 2008). In addition, skippers may need to provide a stable income to their crew in order to retain their services (Marine Scotland Science, 2014).

The age of skippers also affected their trip preferences. The increased aversion to wave height with age reflects the effect of age on risk disposition generally, whereby people become more risk averse as they get older (Dohmen et al., 2011; Mata et al., 2016). The combination of increasing physical disability with age and the discomfort associated with fishing in large waves may explain the greater aversion to higher wave heights of older skippers. The effect of age reducing aversion to higher wind speeds may reflect downsizing to smaller boats as skippers wind down their fishing careers. Small boats fish close to shore, which would allow skippers to benefit from fishing in the lee of the land during the favourable (presumed to be offshore) wind direction assumed in this experiment.

Economic need

We have shown that greater economic need results in lower aversion to physical risk. Skippers for whom fishing provided the main source of income to their household showed less aversion to higher wind speed. Their willingness to take greater physical and economic risk from fishing in higher winds reflects their need to do so. This corresponds with risk sensitivity theory, which posits that individuals with greater need take greater risk when lower risk options will not meet their needs (Mishra and Lalumière, 2010).

Economic need also affected preferences for expected catch, but in multiple complex ways. Skippers showed a greater preference for catch in their trip decisions where they owned their vessel or had experienced worse fishing success in the previous month. In Cornwall, fishers are paid on a crew share system in which trip profits are split amongst the crew. The skipper's share of trip profits is the same whether they own the boat or not. However, owner skippers may have a greater motivation than employed skippers to maximise their revenues in order to contribute to the boat's fixed costs, such as debt repayments and maintenance. Fishers in households less reliant on fishing income are less likely to take trips when expected catch is low because they have less need to and can be more selective in the trips they take.

Implications

The negative quadratic shape of skippers' aversion to wind speed and wave height means that the likelihood of fishers choosing to go to sea reduces at an accelerating rate as wind speed and wave height increase. This suggests that the disruptive effect on fishing activity of any future increased storminess may be non-linear and potentially more severe than might be expected under a linear assumption. The fisheries literature has rightly identified that changing storminess will impact fisheries through an increase in frequency of the most extreme events (Allison et al., 2009; Badjeck et al., 2010; Cheung et al., 2012). However, our findings suggest that a shift in the distribution of storm frequency and intensity will impact fisheries at all levels of storminess, not only the extremes. Whilst such a shift in the distribution of storms may increase the frequency of extreme weather events, it will also increase the frequency of moderate severity storms. Most fishers will find their participation decisions routinely affected by this shift in moderate conditions leading to a gradual reduction in the days they choose to go to sea, or an increase in the physical risks to which they are exposed. The impact of changing storminess on fisheries is therefore more complex than the simple narrative focusing only on extreme events.

The role of technical fishing and socio-economic factors in how skippers trade off physical risk and economic reward confirms that individual skipper characteristics affect the sensitivity of fishers to changing storminess. In the same way that the ecological sensitivity of a fishery to ocean warming is determined by the biological and ecological characteristics of a target species, so conceptualisations of fisheries sensitivity must reflect the role of skippers' technical fishing and socio-economic characteristics in direct socio-economic impacts of changing storminess. As well as direct impacts on target species and their habitats with indirect socio-economic impacts, changing storminess is likely to have direct socio-economic impacts (Sainsbury et al., 2018). These direct socio-economic impacts will alter fishing activities, which may lead to indirect ecological impacts. The linkages between socio-economic and ecological impacts remain unclear. Our findings suggest that fisheries vulnerability assessments should reflect the multi-faceted socio-ecological impact of changing storminess.

Changing storminess poses two direct threats to fishers: disruption to their fishing activities (economic losses from choosing to stay in port); and the physical threat to the fisher themselves (injury and death) and to their assets (their boats and gear). How an individual fisher trades off physical risk and economic reward in daily participation decisions will determine how sensitive that fisher is to alterations in the physical and disruptive risks of changing storminess. If a skipper chooses to stay in port in the face of adverse weather, they eliminate the physical risk of being at sea but bear the full economic loss of a missed fishing day. Alternatively, by choosing to go to sea in adverse conditions, skippers accept a higher risk of injury, death or asset loss but reduce the risk of lost income. Changing storminess therefore impacts different people in different ways and begs the question, “who is sensitive to what?” By taking additional physical risks in adverse weather, fishers are personally sensitive to disability and loss of life, with emotional and socio-economic consequences for their families. Conversely, by staying ashore and avoiding physical risk, fishers protect themselves from the hazards of the sea but expose themselves, their family and potentially the broader local supply chain and community to negative socio-economic impacts.

When aggregated across a fleet, fishers’ individual daily participation decisions amalgamate to form a community level sensitivity to changing storminess. The technical fishing and socio-economic factors we identified as influencing skippers’ decision trade-offs can therefore affect how sensitive a fishery is to the direct socio-economic impacts of changing storminess. For instance, if a fishery has consistent technical or socio-economic characteristics, such as reliance on a single gear or high economic need, then this will strongly influence its sensitivity. Fisheries climate vulnerability assessments require aggregate measures of sensitivity in order to be practical. Our findings provide important insights to help guide the development of measures of fisheries sensitivity to changing storminess. National measures of mean and range of vessel lengths, proportion of gear types used, level of economic need, proportion of vessels using crew, and skipper age may help inform vulnerability assessments. Challenges may exist in developing these measures due to limited availability of detailed data, particularly in tropical and small-scale fisheries.

The technical fishing and individual fisher characteristics governing fishers’ trade-off decisions can help inform adaptation to changing storminess as part of the transition to climate resilient fisheries. Protecting fishers from income and fishing asset losses due to storm events would protect them financially; reducing the role of economic need in motivating greater physical risk-taking. Supporting fishers to move to less sensitive gear types and vessel sizes will help reduce the physical and disruption risks, as fishers may not have the available assets to make this transition unaided. Fisheries management policies that either deliberately, or incidentally, lead to changes in target species, gear types, the vessel profile of a fleet, or the economic viability of skippers using crew should account for the possible effect on fishers' sensitivity to changing storminess. Changes in local storminess will alter the distribution of wind speeds and wave heights, but changes in storminess in distant areas of the same ocean basin may also increase the frequency of large swell waves reaching a fishery's waters. Understanding the exposure of a fishery separately to wind speed and wave height is important for making adaptation decisions.

Concluding remarks

Global capture fisheries and other food-producing systems face a number of climate stressors that threaten the coastal communities that depend upon them, and research is required to deepen our understanding of the vulnerability of fisheries to changing storminess. Building upon this study of a mixed temperate fishery, it would be valuable to identify differences in weather-related decisions across countries and cultures, marine and inland fisheries, fishery types, ecosystems, and regional and local geo-physical and spatial contexts. Exploring at-sea decisions and the role of meteorological and oceanographic factors not used in this study, such as wind direction and lunar tidal cycle, could be critical to developing a broader evidence base for fishers' weather-related decisions. Using stated choice experiments in fisheries can be improved by acknowledging the large degree of uncertainty in fishers' trip decisions. Whilst random utility theory is the most commonly adopted framework for choice experiments, and was employed for this study, expected utility theory (Fishburn, 1988) and cumulative prospect theory (Kahneman and Tversky, 1992; Li and Hensher, 2017) provide alternatives for reflecting choice under uncertainty and risk. As fishers do not know with certainty what weather they will actually encounter at sea, how much they will catch, or the price they will receive for it, there is also potential for future studies to represent this uncertainty in choice attributes levels, following examples in transport and health economics (Hensher et al., 2011; Harrison et al., 2014). The cumulative effect of successive storms on fisher decisions and adaptive capacity also requires further investigation.

Understanding the vulnerability of fisheries to climate change and identifying actions to support their adaptation is critical to reducing negative impacts on fishing communities. This study provides evidence that the decision making of natural resource users affects the climate vulnerability of a social-ecological system, and that technical, social and economic factors are important in mediating this effect. These sources of heterogeneity indicate that adaptation to changing storminess should focus on protecting fishers' assets to reduce the economic need for fishers to take high levels of physical risk, for instance through climate risk insurance (Surminski et al., 2016; Sainsbury et al., 2019), and facilitating access to less sensitive gear types and vessels, for instance through improving access to microfinance (Cull and Morduch, 2018). However, fisheries managers should take care to manage any trade-offs between reduced vulnerability and fisheries management goals, and pursue policies that support the adaption and sustainability of fisheries. Whilst this study provides insight into one aspect of the sensitivity of fishers to changing storminess, further research is required to quantify the socio-economic vulnerability of, and economic impact on, fisheries and individual fishers. Projections of exposure of fisheries to changing storminess, and the consequential effect on the annual distribution of wind speeds and wave heights, are a necessary first step. In addition, the capacity of fishers to adapt to changing storminess (Cinner et al., 2018) requires attention, because it would affect the ability of fishers to mitigate the magnitude of socio-economic impacts. For instance, it will be important to understand the flexibility of fishers to switch fishing gears or fishing location, which may be determined by the prevailing management regime. It would also be valuable to understand the potential for any fisher assets to be used to make resilience-enhancing vessel alterations. Progress towards quantified vulnerability and impact assessments is critical to inform adaptation policy actions.

Chapter 5

“The effect of weather conditions on UK fisheries catches”

Chapter 5: The effect of weather conditions on UK fisheries catches

Introduction

Climate change induced alterations to storm frequency and intensity are already occurring and are projected to alter further over the remainder of the 21st century (Hartmann et al., 2013; Feser et al., 2015; Mölter et al., 2016; Murakami et al., 2017; Kossin et al., 2020). Global fisheries, which provide livelihoods and food security to billions of people, are vulnerable to the impacts of changing storminess. The most extreme weather events can cause fisher fatalities, destroy fishing assets, and interrupt fishing activities (Sainsbury et al., 2018). Less extreme adverse weather, characterised by high wind speeds and disturbed sea states, may also impact fisheries, for instance by disrupting fishing activities (Chapter 3–5). Fishers may remain ashore during adverse weather if they judge the conditions to be unsafe, or if they anticipate a trip not being sufficiently profitable to justify the accompanying physical risk and discomfort (Chapter 3–6). When fishers do choose to go to sea, adverse weather may influence their catch success. Consequently, understanding how weather conditions affect catch levels is an important dimension of identifying the vulnerability of fisheries to changing storminess.

Several observational studies have sought to explore the effect of wind speed or wave height on fishing catches. Trawl catches of European plaice *Pleuronectes platessa* in the North Sea have been shown to decrease with increasing swell wave height (Harden Jones and Scholes, 1980). Trawl catches of Atlantic cod *Gadus morhua* have also been shown to reduce as wind speeds increase (Wieland et al., 2011). Drinkwater and Tremblay (2006) found that increasing alongshore winds elevated American lobster *Homarus americanus* catches. The effect of winds and waves on bottom trawl catch may also last for several days after an adverse weather event (Ehrich and Stransky, 1999). Typically, studies addressing the effect of wind and waves on catches have necessarily been restricted to relatively brief temporal scales (weeks to three months). Nevertheless, some studies have been undertaken over longer temporal scales, for example smooth pink shrimp *Pandalus jordani* catch by otter board and beam trawls was found to increase with wind speed during a one year period (Perry et al., 2000). In a similar study, the trawl catch of nephrops

Nephrops norvegicus was altered by sea state during a two-year period (Maynou and Sardà, 2001). However, there is a dearth of studies based on a wide spatial scale (regional or national), fine spatial resolution over a long temporal scale, and with variety of gear types and species to facilitate a broad comparison.

Wind and wave conditions influence catch levels via the effects of 'fishability' and 'catchability' (Laevastu and Hayes, 1982). Fishability refers to the impact of weather conditions on human fishing operations, and specifically how weather affects the time spent actively fishing at sea and the amount of gear worked in any given period spent at sea. Typically, such "fishing effort" reduces as weather conditions deteriorate, primarily because fishers decide to return to port because weather conditions become unsafe, or expected trip profits do not justify the prevailing risks and discomfort (Stewart et al., 2010; Chapter 3). Even large highly resilient industrial fishing vessels that can safely remain at sea in extreme conditions will cease fishing and ride out a storm until conditions improve (Morel et al., 2008; Chapter 6). In the case of static gears, adverse weather makes it difficult for vessels to stay in the position required to haul gear and large waves pull gear location buoys under water making them difficult to find (Chapter 3).

Catchability is the efficiency of fishing gear at catching fish, that is to say the amount of fish caught per fishing effort (Arreguín-Sánchez, 1996). It concerns gear and fish dynamics occurring below the sea surface. Weather conditions affect gear catchability in three ways: by impacting the functional efficacy of gear; by altering the reaction of fish to gear; and by influencing the availability of fish to gear. Each of these is now discussed in turn.

Wind speed and wave height affect gear efficacy through the physical movement of the fishing boat and gear. Increasing wind speed and wave height reduce the efficacy of bottom trawls by reducing bridle contact with the ground (Somerton and Munro, 2001; Somerton, 2003), changing trawl geometry (Weinberg, 2003; Queirolo et al., 2012), reducing contact of the footrope with the ground (Weinberg et al., 2002; Weinberg, 2003; Wieland et al., 2011), and altering the speed of the trawl net (O'Neill et al., 2003; Politis et al., 2012). Similarly, the close seabed contact required by beam trawls and dredges to manoeuvre fish into their nets may be compromised by vertical wave-induced motion of fishing vessels (Politis et al., 2012). The efficacy of static gear, such as pots and traps and gillnets and entangling nets are generally not affected by wind and waves, except in extreme conditions when gear may become tangled or be moved and lost (Chapter 3).

All fishing methods rely on fish either being able to see, or not see, fishing gear. Sea surface waves disturb the seabed through oscillatory motion and increase turbidity, particularly in shallow waters (Sternberg and Larsen, 1975; Alberello et al., 2019). The effect remains over the short-term, with re-sedimentation taking up to two days depending on the type of suspended sediment (Ehrich and Stransky, 1999). Increased turbidity reduces fish visual acuity and alters their behaviour (Utne-Palm, 2002; Leahy et al., 2011; Ohata et al., 2014). Fish will avoid midwater trawls, seines, and gillnets if they see them and so these gears may benefit from wave-induced turbidity (Murphy, 1959; Laevastu and Hayes, 1982, p.81; Olin et al., 2004; Gabriel et al., 2005). Conversely, hooks and lines perform best in clear waters where fish can see the hooks (Murphy, 1959; Laevastu and Hayes, 1982) and bottom trawls require bentho-pelagic fish to see the sand clouds generated by trawl doors to herd them into the path of the net (Main and Sangster, 1981; Dickson, 1993).

Wind and waves affect the availability of fish to gear by inducing both horizontal and vertical movement. Fish change their distribution and therefore their availability to gear as waves increase water turbidity (Blaber and Blaber, 1980; Cyrus and Blaber, 1987a, 1987b). For example, reduced catch of European plaice by bottom trawls in the North Sea after a period of large waves was thought to be caused by turbidity causing the fish to move vertically into mid-water, bury deep into the sand, or moving to deeper water (Harden Jones and Scholes, 1980). Further evidence of fish behavioural reaction to turbidity has been documented in field and laboratory contexts for important commercial fish species including: Atlantic cod, European Anchovy *Engraulis encrasicolus*, Japanese horse mackerel *Trachurus japonicas*, Atlantic mackerel *Scomber scombrus*, round scad *Decapterus punctatu*, common dab *Limanda limanda*, solenette *Buglossidium luteum*, European plaice, and sole *Solea solea* (Moringa, 1988; He, 1993; Ehrich and Stransky, 1999; Bergeron and Massé, 2011). In addition to turbidity, storms may alter temperature profiles in the water column causing fish to temporarily shift their distribution and activity (Laevastu and Hayes, 1982; Drinkwater and Tremblay, 2006; Hess et al., 2012; Constantin and Johnson, 2019).

Despite efforts to identify the potential mechanisms by which wind and waves affect fishing catches, little empirical evidence exists on the way in which these weather factors alter catch levels at daily or finer temporal resolutions. Quantitative analysis of wind and wave influence on daily catches over long time periods (multiple seasons or years) and large spatial scales (regional or national fisheries) are yet to be undertaken. Furthermore, observational evidence of the mediating effect of gear types and vessel length on the influence of wind and waves on catch success is lacking.

Fisheries vulnerability to storm-driven disturbance of fishing activities is a function of daily participation decisions (Chapters 3 and 4) and the effect of weather conditions on catch success when fishers go to seas (Chapter 3). The objective of this study was to empirically assess the influence of wind and waves on catch levels in order to assess the importance of at sea disruption in fisheries vulnerability to changing storminess. Taking a national scale perspective provides broader and more generalisable insights than previous small-scale quantitative studies and the qualitative study presented in Chapter 3. A national-scale analysis may also shed light on the role of anticipated catch in the economic reward constituent of fishers' short-term decision trade-offs (Chapters 3 and 4).

Given the growing evidence of changing storminess globally, there is an urgent need to identify whether fisheries may be vulnerable to the disruptive effect of weather conditions on at-sea productivity. Using all UK flagged vessels operating in the UK Exclusive Economic Zone as a case study, the impact of wind speed and wave height on the daily landed catch of individual vessels was analysed for a ten-year period from 2008 to 2017. The wide variety of fishing methods employed by UK fishers provides an excellent case study to identify differentiated effects of weather conditions on catch levels by gear type (as identified in Chapters 3 and 4). This is important because insights across gear types have greater application to a broader range of global fisheries, and can inform targeted adaptive action within the UK fishing fleet. The specific aims of the study were to: (1) identify whether wind speed and wave height affect landed catch and, if so, specify the nature of any relationships; (2) examine whether any effects of wind speed and wave height on landed catch differed across the major categories of gear type operated by UK vessels in the UK EEZ; and (3) reveal differences in the effect of weather conditions on the catch of different length vessels for bottom trawls.

Case study

The spatial scope of this study is the United Kingdom Exclusive Economic Zone (UK EEZ), which encompasses the waters within 200 nautical miles of the coast of the UK, or as far as the median line with France, Ireland, Faroe Islands, Belgium, Netherlands, Germany, Denmark and Norway. The waters around the Crown dependencies (except the Isle of Man territorial seas), UK Overseas Territories, and the British Antarctic Territory are excluded from this analysis (Fig. 5.1). The size of the UK EEZ is 773,676 km^2 and extends from 47.43° in the south to 63.88° in the north, 3.40° in the east to -14.90° in the west. In August 2020, there were 5,274 fishing vessels with licenses to fish in UK waters, of which 4,137 were under ten metres and 1,137 were over ten metres (MMO, 2019b). Fishing boats range in size from 3.3 m to 119.7 m (MMO, 2019b). The top five UK ports by landed weight in 2019 were Peterhead, Lerwick, Fraserburgh, Scrabster, and Newlyn (MMO, 2020). The total value of the catch of UK vessels in 2019 consisted of 40% shellfish, 35% demersal, and 25% pelagic species (MMO, 2020). The UK has a temperate climate (Peel et al., 2007) and prevailing winds are from the south-west. The UK is on the North Atlantic storm track and consequently frequently experiences extratropical cyclones. The highest wind gust in the UK (142 mph) was recorded at Fraserburgh, Scotland in 1989 (UK Meteorological Office, 2020) and the world's largest significant wave height (19 m) recorded by a buoy occurred to the north-west of Scotland in 2013 (World Meteorological Organization, 2016). The UK experienced its stormiest winter on record in 2013-2014 (Matthews et al., 2014). Although there is no evidence of increased storminess in the United Kingdom (UK) over recent decades (Kendon et al., 2020) and substantial uncertainty remains, projections indicate an increase of storminess over coming decades (Robinson et al., 2009; Feser et al., 2015; Mölter et al., 2016).7

Methods

The Marine Management Organisation and UK Met Office provided non-publicly available fisheries landings and weather data under an academic data sharing agreement. The landings data related to fish caught in the UK EEZ by UK flagged vessels over 10 metres long. Each data row represented one day’s catch of one species, with one fishing gear, in one ICES statistical rectangle by an individual anonymised fishing vessel, irrespective of the number of days a vessel was continuously at sea. As well as gear type, species and ICES rectangle, each row of data also included vessel length category, landed catch weight and landed value. The temporal scope of the data was a ten-year period from 2008–2017. Vessel length categories were 10.01–14.99 m, 15–19.99 m, 20–24.99 m, 25–29.99 m, 30–34.99 m and 35 m and over. The distribution of landed catch weight data for each gear type and vessel length combinations showed evidence of outliers, which were removed using percentiles that varied by vessel length and by gear type and ranged from 99.99 percentile to 99.5 percentile.. This flexible approach ensured that the removal of outliers reflected the differences in distribution of landed weight across combinations of gears and vessel lengths. In total, 1,193 observations were removed, split by fishing method as follows: 142 from 713,299 bottom trawl; 52.from 7,147 midwater trawl; 357 from 213,908 dredge; 37 from 338,021 pots and traps; 15 from 24,755 seine; 312 from 87,185 beam trawl; 74 from 203,812 gillnets and entangling nets; and 204 from 29,794 hooks and lines. Observations with a difference between catch date and landing date greater than the 99.99 percentile of days were also removed to improve data validity. Raw landed catch weight was preferred to CPUE because CPUE standardises catch using fishing effort and this analysis sought to reflect all ways in which weather conditions affect fishing landed catch weight, including fishing effort.

Figure 5.1. The UK EEZ as defined in this study.

Exploratory interviews (Chapter 3) were carried out at the port of Newlyn, England with skippers representing a range of vessel lengths and gear types to identify meteorological, oceanographic and fishing factors that influence catch levels. Hourly wind speed and significant wave height (wave height from hereon) data were extracted from the Met Office's *WaveWatch III* model, which provides a modelled hindcast representation of meteorological and oceanographic conditions on a high spatial resolution grid (Tolman, 2014). Using *WaveWatch III* data circumvents several issues relating to the use of weather observations. First, meteorological observations from coastal weather stations tend only to be valid in the near locality and not in areas more distant from shore (Laevastu and Hayes, 1982). Second, wave height and wind speed observations taken from ocean observations stations (wave buoys and fixed location ships) are predominantly constrained to coastal waters and limited areas of the UK EEZ (Cefas, 2020). Third, there are insufficient observation stations to provide observed data for every ICES rectangle as required to match the spatial location of UK fisheries catch data observations.

The Met Office's Wavewatch III model provides data on a fine grid for the waters around the UK (Saulter et al., 2016). However, a weakness in the model is that predictions are (unsystematically) biased by fine scale features in near coastal areas (within 24 km of land) that are unaccounted for in the model. This is less of a concern if the coastal wave field is dominated by waves propagating from offshore to the coast (e.g. the UK west coast) (A. Saulter, personal communication, 13 October 2020). Using QGIS 3.4 (QGIS.org, 2020), centroids of the marine section of all UK EEZ ICES rectangles were calculated and the nearest corresponding WaveWatch III grid data points were selected. In order to combine the landings and weather datasets, the daily means of hourly wind speed and wave height were calculated for each ICES rectangle (wind speed and wave height from hereon).

Gear types were grouped into categories using the UN Food and Agricultural Organisation's International Standard Statistical Classification of Fishing Gear (FAO CWP, 2013). The eight gear type categories selected for inclusion in the analysis (Table 5.1) accounted for 86% of landed catch weight and 88% of total landed catch value over the ten-year period. Landed catch weight for each vessel was summed across all species in one day per ICES rectangle. Vessel length categories were removed from the analysis if they did not account for at least 10% of landed weight or landed value, or if they did not account for at least 25% of observations (Appendix E), in order to ensure sufficient statistical power of each vessel length category.

Hexagonal heatmap plots created in the ggplot2 package in R (Wickham, 2016) were used to visually inspect the relationship between landed catch weight (response) and wind speed and wave height (predictor variables) (Fig. 5.2; 5.3). These plots suggested non-linear relationships and the presence of heteroscedasticity. Generalised Additive Models (GAMs) (Wood, 2017) were employed using the BAM function for large datasets in the 'mgcv' package (Wood et al., 2016) in (R Core Team, 2020) to account for the non-paramtertic nature of the relationships. Distributions and a priori transformations were selected to account for heteroscedasticity and maximise the predictive accuracy of the models, evaluated using plots of predicted values against observed values.

Separate BAM models were run for wind speed and wave height for each of the eight gear categories to avoid the issue of concurvity (Spencer et al., 2019). Concurvity exists where one smooth term variable is a smooth function of another smooth term variable a model with multiple smooth terms (Wood, 2017). The models were specified with landed catch weight as the response variable, smooth terms for wind speed (or, wave height), and vessel length category as a fixed covariate. Smooth terms were specified for wind speed and wave height using a thin plate spline (Wood, 2003) and ten basis functions. Landed catch weight was fourth root transformed (FRT) to reduce heteroscedasticity in model residuals. Random intercept effects were included in the main model for individual vessel (to prevent pseudo-replication), ICES rectangle (to account for spatial effects), and year (to account for longer-term effects on catch levels). Insufficient computing memory prevented the inclusion of individual vessel random slopes, which would have accounted for a different shape of the wind or wave smooth term for each vessel. Models were fitted with a gamma distribution with a log link. The gamma distribution and the fourth root *a priori* transformation of the response was necessary to reduce the heteroscedasticity in the models and maximise the predictive accuracy of the models. The model specification is detailed in Appendix F.

To test the mediating effect of vessel length on the relationship between wind or wave and landed catch weight, bottom trawl wind and wave models were fitted with the addition of an interaction smooth term between wind or wave and vessel length. The analysis of the mediating role of vessel length was restricted to bottom trawl as it is the most economically important fishing method in the UK EEZ, had the largest sample size to maximise statistical power. The model specification is detailed in Appendix F. Model validation checks were performed and accepted, including fitted versus response plots, model predicted versus observed values, the distribution of random effects using the ‘appraise’ function in the ‘gratia’ package (Simpson, 2020) and sufficient basis functions using the ‘gam.check’ function in the ‘mgcv’ package (Wood et al., 2016). Partial smooth terms were plotted using the ‘gam.plot’ function in the ‘mgcv’ package (Wood et al., 2016).

Results

Description of landings and weather datasets

The gear types and length categories included in the analysis accounted for 4.04 billion kg of landed catch weight and £5.24 billion landed catch value, which 86% and 88% of the UK fleet total respectively. Bottom trawls accounted for the largest value of landed catch over the ten years whist midwater trawls landed the greatest catch weight of all gear types (Table 5.2). After bottom and midwater trawl, the order of all other gear categories was the same for weight and value, which from largest to smallest was: dredges; pots and traps; beam trawls; seines; hooks and lines; and gillnets and entangling nets (Table 5.2). There was heterogeneity in the range of wind speeds and wave heights for which each fishing method caught fish and in the variance in landed catch across the range of wind speed and wave height (Fig. 5.4; Table 5.2). Wind speed and wave height for the period 2008–2017 inclusive varied between ICES rectangle in the UK EEZ (Fig 5.4). The greatest wave heights and wind speeds were in the offshore waters to the north and west of Scotland, and for wave heights, also the southwest approaches. By contrast the Irish Sea, North Sea and English Channel were characterised by smaller waves and relatively slower winds.

Spatial distribution of landed catch weight varied by gear type (Fig. 5.5; 5.6). A predominance of catches made by the two most economically important fishing methods (bottom trawl and midwater trawl) for the period 2008–2017 were made around Scotland and the Shetland Islands in particular. The majority of bottom trawl catches were made to the east and northeast of Scotland with smaller amounts in the Irish Sea and the far west of Scotland. Midwater trawls catches were also made in the Irish Sea and off the south coast of England. Other gear types with the bulk of their catch around Scotland were hooks and lines (to the north of Scotland with low levels around the south of England) and seines (south of the Shetland Islands with some off the southwest English coast). Beam trawl catches were made almost exclusively around the English coast with a focus in the southwest. Gillnets and entangling net catches were predominantly located off the coast of Cornwall in the English Channel and Celtic Sea with lower levels to the far west of Scotland and north of the Shetland Islands. Dredge catches were distributed around UK nearshore waters, but primarily around the Isle of Man, with other substantial catches off the south coast of England, and East Anglia. Pots and lines catches were made in nearshore areas around the southwest of England, Wales, east England, and to the north of Scotland.

Table 5.1. Categorisation of gear types used by UK vessels in the UK EEZ and those included in the study.

Gear type category	**Gear classification**
Included in study	
Bottom trawl	Bottom trawls (not specified), Nephrops trawls, Otter trawls – bottom, Otter twin trawls, Pair trawls – bottom, Shrimp trawls- bottom
Midwater trawl	Midwater trawls (not specified), Otter trawls – midwater, Pair trawls – midwater, Shrimp trawls - midwater
Dredge	Mechanized dredges, Boat dredges, Hand dredges
Pots	Fyke nets, Pots, Traps (not specified), Aerial traps, Stationary uncovered pound nets
Beam trawl	Beam trawls
Seines	Beach seines, Danish seines, Scottish seines, Pair seines, Boat or vessel seines, Seine nets (not specified)
Hooks and lines	Handlines and pole-lines (hand-operated), Handlines and pole-lines (mechanized), Hooks and lines (not specified), Trolling lines, Longlines (not specified), Set longlines
Gillnets and entangling nets	Combined gillnets-trammel nets, Driftnets, Encircling gillnets, Gillnets (not specified), Gillnets and entangling nets (not specified), Fixed gillnets (on stakes), Trammel nets, Set gillnets (anchored)
Excluded from study	
Surrounding	One boat operated purse seines, With purse lines (purse seines)
Lift nets	Lift nets (not specified), Portable lift nets
Trawl unspecified	Other trawls (not specified), Otter trawls (not specified), Pair trawls (not specified)
Harvesting gear	Harvesting machines (not specified), Pumps
Unknown miscellaneous	Gear not known or not specified, Miscellaneous gear, Hand fishing
Recreational	Recreational fishing gear

Visual inspection of relationships

Scatter heat map plots of landed catch weight with wind speed (Fig 5.2; 5.3) demonstrated that fishing methods catch fish across different ranges of weather conditions and that maximum potential catch occurs in different weather conditions. The general pattern of landed catch weight with wind speed for all fishing methods was of low catch levels across the range of wind speeds but with maximum potential catch increasing, peaking, then decreasing across the wind speed range of recorded catches. The maximum potential catch for bottom trawl, midwater trawl, hooks and lines, and gillnets and entangling nets was at approximately 9 m/s. Maximum potential catch was at lower wind speeds for dredges (circa 7.5 m/s) and pots and lines, beam trawls, and seines (circa 8 m/s). Bottom trawls, pots and lines, and gillnets and entangling nets caught fish across the widest range of wind speeds (2.5–12.5 m/s). Beam trawls and hooks and lines made their catches in the narrowest range of wind speeds. Hooks and lines did not catch any fish below a wind speed of approximately 7 m/s. Patterns of landed weight with wave height showed some similarities to wind speed, in particular for bottom trawls and gillnets and entangling nets. Dredges demonstrated a maximum potential catch at low wave heights, with potential catch falling until all catches ceased over 3.5 m high waves. Beam trawl catches also ceased at 3.5 m wave heights and exhibited their highest potential catch in a uniquely narrow range of wave heights from 1–2 m. Conversely, midwater trawl catch potential appears to increase linearly with wave height until catches cease abruptly at wave heights of 4 m.

Generalised additive models

Visual inspection of the partial smooth terms from the GAMs (Figs 5.7; 5.8) demonstrates that wind speed and wave height influence FRT landed catch weight (landed catch weight from here) in different ways for each gear type. For bottom trawls, FRT landed catch weight fell between 0–7 m/s wind speed, stayed low at moderate wind speeds, before then increasing between 9–12 m/s (Fig. 5.7a). Midwater trawl landed catch weight increased linearly with wind speed (Fig. 5.7b). Dredge landed catch weight fell at lower wind speeds, increased slightly from 7–9 m/s, and then fell slightly at higher wind speeds (Fig. 5.7c). Dredges did however show substantial uncertainty at low and high wind speeds. Pots and traps landed catch weight shows a near-linear negative relationship with wind speed, although confidence intervals suggest that the relationship could be very weak (Fig. 5.7d). Beam trawl and seine landed catch weight both showed a slight linear increase but with high degrees of uncertainty (Fig. 5.7e-f). Both hooks and lines and gillnets and entangling nets landed catch weight show an increase between 9 m/s and 12 m/s but with high degrees of uncertainty (Fig. 5.7g-h).

Landed catch weight increased with larger waves for all fishing methods with the exception of pots and traps, and hooks and lines (Fig. 5.8). Bottom trawl landed catch weight dropped from 0–1 m wave height before staying low from 1–2 m, and then increased sharply between 2–3.5 m before falling from 3.5–4 m wave height (Fig. 5.8a). As with the effect of wind speed, midwater trawl landed catch weight increased in a near linear fashion with wave height (Fig. 5.8b). Dredge landed catch increased at a reducing rate from 0–2.5 m before flattening off from 3.5–3.5 m (Fig. 5.8c). Pots showed a complex (overall) negative relationship entailing an initial increase in landed catch weight from 0–1 m, a decrease at a reducing rate from 1–2 m followed by an increase from 2–3 m and finally a fall in between 3–4 m (Fig. 5.8d). Beam trawl landed catch weight increased slightly with decreasing slightly before raising slightly from 2–3.5 m (Fig. 5.8e). Seines landed weight increased from 1.5–2.5 m wave height levelling off before falling slightly from 3–4 m (Fig. 5.8f). Hooks and lines landed weight show a flat relationship wave height in a non-linear fashion, increasing steeply from 0.5–1 m, with wave height before increasing slightly between 3.5–4.5 m waves (Fig. 5.8g). Finally, gillnets and entangling nets landed weight increased in a non-linear fashion from 1–4 m wave height (Fig. 5.8h).

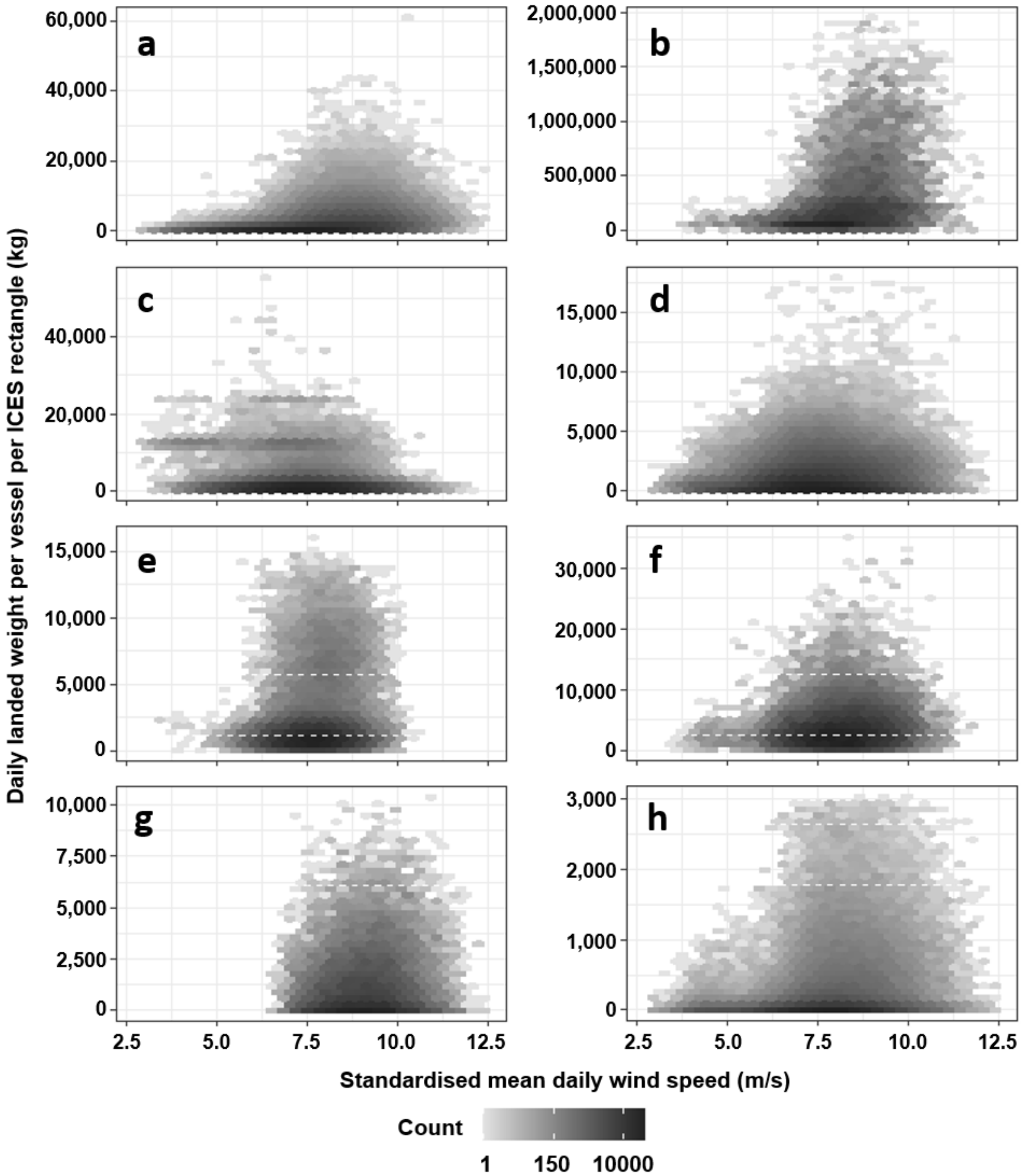

Figure 5.2. Hexagonal heat map scatter plots of daily landed catch weight and daily mean wind speed for (a) bottom trawls, (b) midwater trawls, (c) dredges, (d) pots and traps, (e) beam trawls, (f) seines, (g) hooks and lines, (h) gillnets and entangling nets.

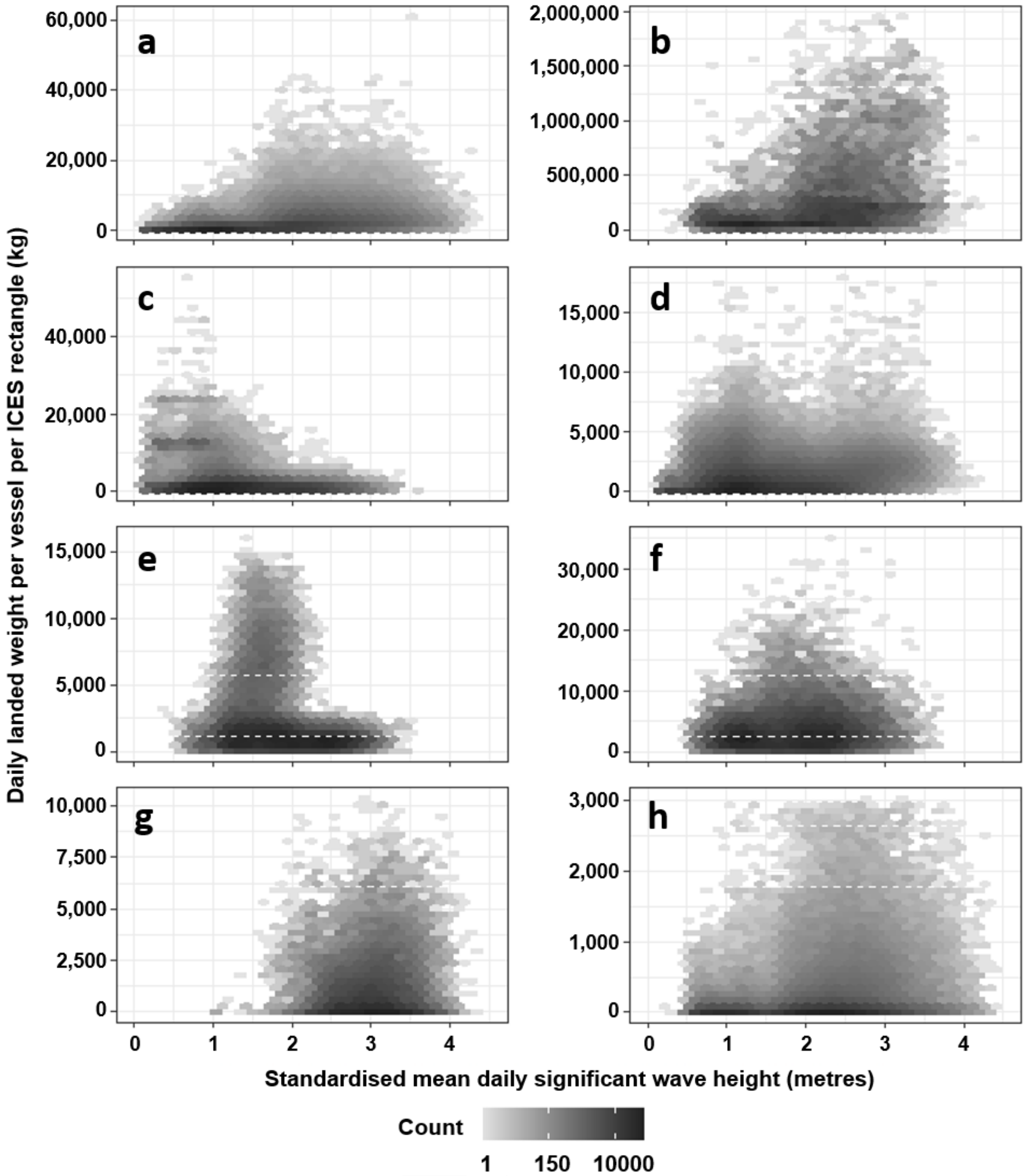

Figure 5.3. Hexagonal heat map scatter plots of daily landed catch weight and daily mean significant wave height for (a) bottom trawls, (b) midwater trawls, (c) dredges, (d) pots and traps, (e) beam trawls, (f) seines, (g) hooks and lines, (h) gillnets and entangling nets.

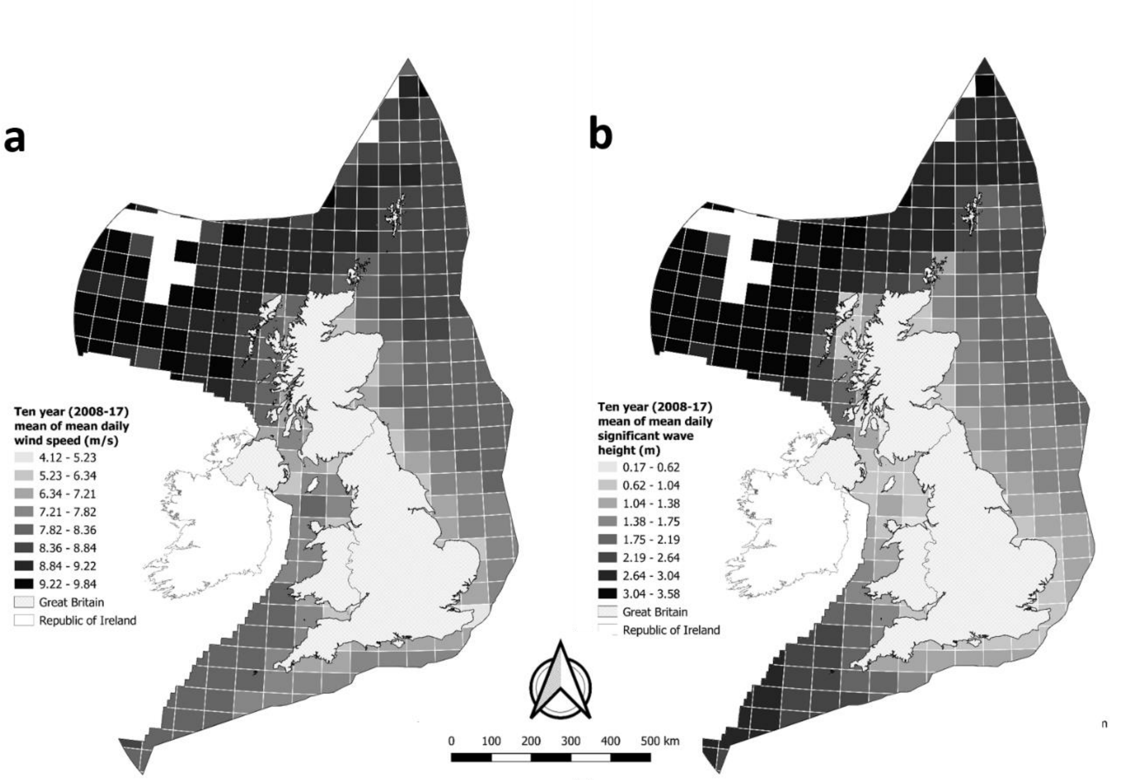

Figure 5.4. The UK EEZ 2008–2017 mean of (a) daily mean wind speed, and (b) daily mean significant wave height. White cells represent areas where no catches were made during the ten-year period. Spatial values classified using the Jenks natural breaks classification method.

The length of bottom trawlers did not meaningfully alter the nature of the relationship between landed catch weight and wind speed (Fig. 5.9), but length did alter the impact of wave height on landed catch weight (Fig. 5.10). In the four vessel length categories, landed catch weight decreased, levelled off and then increased as wind speeds increased. Increasing wave height did not affect landed catch weight for any of the vessel lengths until wave height reached 2.5 m. Above 2.5 m wave height, the relationship differed by vessel length. The landed catch weight of bottom trawlers with a length 10.01–14.99 m began to fall sharply for waves above 3 m (Fig. 5.10a). For 15–19.99 m and 25–29.99 m long vessels, landed catch decreased back to pre-2.5 m levels between 3.5 m and 4.5 m wave heights (Fig. 5.10b; Fig. 5.10d). The landed catch weight of 20–24.99 m long bottom trawlers increase for all wave lengths with no reduction in at the largest wave heights. The landed catch of 20–24.99 m vessels started increasing at 0.5 m wave heights and then increased at a faster rate from 2.5 m wave heights and did not reduce even in the highest wave heights (Fig. 5.10c). Mean landed catch weight varied by vessel length within gear type. Mean catch generally increased with vessel size but (taken from the wind speed models) the largest boats in each gear type did not always demonstrate the highest mean catch (Fig. 5.11).

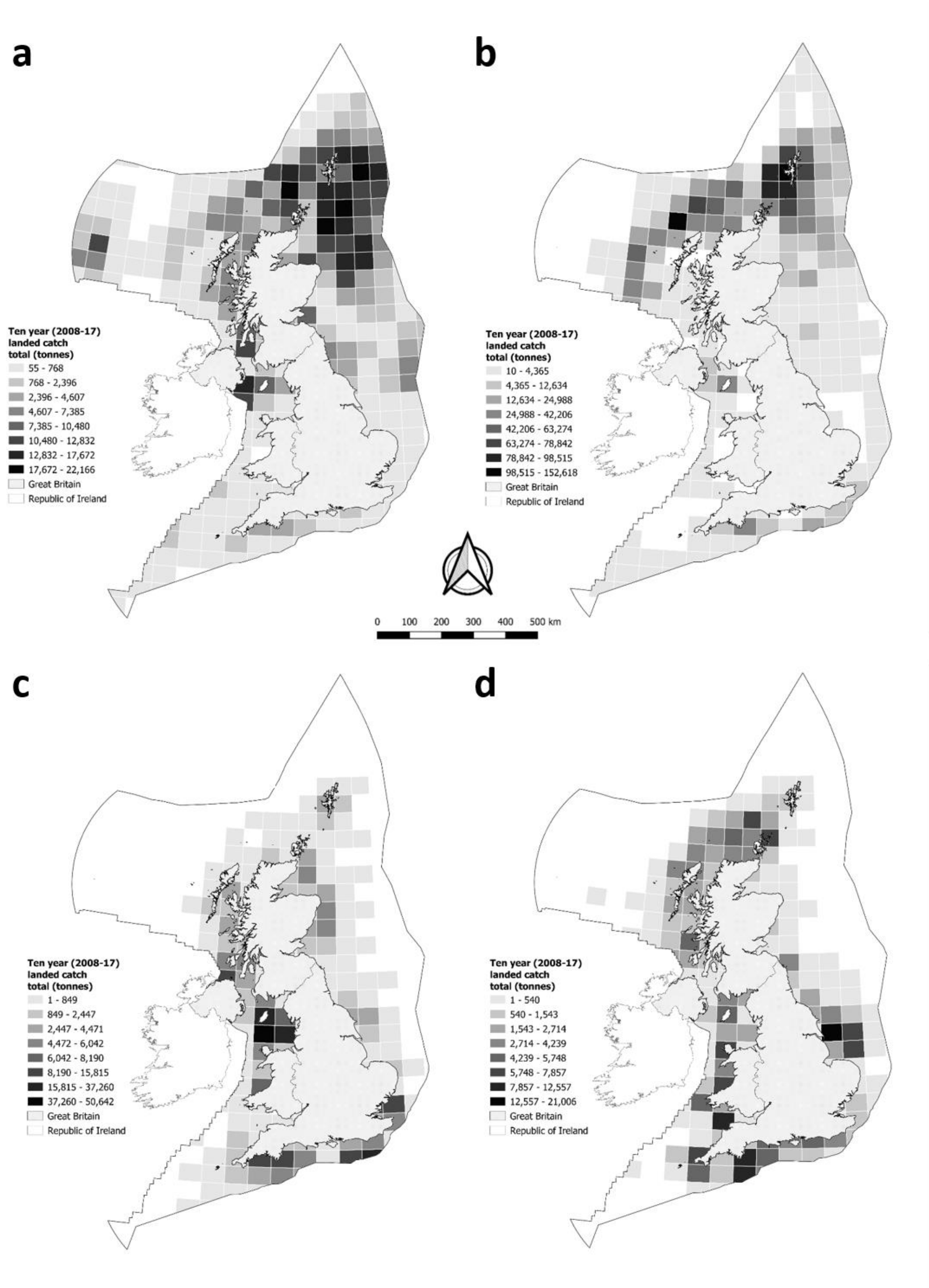

Figure 5.5. Total weight of catch made (and then landed) in each ICES rectangle for the period 2008–2017 for the four most valuable fishing methods (a) bottom trawl, (b) midwater trawl, (c) dredges, and (d) pots and traps. White cells represent areas where no catches were made during the ten-year period. Spatial values classified using the Jenks natural breaks classification method.

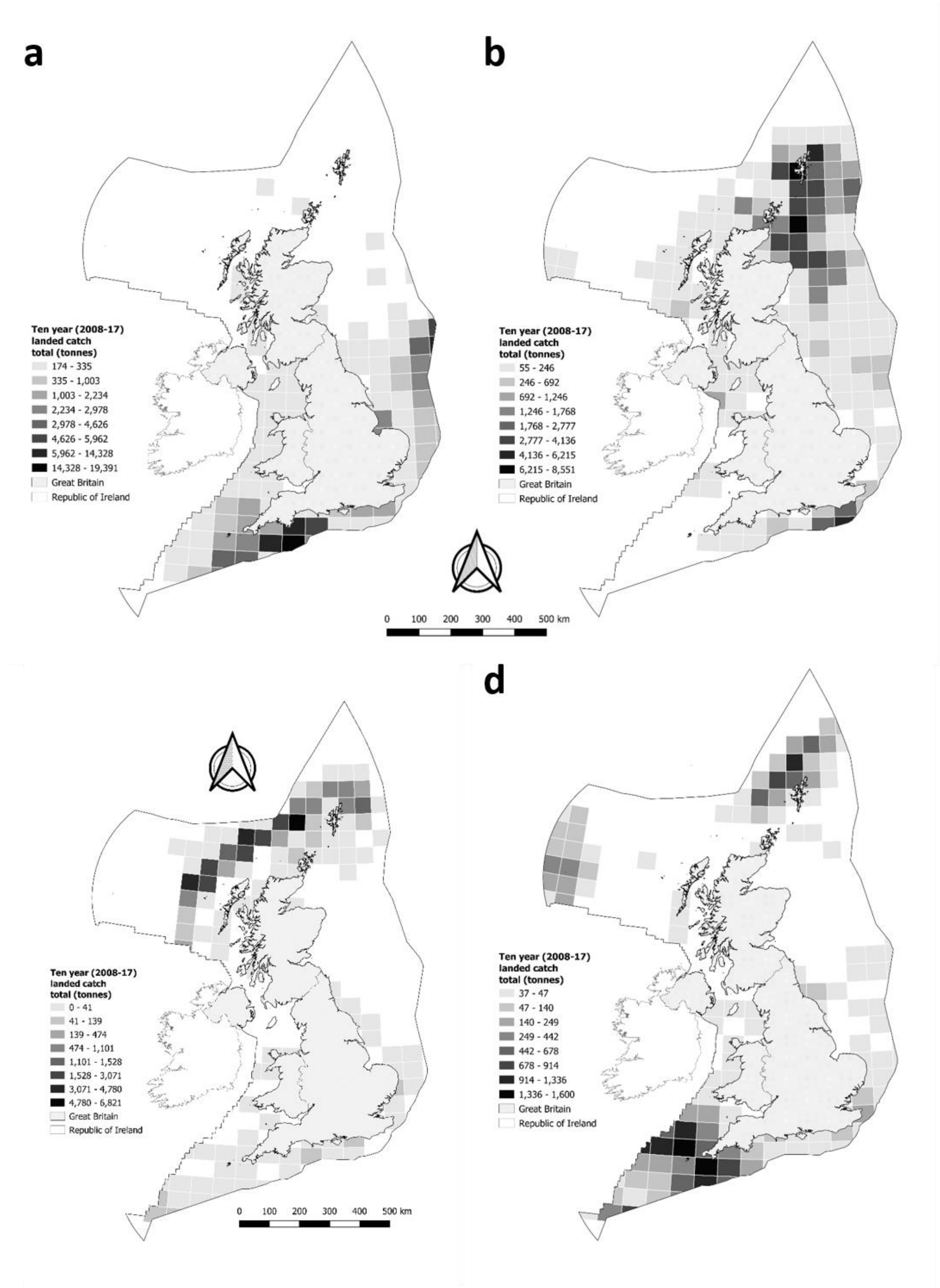

Figure 5.6. Total weight of catch made (and then landed) in each ICES rectangle for the period 2008–2017 for the four least valuable fishing methods (a) beam trawl, (b) seines, (c) hooks and lines, and (d) gillnets and entangling nets. White cells represent areas where no catches were made during the ten-year period. Spatial values classified using the Jenks natural breaks classification method.

Table 5.2. Key characteristics of the eight gear categories over a ten-year period from 2008–2017. Grey length categories within gear types were removed from the analysis. The total column includes only data for vessel length categories included in the analysis.

Fishing method	Vessel length category						Total
	10.01–15m	15–19.99m	20–24.99m	25–29.99m	30–34.99m	35m and over	(included in analysis)
Bottom Trawl							
Number of observations	197,869	292,264	152,586	70,580	6,443	9,385	**713,299**
Weight (kg)	61,128,092	190,895,090	254,781,883	255,307,553	34,006,082	44,496,538	**762,112,618**
Value (£)	196,394,029	581,749,817	600,826,436	468,120,123	63,002,509	74,546,613	**1,847,090,405**
Number of vessels	379	289	159	84	12	33	**911**
Wind speed (minimum / mean / maximum)	3.0 / 7.0 / 11.5	3.0 / 7.6 / 12.3	3.5 / 8.2 / 12.3	4.2/ 8.7 / 12.4	5.1 / 8.8 / 12.2	4.2 / 8.6 / 12.1	-
Wave height (minimum / mean / maximum)	0.1 / 1.0 / 3.8	0.1 / 1.3 / 4.2	0.1 / 1.9 / 4.4	0.2 / 2.4 / 4.4	0.3 / 2.6 / 4.2	0.7 / 2.4 / 4.1	-
Catch composition	Benthic 43% / Bentho-pelagic 42% / Shellfish 15%						-
Midwater Trawl							
Number of observations	3,585	1,570	2,757	491	-	7,147	**7,147**
Weight (kg)	34,419,385	11,739,893	3,416,634	546,286	-	2,206,539,354	**2,206,539,354**
Value (£)	8,622,393	4,370,497	6,700,814	1,464,248	-	1,504,876,668	**1,504,876,668**
Number of vessels	23	29	21	11	-	45	**45**
Wind speed (minimum / mean / maximum)	2.8 / 6.9 / 9.6	4.2 / 7.4 / 10.3	4.2 / 7.0 / 10.5	5.0 / 7.3 / 9.7	-	3.8 / 8.4 / 12.0	-
Wave height (minimum / mean / maximum)	0.2 / 1.2 / 2.6	0.2 / 1.1 / 3.1	0.5 / 1.0 / 3.0	0.6 / 1.2 / 2.6	-	0.2 / 2.2 / 4.1	-
Catch composition	Benthic 18% / Bentho-pelagic 48% / Pelagic 34%						-
Dredges							
Number of observations	90,601	69,899	17,225	18,972	17,211	6,203	**213,908**
Weight (kg)	109,346,209	83,140,058	82,758,638	37,727,871	41,154,078	26,324,354	**354,126,854**
Value (£)	160,597,966	144,074,536	68,086,261	61,199,295	74,306,911	34,316,930	**508,264,969**
Number of vessels	267	102	30	23	12	7	**434**
Wind speed (minimum / mean / maximum)	2.9 / 7.3 / 11.9	3.2 / 7.6 / 11.8	4.0 / 7.6 / 11.2	3.3 / 7.4 / 11.0	3.7 / 7.6 / 11.4	3.9 / 7.6 / 10.3	-
Wave height (minimum / mean / maximum)	0.1 / 0.2 / 3.6	0.1 / 1.2 / 3.5	0.2 / 1.2 / 3.3	0.3 / 1.3 / 3.4	0.1 / 1.4 / 3.3	0.4 / 1.4 / 3.2	-
Catch composition	Benthic 32% / Shellfish 68%						-
Pots and traps							
Number of observations	286,342	51,679	3,360	2,869	5	-	**338,021**
Weight (kg)	160,876,295	95,233,164	6,180,040	8,589,799	710	-	**256,109,459**
Value (£)	297,940,530	133,882,883	12,078,968	13,031,202	2,872	-	**431,823,412**
Number of vessels	438	90	7	2	1	-	**528**
Wind speed (minimum / mean / maximum)	2.8 / 7.4 / 12.1	3.5 / 7.9 / 12.1	4.9 / 7.7 / 11.7	5.6 / 8.7 / 11.7	8.9 / 9.5 / 10.0	-	-
Wave height (minimum / mean / maximum)	0.1 / 1.3 / 4.0	0.2 / 1.7 / 4.1	0.6 / 1.6 / 3.7	1.1 / 2.7 / 3.8	3.1 / 3.3 / 3.6	-	-
Catch composition	100% Shellfish						-

Table 5.2 (continued). Key characteristics of the eight gear categories over a ten year period from 2008–2017. Grey length categories within gear types were removed from the analysis. The total column includes only data for vessel length categories included in the analysis.

Fishing method	Vessel length category						Total
	10.01–15m	**15–19.99m**	**20–24.99m**	**25–29.99m**	**30–34.99m**	**35m and over**	**(included in analysis)**
Beam trawl							
Number of observations	22,698	5,382	35,690	29,912	13,416	8,167	**87,185**
Weight (kg)	8,763,582	2,390,740	32,427,488	28,308,119	17,549,450	38,154,474	**116,439,531**
Value (£)	25,960,776	8,003,244	108,927,537	97,462,308	56,345,053	71,640,832	**334,375,730**
Number of vessels	97	12	26	29	11	20	**86**
Wind speed (minimum / mean / maximum)	3.8 / 6.6 / 10.1	3.2 / 6.7 / 10.1	3.6 / 7.6 / 10.2	4.0 / 8.2 / 10.6	4.9 / 7.7 / 10.2	3.3 / 7..9 / 10.3	-
Wave height (minimum / mean / maximum)	0.3 / 0.9 / 2.8	0.2 / 0.9 / 2.7	0.3 / 1.7 / 3.5	0.5 / 1.9 / 3.5	0.6 / 2.0 / 3.5	0.4 / 1.5 / 2.4	-
Catch composition	Benthic 57% / Benthopelagic 34% / 9% Shellfish						-
Seines							
Number of observations	26	4,395	9,296	8,028	1,083	3,036	**24,755**
Weight (kg)	6,835	15,773,900	40,289,779	37,395,015	2,735,187	8,587,610	**102,046,303**
Value (£)	11,464	19,276,852	56,939,029	60,139,856	6,707,782	22,803,872	**159,159,609**
Number of vessels	3	12	18	14	3	4	**48**
Wind speed (minimum / mean / maximum)	5.5 / 6.9 / 8.1	4.5 / 8.2 / 11.3	4.3 / 8.4 / 12.1	4.0 / 8.5 / 11.8	4.4 / 7.3 / 10.0	3.3 / 7.2 / 10.3	-
Wave height (minimum / mean / maximum)	0.6 / 0.9 / 1.4	0.6 / 1.9 / 3.5	0.3 / 2.1 / 4.0	0.5 / 2.1 / 3.7	0.5 / 1.2 / 2.8	0.5 / 1.2 / 2.6	-
Catch composition	Benthic 47% / Benthopelagic 53%						-
Hooks and lines							
Number of observations	9,368	155	-	12,347	14,046	3,401	**29,794**
Weight (kg)	336,227	29,262	-	14410942.4	19017294.7	5,471,884	**38,900,121**
Value (£)	2,004,587	74,002	-	38,380,942	53,803,303	16,318,725	**108,502,970**
Number of vessels	64	9	-	10	6	5	**21**
Wind speed (minimum / mean / maximum)	4.7 / 7.0 / 10.1	5.9 / 7.2 / 9.4	-	6.5 / 6.1 / 12.3	5.2 / 9.1 / 12.3	6.8 / 9.3 / 12.2	-
Wave height (minimum / mean / maximum)	0.4 / 1.2 / 3.0	0.7 / 1.2 / 2.9	-	1.1 / 3.0 / 4.3	0.4 / 3.0 / 4.2	1.1 / 3.1 / 4.1	-
Catch composition	Benthic 9% / Benthopelagic 91%						-
Gillnets							
Number of observations	83,161	64,518	32,504	1,399	-	23,629	**203,812**
Weight (kg)	4,870,809	7,333,823	3,186,586	1,136,629	-	7,357,315	**22,748,533**
Value (£)	16,351,498	20,848,684	10,007,633	4,959,069	-	43,907,836	**91,115,651**
Number of vessels	101	20	7	2	-	10	**138**
Wind speed (minimum / mean / maximum)	3.0 / 7.2 / 10.6	5.4 / 8.0 / 10.7	5.7 / 8.1 / 10.4	6.2 / 8.4 / 11.6	-	5.7 / 9.1 / 12.5	-
Wave height (minimum / mean / maximum)	0.3 / 1.7 / 3.5	0.7 / 2.3 / 3.6	0.7 / 2.4 / 3.7	2.0 / 2.9 / 3.9	-	1.6 / 2.9 / 4.4	-
Catch composition	Benthic 43% / 42% Benthopelagic / 7% Sharks / 8% Shellfish						-

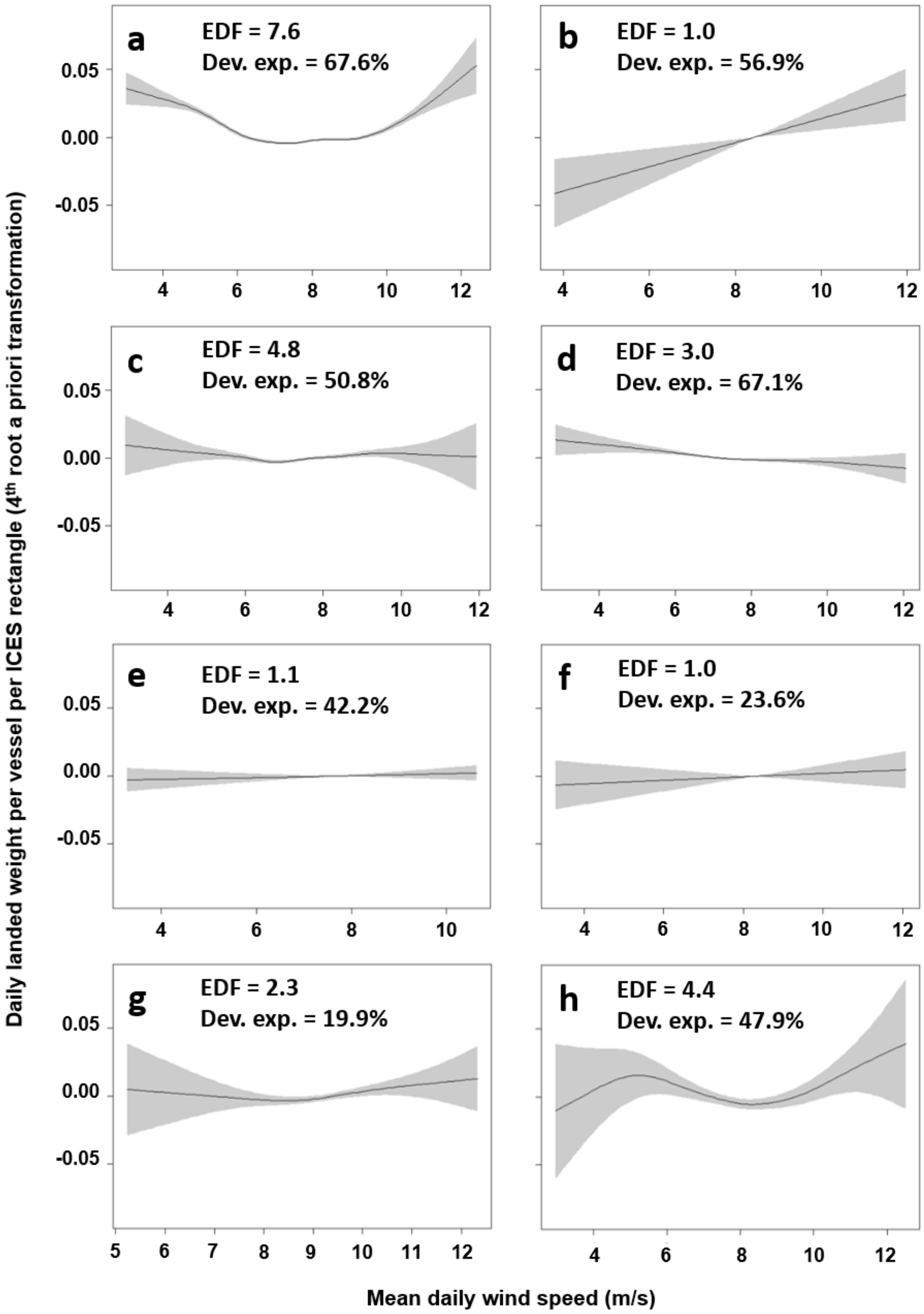

Figure 5.7. Partial daily mean wind speed model smooths from individual gear category generalised additive models with approximate 95% confidence intervals in grey for (a) bottom trawls, (b) midwater trawls, (c) dredges, (d) pots and traps, (e) beam trawl, (f) seines, (g) hooks and lines, and (h) gillnets and entangling nets. Landed catch weight is a priori fourth root transformed. Effective degrees of freedom (EDF) and deviance explained (Dev.Exp) shown for each partial smooth term.

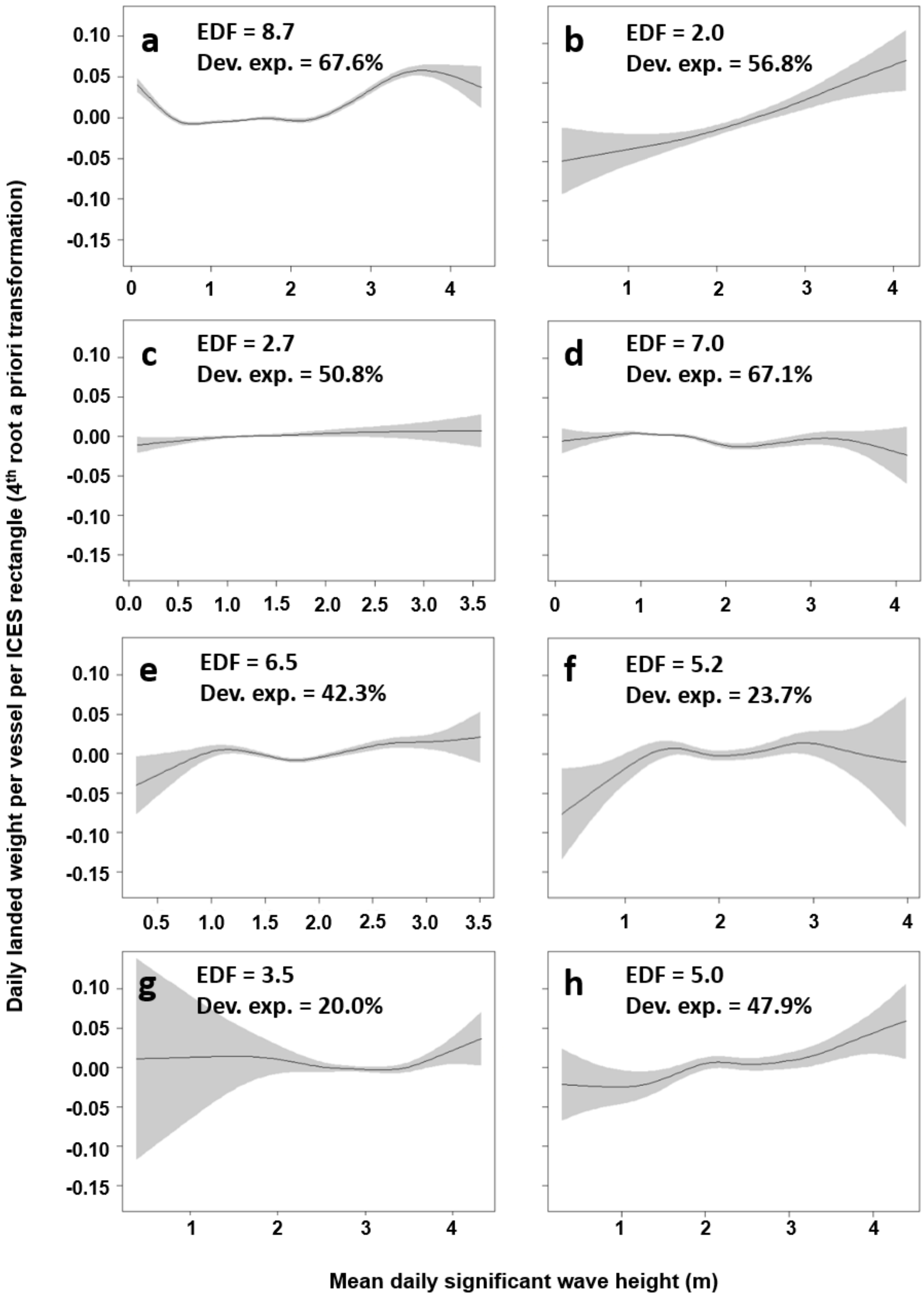

Figure 5.8. Partial daily mean significant wave height model smooths from individual gear category generalised additive models with approximate 95% confidence intervals in grey for (a) bottom trawls, (b) midwater trawls, (c) dredges, (d) pots and traps, (e) beam trawl, (f) seines, (g) hooks and lines, and (h) gillnets and entangling nets. Landed catch weight is a priori fourth root transformed. Effective degrees of freedom (EDF) and deviance explained (Dev.Exp) shown for each partial smooth term.

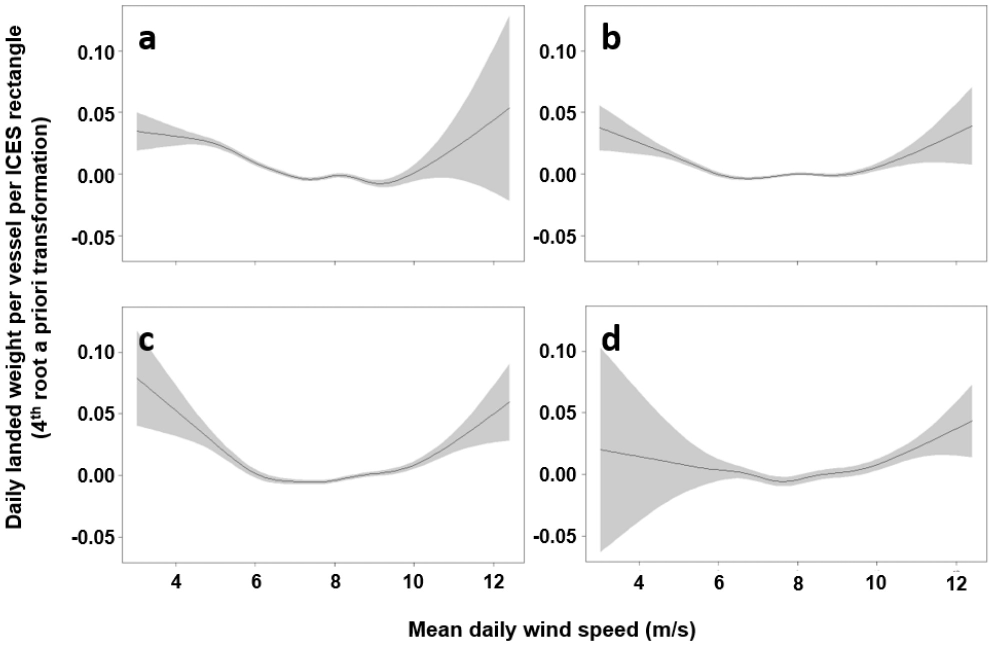

Figure 5.9. Bottom trawl partial daily mean wind speed model smooths for different vessel lengths from generalised additive model with approximate 95% confidence intervals in grey, (a) 10.01–14.99m, (b) 15–19.99m, (c) 20–24.99m, (d) 25–29.99m.

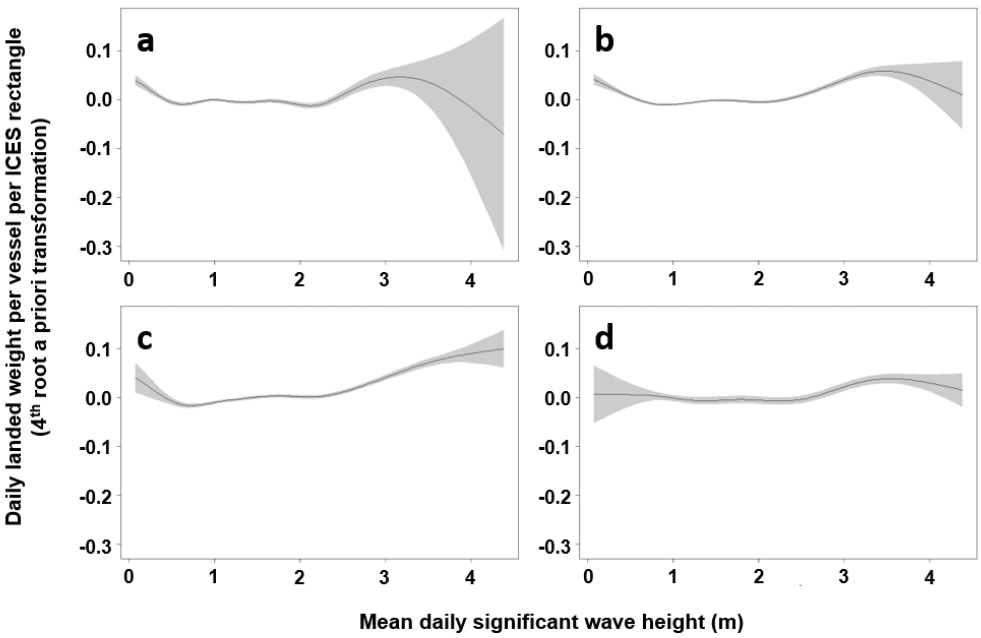

Figure 5.10. Bottom trawl partial daily mean significant wave height model smooths for different vessel lengths from generalised additive model with approximate 95% confidence intervals in grey, (a) 10.01–14.99m, (b) 15–19.99m, (c) 20–24.99m, (d) 25–29.99m.

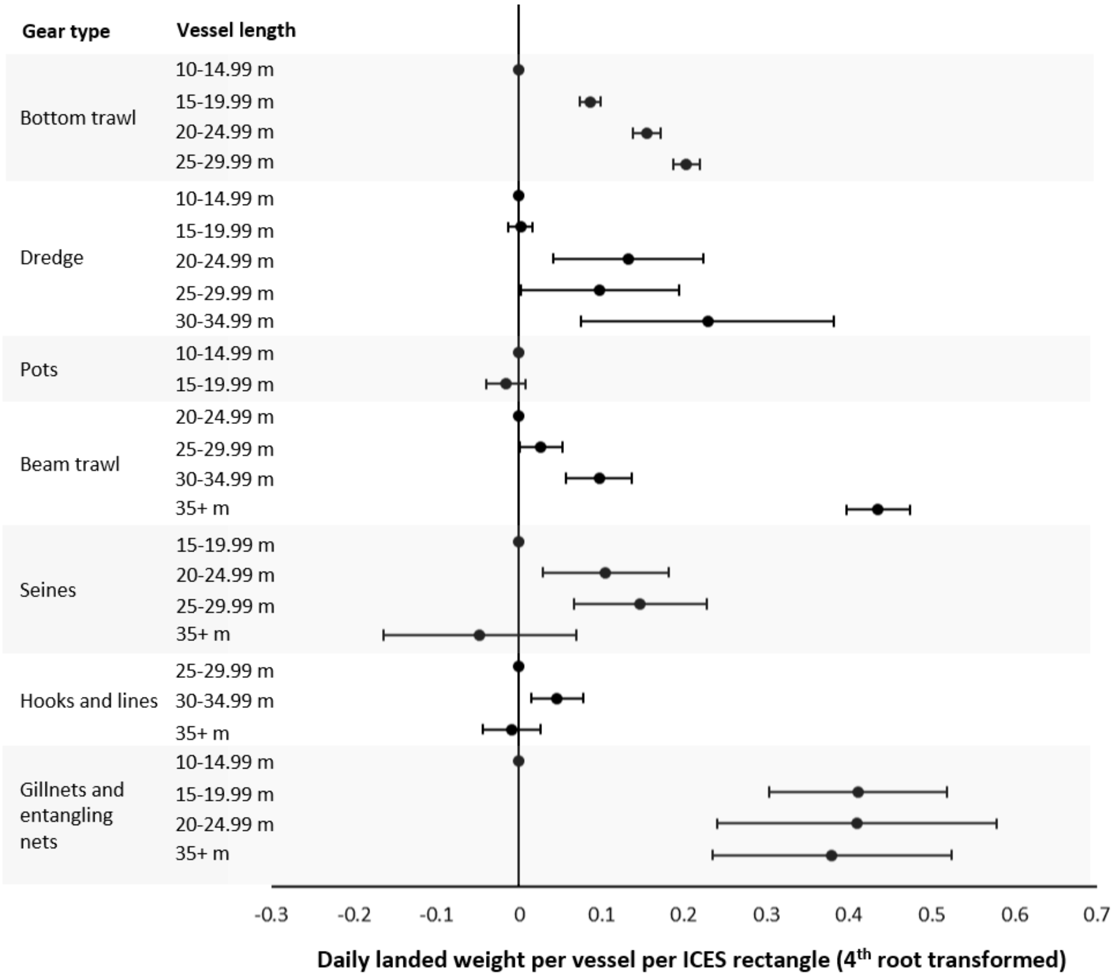

Figure 5.11. Mean parameter coefficient estimates for effect of vessel length category on fourth root transformed landed catch weight per vessel per ICES rectangle, taken from wind speed models for bottom trawls, dredges, pots and traps, beam trawl, seines, hooks and lines, and gillnets and entangling nets. Estimates are each relative to the base category, shown with a zero estimate. Points show mean parameter coefficient estimate and bars show 95% confidence intervals.

Discussion

Given the evidence that storminess may increase in UK waters over the remainder of this century (Robinson et al., 2009; Feser et al., 2015; Mölter et al., 2016), the average wind speed and wave height that the UK fishing fleet has to operate in may rise. This study compliments other studies (Chapters 3–4) that focus on the impact of increased storminess on fishers' daily participation decisions by exploring the impact of wind speed and wave height on catch levels when fishers have chosen to go to sea. A decade of high spatial and temporal resolution data on landed catch from UK vessels in the UK EEZ, as well as concurrent weather datasets, were employed to assess the influence of wind speed and wave height on the productivity of a large mixed-gear national-scale temperate fishery. Stronger winds and larger waves were found to influence landed catch weight, and that this varies by fishing method and vessel length. The findings therefore contribute to our understanding of an important aspect of the vulnerability of UK fisheries to increased storminess.

The effect of wave height on landed catch weight

The finding that bottom trawl, midwater trawl, beam trawl, seine, and gillnet and entangling net landed catch weight increases over at least a section of the range of wave height suggests that deteriorating weather conditions can improve catch levels. This may be the result of a general increase in the availability of fish to gear, possibly through an increase in fish movement and activity during adverse weather (Chapter 3). The increase in fish activity may also be the result of a change in the physiochemical environment caused by wind-induced turbulence mixing warm ocean surface layer and cooler lower layers via a classical Ekman response (Drinkwater et al., 2006; Constantin and Johnson, 2019). Some fishers explain increased fish movement during adverse weather as being the result of an increase in suspended food sediment elevating feeding across the marine ecosystem (Chapter 3). The increase in dredge and beam catch levels with larger waves appears counter to the hypothesis that these gears require seabed contact, which is likely to be reduced by vertical vessel movement in larger waves (Somerton and Munro, 2001; Somerton, 2003; Chapter 3). This suggests that wave-induced improvements in target fish availability to the gear may outweigh reductions in gear efficacy, but confirmation of these mechanisms requires further research.

Some evidence was found for reduced gear efficacy of some gears in the most extreme wave conditions. Bottom trawls and pots and traps landed catch weight fell between 3.5m and 4.5m wave height. For bottom trawls, this reflects previous observations (Wieland et al., 2011) and turbidity-induced reductions in the visibility of gear to target fish (Main and Sangster, 1981; Dickson, 1993). For pots and traps, the reduction in catch at extreme wave heights may be caused by reduced fishabillity as waves pull buoys marking the ends of pot strings under water. However, gillnets and entangling nets also rely on buoys and their catch levels are not affected in the same way. This difference may be explained by the larger size of gillnets and entangling nets vessels (10.01–24.99 m and over 35 m compared to 10.01–19.99 m for pots and traps) maintaining greater fishability at the highest wave heights. Alternatively, the explanation may lie in gillnets' increased efficacy in turbid waters (Olin et al., 2004). Reductions in seine catch levels above 3m wave height may be caused by wave-induced turbidity reducing the necessary visibility of the gear to target fish (Gabriel et al., 2005). The lack of relationship between wave height and hooks and lines catch suggests that neither the fishability nor the catchability of this fishing method are affected by increasing wave height, or positive and negative effects cancel each other out. In addition, given that hooks and lines efficacy reduces in turbid waters because fish cannot see the hooks (Murphy, 1959), it may be that these boats fish in deeper waters where waves produce less turbidity.

Effect of wind speed on landed catch weight

The effect of reduced fishability as wind speeds increased may explain the negative relationship identified between catch levels and wind speed. The negative relationship between catch levels and wind speed from 3.5–8 m/s for bottom trawl, dredges, and hooks and lines, and for pots and traps across the full range of wind speeds may be a result of reduced efficiency as stronger winds make it increasingly difficult to work on deck (Laevastu and Hayes, 1982; Stewart et al., 2010; Chapter 3). The negative effect of wind speed on pots and traps catch levels may also be caused by ever-stronger winds making it increasingly difficult to stay on their gear when hauling (Chapter 3). The increase in catch levels for bottom trawl, dredges and hooks and lines from 8 m/s to 12 m/s wind speed may be the result of the positive effect on catchability (via wind generation of waves) being stronger than the negative effect on fishability. The linear increase in midwater trawl landed catch weight suggests that these vessels do not feel the negative fishability effects of wind speed, which may be because all these vessels in the study are over 35 m in length.

The mediating effect of vessel length for bottom trawls

The finding that 10.01–14.99 m bottom trawl boats were negatively affected by wave height over 3 m suggests that smaller bottom trawl boats are more vulnerable to lower fishability and catchability than larger boats. However, the fact that 20–24.99 m vessels showed no negative effect of the highest wave heights, while 25–29.99 m boats were negatively affected, suggests that other factors may be influencing catch levels that were not included in this study. For instance, vessel power, vessel gross tonnage, and fishing ground attributes may have caused differences in the effect of wave height on catch levels.

Applications

This study contributes to our understanding of UK fisheries' vulnerability to the potentially disruptive effects of increased storminess in two ways. First, whilst the effect of wind speed and wave height on catch levels was non-linear for most fishing methods, with different directions of effect and rates of catch change across the value ranges of wind speed and wave height, most fishing methods showed either little effect or a positive overall effect. The implication of this appears to be that collectively, the UK fleet has low vulnerability to reduced catch levels from increased storminess when vessels are at sea. The vulnerability of the UK fleet to disruption of fishing activity (skippers choosing not to go to sea or returning early to port) is not the subject of this study. Chapter 4 provides some insight into the impact of weather conditions on disruption by focusing on decisions to go to sea.

Second, the study has implications for the risk-discomfort-economic reward trade-offs involved in fishers' short-term fishing decisions. The positive effect of wind speed or wave height on landed catch weight for bottom trawls, midwater trawls, dredges, beam trawls, and gillnets and entangling nets may increase the profit incentive for fishers to take greater physical risk and accept greater discomfort in their short-term fishing decisions. For skippers using these gears, the boats that do choose to accept the physical risk and discomfort of going to sea as conditions become increasingly extreme can, on average, expect to catch more. To compound this, as fewer and fewer fishers choose to go to sea as conditions deteriorate, those that do choose to take a trip will also achieve a higher unit fish price (Abernethy et al., 2010; Chapters 3 and 4). Conversely, for skippers using pots and traps or bottom trawls in the most extreme wave conditions, reductions in expected catch levels may lessen the likelihood of them going to sea if their anticipated profits do not justify the physical risk and discomfort they would face (Chapters 3 and 4). The consequence of this is that fishers using pots and traps in particular will be vulnerable whatever their choices: vulnerable to reduced catch but increased physical risk if they do choose to go to sea, or economically vulnerable should they choose to stay ashore. Future localised studies may reveal variation in the vulnerability of different gear types caused by differences in individual fishing methods, fishing grounds, and species, all aspects omitted from this study.

For bottom trawls, vessel length was found to alter the effect of wave height on catch levels, implying that vulnerability to changing storminess may also differ by the size of vessels. Whilst we found evidence that the catch of bottom trawlers over 15 m in length is resilient to the most extreme conditions, the results suggest that smaller bottom trawlers may be more economically vulnerable to increased storminess. This may be due to the lower fishability of smaller boats in adverse weather, either because of lower operational efficiency slowing production or lower seaworthiness reducing fishing effort (i.e. having to return to port earlier than large boats as weather deteriorates) (Chapter 3). The increase in catch at extreme wave heights shown by 20–24.99-m long bottom trawlers may not necessarily translate to increased economic benefit if they are unable to acquire or lease additional quota (assuming these boats already catch their quota every month). Importantly, the scope of this study did not extend to vessels 10 metres and under in length due to concerns over data integrity. This remains an important avenue for future research.

This study reflects a wide range of fishing gears in a highly developed mixed temperate fishery offering a potential indication of how the productivity of fisheries around the world employing similar fishing methods may be affected by changing storminess. However, the effect of weather on catches may vary by ecosystems, for instance due to differences in species and habitats. For example, fish in the tropics may respond differently to adverse weather compared to those in temperate species. These differences require further research. In developing world small-scale fisheries, the fishability of small low-powered fishing boats may be more negatively affected by adverse waves than in the UK because of the lower seaworthiness of vessels (Ben- Yami, 2000). Research into the effect of weather conditions on catch levels of small-scale fisheries, whilst important, will be more challenging in data poor fisheries. However, high quality meteorological and landings data as used in this study should be available in more highly developed fisheries, such as those in the USA, Canada, Europe and Australia, making it possible to explore comparisons with this UK case study.

Prospective future research

This study provided a broad national-level analysis of the impact of wind speed and wave height on fishing catches. However, limitations in the scope and approach to this study present several prospects for future research to reveal factors mediating the effects of wind speed and wave height on catch levels and the underlying human, ecological and technical fishing mechanisms. First, the role of species was omitted from this study. Second, exploiting established datasets and laboratory-based experimental approaches may reveal fish behavioural responses to wind and wave-induced turbidity, temperature change, and turbulence. Finally, technological advances in deep sea observation of fishing gear (Graham et al., 2004) provide the possibility of observing the effect of weather oceanographic conditions on gear efficacy and fish behaviour.

The national scale of this study may have generated greater variability in catch data due to the variety of species, ecosystems, habitats, the categorisation of fishing methods, and vessel characteristics other than length. Focused local case studies with a single gear type, and a small number of vessels fishing in a smaller area may provide greater precision in relationships between weather conditions and catch levels. Furthermore, the use of average wind speed and wave height variables may have diminished the effect of extreme hourly values. Conducting analysis with maximum daily values and the mean of the daily top 30% of hourly values may better reflect the impact of weather conditions on catch levels. In addition, the daily temporal resolution used masks sub-daily effects of daily weather patterns that may be crucial to explaining the way that weather affects catch. These finer scale processes are difficult to interrogate without hourly catch data, which are not currently recorded by skippers in UK fisheries. Finally, there is some evidence that lagged effect of wind speed and wave height on catch levels for bottom trawls (Ehrich and Stransky, 1999), and future studies could include different time lags to test for this effect.

Conclusion

In this study I have used GAMs to demonstrate that wind speed and wave height affect the daily landed catch weight of a national fleet when fishers go to sea. I have shown that some fishing methods experience increased catches as weather conditions deteriorate, whilst others see reductions. Furthermore, I have demonstrated that for the most valuable part of the fleet, bottom trawls, the smallest vessels in the sample suffer the greatest reduction in catch levels in extremely high wave heights. The findings raise questions about the mechanisms that are at play in the way that wind speed and wave height affect landed catch. They can also help inform the economic and physical vulnerability assessments of fishers and fisheries in the UK to increasing storminess. Fishers using fishing methods that gain from increased storminess may be more physically vulnerable as the incentive to go to take greater risk by going to sea in adverse weather is higher. In contrast, fishing methods that experience lower catch levels in adverse weather conditions (notably pots and traps) face greater economic vulnerability from increasing storminess.

Chapter 6

“Are skippers expert risk managers? Evidence from Newlyn, UK”

Chapter 6: Are skippers expert risk managers? Evidence from Newlyn, UK

Introduction

The changing frequency and intensity of storms resulting from climate change presents a threat to the safety of millions of fishers globally (Sainsbury et al., 2018). Any shift in the distribution of storm intensity and frequency will cause changes in the weather conditions faced by fishers every day across the world's ocean basins (Dowdy et al., 2014; Feser et al., 2015; Mölter et al., 2016; Murakami et al., 2017; Kossin et al., 2020). Fishing is already one of the most dangerous occupations worldwide, with a relatively high prevalence of injury and death (Hasselback and Neutel, 1990; Conway and Lincoln, 1995; Roberts, 2010; Jensen et al., 2014; Kaustell et al., 2016; Fulmer et al., 2019). Weather conditions are a central contributor to the physical risks that fishers face on a daily basis, and increase fishing accident rates (Norrish and Cryer, 1990; Jin and Thunberg, 2005; Wu et al., 2009; Thiery et al., 2016; Rezaee et al., 2016b, 2017; Marvasti and Dakhlia, 2017; Marvasti, 2019). How individual fishers manage the physical risks associated with weather conditions is an important determinant of their capacity to adapt to changing storminess and therefore how physically vulnerable they are to this climate threat. Understanding the level of skill and processes used by fishers to manage weather-related risk can provide insight into the broader vulnerability of fisheries to changing storminess and help inform adaptations to help protect fishers and prevent increasing fatalities.

Adverse weather increases physical risks by inducing movement in vessels, the increased force it exerts on the connection between vessels and attached gears in the water, and the water deposited on deck by waves (Chapter 3). Common fishing accidents leading to fatalities are fishers falling over the side of the vessel (man overboard) and vessel collisions causing the fishing boat to sink (Lincoln and Lucas, 2010; McGuinness et al., 2013). Injuries are caused by slips, trips, appendages trapped in mechanics, being struck by or against an object, entanglements and falls (Lucas and Lincoln, 2007; McGuinness et al., 2013; Myers et al., 2018; Kolawole and Bolobilwe, 2019). Most injuries occur on deck and the majority are sprains and fractures (Rasmussen and Ahsan, 2018). Vessel stability, fisheries management policies, weather conditions, and fatigue have been found to influence the likelihood of fishing accidents occurring (Rezaee et al., 2017). The severity of accident outcomes is influenced by the use of safety equipment, on-board communication technology, and the quality of search and rescue services (Rezaee et al., 2017).

The high incidence of injuries and deaths in the fishing profession has led to extensive interest in how fishers perceive and respond to risk. Fishers recognise that their occupation is hazardous (Kolawole and Bolobilwe, 2019) but are averse to physical risk (Smith and Wilen, 2005; Emery et al., 2014). Nonetheless, fishers tend to downplay the physical risks to which they are exposed, for instance, by comparing it to driving a car (Binkley, 1991), and under-assess physical risks compared to objective measures (Bye and Lamvik, 2007; Davis, 2012). They psychologically adapt to the dangers of their livelihood using fatalism and denial, and develop taboos and ritual behaviours as coping mechanisms (Poggie et al., 1976; Poggie and Pollnac, 1988; Pollnac et al., 1995). Not all fishers have the same perceptions of risk. The extent to which they worry about physical risks varies with prior accident and general fishing experience, cultural differences, and financial investment (Pollnac et al., 1998).

Weather is a key determinant of physical risk at sea and as such, weather forecasts are critical to fishers' assessment of risk (Omar et al., 2017). Detailed and reliable weather forecasts are a necessary aspect of risk assessment to ensure fishers do not take too much risk or unnecessarily miss a fishing trip. Consequently, fishers quickly develop distrust of forecasts and warnings that transpire to be too cautious or optimistic (Malakar et al., 2018). Despite improvements in weather forecast reliability in recent years, modern forecasts are yet to deliver attributes specifically tailored to fishers' risk assessment needs, for instance identifying dangerous wave conditions (Niclasen et al., 2010). Access to forecasts varies between countries. In some countries fishers rely on forecasts broadcast on television (Omar et al., 2017), radio-delivered warnings (Radio Monsoon, 2020), or their traditional knowledge of interpreting the skies (Bezerra et al., 2012). In Atlantic Canada, fishers have begun to embrace digital meteorological information from the media, websites, mobile apps and other fishers who are already at sea (Finnis et al., 2019). However, there is scant evidence available relating to how the recent explosion in digital communication and improvements in forecast accuracy and spatial resolution have affected fishers' assessment of risk.

Fishers' use of safety equipment at sea has received more attention. Given the potential severity of fishing risks is high, and includes death, it is unsurprising that policymakers have focused on the introduction of safety equipment regulations. Some fishers agree with safety regulations in principle (Poggie et al., 1995) and see safety culture, safety equipment, and vessel design and layout as the most important safety factors (Thorvaldsen et al., 2018). However, fishers have several cultural reasons for not adopting the use of safety equipment, including denial of danger, feelings of independence, and affordability (Poggie et al., 1995; Eklöf and Törner, 2002). Some fishers do not see the need for the imposition of formal safety regulations because they perceive it as questioning their seamanship (Knudsen, 2009; Thorvaldsen, 2015) and they believe that they stay safe by evaluating risks and taking precautions (Thorvaldsen, 2013). However, fishers who have experienced a recent serious accident are more likely to adopt safety regulations (Håvold, 2010). Observational studies of fishers' safety equipment use are limited. In Kerala, use of sea safety devices was found to be lower for small scale traditional fishers than for more advanced motorised and mechanised fishers (Sharma and Sethulakshmi, 2019). Little is known about how the use of safety equipment features in fishers' broader approach to risk management.

High fishing injury and fatality rates are widely presumed to be due to a lack of safety management on the part of fishers, yet there is evidence that fishers are adept at reducing risk themselves (McDonald and Kucera, 2007; Morel et al., 2008). Research efforts to date have focused on understanding individual fisher perceptions and attitudes in relation to risk and fishers' willingness to use safety equipment. As a result, we lack a holistic understanding of how fishers actively manage physical risk, for instance the steps they take to identify, assess, evaluate, and treat physical risks. Identifying how fishers manage risk can aid our understanding of fisheries vulnerability to changing storminess and inform adaptation actions.

My aim was to establish how skippers manage weather-related physical risk by assessing the extent to which their actions reflect aspects of risk management theory. To achieve this aim, I employed in-depth semi-structured interviews with skippers fishing from Newlyn, UK. The qualitative methodology employed in this study did not seek to quantitatively measure how fishers manage physical risk or to draw conclusions for a broader population of skippers. Instead, the study sought to capture a rich range of evidence regarding risk management practices for a small group of skippers using different gear types, vessels sizes and vessel designs in a mixed temperate fishery.

Analytical framework

Risk management, including risk assessment, has developed as a scientific discipline over recent decades to deal with many aspects of risk, including enterprise risk, disaster risk and safety risk (Aven, 2016). In their risk analysis glossary (Aven et al., 2018), the Society for Risk Analysis provides seven definitions of "risk". The definition that best reflects the physical risk to which fishers are exposed and that is applied here is, "uncertainty about and severity of the consequences of an activity with respect to something that humans value" (Aven et al., 2018).

The global standard for risk management (ISO 31000) is employed as a framework to assess the extent to which skippers manage physical risk. According to the ISO 31000 'principle and guidelines on risk management' (ISO 31000, 2009), the core of the risk management process consists of: establishing a risk context; risk assessment (which involves risk identification, risk analysis, and risk evaluation); and, risk treatment. Risk treatment options fall into four categories: risk avoidance (stopping an activity so as to not give rise to physical risks at all); risk reduction (taking steps to reduce the likelihood or consequences of exposure to a hazard); risk acceptance (choosing to carry out the activity accepting some degree of risk); and risk transfer (using financial instruments, such as insurance, to transfer some or all risk consequences to other parties). The ISO 31000 standard is designed for use by any individual or group and is not specific to a commercial context. The plain English versions of the ISO 31000 risk management process steps (Marling et al., 2019) have been adopted here as the basis for analysing fishers' management of physical risk in their day to day fishing activities (Table 6.1).

As a framework for the process of risk management, ISO 31000 does not seek to explain human behaviour in relation to risk. Rather, ISO 31000 exists to provide a normative global standard for processes, principles and guidelines in the management of risk that can be applied to any activity and context. Although ISO31000 is not a theory, it carries assumptions and requirements about the nature of risk and how humans behave in relation to risk. ISO 31000 states that risk can be negative (an unwanted outcome) or positive (a desired outcome). Fishers face both positive (good fish catch or price) and negative (physical injury, death poor fish catch or price) risks, although this study focuses on negative physical risks. ISO 31000 requires that individuals or groups consciously think about and make links between the different stages of the process. Furthermore, to follow the ISO 31000 framework, individuals or groups managing risk must rationally process available information to identify, assess, evaluate and treat risk. As such, social-psychological factors that may affect how fishers perceive and manage risk, such as experience and emotions (Kusev et al., 2017), and sense of agency (Damen, 2019), may mean that in reality, individuals do not follow the ISO 31000 process.

Cognitive psychological theories seek to explain how individuals make decisions and these have been applied to climate risk. Such theories provide potential framings to understand why skippers manage risk or adapt to increasing storminess. Protection motivation theory (PMT) (Rogers, 1975) emerged from the health social sciences. PMT is based on the intervention of a ‘fear appeal’, in which a possible negative outcome from an action is highlighted to an individual in an attempt to change their behaviour. Cognitive mediating processes are conceptualised to result from aspects of the fear appeal resulting in a ‘protection motivation’, which changes the individual’s attitude and intent to adopt a new behaviour. Grothmann and Patt (2005) successfully applied PMT to individual adaptation to climate risk by framing the PMT fear appeal as societal narratives of climate risk. They then conceptualised this fear appeal as affecting individuals’ cognitive mediating processes of climate change risk appraisal (perception of risk likelihood and severity) and adaptation appraisal (perception of adaption efficacy, self-efficacy and adaptation cost). Finally, appraisal of climate risk and adaptation are framed as informing adaptation intentions. PMT has also been shown to predict pro-environmental behaviour

(Bockarjova and Steg, 2014). Another highly influential socio-cognitive theory of behaviour, the theory of planned behaviour (TPB) (Ajzen, 1985), states that a behaviour is a function of behavioural intention and perceived behavioural control. Further, the theory posits that behavioural intention is a function of social norms, attitudes and perceived behavioural control. TPB has been supported extensively by empirical evidence (Armitage and Conner, 2001) and applied to predict climate change adaptation (Masud et al., 2016) and risky behaviour (Sullman et al., 2018).

Whilst PMT and TPB provide interesting avenues for future research as theoretical frameworks through which to explain skippers' response to risk, including adaptation to changing storminess, they are not applicable to the specific question pursued in this study. The purpose of this study is not to interrogate why fishers manage risk the way they do or to examine social-psychological aspects of fishers' adaptation to changing storminess, although these are fascinating avenues for future research. The aim of this study is deliberately narrow: to focus on describing fishers' physical risk management practices and compare these to a reference point. The use of a reference point facilitates a structured evaluation of how skippers manage risk across a standard set of risk management process steps. The ISO 31000 risk management standard offers the only global generalisable point of reference against which to evaluate fishers' management of physical risk. In so doing, this study provides valuable insights that can help inform future research and fisheries adaptation to changing storminess.

Methods

Study area

Newlyn plays host to a mixed fishery in the county of Cornwall, which is located on the south-westerly peninsula of England. The Newlyn fleet brings in the second largest catch by value in England and consists of 140 small boats under ten metres in length (72%, of a total of 195 vessels) (MMO, 2019b). Newlyn is home to the majority of Cornwall's larger vessels with 55 over 10 m in length. Fishers at Newlyn use a variety of gear types including nets, pots, hand lines, dredges, purse seines, beam trawls and bottom (otter board) trawls. Whilst the smaller boats in the fleet generally operate within 12 miles of the coast, skippers will take the largest boats as far away as the south of Ireland and the edge of the continental shelf to the south west of Cornwall. Newlyn boats target over 60 species of fish (Cornwall Wildlife Trust, 2020). Cornwall is directly exposed to the south-westerly weather systems arriving from the North Atlantic. Cornwall's fishing activities are influenced daily by weather conditions and storms are common. In 2013–2014 the UK witnessed the worst winter on record (Matthews et al., 2014) and a succession of storms kept many of the medium and small fishing boats in port for an extended period of time causing extensive hardship in Cornwall's fishing communities.

Table 6.1. Plain English descriptions of ISO 31000 risk management process steps, adapted from Marling *et al.* **(2019)**

Process step	Description	Application to fishers
Establishing the risk context	The process of evaluating the external and internal environment in which your organisation operates with respect to the specific objective you are trying to achieve	• Internal – upper weather safety threshold. • Internal - economic need. • Internal – trip profit expectations. • Internal - Crew and owner needs and expectations of physical risk taking. • External - regulations and laws. • External - decisions of other skippers.
Risk identification	The process of identifying the opportunities or hazards (sources of harm) and describing the types of credible risks that could affect your organisation	• Proximate causes of injuries and fatalities. • Environmental, technical and social hazards (i.e. large waves, boat in poor condition, incapable crew).
Risk analysis	The process of determining the relative effect individual risks are likely to exert on your organisation/role	• Likelihood and consequences of each risk, including the effect of weather on risk likelihood.
Risk evaluation	The process of comparing estimated levels of risk against the criteria defined earlier when 'establishing the context'	• Evaluation of total physical risk of being at sea compared to risk context, i.e. safety thresholds, economic rewards, crew and owner expectations and external laws and regulations.
Risk treatment	The process of determining further risk mitigation strategies, with consideration of the hierarchy of controls	• Deciding whether to go to or stay at sea (risk avoidance) • Changing fishing practices (risk reduction) • Use safety devices (risk reduction) • Being at sea (risk acceptance) • Purchase insurance, for instance for property and life (risk transfer)

The United Kingdom has several regulations to protect the safety of fishers, which encourage skippers to manage risks to themselves, their crew and their boat. In 1998, the UK government implemented the Merchant Shipping and Fishing Vessels (Health and Safety at Work) Regulations legislation (UK Government, 1997), under which skippers and owners are required to protect the health and safety of their crew. Among other stipulations, these regulations require employers to carry out and keep up to date a risk assessment. Furthermore, boat owners and skippers have to ensure the health and safety of workers as far as reasonably practical. For this, they use principles of risk avoidance and risk evaluation, taking into account individual work patterns and procedures, procedural adaptation, protective measures on board vessels, as well as available safety training and information on proximate hazards.

In addition, under The Fishing Vessels (Codes of Practice) Regulations 2017 (UK Government, 2017), vessel owners must comply with new vessel construction, vessel maintenance, and seaworthiness requirements. Vessels over 24-m long are surveyed every four years, those between 24 and 15 m in length must be surveyed every four years, and vessels under 15-m long are periodically inspected for seaworthiness by the Maritime Coastguard Agency. After the interviews were completed for this study in the summer and autumn of 2018, the UK ratified the International Labour Organisation Convention No. 188 in January 2019 (UK Government, 2019). The implementation of this convention extended the legal responsibilities of fishing vessel owners and skippers for the safety of their vessel and crew including a legal requirement for the provision and wearing of personal flotation devices or fall/restrain harnesses for crew where the risk of falling overboard has not been eliminated through other actions.

Sample

Interviews were carried out with skippers who fished permanently or on a seasonal basis from Newlyn. Some skippers were primarily based at Mevagissey, on the south coast of Cornwall, but choose to fish from Newlyn during the summer during calmer weather. Pilot interviews were carried out with two skippers at the smaller Cornish ports of Padstow and Porthleven. Data collected from these pilot interviews were retained for analysis. Stratified opportunistic and snowball sampling approaches were used to ensure a variety of gear types and vessel lengths were reflected in the data. I approached skippers on the quayside at Newlyn opportunistically at different times of day to encounter skippers using different gear types. Respondents were asked to provide names of other skippers to approach. Data collection continued until the sample was balanced by gear type and vessel length and no new themes were emerging, which was considered to reflect theoretical saturation (Ando et al., 2014).

In total 26 skippers were interviewed and their boats ranged in length from five to 35-m long with a mean length of 14.9 m. The sample constituted four skippers of beam trawlers, five using static nets, five using bottom trawls, five potters, four using purse seines (known locally as ring nets, three of which also used static nets out of the purse seine season), two using both pots and nets, and one using hand lines. The single hand lining skipper was included to boost the sample size of the smallest vessels. Further skippers using hand lines were unavailable during the study period.

The interview guide (Appendix C) focused on the role of weather in decision making including the way that weather affects short term fishing decisions and the use of weather information in those decisions. The guide was designed to allow respondents to raise and discuss their approaches to managing physical risk, with weather conditions at the heart of the questions. Though the guide was not designed to specifically ask fishers about formal risk management processes or the stages of the risk management process described above, themes relating to this process emerged during interview discussions. Interviews lasted between 30 minutes and four hours. They were transcribed verbatim and transcripts were thematically coded in Nvivo 12 (QSR International Pty Ltd, 2018) based on themes relating to the ISO 31000 risk management process (Table 6.1). The study received ethics approval from the University of Exeter Ethics committee, reference eCORN000055.

Results

Thematic codes reflecting the constituent elements of the ISO 31000 risk management process are presented in turn.

Establishing the risk context

The risk context consists of all the factors used by an individual fisher to decide how much risk to accept. The interview guide did not explicitly question skippers regarding aspects of their external context (factors outside of their business or personal circumstances that affects how they will treat risk, such as health and safety laws and regulations), and none were raised by skippers. However, skippers did describe several ways in which their internal context (aspects of their business and personal circumstances) affected how they choose to treat risk.

As per Chapter 3, skippers expressed the degree of physical risk they were prepared to take on any given day as a combination of economic factors (expected catch levels and fish prices, economic need) and social factors (age, fitness, mental condition, fear of missing out, and where relevant, their crew's abilities and preferences). Several skippers working with crew described their feelings of responsibility for crew safety, comfort, and economic wellbeing and how this affected the amount of risk they would accept. Skippers with children reported taking higher levels of risk after starting a family because they felt incentivised to make a higher income. Most skippers reported taking less risk as they became older, in part because they were suffering from ever-greater disabilities.

Economic need had played a role in some skippers' risk context during their lives. The greater their economic need, the more skippers were prepared to accept greater physical risk. Skippers also emphasised that the levels of catch and price they expected from a trip affected how much risk they were prepared to accept. A key aspect of the risk context for skippers is their own risk tolerance. Skippers described the level of risk they face as being either safe or unsafe, and explained that generally they do not choose to contravene their safety thresholds.

Identifying risks

Weather was described by fishers as the single most important hazard affecting levels of physical risk at sea. They explained that wind speed, wind direction, wind sea, swell waves, and tides combine to generate hazardous conditions (adverse conditions from hereon) that create the possibility of a negative, unwanted outcome occurring. The most commonly identified negative outcomes discussed by skippers were their vessel capsizing or sinking, man overboard, fishers being crushed by moving objects on deck or in machinery such as winches, and slips and trips on deck. Skippers explained that such outcomes are always a possibility, even in fine weather conditions, but hazardous conditions amplify the likelihood and severity of negative outcomes. Whilst skippers generally trusted their ability to manage risk in adverse weather when the risk is isolated, they expressed greater concern about safely navigating the cumulative effect of adverse weather and other risks.

> *“A small problem in fine weather is fine. A small problem in bad weather will definitely turn into a big problem. I always keep an eye…on small problems because the small problem will turn into a big problem.…At some stage, if it's not addressed, it will turn into a major problem.”*

Skippers discussed adverse weather increasing the likelihood of negative outcomes in several ways. “Coming fast”, hitching gear on the seabed or a wreck, can sink a boat in adverse weather because the forces on the boat are greater than in fine weather. Bottom trawl skippers were particularly worried about this because the trawl nets are connected to the vessel by metal ‘warps’ (cables) that are less likely to ‘part’ (snap) than for static gears. Similarly, bottom trawl skippers described the possibility of gear getting caught in their boat’s propeller, which can remove all engine power, leaving the boat at the mercy of the sea. The risk of this occurring in adverse weather is greater because the ability of a skipper to position the boat diminishes and the boat may be turned by the wind and waves into the gear. According to some skippers, the risk of man overboard is elevated by large waves washing over the deck. The forces of the ocean in adverse weather cause a boat to move in extreme ways, making it more difficult for fishers to balance when working on deck and to correctly position their feet and hands relative to machinery and gear. Incorrect positioning in relation to gear can lead to fishers becoming caught up and dragged into the ocean as gear it shot or having a limb crushed in machinery. Similarly, skippers described water from waves on deck making it more slippery, increasing the likelihood of slips and trips.

> *"If the waves come into the scuppers of the boat, it's now washing around. If you pick your feet up to re-balance or stuff like that, is when it all goes wrong. Definitely. On a fine, sunny day, no water involved, no unbalancing, no problem. Definitely worse. Everything's harder, as I keep saying. Everything's more dangerous."*

Risk analysis

Skippers' responses revealed that they continually assess risk, whether on land or at sea. Only one skipper referred to a formal written risk assessment, although the interview guide did not contain specific questions relating to this.

Risk consequences

Negative outcomes were discussed by skippers in broad terms, rather than in detailed specifics. Consequences were described as injury or death, without a detailed continuum of severity identifying the detailed nature of injuries and their relation to weather conditions. Low severity injuries, such as bruises and cuts were mentioned infrequently. High severity injuries, primarily broken bones, were the most commonly raised outcomes. Death was discussed in the context of man overboard and vessel sinking events, for instance when skippers recalled previous accidents that they had either witnessed or that had heard about happening on local fishing grounds. One skipper, who worked single handed or with crew depending on the season, acknowledged that fishing alone leads to a greater severity of outcomes in any given weather conditions.

Risk likelihood

Skippers explained that they gather information about current and future meteorological and oceanographic conditions in order to assess the likelihood of negative outcomes from extreme weather at sea. Digital communications and forecasting were described as a "revolution" in how they assess the likelihood of fishing risks. Some older skippers described calling the Coastguard in order to have the inshore waters forecast read to them. Several skippers described being "caught out" less since the advent of online, more detailed forecasts.

> *"It was gusting 65 mile an hour. They were only giving a 30 mile an hour day and it ended up being 50 miles an hour, gusting 65 and we were*

already out…This is 16, 17 years ago, weather forecast not quite as good as they are nowadays."

The Coastguard could also provide real time wind and wave conditions recorded by the Seven Stones Light Vessel, which is permanently moored between Cornwall and the Scilly Isles in waters near to Newlyn. However, the primary source of weather formation before the advent of mobile technology and proliferation of digital forecasting services, was the Shipping Forecast. Skippers explained that they would religiously tune into BBC Radio Four every six hours to hear the forecast (on the Beaufort Scale) for defined ocean areas around the United Kingdom. Some older skippers still use this service.

> *"I just listen to it [the Shipping Forecast]. It's just force of habit, isn't it? It's my job, I've always done it...you make sure you get to the forecast and write it down. Now it's [the forecast] there at your hand all the time, on your phone or your iPad or your laptop. Then when you put it [the Shipping Forecast] on… you forget what he said…you're not listening to it anymore because you know you just go look at it."*

All skippers explained that they now use mobile and wifi communication to access online forecasts and real time data. They described how immediate access to highly detailed and increasingly reliable weather forecasts at fine spatial resolutions allows them to assess and predict weather risks more accurately. One skipper reported purchasing a mobile signal booster to extend his access to online forecasts at greater distances from shore. The skippers of the largest vessels interviewed were equipped with satellite internet access, providing them with real time and forecast data anywhere at sea. Some inshore fishers explained that they assess risk by observing weather and ocean conditions from the land. One skipper described driving to a headland to witness the sea state, another by looking out of his bedroom window to see how the waves were breaking at the base of St Michael's Mount, which protrudes into the sea near Newlyn. A third skipper explained that he judged the conditions from home by accessing an online webcam pointed out to sea. Several skippers described going to sea to test the conditions and assess the risk likelihood before deciding whether to take a trip or return to port.

"If you're in what I call "last chance saloon", you've got to have a look at it. You've got to have a look at it because you can always turn around. Sometimes, we have to turn around really early to know it's actually out of the question."

Skippers use a wide range of apps to access weather forecasts and real time data and critically assess the reliability of different weather forecast sources in order to decide which to use. Skippers mentioned nine mobile phones apps that they use (XC Weather, Windy, Wind Finder, Wind Guru, Accuweather, Big Salty, Magic Seaweed, PredictWind, and UK Met Office). XC Weather was by far the most popular because of its perceived reliability, simplicity and easily interpreted colour system for wind speed and direction up to seven days ahead. Whilst some skippers used only one source of forecast information, others reported using several apps and some frequently switch based on recent accuracy. Some skippers check multiple apps to access different pieces of information. For others, it is a matter of comparing forecasts to manage forecast accuracy and uncertainty. They explained that they did not trust a single forecast source and by sampling data from multiple sources they were able to triangulate their own judgement of the best forecast. Most skippers reported not trusting forecasts beyond two days and perceived longer-term forecasts to be pessimistic, which they presumed to be the result of forecasters taking a precautionary approach.

"Everyone uses the XC Weather because that one's so easy…Then on the Met Office [online], the inshore waters forecast and the shipping forecast. There's another website I look at lately is windy.com…you press play on it and it's a map and it gives you the live weather, arrows and colours."

Skippers use meteorological and oceanographic data to interpret risk likelihood. They explained that, through their knowledge of how weather patterns affect the sea, they can predict the sea state and from this interpret the nature of the hazards they will face. As a skipper in his sixties explained, "*I know what the sea's going to be like when I get there. After 40 years you know*". Skippers also described interpreting forecasts in the context of recent and current weather.

“If you’ve got sea state disturbed from previous bad weather and there’s another one coming, then it’s already made a start. You can go out there on a flat calm day and it'll blow up a [Beaufort Scale force] five or six and you'll be alright because it hasn’t got going yet. But if it’s a [Beaufort Scale force] five or six or seven and you go out the next day and it’s a [Beaufort scale force] four but it’s still south-westerly, you still got [Beaufort scale force] seven worth of sea there. You know it’s going to be bad because it is bad today. You know it’s going to be bad tomorrow even if it stops blowing. It’s just experience and long term living, eating and breathing weather forecasts.”

Skippers described having always discussed the weather with other skippers to compare their assessments of the associated risk. Some skippers explained that they are just as likely to share forecast data through their mobile phones as they are on the quayside. One skipper showed the interviewer a Whatsapp message in which they had sent a screenshot of a detailed forecast from a mobile forecast app to another skipper to ask their opinion. The importance of social networks for risk assessment is particularly important if a skipper moves to fish in a new area. A skipper explained that when they started fishing seasonally in another part of the UK, they found themselves in higher risk conditions than they had anticipated because they did not know any local fishers with whom to compare risk assessments and lacked the requisite knowledge to interpret the physical risk posed by local weather systems, tides and coastal features.

Fishers explained that they assess risk at sea in real time as weather conditions deteriorate. Some described re-assessing the likelihood of a negative event occurring after a set time period. For instance, skippers described giving it “one more watch”, the period between fishers changing over responsibility for keeping watch (generally two hours). Trawler skippers discussed a strategy of fishing “haul-by-haul”, in which they reassessed the likelihood of a negative outcome occurring after each trawl haul. Skippers mentioned occasions when this strategy led to under-assessment of the likelihood of a negative outcome occurring, resulting in accidental exposure to risks above their safety threshold. Not all skippers agreed with this approach to real time risk assessment. A skipper explained his experience with a skipper he was crewing for earlier in this career,

> *"He was like, "Let's just get one more. Let's just get one more." That's what happens isn't it? It's the people who want to get one more that don't come back… ."*

Skippers stressed the importance of knowing the "capability" of their vessel in different weather conditions. They described developing trust in their boat and an understanding of the likelihood of risks in different weather conditions over time. When first sailing with a new vessel, skippers described assessing risk likelihood to be higher. As they get to know the boat and how it deals with different weather conditions, they begin to incrementally reduce their assessment of risk until they reach a level that reflects an intimate knowledge of the vessel. Skippers also explained that their boat's condition is an important determinant of risk likelihood assessment. Many described having an intimate knowledge of their boat's condition, especially the hull, electrics, engine or gearbox and accepted less risk if they knew that some aspect of their boat was in need of maintenance.

> *"You know what she'll take you through, and she knows what you'll take her through. You got to think about that. When you know your boat's limits and if you think in your mind- if you're in any doubt, there's a no-no. There are some people that have let greed take over and it's ended in tears."*

Skippers' explained that trust in their crew's ability to work safely in poor conditions, individually and as a team, was critical to their management of risk. They expanded that intricate placement of hands and feet relative to the gear and side of the boat represent fine margins of safety. They explained that in bad weather these margins become ever narrower and that properly performing actions that are designed to manage risk is critical to the safety of everyone on board. Skippers emphasised the need for crew to know the intricacies of their tasks and processes and how to carry them out in a safe manner alongside fellow crew, irrespective of the conditions, in order to reduce the likelihood of a negative outcome. A purse seine net skipper explained, *“If I've asked you to tie something in and it comes undone, it really, really makes me cross because that has now become a danger because you haven't done it right the first time. I lose the plot then, because you've got big blue bins of nets surfing across the deck like this that probably weigh 250 kilos. I'm not worried about the bin getting damaged but if somebody gets trapped in between it, they're just going to break their legs.”*

Evaluating risks

After a skipper has assessed the severity and likelihood of risks, they evaluate them against their risk context to decide what risk treatment to pursue. The way they described their decisions included deciding whether the assessed risk level was acceptable relative to their upper safety threshold, their level of economic need and the needs of their crew. They explained that on most days these decisions are easy and are made quickly, either because assessed risks are low, or because a skipper has a very high safety threshold. In scenarios where they considered risks to be borderline relative to their safety threshold, skippers described the process of evaluation as challenging.

“Sometimes it's easy because…you just look at it [weather forecast] and go “no fucking way, too much, I’m not going to deal with that”. Simple. Clear-cut. The worst ones I hate is the iffy ones, “Maybe we might be able to fucking...,” those are the ones I fucking hate. When I'm going to sea I either like to see a fine forecast for the whole trip where I'd like to see a gale of wind for the whole trip and that's a that and we're back home again.”

Risk treatment

Risk avoidance

The most common way that skippers discussed treating risk was by avoiding it, either by deciding not to go to sea, or returning to port. Skippers explained that they generally avoid risk when they evaluate that the risk associated with forecasted or actual weather conditions is greater than their safety threshold. The way that these risk treatments decision were described varied by vessel size and fishing method. Outside of summer, skippers of inshore boats said that they constantly assess the risk of a trip hour by hour to decide whether to avoid the risk or accept it, hoping to find a small window of acceptable risk. Skippers of larger boats and static nets described having to assess weather forecast risk over multiple days in order to decide whether to accept or avoid the risk of a trip. For larger boats this was because skippers are at sea for more than one day. Skippers using static nets, which may be left in the water for days, described the challenge of having to decide how to treat the risk of a whole net cycle: one trip to set the nets and another to haul them, each with different assessed risks and different uncertainties. Some skippers explained that if they expect the level of risk to increase during a trip, they will initially accept the risk by going to sea and then avoid the risk by returning to port when they assess the risk to have become unacceptable.

> *"If we know the weather's going to get rough, we'll make a start while it's still quiet-ish, get out there, and get fishing, and then as the weather turns on, we'll fish and keep going until such times as the weather is too rough, and then we'll come home."*

Risk reduction

Skippers explained that if they evaluate risks to be below their safety threshold, they might accept the risks but take a number of steps to reduce the risk likelihood. The most prominent risk reduction treatment mentioned by skippers was selecting where to fish. Some skippers explained that they limit their distance from shore and port or look for a bay to fish in where they can shelter from the prevailing south-westerly winds. A common strategy described by skippers of medium and large sized trawlers was to fish further east up the English Channel to take advantage of calmer conditions with smaller swell waves. One large static net skipper explained that he cannot generally find his target species in the English Channel, and so instead of heading east, he searches out areas of known weaker tide strength as a way of reducing risk. However, another large static net skipper stated that he refuses to allow weather risk to dictate where he fishes. Two trawl skippers mentioned having to avoid their preferred fishing grounds because of high-risk weather conditions. One trawl skipper explained that the elevated risk of coming fast in bad weather may drive him to avoid fishing in areas with hard bottoms or wrecks, even if they promise better fishing.

“It was less profitable than normal because we couldn't go exactly where we wanted to go, we went where it was more favourable for weather.”

Skippers described investing in their boat and crew in order to reduce risk. Skippers are fastidious about keeping their boat maintained to a high standard to minimise the risk of boat issues creating negative outcomes at sea. Skippers talked about investing in their crew, training them in how to perform fishing processes and actions in such a way as to avoid the risk of injury and man overboard. A skipper will decide whether to avoid or accept the risk presented by a trip based on the make-up and capability of their crew.

“If you’re in a new boat with a crew that you don’t know, no you wouldn’t be making those decisions, because you could be at sea with a bunch of fucking monkeys in a cranky boat and you may not come home. And that’s because you just don’t know how they’re going to react when it gets bad, whether they’re going to stick to their job.”

In contrast:

“If you've got a really experienced crew, that you're all gelled together and you can work as a unit very efficiently, you're laughing. You know that you can carry them through whatever weather you got coming.”

Some skippers detailed other strategies to reduce risk at sea. For the largest (over 15-m long) steel-hulled vessels at Newlyn, which often fish over 100 miles from shore, returning to port may involve a journey of up to 24 hours. Skippers explained that these vessels can remain safely at sea in conditions that have become unsafe to actively fish by turning the boat into the oncoming wind and waves and riding out the storm, a practice known locally as “dodging”. Two medium-sized boat skippers described a process of detailed trip route planning to reduce risk. Using their knowledge of the local effects of wind, wave and tide directions, these skippers explained that they are able to design a route to and from fishing grounds (often indirect) that will minimise the risk exposure to them and their boat. One skipper explained that when he chooses to go to sea in high-risk conditions, he reduces the risk by informing the coastguard of his plans in advance.

> *"Everything you do is deliberate and you get a plan. We show it to the coastguard before as well and let them know exactly where we're to, what conditions are like, and then they'll say, 'Where you're heading for, you should call us again.' There's that comfort as well which is important."*

Skippers alter their operational processes to reduce risk likelihood, taking extra care in decision-making and completing tasks. A medium sized trawler skipper described a meticulous process he follows after he has hauled his net to leave a clear, clean and safe deck for the next shooting of the trawl. Beam trawl skippers described leaving their trawls a short distance below the surface to help stabilise the boat. Pot skippers described working their winches very carefully, taking account of the movement of the ocean. Purse seine skippers explained that they set their nets lower in the water during hauling, which is slower but safer. They also described taking only half the available sardine shoal into their net at one time to reduce the stability risk associated with the weight of the catch alongside the boat. Several skippers mentioned that mental concentration is critical to reducing risk in dangerous conditions. They explained that all conversation ceases in these conditions to allow complete focus on the job at hand and works slows down to reduce the likelihood of errors in hand and feet placement relative to the gear and machinery.

A small number of skippers briefly discussed safety equipment and training. One skipper mentioned that he started to use a life jacket to reduce risk severity after the arrival of his first child. Another stressed the importance of maintaining safety equipment to reduce the outcome severity of man overboard or a sinking ship. One skipper was sceptical about the usefulness of the mandatory sea survival training they had to complete. An older skipper described the futility of attending sea survival training because they felt that as accidents mostly happen in adverse weather, deploying life rafts is next to impossible. In contrast, several skippers recounted their own or others' stories of surviving a boat sinking by carrying and effectively deploying a raft.

> *"You keep your safety gear up to date. You've got your life rack, you've got your EPERB [emergency position-indicating radio beacon]. I know these things you hope you never have to use them. That's certainly there in the*

> *back of your mind as a bit of a comfort should you ever… You've got to keep it all up good."*

Risk transfer

Skippers discussed purchasing insurance for their boat, generally in the context of their operating costs. Insurance was described by some skippers as being a substantial cost, particularly for trawling and dredging. One skipper explained that fishing gear cannot be insured, except where it is lost with a boat, for instance through fire or sinking. The same skipper explained that he was insured for personal injury. Another skipper mentioned that his insurance requires that crew have to undertake sea survival training and have "tickets" before they are allowed to sail on a fishing boat. Only one skipper mentioned claiming on their insurance, which was necessary after their vessel sank in an accident unrelated to weather conditions. Insurance was not discussed specifically relating to the weather risk.

Risk acceptance

The risks that skippers accept are those that remain when skippers go to sea after they have taken risk reduction and risk transfer actions. The level of risk that fishers are prepared to accept appears to differ depending on whether they are making the decision on shore or at sea. Skippers of medium and larger boats described having a higher acceptance level of risk when making the decision at sea than on land and will therefore choose to stay at sea in conditions that they would not choose to go to sea in. A medium sized static net skipper explained,

> *"Sometimes you'll set off on a trip and you're out there and the weather freshens up pretty bad and you'll say, "Well, if we were on the shore now, we wouldn't come out in this, but we're here now, so you've got to make the best of it."*

Discussion

Assessing the physical vulnerability of fishers to changing storminess and designing appropriate adaption actions requires an understanding of how fishers manage weather-related physical risk in their everyday fishing activities.

This study is the first to compare fishers' approaches to risk management with risk management theory. The findings suggest that skippers in Newlyn deal with risk in a manner broadly consistent with the ISO 31000 risk management process. Our findings provide a new perspective on the way that fishers think about and deal with the dangers of their profession.

The Newlyn skippers involved in this study appeared to manage risk informally. They did not discuss, and are unlikely to be familiar with, ISO 31000 or formal risk management proceses more generally. However, people have fished from Newlyn for centuries. Many of the skippers involved in this study came from local fishing families and are intimately aware of fishing disasters, injuries and fatalities within the local community over generations. As such, a culture of safety, consisting of values and artefacts relating to safety (Guldenmund, 2000), may have evolved naturally over time among Newlyn fishers from generations of experience and exposure to extreme risk. Newlyn skippers have always faced particularly dangerous swell wave systems and must regularly contend with storms in the autumn and winter months (Carew, 1769; Masselink et al., 2016). In addition, the requirement for annual documentation of a risk assessment introduced in the Merchant Shipping and Fishing Vessels (Health and Safety at Work) Regulations 1997 (UK Government, 1997) may have generated increased focus on risk management.

Skippers may not have described a formal process of risk management, as might be carried out in a large organisation, but evidence was found that fishers follow each step of the process in a rapid undocumented and repetive manner every day. Whilst the marine environment that Newlyn skippers must contend with is highly uncertain, their activities appear to be highly repetitive in terms of fishing processes and locations over years. As such, the types of hazards and the potential negative outcomes fishers face do not change regularly, and probably only with a new boat, gear or crew. The repetitive risk management process and the stability of risks they face may be a reason why they do not formalise their management of risk.

Skippers followed every step of the ISO 31000 risk mansgement process to some extent. Skippers discussed their internal risk context (own safety thresholds, economic need and their crew's needs and capabilites) but did not explicitly mention the regulatory and legal aspect of their external risk context (and were not prompted to do so). Fishers are used to operating in a highly regulated environment and it is likely that they are aware of the requirement to complete a risk assessment. As per ISO 31000, skippers identified hazards (e.g. large waves), proximate causes (e.g. leg caught in gear), and potential consequences (e.g. man overboard). Although skippers treated risks to reduce consequences, for instance by maintianing their vessel to a high standard to reduce the potential for small risks to become amplified in advserse weather, they tended to focus their risk analysis and risk treatment on risk likelihood. Skippers demonstrated their use of avoidance, reduction and acceptance risk treatments. That risk transfer (insurance) was only mentioned briefly by a small number of skippers and not directly in relation to weather risks may not be because insurance is purchased by few skippers. It is more likely that it is because fishers do take out insurance for their vessel, personal injury and third party liability because of the significant economic value at stake, and that doing so is a given. Fishers buying insurance but it not featuring in their risk management thinking may be akin to a car owner buying car insurance and then not thinking about it in terms of how they manage the day-to-day risks of driving.

Skippers interviewed in this study held strong views about their risk context (the first stage of the risk management process), in particular their willingness to take physical risks. The study revealed a wider range of risk perspectives and causes of individual differences than has previously been reported. Fishers have to date been predominantly characterised in the literature as having personalities that minimise perceived dangers (Pollnac et al., 1998) and using denial as a psycho-cultural adaptation to the risks they face (Poggie, 1995). These characteristics may be true for Newlyn skippers and are not mutually exclusive with being expert risk managers. Even the moderate level of risk that some of the skippers were willing to accept might appear extreme relative to an average person. This could be the result of the skippers underrating risk relative to objective assessments (Davis, 2012), being more resilient to extreme risk because they frequently encounter it (Morel et al., 2008), or because of their social and economic circumstances (Chapter 3; Chapter 4). However, fishers' may be willing to accept high levels of risk because they perceive that they have greater control through their risk management activities. Perceived control has been shown to increase risk taking in other contexts (Horswill and McKenna, 1999; Damen, 2019).

The finding that fishers rely heavily on weather data to analyse risk emphasises the importance of fishers having timely access to reliable weather forecasts and current conditions. The way in which Newlyn skippers use weather forecasts, real time weather data and discussions with other skippers to assess weather-related risk likelihood reflects recent research in Atlantic Canada (Finnis et al., 2019). However, whereas all Newlyn skippers interviewed have adopted digital access to weather forecasts and data, uptake in Atlantic Canada is less complete (Finnis et al., 2019). Furthermore our findings differ from Finnis et al. (2019) in that we found that skippers observe sea states from land and go to sea to test conditions before deciding whether to avoid or accept the risk of a trip.

The central role played by digital communication technology and high quality, high resolution weather forecasts and real-time data in skippers' risk likelihood assessments emphasises the importance of adaptations in this area, particularly outside of highly developed industrial fisheries such as Newlyn. Adaptive improvements in marine weather forecasts and real-time data would provide fishers with the tools they require to effectively asses the risks they face. Fishers have specific weather forecast needs (Niclasen et al., 2010) because there are specific meteorological and oceanographic dimensions that affect the risks they face and their fishing success (Chapter 3). The importance of trust in forecasts highlighted by Newlyn skippers reflects previous findings (e.g. Malakar et al., 2018) and demonstrates the criticality of reliable forecasts. The development of local weather forecasts by national meteorological offices specifically for fishers should take place in consultation with skippers to ensure that their needs are met and to benefit from their traditional risk knowledge. Even in developed fisheries, skippers' ability to accurately assess physical risks would be enhanced by improvements in the forecasted wave environment (Niclasen et al., 2010). Access to forecasts at sea remains a barrier to effective risk management in many fisheries around the world. Efforts to increase access to weather forecasts and warnings at sea through affordable technological innovations have been made in India and on Lake Victoria (Tushemereirwe *et al*., 2017; Vora et al., 2018; Shibu et al., 2019; Radio Monsoon, 2020). A well-funded multinational research effort to innovate in this space could generate a step change in fisheries risk reduction.

Risk reduction measures used by skippers at Newlyn focused on reducing risk likelihood as opposed to risk consequences. This provides an interesting contrast to the prevailing trend that health and safety decisions are generally influenced by severity, because people find it more difficult to conceptualise likelihood than severity (Woodruff, 2005). Only a small number of fishers discussed use of safety equipment, which could be due to reducing risk likelihood being a greater focus in their risk management efforts. This does not necessarily mean that they do not keep safety equipment on board, they may simply not have thought it important enough to mention. Either way, it could be the result of the skippers rejecting interference from regulators (Loughran et al., 2002) or having assessed the risk of man overboard to be low because in their experience it is a low likelihood risk (Brooks, 2005). The International Labour Organisation's Work in Fishing Vessel Convention (ILO188) 2007 was ratified by the United Kingdom in January 2019, shortly after this study's data was collected (UK Government, 2019). This regulation far reaching consequences for risk management in UK fisheries, including the legal requirement for fishers to wear personal flotation devices or safety harnesses if the risk of man overboard cannot be eliminated. It provides an opportunity for further research to study the impact of new regulations on Newlyn fishers' approach to risk management.

Other risk reduction strategies employed by Newlyn skippers have been documented elsewhere. The use of "dodging", a strategy to reduce risk whereby skippers turn their boat to face the wind and waves and ride out a storm, has been identified in previous studies, albeit under the different local nomenclature of "heaving to" (Morel et al., 2008) and "jogging" (Finnis et al., 2019). Newlyn skippers' use of spatial fishing effort allocation to reduce risk reflects a previous study of French trawlers (Morel et al., 2008). Maintenance of vessel structure, electronics and mechanics is recognised an important aspect of reducing physical risk is recognised more broadly, for instance by the FAO's in their

‘Safety guide for small fishing boats’ (Gulbrandsen, 2009). Safety guides such as this can support the adaptation of developing world small-scale fisheries to changing storminess. Policy makers could further support skippers’ maintenance of vessels through the provision of financial support, increasing access to credit, and delivering technical training. The level of expertise that skippers show in managing risk suggests that policymakers should co-develop fishing risk management regulations with skippers so that the regulations reflect fishers’ traditional risk knowledge.

My findings suggest that skippers are far more skilled in their management of risk than previously understood and that their use of risk management approaches is potentially under-recognised. This may be because safety science tends to marginalise local and system-specific safety knowledge (Almklov et al., 2014) or because fishers often downplay their approach to aspects of their management of risk, referring to it as “common sense” (Power, 2008; Thorvaldsen, 2013). The idea of skippers as risk managers builds on previous studies in the USA and Norway, which found that regard for safety is the norm among fishers, that fishers evaluate risks and take precautions, and that skippers use expert strategies to stay safe (McDonald and Kucera, 2007; Morel et al., 2008; Thorvaldsen, 2013). In the USA study, fishers identified a number of factors to reduce physical risk, including specific safety actions, maintenance of gear and boat, decisions relating to the weather, and the ability of the crew to work cohesively (McDonald and Kucera, 2007).

In Newlyn, the expert management of risk by the skippers spoken to indicates that these fishers may be well placed to manage the increased physical risk of increased storminess in UK waters. They have benefited from a revolution in digital access to better weather forecasts, real-time weather data, and the experience of frequent exposure to high-risk conditions. The findings suggest that Newlyn skippers have a lower sensitivity to the physical risk of changing storminess because their risk management skills allow them to make better judgements about when it is safe to go to sea, and to reduce risks to acceptable levels when at sea. Furthermore, Newlyn skippers’ risk management expertise may help them to recognise and respond to changing storminess, providing them with a degree of adaptive capacity (Cinner et al., 2018). Consequently, risk management capabilities and tools can be important determinants of fishers' physical vulnerability to changing storminess.

Concluding comments

Through a qualitative approach, this study provides evidence that skippers in a temperate mixed fishery at Newlyn, UK, are expert risk managers, identifying, analysing, evaluating and treating the extreme physical risks to which they are exposed at sea. Our findings emphasise the need to deepen our understanding of how fishers manage risk. Future research should explore how skippers' management of risk differs by local cultures, fishery history, individual personalities and risk attitudes, local climate, oceanography and exposure to extreme weather events. This study suggests that Newlyn skippers have a strong risk management capacity from which to respond to increasing storminess in UK waters over the remainder of the 21st century and therefore a low vulnerability in this particular aspect. Policymakers have historically failed to recognise the informal risk management knowledge and skills that fishers possess. Future efforts to help fishers adapt to the elevated dangers of increasing storminess should engage skippers in order to harness their risk management expertise.

Chapter 7

Discussion

Chapter 7: Discussion

This thesis has employed a mixed methods interdisciplinary bottom-up approach (Conway et al., 2019) to investigate the role of short-term human behaviour in the vulnerability of resource users to changing storminess in a social-ecological system. A review of the field of changing storminess and capture fisheries revealed that it is new field of study, and an interdisciplinary research roadmap was proposed. Using a case study of the United Kingdom's fisheries focusing on southwest England, fishers' behavioural responses to adverse weather were shown to influence the extent to which they are sensitive to physical and economic risks. Furthermore, fishers' behavioural responses varied among individuals. In addition, evidence was found that fishers' catch success is affected by wind and wave conditions and varies by fishing method. Finally, it was found that despite the dangers of their profession, Newlyn fishers are expert risk managers and so exert some control over their sensitivity to physical risk. These findings contribute to theoretical concepts of fisheries climate vulnerability and may help to inform fisheries vulnerability assessments and adaptive action.

Key findings

As changing storminess and global capture fisheries is a wide open field, a research roadmap was proposed in Chapter 2. Infographics were employed to communicate keys aspects of the issue. A non-systematic review of global past and projected changing storminess were presented by ocean basin to provide an indication of spatial heterogeneity. Examples of ecological impacts of storms on fish and marine habitats were displayed along with socio-economic impacts of extreme storm events on fisheries since the turn of the 20^{th} century to demonstrate the social-ecological risks that storms present to global fisheries. I argue that progress is required in climate modelling of storms, understanding how storms effect fish and fishers and the linkages between these, and using this new knowledge to better understand the vulnerability of global fisheries to changing storminess and adaptation options. The proposed research roadmap has been cited by the IPCC (IPCC, 2019) and has started to influence research in the area of fisheries' behavioural response to storms (Pfeiffer, 2020).

Qualitative in-depth semi-structured interviews employed in Chapter 3 revealed that a complex interaction of meteorological and oceanographic processes affect physical risk, discomfort and trip profitability. Skippers working from Newlyn, UK, were shown to trade off physical risk, discomfort and economic rewards in their daily fishing participation decisions. It was revealed that Newlyn skippers have a binary perspective of safety, and generally do not choose to be at sea in conditions they judge to be unsafe. The identification of discomfort as a physical experience affecting short-term decisions in parallel with physical risk, may provide a new perspective on the importance of the challenges of working at sea. Chapters 3 and 4 provided evidence that fishing methods, vessel characteristics, individual fisher socio-economic differences, and fishers' response to social dynamics with crew and other skippers create heterogeneity in their behavioural response to storms. Feelings of responsibility for their crew's safety, comfort and economic wellbeing featured in the decisions of some skippers, as did a fear of missing out on a successful trip by choosing to stay ashore. Economic need was identified as an important driver of willingness to take physical risk and suffer discomfort. Chapter 3 is the first to qualitatively describe in detail how weather features in fishers' short-term decisions. It adds weight to previous empirical evidence of physical risk-economic reward trade-offs (Smith and Wilen, 2005; Emery et al., 2014; Pfeiffer, 2020).

Chapter 4 confirmed the nature of the trade-offs identified in Chapter 3 using a stated choice experiment with fishers operating in Cornwall. Econometric analysis of the choice experiment data provided evidence that fishers have non-linear preferences for wind speed and wave height. Skippers' initially valued an increase in wind speed and wave height, before their preferences reduced at an increasing rate as wind speed and wave height became more extreme. Chapter 4 supported the evidence that skippers' trade-offs vary by individual, technical fishing, and social dimensions. Furthermore, Chapters 3 and 4 also revealed that in their trade-off decisions, fishers choose between their exposure to the risks of death and injury or lower income.

The effect of waves on the physical risk faced by Cornish purse seiners described in Chapter 3 was confirmed by the choice experiment results in Chapter 4. Purse seine skippers described a safety threshold of 2-m-high waves during interviews and this was closely aligned with the peak of their utility from wave height (Chapter4). The ability of small boats to exploit fishing opportunities near to the land during strong winds and large waves identified in Chapter 3 was not confirmed by evidence from Chapter 4. However, skippers using hook and lines, which tend to be the smallest boats in the Cornwall fleet, had the greatest propensity of all sampled fishing methods to go to sea in adverse weather. This may be because the experiment assumed a favourable wind direction, allowing hook and line boats to fish safely in the lee of the land. Chapter 4 represents one of the first applications of the choice experiment methodology to study commercial fishers' preferences (see for example Eggert and Lokina, 2007) and, as far as I am aware, the first to feature physical risk in short-term decisions. Whilst other revealed preference studies have explored physical risk and economic reward trade-offs in fishers' decisions (Smith and Wilen, 2005; Emery et al., 2014; Pfeiffer, 2020), this the first to identify sources of individual heterogeneity.

A study was designed to resolve interactions between weather and vessel movements using satellite vessel monitoring system (VMS) data for 12 and over metre boats operating from Cornish ports. However, this was not carried out due to data access issues. This study would have provided further evidence of fishers' daily participation decisions to link with findings of Chapters 3 and 4. There remains merit in future research analysing the effect of weather variables on observed vessel behaviour, for example whether a boat is in port or at sea and spatial location when at sea. By observing the impact of weather conditions on fishers' participation decisions spatial effort allocation in this way, these revealed preference studies could triangulate the findings of the stated choice approach in Chapter 4. Increasing our understanding of weather influence on daily participation decisions would help to further inform fishers' vulnerability to changing storminess by ascertaining how adverse weather limits fishing activity. The spatial fishing effort analysis using satellite observational data could then be associated with qualitative participatory mapping data to provide a rich explanation of skippers' spatial effort decisions. The effect of weather conditions on spatial fishing efforts may have broader consequences for ecological sensitivity and fisheries management.

Chapter 5 employed an empirical analysis at a national fishery level to confirm, for vessels over 10 m in length, the finding from Chapter 3 that the impact of wind speed and wave height affects catch levels and differs by fishing methods. The majority of relationships were non-linear and broadly similar for wind and waves within each gear type. The effect of wind speed on landings was found to be highly uncertain for most gear types, but relationships with wave height had greater certainty. Effects of wind speed and wave height varied across the eight fishing methods. Wave height predominantly has a positive or neutral effect on landed catch weight. The effect of wind and wave height on landings generally confirmed skippers' qualitative description of weather condition impact on catch success in Chapter 3.

Landings of large industrial midwater trawlers and vessels using gillnets and entangling nets increased with wind speed and wave height. Conversely, pots and traps was the only fishing method found to experience reduced landings with increasing wave height, suggesting that they are the most vulnerable gear type to increased storminess. Skippers using otter board trawls in Chapter 3 described their catches reducing to unprofitable levels before conditions became unsafe. Chapter 5 provided some empirical evidence to support this, showing a marked decrease in catch levels in the most extreme wave conditions. These findings help inform our understanding of the role of trip rewards in the trade-offs highlighted in Chapters 3 and 4. Expected trip profitability is a critical aspect of these trade-offs and Chapter 5 provides evidence that catch does alter with weather conditions, particularly wave height. The data used in the analysis represented 86% of landed value from UK vessels in the UK EEZ for 2008–2017 and therefore provided a robust national perspective. Previous studies have explored the effect of weather factors on catch at fine temporal resolution over a 1–2-year period for single species and a narrow selection of fishing methods (Perry et al., 2000; Maynou and Sardà, 2001). However, in this study a fine temporal scale dataset was compiled and exploited that was novel in its extent of temporal scale (a decade), spatial scale (a national EEZ), spatial resolution (approximately 30 nautical mile grid cells), and variety of fishing methods (39 gear types placed in eight categories). This novelty allowed a study of weather conditions on fisheries catches of unparalleled scope.

From a social-ecological systems perspective, the positive impact of wind and waves on catch levels may be somewhat surprising as storms are generally associated with negative outcomes. The reasons for this are likely due to improved catchability, as there was no evidence provided in Chapters 3 that fishability improves during storms. Little observational evidence exists to explain this positive effect, which may be the result of ecological responses to wave-induced turbidity and temperature changes. The social-ecological linkages that determine how the ecological effects of storms impact fisher behaviour, and how fishers' behavioural responses to storms, in the form of daily participation and spatial effort decisions, affect ecological aspects of the system are of interest because they may be important in explaining fisheries outcomes from changing storminess. Whilst this thesis has focused on short-term dynamics, social-ecological linkages may also take place over longer temporal scales. For instance, storms may cause medium-term changes in species distributions (Chapter 3), forcing fishers to change their spatial effort or target different species. This could have economic implications for fishers operating in a management regime using individual fishing quotas. In the human aspect of the system, fishers may make boat investments that improve their resilience to adverse weather (Chapter 6), allowing them to exploit new fishing grounds further from shore, increasing pressure on fish populations on the new grounds.

The analysis of the relationship between landings, wind speed and wave height in Chapter 5 provided a broad national-scale perspective. Although Chapter 3 revealed that a wide range of weather variables affect catch levels, including wind direction and tidal strength, Chapter 5 focused on wind speed and wave height. However, data is available for these additional weather variables, so researchers could employ them in future research. Chapter 5 did not seek to reveal effects of weather conditions on landings at regional or local levels. Carrying out a similar analysis for homogenous local fisheries would facilitate testing how weather conditions impact landings by species. Furthermore, the same dataset employed in Chapter 5 could be used to investigate the effect of weather conditions on total daily landings at a regional fleet resolution. Daily total fleet landings would vary with the number of boats choosing to participate and their fishing success. As such, by moving away from individual vessel landings to an aggregated fleet catch resolution, fishers' choices to stay ashore would be reflected in how weather conditions affect landed catch levels. Volunteer logbooks, diaries and satellite observation data could also be used to ascertain when fishers choose to go to sea or stay ashore. Although Chapter 5 described the way in which wind and waves affect landings, further research is required to build on existing evidence of the mechanisms explaining why, particularly in relation to gear efficacy and fish behaviour.

Skippers at Newlyn were shown to be expert risk managers in Chapter 6, explaining and enriching the binary notion of safety that fishers described in Chapter 3. Evidence was found that the skippers identify, analyse, evaluate and treat the physical risks they face at sea, which are created and amplified by extreme weather. The recent revolution in digital forecasts that can be accessed via mobile phones, laptops, and satellite communication, and the increasingly fine spatial resolution and reliability of these forecasts have elevated the ability of skippers to analyse risk and make better informed risk treatment decisions. This expertise may reduce the sensitivity of Newlyn skippers, at least, to the physical risk of increased storminess projected for UK waters over the remainder of the century (Feser et al., 2015; Mölter et al., 2016) and suggests that these skippers may have a strong learning adaptive capacity (Cinner et al., 2018) relating to risk management. Whether skippers in other part of the UK and world also possess expert risk management skills is an interesting question for future research. The findings in Chapter 6 are important because they challenge the characterisation of fishers as limitless risk takers who, through resistance to the adoption of safety equipment, are not willing to manage risk. Furthermore, the insights from the Chapter 6 have implications for how policymakers and fisheries managers seek to reduce fatalities and injuries. The local risk knowledge shown by the Newlyn skippers involved in the study suggest that policies should be designed participatively with skippers to harness their expertise.

Reflections on research decisions

The use of a multiple methods in this thesis has proved valuable in linking results between studies. Employing qualitative and quantitative methods and using inductive and deductive approaches has proved effective in achieving the aims of the thesis outlined in the introduction. The inductive approach of the semi-structured interviews in Chapter 3 facilitated the identification of new ideas in an under-studied field. Subsequent application of quantitative approaches in Chapters 4 and 5 to test aspects of these ideas provided further insights. The interdisciplinary approach to the thesis, calling on social sciences, ecology, meteorology, and oceanography was necessary to study the effect of environmental change on a complex social-ecological system. Collaborating with scientists from these disciplines has been enlightening and challenging. The long-standing scientific culture of adopting traditional narrow discipline-specific epistemologies, methodologies and language undoubtedly has advantages for expertise and communication within a field. It also contributed to a style of writing that is more accessible to a wider audience, which is critical in a problem-focused context that is of interest to scientists of many disciplines. However, between disciplines there can be misunderstandings and conflicting expectations that must be managed. Training to be a scientist in an applied, problem-focused environment requiring the navigation of these challenges has been enormously beneficial.

My choice of the UK, and Cornwall in particular, as a case study for this thesis had benefits and drawbacks. The highly diverse mixed fishery targeting an array of fish species with a wide variety of fishing methods, and a plethora of vessel characteristics, provided a rich source heterogeneity to study. Such diversity increases the likelihood of research insights having relevance to other fisheries around the world, particularly for those that use similar fishing methods and vessel sizes. However, the specificity of the case study and the chosen sampling methods used in Chapters 3, 4, and 6 may limit the generalisability of the research.

I chose to focus the research in this thesis on short-term behaviour, but the way in which extreme events affect fishers' long-term decisions, such as exiting a fishery or investing in the seaworthiness of vessels, and the way in which aspects of adaptive capacity (Cinner et al., 2018) influence these decisions is of great interest. In addition, the idea of economic risk, the variability of economic outcomes from a fishing trip, including operating profit (i.e. catch value less costs) and fishing asset losses (i.e. gear damage or loss and vessel damage), was not addressed in this thesis but warrants investigation. Fishers have been shown to be averse to economic risk (Mistiaen and Strand, 2000), and if weather conditions affect the variability of trip profitability, then this may influence fishers' response to storms.

Implications of findings for fisheries climate vulnerability

The focus of this work has been on explaining fisher behaviour in order to better understand the vulnerability of fisheries to changing storminess. This thesis also sought to explore how current conceptualisations of fisheries climate vulnerability encompass the direct risks that storms pose to fishers. This thesis has employed the most established conceptualisation of vulnerability (McCarthy et al., 2001). Although refinements were made to the concept of climate risk by the IPCC in Assessment Report 5 (IPCC, 2014), the idea of sensitivity remains unaltered in the new model. The concept of sensitivity as the susceptibility of fisheries to the exposure of a climate stressor is often interpreted in a social context as the extent to which a community is dependent on fisheries for livelihoods, nutrition, and food security (Allison et al., 2009; Cinner et al., 2013; Colburn et al., 2016; Hoang et al., 2020; Jara et al., 2020). This interpretation remains valid for changing storminess, because a community that relies heavily on fishing for wellbeing will be more heavily impacted than one for which fisheries are of little importance. However, this interpretation of sensitivity does not account for the direct exposure of fishers to the direct physical threat of changing storminess at short temporal scales.

This thesis presents evidence that the effect of a storm on an individual fisher and their community is mediated by the fisher's own behaviour. As such the concept of sensitivity to changing storminess should reflect fishers' behavioural response to storms. If they choose to remain ashore or return to port at the onset of adverse weather, sensitivity to socio-economic perturbation is high. Conversely, if they decide to go to, or stay at, sea as a storm approaches, they may continue to catch fish, but risk loss of life, disability, and loss of fishing assets. Fishers' behaviour therefore dictates the risks to which they are sensitive. As such, exposure to the same environmental conditions can lead to sensitivity to different risks depending on fishers' choices. Importantly, although going to sea in adverse weather conditions presents the opportunity of catches, it does not eliminate economic risk. Although Chapter 5 provides evidence that, for most gear types, catches will not reduce in adverse weather, catches remain highly variable. As such, a trip in adverse weather may bring high physical risk and low catches. Furthermore, going to sea in adverse weather introduces the economic risk of a fisher losing or damaging a boat or fishing gear, which can result in extensive economic losses.

Factors such as vessel length, fishing method, crew capability (Chapters 3 and 4), and risk management ability (Chapter 6) will determine the extent to which fishers who choose to be at sea in a storm are sensitive to physical risk. A large steel-hulled gillnetter operating from Newlyn may choose to stay at sea because it is resilient to even the most extreme weather (Chapter 3). For these boats, not only are they insensitive to physical risk, but on average they will benefit from better catch levels in stronger winds and larger waves (Chapter 5). These skippers stand to benefit economically from future increases in storminess in UK waters. For the smallest boats that have lower safety thresholds, being at sea in adverse weather brings heightened physical risk. If these skippers use pots and traps, they will be more sensitive to economic risks because on average they catch less as weather conditions worsen (Chapter 5). Fishers' physical and economic sensitivity is therefore individually differentiated, with implications for assessment of vulnerability and adaptive action.

There is increasing evidence that storminess will change over the remainder of this century, and that it will differ across the world's oceans (Murakami and Sugi, 2013; Hartmann et al., 2013; Feser et al., 2015; Kossin et al., 2016, 2020; Mölter et al., 2016; Murakami et al., 2017). Therefore there is a need for this to be included in fisheries climate vulnerability assessments, but this has yet to happen, with the exception of one example for Dominica (Pinnegar et al., 2019), which reflected the exposure of different parts of the island to storms. Change to the theoretical construction of fisheries climate sensitivity has implications for the indicators used in vulnerability assessments. For the sensitivity of fisheries in Cornwall, aggregated indicators for economic need, gear types, and vessel size should be included. Although Chapter 5 provides evidence at the UK level for the effect of wind speed and wave height on catch levels when fishers do go to sea, the insights from Chapters 3 and 4 cannot be generalised at the national scale because of the methodology or sampling strategy employed. Research into the trade-off decisions of skippers across gear types and vessel lengths at the UK level would be required to confirm this.

Applications

The results in this thesis can be applied to inform the development of climate risk insurance for fisheries adaptation to changing storminess. Climate risk insurance (Linnerooth-Bayer and Mechler, 2006; Surminski et al., 2016), often in the form of parametric instruments that pay based on trigger levels of environmental parameters, has been prevalent in agriculture for over a decade, increasing the resilience of farmers to extreme events such as drought (Daron and Stainforth, 2014). The first example of extending this idea to fisheries launched in the Caribbean in 2019 (CCRIF SPC, 2019; Appendix A, published as Sainsbury et al., 2019). The aim of this insurance is to pay individuals or governments (who subsequently distribute funds to individuals) an agreed amount when an environmental parameter trigger level is reached. In the case of drought in an agricultural context, this might be cumulative rainfall or a drought index. In the case of storms, it might be wind speed or wave height.

The principle of this insurance is that payments help fisheries return to a fully-operational state more quickly than it would do otherwise and hence, increase their resilience (Surminski et al., 2016). In the context of increasing storminess specifically increases in mean storm intensity and frequency, fishers will find they are able to safely go to sea less often. In this context, resilience outcomes may be improved by setting parameter trigger levels at values reflecting skippers' safety thresholds (Chapter 3). Such an approach would provide skippers an incentive to stay ashore in conditions that are unsafe, reducing the risk of death and injury in the fishery. However, the finding in Chapter 3 that a complex interaction of meteorological and oceanographic variables affect safety and catch levels suggests that a combination of parameters would be required. Furthermore, in a mixed fishery where vessels use different gears and different vessel sizes, one uniform parametric trigger level could lead to inequitable outcomes for the skippers of smaller boats, who would not receive protection until parameter values reached a level above their safety threshold.

Notwithstanding a high degree of uncertainty, evidence that storminess may increase in the waters around the UK over the remainder of the 21st century (Feser et al., 2015; Mölter et al., 2016) requires that the risk to the UK's fisheries is better understood. If the insights from Chapters 3, 4, and 6 are applied to the UK fleet, then policy makers should focus on increasing the resilience of smaller boats, purse seiners and trawlers, as these are particularly vulnerable to increased storminess. Conversely, larger boats, those with shelter decks, and static netters are among the least vulnerable. At a UK level, fishers using pots and traps are most vulnerable to reduced landings from increased wave height when they choose to go to sea. Small potting vessels may therefore be the most vulnerable vessels in the fleet because they are physically vulnerable if they do go to sea in adverse weather and economically vulnerable either way. The risk management expertise demonstrated by Newlyn skippers, if consistent across the UK, suggests that policymakers should engage with skippers to understand what support, if any, they need to manage risk.

Chapters 3 and 4 demonstrated that economic need forces fishers to take additional physical risk by going to sea in more extreme weather conditions. Recent evidence that UK fishers, particularly the small-scale fleet, have low financial resilience and face financial hardship (Jones, 2020) suggests that fisheries policy should engage with issues of poverty and financial insecurity in fisheries that may exacerbate risk-taking.

At a larger scale, fisheries are an important source of food security and nutrition for billions of people around the world, primarily in coastal developing nations and small island developing states (FAO, 2016). If storminess increases in global regions with high dependency on fisheries for food security, evidence from this thesis suggests that storms may increasingly prevent fishers accessing fish resources as they avoid extreme physical risks. In these circumstances, changing storminess may reduce fish production, posing a threat to food security in the long term. Alternatively, storms may claim a rising number of fishers' lives as they continue fishing in conditions that are unsafe. In developing nations, high economic need and low vessel seaworthiness may leave fishers particularly vulnerable to this latter scenario. Extreme storm events already pose a catastrophic risk to fishers (Sainsbury et al., 2018). Therefore adapting to changing storminess now could bring substantial benefits in terms of protecting food security and safety in the short and long term.

Future research into fishers' behavioural response to storms

There is great potential for further research to investigate fishers' behavioural response to storms. There are many socio-economic contexts, cultures, gear types, weather conditions, and marine ecosystems in global fisheries that are not reflected in the studies reported in this thesis. Research into the behavioural response of fishers is particularly needed in small-scale fisheries, which tend to have smaller, less seaworthy and therefore more vulnerable vessels than larger-scale fisheries. This is particularly in the developing world due to higher levels of poverty. However, small-scale fisheries tend to lack extensive and complete data sets that can be analysed. This is the case in the UK, where landings data for small-scale fisheries tends to be less robust than those of larger-scale fisheries, and satellite monitoring data are generally not collected. As such, engagement with local fishers and meteorological offices will be critical for data collection required for future studies focused on small-scale fisheries, in the UK and elsewhere.

Several opportunities for future research in the field of fishers' behavioural response to storms have been noted throughout this thesis, but there are additional broader scale research efforts that offer the potential to progress the field. The insights into vulnerability to changing storminess presented in this thesis offer key inputs into an effort to map national vulnerability to changing storminess at a global level. This might start at the UK level in order to establish a methodology, for instance similar to that used for the vulnerability of US shellfisheries to ocean acidification (Ekstrom et al., 2015). To expand the study to a global scale, several additional research steps would be required. Firstly, a systematic global review of changing storminess projections would provide an indication of national exposure. Secondly, it would be necessary to establish fishers' behavioural response to wind and waves for different fishing methods, vessel types and sizes, target species, fish habitats, and cultures, thereby reflecting the reality of global fisheries.

A further avenue of research would be to use the fisher behavioural insights in this thesis to build agent based models (ABM) to predict the behavioural response of a fishing fleet to changing storminess. Using an ABM in this way would take top-down climate inputs and bottom-up individual fisher behaviour to create fleet-level outcome predictions that could be fed into top down approaches to climate vulnerability (Conway et al., 2019). An ABM approach could be improved by the inclusion of the response of fish populations to storms and social-ecological linkages. In this instance, social-ecological linkages reflect the way in which fishers' behavioural response to storms affects fish stocks, and where fish behavioural responses to storms affects fisher behaviour. Further research would be required to achieve this, as little is known about how fish populations respond to storms or how fishers respond to the ecological impacts of storms. Finally, the interaction between changing storminess and other climate stressors is little understood. The combination of rising sea levels and increasing storminess may amplify risks to fishing assets and infrastructure onshore. Potential ecological and biological effects of changing storminess may combine with the effects of ocean warming, acidification and deoxygenation in ways that are not yet understood. Research into these interactions is required to provide a more complete understanding of how climate stressors will affect fisheries in future.

Concluding remarks

Efforts to understand changing storminess and fisheries are in their infancy and my hope is that the research in this thesis will act as a catalyst for extensive interdisciplinary research efforts to move this critical area of fisheries climate risk forward. My focus on the human dimension of the issue was based on the idea that climate risks mediate behaviour. In doing so, I have shown that behaviour mediates vulnerability. The insights in this thesis can inform vulnerability assessments and adaptation action to reduce the effect of changing storminess on the wellbeing of fishers and coastal communities.

Appendices

Appendix A: The challenges of extending climate risk insurance to fisheries

This appendix has been published as:

Sainsbury, N.C, Turner, R.A., Townhill B.L., Mangi S.C., Pinnegar, J.K., (2019) The challenges of extending climate risk insurance to fisheries. *Nature Climate Change* 9, 896–897.

To the editor – As the frequency and intensity of storms alter in a changing climate (Feser et al., 2015; Hartmann et al., 2013), fisheries food production systems must adapt to protect global food security and livelihoods. July 2019 saw the launch of the world's first fisheries index insurance scheme to protect against extreme weather events. Highly innovative climate risk insurance of this type offers the promise of increasing the resilience of billions of people around the world to climate-driven changes in storminess (Sainsbury et al., 2018).

Whilst index insurance schemes have become widespread in terrestrial agriculture for protection against extreme weather events (Tadesse et al., 2015), the Caribbean Oceans and Aquaculture Sustainability faciliTy (COAST) is the first for fisheries. Initially launched in St Lucia and Grenada, COAST is funded by the US State Department and relies on the specialist capabilities of the Caribbean Catastrophe Risk Insurance Facility (CCRIF SPC) and The World Bank (CCRIF SPC, 2019). COAST operates at the national, as opposed to the individual 'micro-insurance' level. Pre-defined benefits are calculated to reflect the likely national financial loss from damage to fishing vessels, gear and infrastructure caused by a hurricane. The specific trigger indices used in COAST are wave height, rainfall, wind and storm surge. Payments will reach the national finance ministries within 14 days of an index-triggering event and will be rapidly channelled to a list of pre-determined fisheries actors including individual fishers, vessel owners, fish vendors and fish processors (CCRIF SPC, 2019).

While it is too early to evaluate the impacts of COAST, wider insights from agricultural index insurance and fisheries governance highlight several challenges of extending weather index insurance schemes to fisheries.

Unlike agriculture, fishing is a daily pursuit with immediate outcomes. Storms do not only threaten fishing industry assets and infrastructure, but also daily production and fishers' lives. Even if financial payments for damaged or lost assets reach fishery actors quickly, lags in production may be experienced whilst vessels, engines, gear and infrastructure are repaired or replaced and market chains are re-established. A compensatory element for lost income in the short to medium term following a storm would further support recovery. It may encourage fishers to avoid the risks of fishing in extreme weather conditions. This would be dependent on fishers having access to frequently updated, locally relevant and reliable weather forecasts at sea and on land. Even with such risk mitigations, fisheries weather index insurance payments should provide for disability and loss of life to enhance the resilience of fishers and their families.

Maladaptation is a significant concern for climate risk instruments in the agricultural domain (Müller et al., 2017). In a fisheries context, the distribution of insurance payments among fishing actors is key. Disproportionately higher payments to larger vessels and insufficient provision of funds to small-scale fleets could risk negative socio-economic outcomes for small-scale fishers, and may rebalance fishing fleets towards larger vessels that have greater fishing capacity. While larger vessels may be less vulnerable to extreme weather, costs to social and environmental sustainability could place the fishery on a maladaptive path (Finkbeiner et al., 2018).

Weather index insurance must not become a substitute for fisheries adaptation action or storm preparedness, as a failure to adapt threatens the long-term acceptability of extreme weather risks to underwriters (Surminski et al., 2016). Adaptation measures that reduce vulnerability to weather events, such as restoring mangroves (Blankespoor et al., 2017), establishing pre-storm preparation plans (Cattermoul et al., 2014), and investing in more resilient fishing vessels and gear, could be incentivised through reduced premiums. Such approaches also mitigate the risk of moral hazard. The COAST scheme seeks to incentivise sustainable fishing outcomes and improve climate resilience by making it a prerequisite for insured nations to implement the Caribbean Community Common Fisheries Policy.

Issues of equity and justice must be considered in the design of fisheries weather index insurance to avoid the risk of increasing social inequality (Fisher et al., 2019). This is particularly important where coastal communities are reliant on small-scale fisheries for livelihoods and nutrition (Kalikoski et al., 2010). The division of payments within a fishing community must be carefully considered to avoid more marginalised actors losing out to those who are better organized. If insurance payments are dispersed to government ministries, as is the case for COAST, national processes of governing the further dispersal of funds will be critically important in determining outcomes. The institutional rules and processes by which beneficiaries are identified, payment levels to individuals are set, and funds are dispersed will influence the equity of outcomes. These rules and processes will need to reflect individuals exiting and entering fisheries. This will be especially challenging in data-poor tropical fisheries, where small-scale and part-time fishery actors are less likely to be formally registered. Applying a gender lens to fisheries weather index insurance design will also be necessary to ensure that women's important but less visible roles in fisheries are not forgotten (Harper et al., 2017).

The continued expansion of weather index insurance is supported by the 2017 launch of the InsuResilience partnership initiative between the G20 and V20, which aims to provide climate insurance protection to 400 million vulnerable and uninsured people by 2020 (UNFCCC, 2017). Ensuring that climate adaptation, equity, justice and sustainability issues are reflected in the design and delivery of fisheries weather index insurance schemes is critical if improved resilience and desirable socio-ecological outcomes are to be achieved.

Appendix B: Chapter 2 supplementary materials

References and additional detail for Figure 2.1a.

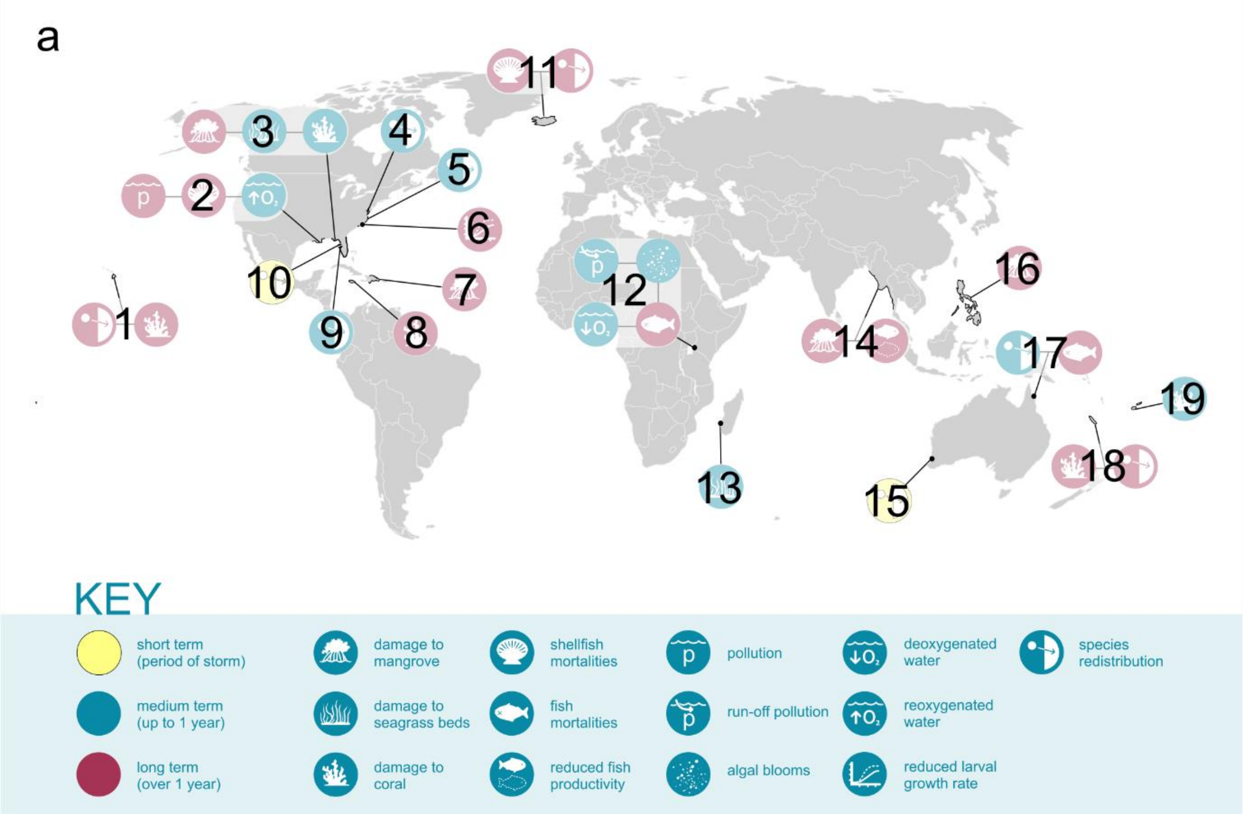

Figure s2.1a. Supplementary figure of ecological storm impacts with additional case study reference numbers linking to Supplementary Table s2.1a.

Table s2.1a. Supplementary table with additional detail and references for Figure s2.1a.

Supplementary Figure s2.1a Map Reference	Location	Species	Storm type	Impacts (and source reference)	Time period of impact	Notes
1	Kona, Hawaii	Corals and various reef fish including *Paracirrhites arcatus, Cirrhitops fasciatus* and *Chromis vanderbilti*	Unnamed storm (1980)	Species redistribution; Coral damage[1]	Long term	After 16 months whilst some fish had returned to their pre-storm areas, other remained in shifted locations
2	Mississippi / Louisiana, USA	Shellfish and offshore habitat	Hurricanes Rita, Wilma and Katrina (2005)	Pollution (debris); Shellfish mortalities; Reoxygenated coastal waters[2]	Pollution (long term); shellfish (long term); reoxygenation of water (medium term)	Pollution includes chemical from onshore and offshore industry, organic pollutants and debris from damaged infrastructure
3	Florida, USA	Mangroves	Hurricane Wilma (2005)	Mangrove damage; seagrass bed damage; coral damage[2]	Mangrove damage (long term); seagrass bed damage (medium term); coral damage (medium term)	Timing of damage assessment places seagrass bed and coral damage as medium term impacts. Mangrove damage stated as longer than one year
4	Chesapeake Bay, Washington/Virginia, USA	Pelagic and bentho-pelagic fish species including *Anchoa mitchilli, Ameiurus nebulosus, Lepomis sp., Etheostoma olmstedi* and *Perca flavescens*	Hurricane Isabel (2003)	Species redistribution[3]	Medium term	Fish surveys took places in the months following Hurrricane Isabel
5	North Carolina, USA	Blue crab *Callinectes sapidus*	Hurricanes Dennis and Floyd (1999)	Species redistribution[4]	Medium term	Storm caused river flooding that flushed blue crabs downstream into offshore waters where they were heavily harvested by commercial fisheries
6	Onslow Bay, North Carolina, USA	Atlantic menhaden *Brevoortia tyrannus*	Unnamed storm (1986)	Reduction in larval growth rate[5]	Long term	Data collected within two months of storm. Impact for fish popoulation will be greater than one year
7	Dominican Republic	Mangroves	Hurricane Georges (1998)	Mangrove damage[6]	Long term	Damage surveyed at 7 and 18 months after the storm
8	Jamaica	Corals	Hurricane Allen (1980)	Coral damage[7]	Long term	Post-storm recruitment by the coral, *Acropora* , was nominal. Others were showing signs of recovery over the three years after the storm
9	Charlotte Harbor estuary and Peace River watershed, Florida, USA	Various estuarine fish including *Micropterus salmoides, Lepomis macrochirus, Paralichthys albigutta, Lutjanus griseus, Arius felis, Epinephelus itajara, and Centropomus undecimalis, Hoplosternum littorale and Pterygoplichthys spp.*	Hurricane Charley (2004)	Species redistribution[8]	Medium term	Changes in fish assemblages observed in the two months following the storm. Alterations associated with storm-related hypoxia
10	Terra Ceia Bay, Florida, USA	Blacktip sharks *Carcharhinus limbatus*	Hurricane Gabrielle (2001)	Species redistribution[9]	Short term	Blacktip sharks evacuated the affected area in the period leading up to the storm and returned immediately afterwards
11	Iceland	Ocean quahog *Arctica islandica*	Unnamed strorm (2006)	Shellfish redistribution; Shellfish mortality[10]	Long term	Ocean quahog moved by storm to a hard ocean bottom where, a year later, they were found to have been subject to easy predation
12	Nyanza Gulf of Lake Victoria, Kenya	Fish species (*Lates niloticus* and *Oreochromis niloticus*)	Unnamed storm (1984)	Algal bloom; Run-off pollution; De-oxygenation; Fish mortalities[11]	Algal bloom (medium term); Run-off pollution (medium term); De-oxygenation (medium term); Fish mortalities (long term)	Lower than average lake levels combined with run-off sediment, churned-up lake bottom mud, water hypoxia and algal bloom to cause mass fish mortality event. Whilst the environmental conditions caused by the storm were medium term, the fish mortality event has been classified as long term
13	Andavadoaka, Madagascar	Seagrass	Tropical Cyclone Haruna (2013)	Seagrass bed damage[12]	Medium term	Damage assessed within a month of the storm. Further studies would have been required to establish whether damage lasted more than a year
14	Myanmar	Mangroves and fish species	Cyclone Nargis (2008)	Mangrove damage; Reduced fish productivity[13]	Long term	Cyclone Nargis destroyed 38,000 hectares of mangroves. It has been assumed that the recovery will take morwe than one year. The loss of mangrioves destroyed fish breeding grounds, reducing fish productivity (as with mangrove impacts, this has been assumed to be long term)
15	Warnbro Sound,Western Australia, Australia	Various reef fish including *Austrolabrus maculatus* and *Parma mccullochi*	Four unnamed storms (2013)	Species redistribution[14]	Short term	Study noted variation in the sensitivity of species to storm-related environmental factors during storms.
16	Phillipines	Mangroves	Typhoon Haiyan (2013)	Mangrove damage[15]	Long term	Damage to mangroves remained when study areas were revisited 18 months after the storm
17	Lizard Island (northern Great Barrier Reef), Australia	Reef fish (extensive list of species)	Cyclone Eddie (1981)	Species redistribution; Fish mortality[16]	Species redistribution (medium term); Fish mortality (long term)	High mortality rates of juvenile fish (classified as loing term). Sub-adult fish re-distributed but adult fish did not appear to be affected by the storm. Studies took place regularly in the lead up to, and two days after, the storm
18	New Calidonia	Reef fish and coral	Cyclone Erica (2003)	Coral damage; Species redistribution[17]	Long term	Data collected within a month of the storm and 20 months after the storm. Impact on fish assemplages found to be greater after 20 months than before or just after the storm
19	Fiji	Corals	Cyclone Winston (2016)	Coral damage[18]	Medium term	Damage to coral assessed within a month of the storm. No follow up studies were reported, so impact has been classified as medium term

References and additional detail for Figure 2.1b.

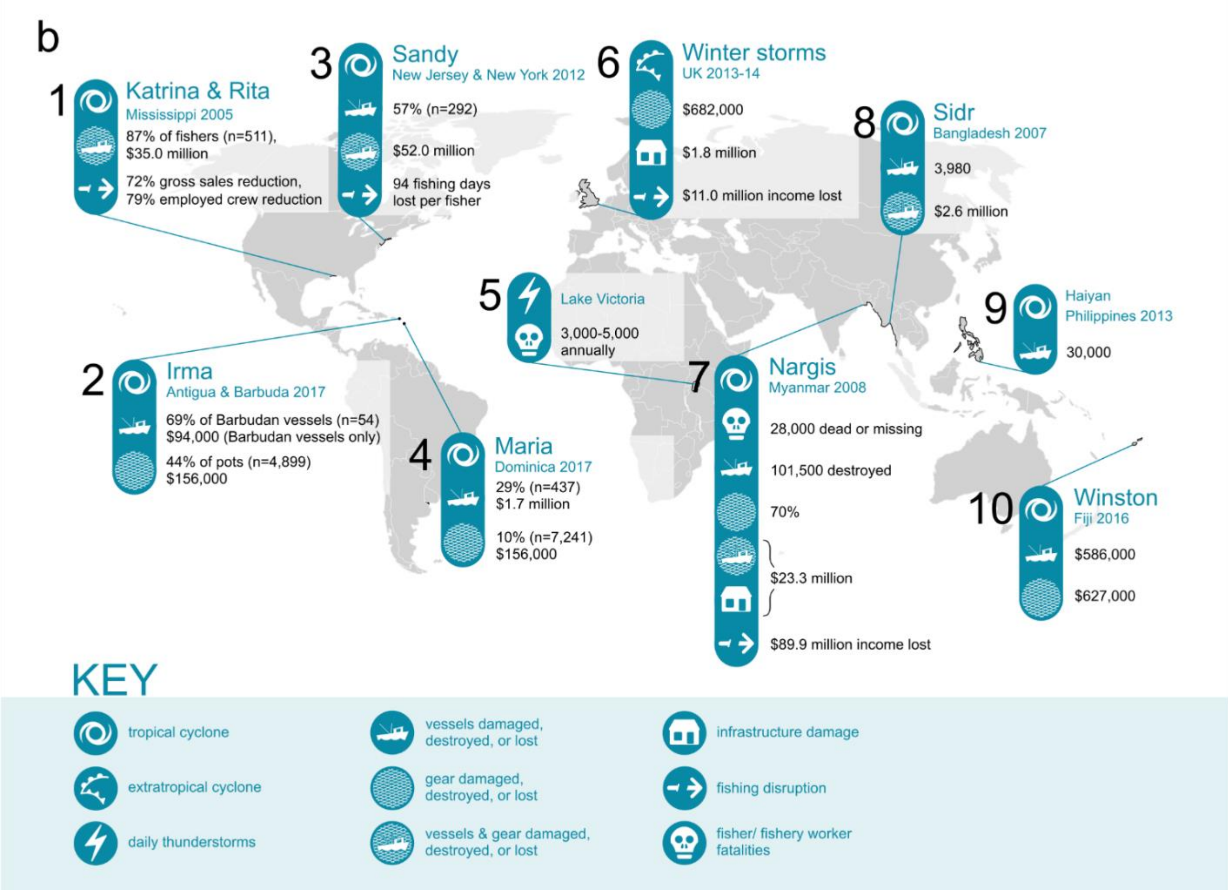

Figure s2.1b. Supplementary figure of socio-economic storm impacts with additional case study reference numbers linking to Supplementary Table s2.1b.

Table s2.1b. Supplementary table with additional detail and references for Figure s2.1b.

Supplementary Figure s2.1b Map Reference	Location	Event	Impact type	Extent of impact (and source reference)	Notes
1	USA (Mississippi only)	Hurricanes Katrina and Rita 2005	Vessels/gear damaged/lost/destroyed	87% (n = 511)[19]	% of resident licensed Mississippi commercial fishing units damaged estimated based on sample (of 1,030 licensed vessels, 511 returned surveys)
			Vessels/gear damaged/lost/destroyed	$35.0 million[19]	Estimate calculated using average total damages reported by resident licensed Mississippi commercial fishing sample units (n = 511) multiplied by total number of fishing units (n = 1030)
			Fishing disruption	72% gross sales reduction in 2006 compared to 2004[19]	Based on estimates of projected gross sales reduction due to lost market channels from resident licensed Mississippi commercial fishing survey respondents (n = 511)
			Fishing disruption	79% employed crew reduction[19]	Based on reduction in employed crew in 2006 compared to 2004 reported by resident licensed Mississippi commercial fishing survey respondents (n = 511)
2	Antigua and Barbuda	Hurricane Irma 2017	Vessels damaged/lost/destroyed	69% (n = 54) of Barbudan vessels[20]	37 out of 54 active fishing vessels in Barbuda damaged or destroyed
			Vessels damaged/lost/destroyed	$94,000 (Barbudan vessels only)[20]	All vessels affected were Barbudan. XCD to US$ conversion 1:0.37 taken from www.xe.com historic exchange rate database for 01/09/17 (source report published September 2017)
			Gear damaged/lost/destroyed	44% (n = 4,899)[20]	Some losses may be attributable to Hurricanes Jose and Maria. 2,177 of 4,899 fishing pots lost
			Gear damaged/lost/destroyed	$156,000[20]	Some losses may be attributable to Hurricanes Jose and Maria. Losses experiences across Antigua and Barbuda. XCD to US$ conversion 1:0.37 taken from www.xe.com historic exchange rate database for 01/09/17 (source report published September 2017)
3	USA (New Jersey and New York)	Hurricane Sandy 2012	Vessels/gear damaged/lost/destroyed	$52.0 million[21]	Based on surveys conducted with sample of New york and New Jersey commercially licensed fishers (n = 292). Estimate based on average value of damages and losses per vessel multiplied by total number of licensed vessels
			Vessels damaged/lost/destroyed	57% (n = 292)[21]	Based on surveys conducted with sample of New york and New Jersey commercially licensed fishers (n = 292)
			Fishing disruption	94 fishing days per fisher on average[21]	Based on surveys conducted with sample of New york and New Jersey commercially licensed fishers (n = 292)
4	Dominica	Hurricane Maria 2017	Vessels damaged/lost/destroyed	29% (n = 437)[22, 23]	128 out of 437 fishing vessels damaged or destroyed
			Vessels and engine damaged/lost/destroyed	$1.7 million[22]	Estimate
			Gear damaged/lost/destroyed	10% (n = 7,241)[23]	746 out of 7,241 gears affected
			Gear damaged/lost/destroyed	$156,000[23]	Initial estimate. XCD to US$ conversion 1:0.37 taken from www.xe.com historic exchange rate database for 01/10/17 (source report published October 2017)
5	Kenya / Tanzania / Uganda	Daily thunderstorms	Fisher / fishery worker fatalities	3000–5000 annually[24]	Estimate
6	UK	Winter storms 2013–2014	Gear damaged/lost/destroyed	$682,000[25]	Based on the value of claims made by fishers under the UK Government's Gear Replacement Scheme. GB£ to US$ conversion 1:1.710 taken from www.xe.com historic exchange rate database for 30/0/6/14 (date applications closed for the grear replacement scheme)
			Fishing disruption	$11.0 million income lost[26]	Estimate made based on reduced catch at port of Newlyn, Cornwall during January and February 2014. GB£ to US$ conversion 1:1.567 taken from www.xe.com historic exchange rate database for 19/11/14 (date source report published)
			Fishery infrastructure damage	$1.8 million[27]	Level of funding support provided by UK Government to repair damage to fishing ports. GB£ to US$ conversion 1:1.622 taken from www.xe.com historic exchange rate database for 01/10/14 (date source report published)
7	Myanmar	Cyclone Nargis 2009	Fisher / fishery worker fatalities	28,000 dead or missing[28]	Estimate
			Vessels damaged/lost/destroyed	101,500 destroyed[28]	Mostly small inland vessels
			Gear damaged/lost/destroyed	70%[28]	Estimate
			Vessels/gear/facilities/ transport and infrastructure damaged/lost/destroyed	$23.3 million[29]	Estimate. KYAT to US$ conversion 1:0.0009 as used elsewhere within the source document
			Fishing disruption	$89.9 million income lost[29]	Estimate of foregone income. KYAT to US$ conversion 1:0.0009 as used elsewhere within the source document

Table s2.1b (continued). Supplementary table with additional detail and references for Figure 2.1b.

Supplementary Figure s2.1b Map Reference	Location	Event	Impact type	Extent of impact (and source reference)	Notes
8	Bangladesh	Cyclone Sidr 2007	Vessels damaged/lost/destroyed	3,980[30]	Based on field trips to eight districts and cross checked with damage estimates carried out by Bangladesh Department of Fisheries
			Vessels/gear damage/lost/destroyed	$2.6 million[30]	Damage to boats and gear. Estimates range from US$1.9 million to US$3.3 million. An average of the two has been used. Based on field trips and cross checked with independent estimates
9	Phillippines	Typhoon Haiyan 2013	Vessels damaged/lost/destroyed	30,000[31]	Estimate.
10	Fiji	Cyclone Winston 2016	Vessels and engine damaged/lost/destroyed	$586,000[32]	Total of estimates made by fishers during surveys conducted with across a sample of affected villages (74%, n = 207) within six provinces. Bamboo rafts (bilibili) were not included. FJD to US$ conversion 1:0.485 taken from www.xe.com historic exchange rate database for 01/05/16 (mid-point of survey period)
			Gear damaged/lost/destroyed	$627,000[32]	Total of estimates made by fishers during surveys conducted with across a sample of affected villages (74%, n = 207) within six provinces. Bamboo rafts (bilibili) were not included. FJD to US$ conversion 1:0.485 taken from www.xe.com historic exchange rate database for 01/05/16 (mid-point of survey period)

References and additional detail for Figure 2.2.

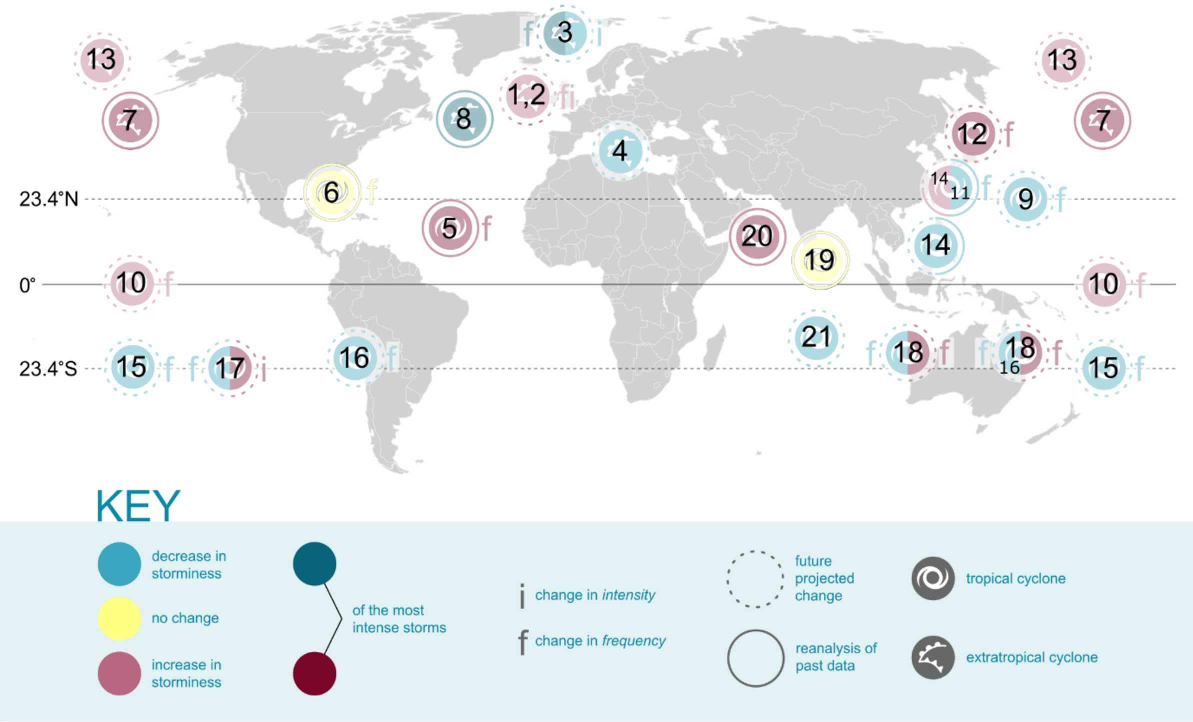

Figure s2.2. Supplementary figure of changing storminess with additional case study reference numbers linking to supplementary table s2.2.

Table s2.2. Supplementary table with additional detail and references for Figure s2.2.

Supplementary Figure s2.2 Map Reference	Study type	Area	Type of storm	Reanalysis or Projection	Time period	Change described (and source reference)	Time of year
1	Review	Western Europe	Extra-tropical	Projection	Mix spanning 2020–2190 across 33 studies	Increase in frequency and intensity of storms[33]	Mix spanning September–April across 33 studies
2	Review	Eastern North Atlantic south of 60°N	Extra-tropical	Projection	Mix spanning 2020–2190 across 16 studies	Increase in frequency and intensity of storms[33]	Mix spanning September–April across 14 studies, 1 study May–December, 1 study not specified
3	Review	North Atlantic north of 60°N	Extra-tropical	Projection	Mix spanning 2020–2190 across 11 studies	Decrease in frequency of extreme cyclones and decrease in cyclone intensity[33]	Mix spanning September–April across 11 studies
4	Review	Southern Europe	Extra-tropical	Projection	Mix spanning 2020–2190 across 11 studies	Decrease behaviour of storminess over long term[33]	Mix spanning September–April across 9 studies, 2 studies not specified
5	Review	North Atlantic tropics	Tropical	Reanalysis	1970–2013	Most intense tropical cyclones are becoming more frequent since 1970s[34]	Not specified
6	New data	North Atlantic tropics	Tropical	Reanalysis	1900–2000	Hurricanes making landfall in USA have not become more frequent over last century[35]	All year
7	New data	Mid-latitude North Pacific	Extra-tropical	Reanalysis	1958–1977 and 1982–2001	Increasing trend in strong cyclonic activity[36]	January/February/March
8	New data	Mid-latitude North Atlantic	Extra-tropical	Reanalysis	1958–1977 and 1982–2001	Decreasing trend in strong cyclonic activity[36]	January/February/March
9	New data	Western part of Western North Pacific	Tropical	Projection	2075–2099	Decrease in frequency of tropical cyclones[37]	Peak tropical cyclone season in northern hemisphere
10	New data	Central Pacific	Tropical	Projection	2075–2099	Increase in frequency of tropical cyclones[37]	Peak tropical cyclone season in each hemisphere
11	New data	Western North Pacific	Tropical	Projection	2075–2099	Decrease in frequency of tropical cyclones approaching coastal regions[37]	Peak tropical cyclone season in northern hemisphere
12	New data	North-Western Northern Pacific	Tropical	Projection	2075–2099	Increase in frequency of most intense tropical cyclones[37]	Peak tropical cyclone season in northern hemisphere
13	New data	North Pacific near the Aleutian Islands	Extra-tropical	Projection	2081–2100	Enhanced storminess[38]	Not specified
14	New data	Western Northern Pacific	Tropical	Reanalysis and Projection	Reanalysis: 1980–2013; Projection: 2070–2099	Decreased tropical cyclone exposure in the Philippine and South China Sea regions and increased exposure in the East China Sea region[39]	July–November
15	New data	South Pacific	Tropical	Projection	2075–2099	Decrease in frequency of tropical cyclones[37]	Peak tropical cyclone season in southern hemisphere
16	New data	South Pacific	Tropical	Projection	2075–2099	Decrease in frequency of tropical cyclones approaching coastal regions[37]	Peak tropical cyclone season in southern hemisphere
17	Review	South Pacific	Tropical	Projection	Mix from 2061–2200	Tropical cyclone frequency will decrease. The intensity of the most intense storms will likely increase[40]	Not specified
18	New data	Australia	Tropical	Projection	2046–2065 and 2081–2100	Decrease in numbers of tropical cyclones overall, small increase in the most intense tropical cyclones[41]	All year
19	New data	North Indian Ocean	Tropical	Reanalysis	1901–1951 and 1951–2001	No increase in storms despite increase in sea surface temperature in Bay of Bengal and Arabian Sea[42]	Winter/ Pre-Monsoon / Monsoon / Post Monsoon
20	New data	Arabian Sea	Tropical	Reanalysis	Control experiments for 1860 (600 years), 1940 (200 years), 1990 (300 years), 2015 (200 years)	Global warming has increased the probability of post-monsoon extremely severe cyclonic storms over the Arabian Sea[43]	October–December
21	New data	South Indian Ocean	Tropical	Projection	2075–2099	Decrease in number of tropical cyclones[37]	Peak tropical cyclone season in southern hemisphere (November–April)

Chapter 2 supplementary materials references

1. Walsh, W.J., *Coral Reefs* **2,** 49–63 (1983).
2. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service*. Report to Congress on the Impact of Hurricanes Katrina, Rita, and Wilma on Commercial and Recreational Fishery Habitat of Alabama, Florida, Louisiana, Mississippi, and Texas* (Maryland, 2007).
3. Houde, E.D., Bichy, J. and Jung, S. K.G. *Effects of Hurricane Isabel on Fish Populations and Communities in Chesapeake Bay.* In: *Hurricane Isabel In Perspective* (ed. Sellner, K.G.). pp. 193–199 (Maryland, 2005).
4. Burgess, C., Bianchi, A., Murauskas, J. and Crosson, S. *Impacts of Hurricanes on North Carolina Fisheries* (North Carolina, 2007).
5. Maillet, G.L. and Checkley, Jr, D.M. *Mar. Ecol. Prog. Ser.* **79,** 1-16 (1991).
6. Sherman, R.E., Fahey, T.J. and Martinez, P. *Biotropica* **33,** 393–408 (2001).
7. Hughes, T.P., *Science* **265,** 1547–1551 (1994).
8. Stevens, P.W., Blewett, D.A. and Casey, J.P. *Estuar. Coast* **29,** 997–1003 (2006).
9. Heupel, M.R., Simpfendorfer, C.A. and Hueter, R.E. *J. Fish Bio.* **63,** 1357–1363 (2003).
10. Thórarindsóttir, G.G., Gunnarsson, K. and Bogason, E. *Mar. Biodivers. Rec.* **2** (2009).
11. Ochumba, P.B. *Hydrobiologia* **208,** 93–99 (1990).
12. Côté-Laurin, M.C., Benbow, S. and Erzini, K. *Cont. Shelf Res.* **138,** 132–141 (2017).
13. United Nations Environment Programme. *Learning from Cyclone Nargis*. (Nairobi, 2009).
14. Munks, L.S., Harvey, E.S. and Saunders, B.J. *J. Exp. Mar. Biol. Ecol.* **472,** 77–88 (2015).
15. Long, J., Giri, C., Primavera, J. and Trivedi, M. *Mar. Pollut. Bull.* **109,** 734–743 (2016).
16. Lassig, B.R., *Environ. Biol.Fish.* **9,** 55–63 (1983).
17. Wantiez, L., Chateau, O. and Le Mouellic, S*. J. Mar. Biol. Assoc. U.K.* **86,** 1229–1236 (2006).
18. Mangubhai, S. *Impact of Tropical Cyclone Winston on Coral Reefs in the Vatu-i-Ra Seascape. WCS Report No. 01/16* (Fiji, 2016).
19. Posadas, B.C. *Mississippi Agricultural and Forestry Experiment Station Bulletin 1165* (Mississippi State, 2008).
20. Horsford, I. *Hurricane Irma – Preliminary Damage Assessment for Antigua And Barbuda's Fisheries Sector* (Fisheries Division Ministry of Agriculture, Lands, Fisheries and Barbuda Affairs, St John's, 2017).

21. Colburn, L.L., Clay, P.M., Seara, T., Weng, C. and Silva, A. *U.S. Dept. of Commerce, NOAA. NOAA Technical Memorandum NMFS-F/SPO-157* (Narragansett, 2015).
22. Government of Commonwealth of Dominica Fisheries Division. *Preliminary Damage Assessment for Dominica's Fisheries Sector - Post Hurricane Maria* (Roseau, 2017).
23. Government of Commonwealth of Dominica. *Post-Disaster Needs Assessment Hurricane Maria September 18, 2017* (Dominica, 2018).
24. International Federation of the Red Cross and Red Crescent Societies. *World Disasters Report Focus on culture and risk* (2014).
25. UK Marine Management Organisation Media Team, Personal comms., 23 November 2017 and 2 May 2018.
26. Andrew, R. and Read, D. *Cumulative Impact of Severe Weather in Cornwall: Winter 2013/2014* (Cornwall Council, 2014).
27. Watkins, D. *The winter storms of 2014: How Cornwall fared* (Cornwall Council, 2014).
28. FAO. *Myanmar Post-Nargis Recovery and Rehabilitation Programme Strategy* (Myanmar, 2009)
29. Government of Myanmar, ASEAN and UN. *Post-Nargis Joint Assessment* (Myanmar, 2008).
30. Government of Bangladash. *Cyclone Sidr in Bangladesh Damage, Loss and Needs Assessment For Disaster Recovery and Reconstruction* (Bangladesh, 2008).
31. FAO. *Typhoon Haiyan - One year later*, accessed 30 November 2017, http://www.fao.org/news/story/en/item/264765/icode/
32. Chaston Radway, K. et al. *Impact of Tropical Cyclone Winston on Fisheries-Dependent Communities in Fiji. WCS Report No. 03/16* (Fiji, 2016).
33. Mölter, T., Schindler, D., Albrecht, A.T. and Kohnle, U. *Atmosphere-Basel* **7,** 60 (2016)
34. Hartmann, D.L. et al. Observations: Atmosphere and Surface. *In: Climate Change 2013: The Physical Science Basis* (eds. Stocker, T.F. et al.) (Cambridge Univ. Press, 2013).
35. Landsea, C.W. *Bull. Am. Meteorol. Soc.* **96,** 1175–1176 (2015).
36. Wang, X.L., Swail, V.R. and Zwiers, F.W. *J. Clim.* **19,** 3145–3166 (2006).
37. Murakami, H. et al. *J. Clim.* **25,** 3237–3260 (2012).
38. Ulbrich, U. et al. *J. Clim.* **21,** 1669–1679 (2008).
39. Kossin, J.P., Emanuel, K.A. and Camargo, S.J. *J. Clim.* **29,** 5725–5739 (2016).
40. Walsh, K.J., McInnes, K.L. and McBride, J.L. *Global Planet. Change* **80,** 149–164 (2012).
41. Lavender, S.L. and Walsh, K.J.E. *Geophys. Res. Lett.* **38,** 5725–5739 (2011).
42. Ramesh Kumar, M R. and Sankar, S. *Indian J. Geo-Mar. Sci.* **39,** 516-520 (2010).
43. Murakami, H., Vecchi, G.A. and Underwood, S. *Nat. Clim. Change* **7,** 885–889 (2017).

Appendix C: Semi-structured interview guide

1. Background information
- Gears used?
- Boat length and power?
- Size of crew?
- What kind of communication and fish finding teach do you use?
- Do you own your boat?
- Do you run more than one boat?
- What's the size of your crew?
- What species do you target?
- Where do you go to fish? Does this vary much?
- How long are your fishing trips?
- How many years have you been a skipper?

2. What weather conditions are relevant to your decisions?
- Waves, wind, swell? Interaction between tides and conditions?
- Why are these conditions important?

3. Do you consider any conditions to be dangerous?
- What is it about these conditions that make them dangerous?
- Are there some conditions you'll not go out in? Or that'll drive you back to port?
- Impact of conditions on gear (operating efficiency/safety/risk to vessel)?
- Have you ever been out in conditions where you genuinely feared for the vessel and the crew?
- Does the design of the boat and the tech you have on-board affect the risk of conditions?

4. How does the weather factor in your decision to go to sea?
- When do you decide whether to go to sea?
- How do you make the decision?
- How far do you plan your fishing days ahead?
- Do you fish every day when weather is acceptable? Or certain days of week only? Weekend off?
- If you do go out, how does the weather affect where you choose to fish? Why?
- If you're at sea, how do you decide whether to return to port or stay out if the weather turns?

5. If the weather is bad, how do financial factors affect your decisions?
- How do you decide whether a trip in bad weather is going to be profitable?
- Does fish price affect your decisions?
- Have you ever been tempted to fish in bad weather because the price is high?
- How do you find out about fish prices?
- Would the fuel costs be higher and does that put you off?
- How does the weather affect your fishing success?
- Does bad weather reduce your control over the species and quality you catch?

- Would you risk going out in bad weather if you were worried that you wouldn't use your quota?

6. **Do you ever feel a pressure to go to sea in conditions that you don't think are safe or profitable?**
- Have you ever been to sea in weather you felt was very risky because you had to for financial reasons?
- Do you have a number of days you have to fish in a year? Is this on your mind as the year progresses?
- Do you have a level of income in mind that you have to make in the year?
- Does your willingness to fish in bad weather reduce or increase as the year progresses?

7. **Does seeing other fishers going to sea or staying in port affect your decision?**
- Do you feel that your decision to fish in bad weather has been affected by family? Vessel owner?
- If your health isn't great or you are carrying injuries, does that affect your decision?
- If you have crew with you, does that play a role in your decision?

8. **Do you use the weather forecast?**
- What source do you use on land/at sea?
- Do you trust it? How far in advance?
- What information do you use?
- How often do you check it?
- Do you share or discuss weather information with other fishermen?

9. **Have your decisions about fishing in bad weather changed during your life?**

10. **Have you seen a trend up or down in the number of days you can fish during your career?**
- If storms were to get more frequent or more extreme, what impact would this have on your business?
- How would you respond to this?

Appendix D: Specification of econometric models

Conditional logit and random parameter logit models can be used to explain choices made based on the attributes of choice alternatives. The modelling approach is based on the assumption that the level of utility derived from an alternative is a function of its attributes (Lancaster, 1966), respondents have perfect information, and choose the alternative that provides them with the greatest utility (that is to say, value or desirability). Under Random Utility Theory, on which choice experiments are generally based, the utility a respondent derives from an alternative is the sum of a systematic and a random component (McFadden, 1973). The deterministic dimension can be estimated based on the data collected, whilst the random dimension is assumed to be known to the respondent but cannot be inferred from the data.

$$U = U\ (x_i, \ldots., x_m; z_i, \ldots., z_m) = V(x,z) + \ \varepsilon$$

Where U is the utility of the alternative, $x_{i\text{-}m}$ are the alternative's attribute, $Z_{i\text{-}m}$ are characteristics of the individual respondents, V is the deterministic component of utility and ε is the unobserved random component of utility. The probability of a respondent choosing alternative *i* over alternative *j* can be expressed as,

$$P(i\ |C) = P\big(U_i > U_j\big) = P[(V_i + \varepsilon_i) > (V_j + \varepsilon_j)] = P[(V_i - V_j) > (\varepsilon_j - \varepsilon_i)]$$

$$\forall i; j \in C; i \neq j$$

The conditional logit model relies on three assumptions: (1) the random error component is independently and identically distributed (IID) across alternatives (i.e. there is no covariance in between $\varepsilon_j \text{and } \varepsilon_i$ and the variance of $\varepsilon_j \text{and } \varepsilon_i$ are equal); (2) choice alternatives are independent from irrelevant alternatives (IIA), i.e. that the value placed on one alternative is not affected by another alternative within the choice set; and (3) the random error component is type I generalised extreme value (Gumbel) distributed (Hensher et al., 2015b). Under these assumptions, the conditional logit can be expressed as,

$$P(i\ |C) = \ \frac{\exp \beta V_i}{\Sigma_{\mathrm{j=1}}^{\mathrm{C}} \exp \beta V_j}$$

$$\forall i; j \in C; i \neq j$$

Now assuming that V_i, the deterministic portion of utility of an alternative i, is a function of four individual attributes (x_{1i} – x_{4i}), weighted by coefficients that define their relative contribution to the utility of the alternative ($\beta_1, \ldots, \beta_4$) then,

$$V_i = ASC + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4$$

The alternative specific constant (*ASC*) is an indicator variable equal to the unobserved utility and included to capture preferences for taking fishing trips versus staying in port.

The random parameter logit model (RPL, also known as mixed logit model) is commonly employed to explain heterogeneity in individual preferences (Hensher and Greene, 2003). The unobserved component of utility (ε) is split into two parts: (1) one is assumed to be correlated across alternatives with non-constant variance and is a random term with a distribution that is defined by observed individual and alternative parameters; and (2) another is a random term as per the conditional logit model, which is IID, IIA and type I extreme value distributed. The choice probability (*P*) in a RPL model is the integral of the mean of a mix of conditional logit functions,

$$P(i\,|C) = \int \frac{\exp\beta V_i}{\Sigma_{\mathrm{j=1}}^{\mathrm{C}} \exp\beta V_j}\, f(\beta) d\beta$$

Where β is a vector of parameter values and the mix of CL functions is defined by a parameter density function, $f(\beta)$.

Appendix E: Choice of vessel lengths within gear type categories

Fishing method	Vessel length category						Total
	10.01–15m	15–19.99m	20–24.99m	25–29.99m	30–34.99m	35m and over	
Bottom Trawl							
Number of observations	197,869	292,264	152,586	70,580	6,443	9,385	**729,127**
% observations	27.1%	40.1%	20.9%	9.7%	0.9%	1.3%	
Weight (kg)	61,128,092	190,895,090	254,781,883	255,307,553	34,006,082	44,496,538	**840,615,238**
% weight	7.3%	22.7%	30.3%	30.4%	4.0%	5.3%	
Value (£)	196,394,029	581,749,817	600,826,436	468,120,123	63,002,509	74,546,613	**1,984,639,527**
% value	9.9%	29.3%	30.3%	23.6%	3.2%	3.8%	
Number of vessels	379	289	159	84	12	33	**956**
% of vessels	39.6%	30.2%	16.6%	8.8%	1.3%	3.5%	
Midwater Trawl							
Number of observations	3,585	1,570	2,757	491		7,147	**15,550**
% observations	23.1%	10.1%	17.7%	3.2%		46.0%	
Weight (kg)	34,419,385	11,739,893	3,416,634	546,286		2,206,539,354	**2,256,661,552**
% weight	1.5%	0.5%	0.2%	0.0%		97.8%	
Value (£)	8,622,393	4,370,497	6,700,814	1,464,248		1,504,876,668	**1,526,034,620**
% value	0.6%	0.3%	0.4%	0.1%		98.6%	
Number of vessels	23	29	21	11	-	45	**129**
% of vessels	17.8%	22.5%	16.3%	8.5%		34.9%	
Dredges							
Number of observations	90,601	69,899	17,225	18,972	17,211	6,203	**220,111**
% observations	41.2%	31.8%	7.8%	8.6%	7.8%	2.8%	
Weight (kg)	109,346,209	83,140,058	82,758,638	37,727,871	41,154,078	26,324,354	**380,451,208**
% weight	28.7%	21.9%	21.8%	9.9%	10.8%	6.9%	
Value (£)	160,597,966	144,074,536	68,086,261	61,199,295	74,306,911	34,316,930	**542,581,899**
% value	29.6%	26.6%	12.5%	11.3%	13.7%	6.3%	
Number of vessels	267	102	30	23	12	7	**441**
% of vessels	60.5%	23.1%	6.8%	5.2%		1.6%	
Pots and traps							
Number of observations	286,342	51,679	3,360	2,869	5	-	**344,255**
% observations	83.2%	15.0%	1.0%	0.8%	0.0%	-	
Weight (kg)	160,876,295	95,233,164	6,180,040	8,589,799	710	-	**270,880,009**
% weight	59.4%	35.2%	2.3%	3.2%	0.0%	-	
Value (£)	297,940,530	133,882,883	12,078,968	13,031,202	2,872	-	**456,936,454**
% value	65.2%	29.3%	2.6%	2.9%	0.0%	-	
Number of vessels	438	90	7	2	1	-	**538**
% of vessels	81.4%	16.7%	1.3%	0.4%	0.2%	-	

Fishing method	Vessel length category						Total
	10.01–15m	15–19.99m	20–24.99m	25–29.99m	30–34.99m	35m and over	
Seines							
Number of observations	26	4,395	9,296	8,028	1,083	3,036	**25,864**
% observations	0.1%	17.0%	35.9%	31.0%	4.2%	11.7%	
Weight (kg)	6,835	15,773,900	40,289,779	37,395,015	2,735,187	8,587,610	**104,788,324**
% weight	0.0%	15.1%	38.4%	35.7%	2.6%	8.2%	
Value (£)	11,464	19,276,852	56,939,029	60,139,856	6,707,782	22,803,872	**165,878,855**
% value	0.0%	11.6%	34.3%	36.3%	4.0%	13.7%	
Number of vessels	3	12	18	14	3	4	**54**
% of vessels	5.6%	22.2%	33.3%	25.9%	5.6%	7.4%	
Beam trawl							
Number of observations	22,698	5,382	35,690	29,912	13,416	8,167	**115,265**
% observations	19.7%	4.7%	31.0%	26.0%	11.6%	7.1%	
Weight (kg)	8,763,582	2,390,740	32,427,488	28,308,119	17,549,450	38,154,474	**127,593,853**
% weight	6.9%	1.9%	25.4%	22.2%	13.8%	29.9%	
Value (£)	25,960,776	8,003,244	108,927,537	97,462,308	56,345,053	71,640,832	**368,339,750**
% value	7.0%	2.2%	29.6%	26.5%	15.3%	19.4%	
Number of vessels	97	12	26	29	11	20	**195**
% of vessels	49.7%	6.2%	13.3%	14.9%	5.6%	10.3%	
Hooks and lines							
Number of observations	9,368	155	-	12,347	14,046	3,401	**39,317**
% observations	23.8%	0.4%	-	31.4%	35.7%	8.7%	
Weight (kg)	336,227	29,262		14410942.4	19017294.7	5,471,884	**39,265,610**
% weight	0.9%	0.1%	0.0%	36.7%	48.4%	13.9%	
Value (£)	2,004,587	74,002		38,380,942	53,803,303	16,318,725	**110,581,559**
% value	1.8%	0.1%	0.0%	34.7%	48.7%	14.8%	
Number of vessels	64	9	0	10	6	5	**94**
% of vessels	68.1%	9.6%	0.0%	10.6%	6.4%	5.3%	
Gillnets							
Number of observations	83,161	64,518	32,504	1,399		23,629	**205,211**
% observations	40.5%	31.4%	15.8%	0.7%	0.0%	11.5%	
Weight (kg)	4,870,809	7,333,823	3,186,586	1,136,629		7,357,315	**23,885,162**
% weight	20.4%	30.7%	13.3%	4.8%	0.0%	30.8%	
Value (£)	16,351,498	20,848,684	10,007,633	4,959,069		43,907,836	**96,074,720**
% value	17.0%	21.7%	10.4%	5.2%	0.0%	45.7%	
Number of vessels	101	20	7	2		10	**140**
% of vessels	51.8%	10.3%	3.6%	1.0%	0.0%	5.1%	

Appendix F: GAM model specification

Each of the eight fishing method models (bottom trawl, midwater trawl, dredge, pots, seines, beam trawl, gillnets and entangling nets, and hooks and line) were specified as follows:

$$
\begin{aligned}
g(E(\mathit{Landed\ weight}_{ijkm})) \; = \; & \beta_0 + \beta_1\,\mathit{Length} + \\
& f(\mathit{Wind\ or\ Wave}) + \\
& u_j(\mathit{Vessel}) + u_k(\mathit{ICES\ rectangle}) + \\
& u_m(\mathit{Activity\ year}) + \varepsilon
\end{aligned}
$$

Where: g is the gamma continuous probability distribution with a log link; $E(\mathit{Landed\ weight}_{ijkm})$ is the i^{th} observation of landed weight for vessel j in ICES rectangle k in activity year m; β_0 is the mean observed landed weight; β_1 is the parameter coefficient estimate for vessel length category; $f(\mathit{Wind\ or\ Wave})$ is the smoothing term for non-parametric wind speed or wave height; $u_j(\mathit{Vessel})$, $u_k(\mathit{ICES\ rectangle})$, and $u_m(\mathit{Activity\ year})$ are the smooth random intercept effects for each j fishing vessel, k ICES rectangle*, and* m activity year, so that the mean landed weight for each j vessel is $\beta_0 + u_j$, for each k ICES rectangle is $\beta_0 + u_k$, and for each m activity year is $\beta_0 + u_m$,; and ε is the random error in the data unaccounted for by other explanatory variables.

The model of bottom trawl by vessel length category takes the model specification above and adds an smooth term containing the interaction between wind speed or wave height and vessel length category, $f(\mathit{Wind\ or\ Wave} * \mathit{Length})$ as follows:

$$
\begin{aligned}
g(E(\mathit{Landed\ weight}_{ijkm})) \; = \; & \beta_0 + \beta_1\,\mathit{Length} + \\
& f(\mathit{Wind\ or\ Wave}) + f(\mathit{Wind\ or\ Wave} * \mathit{Length}) + \\
& u_j(\mathit{Vessel}) + u_k(\mathit{ICES\ rectangle}) + \\
& u_m(\mathit{Activity\ year}) + \varepsilon
\end{aligned}
$$

References

References

Abernethy, K.E., Trebilcock, P., Kebede, B., Allison, E.H., Dulvy, N.K., 2010. Fuelling the decline in UK fishing communities? *ICES J. Mar. Sci*. **67**, 1076–1085. https://doi.org/10.1093/icesjms/fsp289

Acheson, J.M., 1981. Anthropology of fishing. *Annu. Rev. Anthropol*. **10**, 275–316. https://doi.org/10.1146/annurev.an.10.100181.001423

Adger, W.N., 2006. Vulnerability. *Glob. Environ. Chang.* **16**, 268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Adger, W.N., Hughes, T.P., Folke, C., Carpenter, S.R., Rockström, J., 2005. Social-ecological resilience to coastal disasters. Science **309(5737)**, 1036–1039. https://doi.org/10.1126/science.1112122

Ajzen, I, 1985. From intentions to actions: A theory of planned behavior. in *Action control: From cognition to behavior* (eds. Kuhl, J. & Beckmann, J.) 11–39, Springer-Verlag, Berlin. https://doi:10.1007/978-3-642-69746-3_2

Alberello, A., Onorato, M., Frascoli, F., Toffoli, A., 2019. Observation of turbulence and intermittency in wave-induced oscillatory flows. *Wave Motion* **84**, 81–89. https://doi.org/10.1016/j.wavemoti.2018.10.003

Allen, M.R., Dube, O.P., Solecki, W., Aragón-Durand, F., Cramer, W., Humphreys, S., Kainuma, M., Kala, J., Mahowald, N., Mulugetta, Y., Perez, R., Wairiu, M., Zickfeld, K., 2019. *Framing and Context*, in: Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T. (Eds.), Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change. p. 42.

Allison, E.H., Adger, W.N., Badjeck, M.-C., Brown, K., Conway, D., Dulvy, N.K., Halls, A., Perry, A., Reynolds, J.D., 2005. *Effects of climate change on the* *sustainability of capture and enhancement fisheries important to the poor: analysis of the vulnerability and adaptability of fisherfolk living in poverty., Analysis.* Norwich.

Allison, E.H., Ellis, F., 2001. The livelihoods approach and management of small-scale fisheries. *Mar. Policy* **25**, 377–388. https://doi.org/10.1016/S0308-597X(01)00023-9

Allison, E.H., Perry, A.L., Badjeck, M.C., Neil Adger, W., Brown, K., Conway, D., Halls, A.S., Pilling, G.M., Reynolds, J.D., Andrew, N.L., Dulvy, N.K., 2009. Vulnerability of national economies to the impacts of climate change on fisheries. *Fish Fish*. **10**, 173–196. https://doi.org/10.1111/j.1467-2979.2008.00310.x

Almklov, P.G., Rosness, R., Størkersen, K., 2014. When safety science meets the practitioners: Does safety science contribute to marginalization of practical knowledge? *Saf. Sci*. **67**, 25–36. https://doi.org/10.1016/j.ssci.2013.08.025

Andersen, B.S., Ulrich, C., Eigaard, O.R., Christensen, A.S., 2012. Short-term choice behaviour in a mixed fishery: Investigating métier selection in the Danish gillnet fishery. *ICES J. Mar. Sci.* **69**, 131–143. https://doi.org/10.1093/icesjms/fsr181

Ando, H., Cousins, R., Young, C., 2014. Achieving Saturation in Thematic Analysis: Development and Refinement of a Codebook. *Compr. Psychol*. **3**, 1–7. https://doi.org/10.2466/03.cp.3.4

Ares, B.E., Rhodes, C., Ward, M., 2017. *The UK Fishing Industry*. London, UK.

Armitage, C. J. & Conner, M., 2001. Efficacy of the Theory of Planned Behaviour: A meta-analytic review. *Br. J. Soc. Psychol.* **40**, 471–499. https://doi.org/10.1348/014466601164939

Arreguín-Sánchez, F., 1996. Catchability: A key parameter for fish stock assessment. *Rev. Fish Biol. Fish*. **6**, 221–242. https://doi.org/10.1007/bf00182344

Ashoka Deepananda, K.H.., Macusi, E.D., 2012. The changing climate and its implications to capture fisheries: a review. *J. Nat. Stud*. **11**, 71–87.

Aven, T., 2016. Risk assessment and risk management: Review of recent advances on their foundation. *Eur*. *J. Oper. Res*. **253**, 1–13. https://doi.org/10.1016/j.ejor.2015.12.023

Aven, T., Ben-Haim, Y., Andersen, H.B., Cox, T., Droguett, E.L., Greenberg, M., Guikema, S., Renn, O., Kröger, W., Thompson, K.M., Zio, E., 2018. *Society for Risk Analysis Glossary*, Society for Risk Analysis. https://www.sra.org/wp-content/uploads/2020/04/SRA-Glossary-FINAL.pdf

Badjeck, M., Allison, E.H., Halls, A.S., Dulvy, N.K., 2010. Impacts of climate variability and change on fishery-based livelihoods. *Mar. Policy* **34**, 375–383. https://doi.org/10.1016/j.marpol.2009.08.007

Bastardie, F., Nielsen, J.R., Andersen, B.S., Eigaard, O.R., 2013. Integrating individual trip planning in energy efficiency – Building decision tree models for Danish fisheries. *Fish. Res.* **143**, 119–130. https://doi.org/10.1016/j.fishres.2013.01.018

Bech, M. & Gyrd-Hansen, D, 2005. Effects coding in discrete choice experiments. Health Econ*.* **14**, 1079–1083. https://doi.org/10.1002/hec.984

Ben-Yami, M., 1987. *Purse-seining with small boats*, FAO Trainiing series. FAO, Rome.

Ben- Yami, M., 2000. *Risks and dangers in small-scale fisheries: an overview*. International Labour Office, Geneva.

Bergeron, J.P., Massé, J., 2011. Change in the shoaling behaviour and nutritional condition of anchovies (engraulis encrasicolus L.) during a wind-induced water column disturbance: A natural event test of a general hypothesis. *Mar. Freshw. Behav. Physiol*. **44**, 93–107. https://doi.org/10.1080/10236244.2011.568600

Bezerra, D.M.M., Nascimento, D.M., Ferreira, E.N., Rocha, P.D., Mourão, J.S., 2012. Influence of tides and winds on fishing techniques and strategies in the mamanguape River Estuary, Paraíba State, NE Brazil. *An. Acad. Bras. Cienc.* **84**, 775–787. https://doi.org/10.1590/S0001-37652012005000046

Bindoff, N.L., Stott, P.A., AchutaRao, K.M., Allen, M.R., N. Gillett, Gutzler, D., Hansingo, K., Hegerl, G., Hu, Y., Jain, S., Mokhov, I.I., Overland, J., Perlwitz, J. Sebbari, R., Zhang, X.. 2013. Detection and attribution of climate change: From global to regional. in *Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.). Cambridge University Press, Cambridge. 867–952. doi:10.1017/CBO9781107415324.022

Binkley, M., 1991. Nova Scotian offshore fishermen's awareness of safety. *Mar. Policy* **15**, 170–182. https://doi.org/10.1016/0308-597X(91)90060-O

Binkley, M., 1995a. *The Stress and Strain of Fishing, in: Risks, Dangers, and Rewards in the Nova Scotia Offshore Fishery*. McGill-Queen's University Press, pp. 128–141, Canada.

Binkley, M., 1995b. *Toward a Safer Fishery, in: Risks, Dangers, and Rewards in the Nova Scotia Offshore Fishery*. McGill-Queen's University Press, pp. 156–160, Canada.

Blaber, S.J.M., Blaber, T.G., 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. *J. Fish Biol*. **17**, 143–162. https://doi.org/10.1111/j.1095-8649.1980.tb02749.x

Blankespoor, B., Dasgupta, S., Lange, G.M., 2017. Mangroves as a protection from storm surges in a changing climate. *Ambio* **46**, 478–491. https://doi.org/10.1007/s13280-016-0838-x

Blasiak, R., Spijkers, J., Tokunaga, K., Pittman, J., Yagi, N., Österblom, H., 2017. Climate change and marine fisheries: Least developed countries top global index of vulnerability. *PLoS One* **12**, 1–15. https://doi.org/10.1371/journal.pone.0179632

Bliemer, M.C.J., Rose, J.M., 2011. Experimental design influences on stated choice outputs: An empirical study in air travel choice. *Transp. Res. Part A Policy Pract*. **45**, 63–79. https://doi.org/10.1016/j.tra.2010.09.003

Bockarjova, M. & Steg, L., 2014 Can Protection Motivation Theory predict pro-environmental behavior? Explaining the adoption of electric vehicles in the Netherlands. *Glob. Environ. Chang.* **28**, 276–288. https://doi.org/10.1016/j.gloenvcha.2014.06.010

Bockstael, N.E., Opaluch, J.J., 1983. Discrete modelling of supply response under uncertainty: the case of the fishery. *J. Environ. Econ. Manage*. **10**, 125–137. https://doi.org/10.1016/0095-0696(83)90021-9

Bopp, L., Resplandy, L., Orr, J.C., Doney, S.C., Dunne, J.P., Gehlen, M., Halloran, P., Heinze, C., Ilyina, T., Séférian, R., Tjiputra, J., Vichi, M., 2013. Multiple stressors of ocean ecosystems in the 21st century: Projections with CMIP5 models. *Biogeosciences* **10**, 6225–6245. https://doi.org/10.5194/bg-10-6225-2013

Brander, K.M., 2007. Global fish production and climate change. *Proc. Natl. Acad. Sci. U. S. A*. **104**, 19709–19714. https://doi.org/10.1073/pnas.0702059104

Brennan, S.L., 2008. *"In God's Pocket": Accidents, injuries and perceptions of risk among comtemporary Newfoundland fish harvesters*. Masters thesis, Memorial University of Newfoundland, Canada. https://research.library.mun.ca/9193/ (accessed 29.09.18)

Brett Hauber, A., Fairchild, A.O., Reed Johnson, F., 2013. Quantifying benefit-risk preferences for medical interventions: An overview of a growing empirical literature. *Appl. Health Econ. Health Policy* **11**, 319–329. https://doi.org/10.1007/s40258-013-0028-y

Brooks, B., 2005. Not drowning, waving! Safety management and occupational culture in an Australian commercial fishing port. *Saf. Sci*. **43**, 795–814. https://doi.org/10.1016/j.ssci.2005.02.007

Bryman, A., 2012. *Sampling*, in: Social Research Methods. Oxford University Press, pp. 183–206, Oxford, UK.

Bye, R., Lamvik, G.M., 2007. Professional culture and risk perception: Coping with danger on board small fishing boats and offshore service vessels. Reliab. Eng. *Syst. Saf.* **92**, 1756–1763. https://doi.org/10.1016/j.ress.2007.03.024

Carew, R., 1769. *The Survey of Cornwall. And An Epistle concerning the Excellencies of the English Tongue*, Third. ed. B. Law and J. Hewett, London and Penzance, UK.

Cattermoul, B., Brown, D., Poulain, F., 2014. *Fisheries and aquaculture emergency response guidance*. Rome, Italy. http://www.fao.org/3/a-i3432e.pdf (accessed 07.07.2017)

CCRIF SPC, 2019. *Caribbean countries to benefit from access to insurance for the fisheries sector*. https://www.ccrif.org/ en/news/caribbean-countries-benefit-access-insurance-fisheries-sector (accessed 9.1.19).

Centre for Environment Fisheries and aquaculture Science (Cefas), 2020. *Wavenet interactive map*. http://wavenet.cefas.co.uk/Map (accessed 10.12.20).

Cheung, W.W.L., Pinnegar, J., Merino, G., Jones, M.C., Barange, M., 2012. Review of climate change impacts on marine fisheries in the UK and Ireland. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **22**, 368–388. https://doi.org/10.1002/aqc.2248

Cheung, W., Sarmiento, J.L., Kearney, K., Watson, R., Zeller, D., 2010. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Glob. Chang. Bio.* **16** 24–35. https://doi.org/10.1111/j.1365-2486.2009.01995.x

Cheung, W.W.L., Watson, R., Pauly, D., 2013. Signature of ocean warming in global fisheries catch. *Nature* **497**, 365–368. https://doi.org/10.1038/nature12156

Choicemetrics, 2018. *Ngene 1.2 user manual and reference guide*.

Christensen, A.S., Raakjær, J., 2006. Fishermen’s tactical and strategic decisions. A case study of Danish demersal fisheries. *Fish. Res*. **81**, 258–267. https://doi.org/10.1016/j.fishres.2006.06.018

Cinner, J.E., Adger, W.N., Allison, E.H., Barnes, M.L., Brown, K., Cohen, P.J., Gelcich, S., Hicks, C.C., Hughes, T.P., Lau, J., Marshall, N.A., Morrison, T.H., 2018. Building adaptive capacity to climate change in tropical coastal communities. *Nat. Clim. Chang*. **8**, 117–123. https://doi.org/10.1038/s41558-017-0065-x

Cinner, J.E., Huchery, C., Darling, E.S., Humphries, A.T., Graham, N.A.J., Hicks, C.C., Marshall, N., McClanahan, T.R., 2013. Evaluating social and ecological vulnerability of coral reef fisheries to climate change. *PLoS One* **8**. https://doi.org/10.1371/journal.pone.0074321

Clark, M.D., Determann, D., Petrou, S., Moro, D., de Bekker-Grob, E.W., 2014. Discrete Choice Experiments in Health Economics: A Review of the Literature. *Pharmacoeconomics* **32**, 883–902. https://doi.org/10.1007/s40273-014-0170-x

Colburn, L.L., Jepson, M., Weng, C., Seara, T., Weiss, J., Hare, J.A., 2016. Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the United States. *Mar. Policy* **74**, 323–333. https://doi.org/10.1016/j.marpol.2016.04.030

Constantin, A., Johnson, R.S., 2019. Ekman-type solutions for shallow-water flows on a rotating sphere: A new perspective on a classical problem. *Phys. Fluids* **31**. https://doi.org/10.1063/1.5083088

Conway, G.A., Lincoln, J.M., 1995. Preventing deaths in Alaska's fishing industry. Public Health Rep. **110(6)**, 700.

Conway, D., Nicholls, R.J., Brown, S., Tebboth, M.G.L., Adger, W.N., Ahmad, B., Biemans, H., Crick, F., Lutz, A.F., De Campos, R.S., Said, M., Singh, C., Zaroug, M.A.H., Ludi, E., New, M., Wester, P., 2019. The need for bottom-up assessments of climate risks and adaptation in climate-sensitive regions. *Nat. Clim. Chang*. **9**, 503–511. https://doi.org/10.1038/s41558-019-0502-0

Cornwall Rural Community Charity, 2016. *Local Development Strategy for Cornwall & Isles of Scilly*, UK. https://www.seafoodcornwalltraining.co.uk/wp-content/uploads/2017/04/FLAG-LDS-Stage-2-Cornwall-and-IoS-Final-v23.pdf (accessed 05.04.2017)

Cornwall Wildlife Trust, 2020. *Cornwall good seasfood guide*. https://www.cornwallgoodseafoodguide.org.uk/fish-guide.php (accessed 5.4.20).

Coulthard, S., Johnson, D. and McGregor, J.A., 2011. Poverty, sustainability and human wellbeing: A social wellbeing approach to the global fisheries crisis. *Glob. Environ. Change* **21,** 453–463. https://doi.org/10.1016/j.gloenvcha.2011.01.003

Coulthard, S., Britton, E., 2015. Waving or Drowning: An Exploration of Adaptive Strategies Amongst Fishing Households and Implications for Wellbeing Outcomes. *Sociol. Ruralis* **55**, 275–290. https://doi.org/10.1111/soru.12093

Crabbe, M., Vandebroek, M., 2012. Using appropriate prior information to eliminate choice sets with a dominant alternative from D-efficient designs. *J. Choice Model*. **5**, 22–45. https://doi.org/10.1016/S1755-5345(13)70046-0

Cull, R., Morduch, J., 2018. *Microfinance and economic development, policy research working paper 8252.* Handbook of Finance and Development, 550–572. World Bank Group. https://doi.org/10.4337/9781785360510.00030

Cyrus, D.P., Blaber, S.J.M., 1987a. The influence of turbidity on juvenile marine fishes in estuaries. part 1. field studies at Lake St. Lucia on the southeastern coast of Africa. J. Exp. Mar. Bio. Ecol. **109**, 53–70. https://doi.org/10.1016/0022-0981(87)90185-7

Cyrus, D.P., Blaber, S.J.M., 1987b. The influence of turbidity on juvenile marine fish in the estuaries of Natal, South Africa. Cont. Shelf Res. **7**, 1411–1416. https://doi.org/10.1016/0278-4343(87)90046-X

Daly, A., Dekker, T., Hess, S., 2016. Dummy coding vs effects coding for categorical variables: Clarifications and extensions. *J. Choice Model*. **21**, 36–41. https://doi.org/10.1016/j.jocm.2016.09.005

Damen, T.G.E., 2019. Sense of Agency as a predictor of risk-taking. *Acta Psychol. (Amst)*. **197**, 10–15. https://doi.org/10.1016/j.actpsy.2019.04.015

Daron, J.D., Stainforth, D.A., 2014. Assessing pricing assumptions for weather index insurance in a changing climate. Clim. *Risk Manag*. **1**, 76–91. https://doi.org/10.1016/j.crm.2014.01.001

Davies, T.K., Mees, C.C., Milner-Gulland, E.J., 2014. Modelling the spatial behaviour of a tropical tuna purse seine fleet. *PLoS One* **9**, 1–18. https://doi.org/10.1371/journal.pone.0114037

Davis, M.E., 2012. Perceptions of occupational risk by US commercial fishermen. *Mar. Policy* **36**, 28–33. https://doi.org/10.1016/j.marpol.2011.03.005

Daw, T., Adger, W.N., Brown, K., Badjeck, M.-C., 2009. *Climate change and aquaculture: potential impacts, adaptation and mitigation*, in: K. Cochrane, C. De Young, D.S. and T.B. (Ed.), Climate Change Implications for Fisheries and Aquaculture: Overview of Current Scientific Knowledge. FAO Fisheries and Aquaculture Technical Paper, Rome, pp. 107–150. http://www.fao.org/fileadmin/user_upload/newsroom/docs/FTP530.pdf (accessed 27.11.16)

de Bekker-Grob, Esther W., Ryan, M., Gerard, K., 2012. Discrete choice experiments in health economics: a review of the literature. *Heal. Econ*. **21**, 145–172. https://doi.org/10.1002/hec.1697

DeShazo, J.R., Fermo, G., 2002. Designing choice sets for stated preference methods: The effects of complexity on choice consistency. *J. Environ. Econ. Manage*. **44**, 123–143. https://doi.org/10.1006/jeem.2001.1199

Dickson, W., 1993. Estimation of the capture efficiency of trawl gear. I: Development of a theoretical model. *Fish. Res*. **16**, 239–253. https://doi.org/10.1016/0165-7836(93)90096-P

Dohmen, T., Falk, A., Huffman, D., Sunde, U., Schupp, J., Wagner, G.G., 2011. Individual risk attitudes: Measurement, determinants, and behavioral consequences. *J. Eur. Econ. Assoc*. **9**, 522–550. https://doi.org/10.1111/j.1542-4774.2011.01015.x

Dowdy, A.J., Mills, G.A., Timbal, B., Wang, Y., 2014. Fewer large waves projected for eastern Australia due to decreasing storminess. *Nat. Clim. Chang*. **4**. https://doi.org/10.1038/NCLIMATE2142

Drinkwater, K.F., Tremblay, M.J., Comeau, M., 2006. The influence of wind and temperature on the catch rate of the American lobster (Homarus americanus) during spring fisheries off eastern Canada. *Fish. Oceanogr*. **15**, 150–165. https://doi.org/10.1111/j.1365-2419.2005.00349.x

Econometrics Software Inc., 2019. *NLOGIT6*.

Eggert, H., Lokina, R.B., 2007. Small-scale fishermen and risk preferences. *Mar. Resour. Econ*. **22**, 49–67. https://doi.org/10.1086/mre.22.1.42629535

Ehrich, S., Stransky, C., 1999. Fishing effects in northeast Atlantic shelf seas: patterns in fishing effort, diversity and community structure. VI. Gale effects on vertical distribution and structure of a fish assemblage in the North Sea. *Fish. Res.* **40**, 185–193. https://doi.org/10.1016/S0165-7836(98)00211-2

Eklöf, M., Törner, M., 2002. Perception and control of occupational injury risks in fishery **-** A pilot study. *Work Stress* **16**, 58–69. https://doi.org/10.1080/02678370110114694

Ekstrom, J.A., Suatoni, L., Cooley, S.R., Pendleton, L.H., Waldbusser, G.G., Cinner, J.E., Ritter, J., Langdon, C., Van Hooidonk, R., Gledhill, D., Wellman, K., Beck, M.W., Brander, L.M., Rittschof, D., Doherty, C., Edwards, P.E.T., Portela, R., 2015. Vulnerability and adaptation of US shellfisheries to ocean acidification. *Nat. Clim. Chang*. **5**, 207–214. https://doi.org/10.1038/nclimate2508

Emery, T.J., Hartmann, K., Green, B.S., Gardner, C., Tisdell, J., 2014. Fishing for revenue: how leasing quota can be hazardous to your health. *ICES J. Mar. Sci*. **71**, 1854–1865. https://doi.org/10.1093/icesjms/fsu019

Fabry, V.J., Seibel, B.A., Feely, R.A., Orr, J.C., 2008. Impacts of ocean acidification on marine fauna and ecosystem processes. *ICES J. Mar. Sci*. **65**, 414–432. https://doi.org/10.1093/icesjms/fsn048

FAO, 2016. *The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all*. Rome, Italy. http://www.fao.org/3/a-i5555e.pdf (accessed 05.04.17)

FAO, 2018. *The state of world fisheries and aquaculture 2018 - Meeting the sustainable development goals*. Rome, Italy. http://www.fao.org/documents/card/en/c/I9540EN/ (accessed 13.12.18)

FAO, 2019. *European Boat Operated Purse Seining*. Fish. Tech. http://www.fao.org/fishery/fishtech/1005/en (accessed 09.01.20)

FAO Coordinating Working Party on Fishery Statistics Handbook of Fishery Statistics (FAO CWP), 2013*. International Standard Statistical Classification of Fishing Gear (ISSCFG Rev. 1, 2013)*. Rome, Italy.

Faugier, J., Sargeant, M., 1997. Sampling hard to reach populations. *J. Adv. Nurs.* **26**, 790–797. https://doi.org/10.1046/j.1365-2648.1997.00371.x

Feenstra, J., Mcgarvey, R., Linnane, A., Punt, A.E., Bean, N., 2014. Environmental influences on daily commercial catch rates of South Australia’s southern rock lobster (Jasus edwardsii). *Fish. Oceanogr.* **23**, 362–374. https://doi.org/10.1111/fog.12069

Feser, F., Barcikowska, M., Krueger, O., Schenk, F., Weisse, R., Xia, L., 2015. Storminess over the North Atlantic and northwestern Europe-A review. *Q. J. R. Meteorol. Soc.* **141**, 350–382. https://doi.org/10.1002/qj.2364

Finkbeiner, E.M., Micheli, F., Bennett, N.J., Ayers, A.L., Le Cornu, E., Doerr, A.N., 2018. Exploring trade-offs in climate change response in the context of Pacific Island fisheries. *Mar. Policy* **88**, 359–364. https://doi.org/10.1016/j.marpol.2017.09.032

Finnis, J., Shewmake, J.W., Neis, B., Telford, D., 2019. Marine forecasting and fishing safety: improving the fit between forecasts and harvester Needs. *J.*

Agromedicine **24**, 324–332. https://doi.org/10.1080/1059924X.2019.1639576

Fishburn, P.C., 1988. Expected utility: An anniversary and a new era. *J. Risk Uncertain*. **1**, 267–283. https://doi.org/10.1007/BF00056138

Fisher, E., Hellin, J., Greatrex, H., Jensen, N., 2019. Index insurance and climate risk management: Addressing social equity. *Dev. Policy Rev*. **37** 581–602. https://doi.org/10.1111/dpr.12387

Flizik, A., 2011. Show card, in: Lavrakas, P.J. (Ed.), *Encyclopedia of Survey Research Methods*. Sage Publications, Inc. Toronto, Canada. pp. 818–819. https://doi.org/10.4135/9781412963947

Forster, J., Schuhmann, P.W., Lake, I.R., Watkinson, A.R., Gill, J.A., 2012. The influence of hurricane risk on tourist destination choice in the Caribbean. *Clim. Change* **114**, 745–768. https://doi.org/10.1007/s10584-012-0433-5

Fulmer, S., Buchholz, B., Jenkins, P., Scribani, M., 2019. Injuries and exposure to time lobstering in Northeast US inshore lobster fleet. *J. Agromedicine* **24**, 333–340. https://doi.org/10.1080/1059924X.2019.1645780

Fulton, E.A., Smith, A.D.M., Smith, D.C., Van Putten, I.E., 2011. Human behaviour: The key source of uncertainty in fisheries management. *Fish Fish.* **12**, 2–17. https://doi.org/10.1111/j.1467-2979.2010.00371.x

Gabriel, O., Lange, K., Dahm, E., Wendt, T., 2005. *Seining in Fresh and Sea Water*, in: Gabriel, O., Lange, K., Dahm, E., Wendt, T. (Eds.), Fish Catching Methods of the World. Blackwell Publishing Ltd, Hamburg, Germany. pp. 431–448. https://doi.org/10.1002/9780470995648

Gianelli, I., Ortega, L., Defeo, O., 2019. Modeling short-term fishing dynamics in a small-scale intertidal shellfishery. *Fish. Res*. **209**, 242–250. https://doi.org/10.1016/j.fishres.2018.09.028

Golden, C.D., Allison, E.H., Dey, M.M., Halpern, B.S., McCauley Douglas J., Smith M., Vaitla, B., 2016. Fall in fish catch threatens human health. *Nature* **534**, 317–320. https://doi.org/10.1038/534317a

Graham, N., Jones, E.G., Reid, D.G., 2004. Review of technological advances for the study of fish behaviour in relation to demersal fishing trawls. *ICES J. Mar. Sci.* **61**, 1036–1043. https://doi.org/10.1016/j.icesjms.2004.06.006

Greene, W.H., Hensher, D.A., 2003. A latent class model for discrete choice analysis: Contrasts with mixed logit. *Transp. Res. Part B Methodol*. **37**, 681–698. https://doi.org/10.1016/S0191-2615(02)00046-2

Griffiths, P., Gossop, M., Powis, B., Strang, J., 1993. Reaching hidden populations of drug users by privileged access interviewers: methodological and practical issues. Addiction **88**, 1617–1626. https://doi.org/10.1111/j.1360-0443.1993.tb02036.x

Grothmann, T., Patt, A., 2005. Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Glob. Environ. Chang.* **15**, 199–213. https://doi.org/10.1016/j.gloenvcha.2005.01.002

Gulbrandsen, O., 2009. *Safety guide for small fishing boats (FAO/SIDA/IMO/BOBP-IGO)*. http://www.fao.org/3/a-ak191e.pdf (accessed 10.01.18)

Guldenmund, F.W., 2000. The nature of safety culture: A review of theory and research. *Saf. Sci*. **34**, 215–257. https://doi.org/10.1016/S0925-7535(00)00014-X

Gustavsson, M., Riley, M., 2020. (R)evolving masculinities in times of change amongst small-scale fishers in North Wales. *Gender, Place Cult.* **27**, 196–217. https://doi.org/10.1080/0966369X.2019.1609914

Hanley, N., Mourato, S., Wright, R.E., 2002. Choice modelling approaches: a superior alternative for environmental valuation? *J. Econ. Surv*. **15**, 435–462. https://doi.org/10.1111/1467-6419.00145

Harden Jones, F.R., Scholes, P., 1980. Wind and the catch of a Lowestoft trawler. ICES J. *Mar. Sci*. **39**, 53–69. https://doi.org/10.1093/icesjms/39.1.53

Harper, S., Grubb, C., Stiles, M., Sumaila, U.R., 2017. Contributions by Women to Fisheries Economies: Insights from Five Maritime Countries. *Coast. Manag.* **45**, 91–106. https://doi.org/10.1080/08920753.2017.1278143

Harrison, M., Rigby, D., Vass, C., Flynn, T., Louviere, J., Payne, K., 2014. Risk as an Attribute in Discrete Choice Experiments : A Systematic Review of the Literature. *Patient* **7(2),** 151–170. https://doi.org/10.1007/s40271-014-0048-1

Hartmann, D.L., Klein Tank, A.M.G., Rusticucci, M., Alexander, L. V., Brönnimann, S., Charabi, Y.A.R., Dentener, F.J., Dlugokencky, E.J., Easterling, D.R., Kaplan, A., Soden, B.J., Thorne, P.W., Wild, M., Zhai, P., 2013. *Observations: Atmosphere and surface*, in: Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, P.M.M. (Ed.), Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Cambridge, pp. 159–254. https://doi.org/10.1017/CBO9781107415324.008

Hasselback, P., Neutel, C.I., 1990. Risk for commercial fishing deaths in Canadian Atlantic provinces. Br. *J. Ind. Med*. **47**, 498–501. https://doi.org/10.1136/oem.47.7.498

Håvold, J.I., 2010. Safety culture aboard fishing vessels. *Saf. Sci*. **48**, 1054–1061. https://doi.org/10.1016/j.ssci.2009.11.004

He, P., 1993. The behaviour of cod around a cod trap as observed by an underwater camera and a scanning sonar. *ICES Mar. Sci. Symp. fish Behav. Relat. to Fish. Oper*. **196**, 21–25.

Hensher, D.A., 2006. How do respondents process stated choice experiments? Attribute consideration under varying information load. *J. Appl. Econom*. **21**, 861–878. https://doi.org/10.1002/jae.877

Hensher, D.A., 2010. Hypothetical bias, choice experiments and willingness to pay. *Transp. Res. Part B Methodol*. **44**, 735–752. https://doi.org/10.1016/j.trb.2009.12.012

Hensher, D.A., Greene, W.H., 2003. The mixed logit model: the state of practice. *Transportation (Amst)*. **30**, 133–176. https://doi.org/10.1023/A:1022558715350

Hensher, D.A., Greene, W.H., Li, Z., 2011. Embedding risk attitude and decision weights in non-linear logit to accommodate time variability in the value of expected travel time savings. *Transp. Res. Part B Methodol*. **45**, 954–972. https://doi.org/10.1016/j.trb.2011.05.023

Hensher, D.A., Rose, J., Greene, W.H., 2005. The implications on willingness to pay of respondents ignoring specific attributes. *Transportation (Amst)*. **32**, 203–222. https://doi.org/10.1007/s11116-004-7613-8

Hensher, D.A., Rose, J.M., Greene, W.H., 2015a. *Choice and utility*, in: Applied Choice Analysis. Cambridge University Press, Cambridge, UK, pp. 30–79.

Hensher, D.A., Rose, J.M., Greene, W.H., 2015b. *Families of discrete choice models*, in: Applied Choice Analysis. Cambridge University Press, Cambridge, UK, pp. 80–116.

Hess, S., Hensher, D.A., Daly, A., 2012. Not bored yet - Revisiting respondent fatigue in stated choice experiments. *Transp. Res. Part A Policy Pract.* **46**, 626–644. https://doi.org/10.1016/j.tra.2011.11.008

Hoang, H.D., Momtaz, S., Schreider, M., 2020. Assessing the vulnerability of small-scale fishery communities in the estuarine areas of Central Vietnam in the context of increasing climate risks. *Ocean Coast. Manag*. **196**, 105302. https://doi.org/10.1016/j.ocecoaman.2020.105302

Holland, D.S., 2008. Are Fishermen rational? A fishing expedition. *Mar. Resour. Econ*. **23**, 325–344. https://doi.org/10.1086/mre.23.3.42629621

Horswill, M.S., McKenna, F.P., 1999. The effect of perceived control on risk taking. *J. Appl. Soc. Psychol*. **29**, 377–391. https://doi.org/10.1111/j.1559-1816.1999.tb01392.x

Hoyos, D., 2010. The state of the art of environmental valuation with discrete choice experiments. *Ecol. Econ***. 69**, 1595–1603.

https://doi.org/10.1016/j.ecolecon.2010.04.011

Huchim-Lara, O., Salas, S., Fraga, J., Méndez-Domínguez, N., Chin, W., 2016. Fishermen's perceptions and attitudes toward risk diving and management issues in small-scale fisheries. *Am. J. Hum. Ecol*. **5**, 1–10. https://doi.org/10.11634/216796221605760

Husni, M.E., Betts, K.A., Griffith, J., Song, Y., Ganguli, A., 2017. Benefit-risk trade-offs for treatment decisions in moderate-to-severe rheumatoid arthritis: focus on the patient perspective. *Rheumatol. Int*. **37**, 1423–1434. https://doi.org/10.1007/s00296-017-3760-z

IPCC, 2014. *Summary for policymakers*, in: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, p. 1132. https://www.ipcc.ch/site/assets/uploads/2018/02/ar5_wgII_spm_en.pdf (accessed 20.10.20)

IPCC, 2019. *Summary for Policymakers*, in: Pörtner, H.-O., Roberts, D.C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Nicolai, M., Okem, A., Petzold, J., Rama, B., Weyer, N.M. (Eds*.),* IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. p. 42. https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/03_SROCC_SPM_FINAL.pdf (accessed 20.02.2020)

International Organization for Standardization (ISO), 2009. *International Organization for Standardization ISO 31000: Risk management - Principles and guidelines*. https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-1:v1:en (accessed 23.08.20)

Jacklin, M., Combes, J., 2007. *The good practice guide to handling and storing* *live Crustacea*. Seafish. Edinburgh, Scotland. https://www.seafish.org/document/?id=4b3b6210-51d6-4e21-97b5-a6eab65020a6

Jara, H.J., Tam, J., Reguero, B.G., Ganoza, F., Castillo, G., Romero, C.Y., Gévaudan, M., Sánchez, A.A., 2020. Current and future socio-ecological vulnerability and adaptation of artisanal fisheries communities in Peru, the case of the Huaura province. *Mar. Policy* **119**. https://doi.org/10.1016/j.marpol.2020.104003

Jensen, O.C.C., Petursdottir, G., Holmen, I.M. ari., Abrahamsen, A., Lincoln, J., 2014. A review of fatal accident incidence rate trends in fishing. *Int. Marit. Health* **65**, 47–52. https://doi.org/10.5603/IMH.2014.0011

Jin, D., Kite-Powell, H.L., Thunberg, E., Solow, A.R., Talley, W.K., 2002. A model of fishing vessel accident probability. *J. Safety Res*. **33**, 497–510. https://doi.org/10.1016/S0022-4375(02)00050-6

Jin, D., Thunberg, E., 2005. An analysis of fishing vessel accidents in fishing areas off the northeastern United States. *Saf. Sci*. **43**, 523–540. https://doi.org/10.1016/j.ssci.2005.02.005

Johnston, R.J., Boyle, K.J., Vic Adamowicz, W., Bennett, J., Brouwer, R., Ann Cameron, T., Michael Hanemann, W., Hanley, N., Ryan, M., Scarpa, R., Tourangeau, R., Vossler, C.A., 2017. Contemporary guidance for stated preference studies. *J. Assoc. Environ. Resour. Econ*. **4**, 319–405. https://doi.org/10.1086/691697

Jones, P.A., 2020. *Fishing Without a Safety Net*. Seafarers UK. London, UK. https://www.seafarers.uk/wp-content/uploads/2020/09/Seafarers-UK-Fishing-Without-a-Safety-Net-Report.pdf (accessed 01.11.20)

Kahneman, D., Tversky, A., 1992. Advances in Prospect Theory: Cumulative Representation of Uncertainty. *J. Risk Uncertain*. **5**, 297–323. https://doi.org/10.1007/BF00122574

Kahui, V., Alexander, W.R.J., 2008. A bioeconomic analysis of marine reserves for paua (abalone) management at Stewart Island, New Zealand. *Environ.*

Resour. Econ. **40**, 339–367. https://doi.org/10.1007/s10640-007-9157-9

Kalikoski, D.C., Quevedo, P., Almudi, T., 2010. Building adaptive capacity to climate variability : The case of artisanal fisheries in the estuary of the Patos Lagoon , Brazil. *Mar. Policy* **34**, 742–751. https://doi.org/10.1016/j.marpol.2010.02.003

Kaustell, K.O., Mattila, T.E.A., Rautiainen, R.H., 2016. Occupational injuries and diseases among commercial fishers in Finland 1996-2015. *Int. Marit. Health* **67**, 163–170. https://doi.org/10.5603/IMH.2016.0031

Keeling, R.F., Körtzinger, A., Gruber, N., 2010. Ocean Deoxygenation in a Warming World. *Ann. Rev. Mar. Sci.* **2**, 199–229. https://doi.org/10.1146/annurev.marine.010908.163855

Kendon, M., McCarthy, M., Jevrejeva, S., Matthews, A., Sparks, T., Garforth, J., 2020. State of the UK Climate 2019. *Int. J. Climatol*. **40**, 1–69. https://doi.org/10.1002/joc.6726

Kløjgaard, M.E., Bech, M., Søgaard, R., 2012. Designing a stated choice experiment: The value of a qualitative process. *J. Choice Model.* **5**, 1–18. https://doi.org/10.1016/S1755-5345(13)70050-2

Knudsen, F., 2009. Paperwork at the service of safety? Workers' reluctance against written procedures exemplified by the concept of "seamanship." *Saf. Sci*. **47**, 295–303. https://doi.org/10.1016/j.ssci.2008.04.004

Kolawole, O.D., Bolobilwe, K., 2019. Survival at a cost: how artisanal fishers perceive occupational hazards in the Okavango Delta, Botswana. *South African Geogr. J*. **101**, 51–71. https://doi.org/10.1080/03736245.2018.1541019

Kossin, J.P., Emanuel, K.A., Camargo, S.J., 2016. Past and projected changes in western north pacific tropical cyclone exposure. *J. Clim.* **29**, 5725–5739. https://doi.org/10.1175/JCLI-D-16-0076.1

Kossin, J.P., Knapp, K.R., Olander, T.L., Velden, C.S., 2020. Global increase in major tropical cyclone exceedance probability over the past 40 years. *Proc.*

Natl. Acad. Sci. U. S. A. **117**, 11975–11980. https://doi.org/10.1073/pnas.1920849117

Kusev, P., Purser, H., Heilman, R., Cooke, A., Van Schaik, P., Baranova, V., Martin, R., Ayton, P., 2017*.* Understanding risky behavior: The influence of cognitive, emotional and hormonal factors on decision-making under risk. *Front. Psychol.* **8**, 1–10. https://doi.org/10.3389/fpsyg.2017.00102

Laevastu, T., Hayes, M.L., 1982. *Fisheries Oceanography and Ecology*. Fishing News Books Ltd, Farnham, UK.

Lam, V.W.Y., Cheung, W.W.L., Reygondeau, G., Sumaila, U.R., 2016. Projected change in global fisheries revenues under climate change. *Sci. Rep.* **6** 6–13. https://doi.org/10.1038/srep32607

Lancaster, K., 1966. A New Approach to Consumer Theory. *J. Polit. Econ*. **74**, 132–157. https://doi.org/10.1086/259131

Laursen, L.H., Hansen, H.L., Jensen, O.C., 2008. Fatal occupational accidents in Danish fishing vessels 1989-2005. *Int. J. Inj. Contr. Saf. Promot*. **15**, 109–117. https://doi.org/10.1080/17457300802240503

Leahy, S.M., McCormick, M.I., Mitchell, M.D., Ferrari, M.C.O., 2011. To fear or to feed: The effects of turbidity on perception of risk by a marine fish. *Biol. Lett*. **7**, 811–813. https://doi.org/10.1098/rsbl.2011.0645

Leeney, R.H., Poncelet, P., 2015. Using fishers' ecological knowledge to assess the status and cultural importance of sawfish in Guinea-Bissau. *Aquat. Conserv. Mar. Freshw. Ecosyst*. **25**, 411–430. https://doi.org/10.1002/aqc.2419

Lê, S., Josse, J., Husson, F., 2008. FactoMineR: An R Package for Multivariate Analysis. *J. Stat. Softw*. **25**, 1–18. https://doi.org/10.18637/jss.v025.i01

Li, B., Hensher, D.A., 2017. Risky weighting in discrete choice. *Transp. Res. Part B Methodol*. **102**, 1–21. https://doi.org/10.1016/j.trb.2017.04.014

Lincoln, J.M., Lucas, D.L., 2010. Occupational fatalities in the United States commercial fishing industry, 2000-2009. *J. Agromedicine* **15**, 343–350.

https://doi.org/10.1080/1059924X.2010.509700

Linnerooth-Bayer, J., Mechler, R., 2006. Insurance for assisting adaptation to climate change in developing countries: A proposed strategy. *Clim. Policy* **6**, 621–636. https://doi.org/10.1080/14693062.2006.9685628

Lopes, P.F.M., Begossi, A., 2011. Decision-making processes by small-scale fishermen on the southeast coast of Brazil. *Fish. Manag. Ecol*. **18**, 400–410. https://doi.org/10.1111/j.1365-2400.2011.00795.x

Loughran, C.G., Pillay, A., Wang, J., Wall, A., Ruxton, T., 2002. A preliminary study of fishing vessel safety. *J. Risk Res*. **5**, 3–21. https://doi.org/10.1080/136698702753329135

Louviere, J., 2000. *Introduction to stated preference models and methods*, in: Stated Choice Methods Analysis and Applications. Cambridge University Press, Cambridge, UK, pp. 20–33. https://doi.org/10.1017/CBO9780511753831.002

Lucas, D.L., Lincoln, J.M., 2007. Fatal falls overboard on commercial fishing vessels in Alaska. *Am. J. Ind. Med*. **50**, 962–968. https://doi.org/10.1002/ajim.20509

Macusi, E.D., Babaran, R.P., van Zwieten, P.A.M., 2015. Strategies and tactics of tuna fishers in the payao (anchored FAD) fishery from general Santos city, Philippines. *Mar. Policy* **62**, 63–73. https://doi.org/10.1016/j.marpol.2015.08.020

Main, J., Sangster, G., 1981. *A study of the sand clouds produced by trawl boards and their possible effect on fish capture*, Scottish Fisheries Research Report. Department of Agriculture and Fisheries for Scotland, Marine Laboratory, Aberdeen, UK.

Malakar, K., Mishra, T., Patwardhan, A., 2018. Drivers of response to extreme weather warnings among marine fishermen. *Clim. Change* **150**, 417–431. https://doi.org/10.1007/s10584-018-2284-1

Marine Management Organisation (MMO), 2019a. *Latest dataset - UK and* *foreign vessels landings by UK port and UK vessel landings abroad: 2014 to 2018 and 2019 (year to date).* https://www.gov.uk/government/statistical-data-sets/uk-and-foreign-vessels-landings-by-uk-port-and-uk-vessel-landings-abroad (accessed 9.23.19).

Marine Management Organisation (MMO), 2019b. *UK fishing vessel lists*. Newcastle upon Tyne, UK. https://www.gov.uk/government/collections/uk-vessel-lists (accessed 9.23.19).

Marine Management Organisation (MMO), 2020. *UK sea fisheries statistics 2019*. Newcastle upon Tyne, UK. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/920679/UK_Sea_Fisheries_Statistics_2019_-_access_checked-002.pdf (accessed 05.10.20)

Marine Scotland Science, 2014. *Scottish Sea Fisheries Employment 2013*. https://www.researchgate.net/profile/Estelle_Jones/publication/311675475_Scottish_Sea_Fisheries_Employment_2013/links/5853ccc208ae7d33e01d087a/Scottish-Sea-Fisheries-Employment-2013.pdf (accessed 05.07.20)

Marling, G., Horberry, T., Harris, J., 2019. Development and validation of plain english interpretations of the seven elements of the risk management process. *Safety* **5**. https://doi.org/10.3390/safety5040075

Marshall, N.A., Tobin, R.C., Marshall, P.A., Gooch, M., Hobday, A.J., 2013. Social Vulnerability of Marine Resource Users to Extreme Weather Events. *Ecosystems* **16**, 797–809. https://doi.org/10.1007/s10021-013-9651-6

Marvasti, A., 2019. Effect of government regulations on the severity of injuries in fisheries. *Appl. Econ.* **51**, 4164–4175. https://doi.org/10.1080/00036846.2019.1590525

Marvasti, A., Dakhlia, S., 2017. Occupational safety and the shift from common to individual fishing quotas in the Gulf of Mexico. *South. Econ. J.* **83**, 705–720. https://doi.org/10.1002/soej.12154

Masselink, G., Scott, T., Poate, T., Russell, P., Davidson, M., Conley, D., 2016. The extreme 2013/2014 winter storms: Hydrodynamic forcing and coastal response along the southwest coast of England. *Earth Surf. Process. Landforms* **41**, 378–391. https://doi.org/10.1002/esp.3836

Masud, M. M., Al-Amin, A. Q., Junsheng, H., Ahmed, F., Yahaya, S. R., Akhtar, R., Banna, H., 2016. Climate change issue and theory of planned behaviour: Relationship by empirical evidence. *J. Clean. Prod.* **113**, 613–623. https://doi.org/10.1016/j.jclepro.2015.11.080

Mata, R., Josef, A.K., Hertwig, R., 2016. Propensity for risk taking across the life span and around the globe. *Psychol. Sci*. **27**, 231–243. https://doi.org/10.1177/0956797615617811

Matthews, T., Murphy, C., Wilby, R.L., Harrigan, S., 2014. Stormiest winter on record for Ireland and UK. *Nat. Clim. Chang*. **4**, 738–740. https://doi.org/10.1038/nclimate2336

Maynou, F., Sardà, F., 2001. Influence of environmental factors on commercial trawl catches of *Nephrops norvegicus* (L.). *ICES J. Mar. Sci.* **58**, 1318–1325. https://doi.org/10.1006/jmsc.2001.1091

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S., *2001. Climate change 2001: impacts, adaptation, and vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.

McDonald, M.A., Kucera, K.L., 2007. Understanding non-industrialized workers' approaches to safety: How do commercial fishermen "stay safe"? *J. Safety Res.* **38**, 289–297. https://doi.org/10.1016/j.jsr.2006.10.009

McFadden, D. 1973. Conditional logit analysis of qualitative choice behaviour. in Zarembka, P. (Ed.) *Frontiers of Econometrics. New York: Academic Press*, 105–142. doi:10.1108/eb028592

McGuinness, E., Aasjord, H.L., Utne, I.B., Holmen, I.M., 2013. Fatalities in the Norwegian fishing fleet 1990-2011. *Saf. Sci*. **57**, 335–351. https://doi.org/10.1016/j.ssci.2013.03.009

McWilliams, J., 2014. *The Cornish Fishing Industry*, an illustrated history.

Amberley Publishing, Stroud, UK.

Metcalf, S.J., van Putten, E.I., Frusher, S., Marshall, N.A., Tull, M., Caputi, N., Haward, M., Hobday, A.J., Holbrook, N.J., Jennings, S.M., Pecl, G.T., Shaw, J., 2015. Measuring the vulnerability of marine social-ecological systems: A prerequisite for the identification of climate change adaptations. *Ecol. Soc*. **20**, 35. https://doi.org/10.5751/ES-07509-200235

Mishra, S., Fiddick, L., 2012. Beyond gains and losses: The effect of need on risky choice in framed decisions. *J. Pers. Soc. Psychol*. **102**, 1136–1147. https://doi.org/10.1037/a0027855

Mistiaen, J.A., Strand, I.E., 2002. Spatial Models in Fisheries Economics - Location Choice of Commercial Fishermen with heterogenous risk preferences. Am. *J. Agric. Econ.* **82**, 1184–1190. https://doi.org/10.1111/0002-9092.00118

Mölter, T., Schindler, D., Albrecht, A.T., Kohnle, U., 2016. Review on the projections of future storminess over the North Atlantic European region. *Atmosphere* **7**, 1–40. https://doi.org/10.3390/atmos7040060

Monnereau, I., Mahon, R., McConney, P., Nurse, L., Turner, R., Vallès, H., 2017. The impact of methodological choices on the outcome of national-level climate change vulnerability assessments: An example from the global fisheries sector. *Fish Fish*. **18**, 717–731. https://doi.org/https://doi.org/10.1111/faf.12199

Morel, G., Amalberti, R., Chauvin, C., 2008. Articulating the Differences Between Safety and Resilience: The Decision-Making Process of Professional Sea-Fishing Skippers. Hum. Factors *J. Hum. Factors Ergon. Soc*. **50**, 1–16. https://doi.org/10.1518/001872008x250683

Moringa, 1988. Response of a fish school to turbid water*. La Mer* **26**, 19–28. http://www.sfjo-lamer.org/la_mer/26-1/26-1.pdf (accessed 09.06.20)

Mühlbacher, A., Reed Johnson, F., 2016. Choice Experiments to Quantify Preferences for Health and Healthcare: State of the Practice. *Appl. Health Econ. Health Policy* **14**, 253–266. https://doi.org/10.1007/s40258-016-

0232-7

Muir, W.D., Durkin, J.T., Coley, T.C., Mccabe, G.T., 1984. Escape of captured Dungeness crabs from commercial crab pots in the Columbia river estuary. *North Am. J. Fish. Manag*. **4**, 552–555. https://doi.org/10.1577/1548-8659(1984)4<552:eocdcf>2.0.co;2

Müller, B., Johnson, L., Kreuer, D., 2017. Maladaptive outcomes of climate insurance in agriculture. *Glob. Environ. Chang*. **46**, 23–33. https://doi.org/10.1016/j.gloenvcha.2017.06.010

Murakami, H., Sugi, M., Kitoh, A., 2013. Future changes in tropical cyclone activity in the North Indian Ocean projected by high-resolution MRI-AGCMs. *Clim. Dyn.* **40**, 1949–1968. https://doi.org/10.1007/s00382-012-1407-z

Murakami, H., Vecchi, G.A., Underwood, S., 2017. Increasing frequency of extremely severe cyclonic storms over the Arabian Sea. *Nat. Clim. Chang.* **7**, 885–889. https://doi.org/10.1038/s41558-017-0008-6

Murphy, G.I., 1959. Effect of Water Clarity on Albacore Catches. *Limnol. Oceanogr.* **4**, 86–93. https://doi.org/10.4319/lo.1959.4.1.0086

Murray, L.G., Hinz, H., Kaiser, M.J., 2011. Functional response of fishers in the Isle of Man scallop fishery. *Mar. Ecol. Prog. Ser*. **430**, 157–169. https://doi.org/10.3354/meps09067

Myers, M.L., Durborow, R.M., Kane, A.S., 2018. Gulf of Mexico seafood harvesters: Part 1. Occupational injury and fatigue risk factors. *Safety* **4**, 2000–2009. https://doi.org/10.3390/safety4030031

Naranjo-Madrigal, H., van Putten, I., Norman-López, A., 2015. Understanding socio-ecological drivers of spatial allocation choice in a multi-species artisanal fishery: A Bayesian network modeling approach. *Mar. Policy* **62**, 102–115. https://doi.org/10.1016/j.marpol.2015.09.003

Niclasen, B.A., Simonsen, K., Magnusson, A.K., 2010. Wave forecasts and small-vessel safety: A review of operational warning parameters. *Mar.*

Struct. **23**, 1–21. https://doi.org/10.1016/j.marstruc.2010.02.001

Norrish, A.E., Cryer, P.C., 1990. Work related injury in New Zealand commercial fishermen. *Br. J. Ind. Med*.**47**, 726–732. https://doi.org/10.1136/oem.47.11.726

Ochumba, P.B., 1990. Massive fish kills within the Nyanza Gulf of Lake Victoria, *Hydrobiologia* **208**, 93–99. https://doi.org/10.1007/BF00008448

Ohata, R., Masuda, R., Takahashi, K., Yamashita, Y., 2014. Moderate turbidity enhances schooling behaviour in fish larvae in coastal waters. *ICES J. Mar. Sci.* **71**, 925–929. https://doi.org/10.1093/icesjms/fss194

Olin, M., Kurkilahti, M., Peitola, P., Ruuhijärvi, J., 2004. The effects of fish accumulation on the catchability of multimesh gillnet. *Fish. Res*. **68**, 135–147. https://doi.org/10.1016/j.fishres.2004.01.005

Omar, S.Z., Shaffril, H.A.M., Kamaruddin, N., Bolong, J., D'Silva, J.L., 2017. Weather Forecasting as an Early Warning System: Pattern of Weather Forecast Usage among Coastal Communities in Malaysia. *J. Chem. Inf. Model*. **53**, 1689–1699. https://doi.org/10.7537/marslsj100413.70

O'Neill, F.G., McKay, S.J., Ward, J.N., Strickland, A., Kynoch, R.J., Zuur, A.F., 2003. An investigation of the relationship between sea state induced vessel motion and cod-end selection. *Fish. Res*. **60**, 107–130. https://doi.org/10.1016/S0165-7836(02)00056-5

Orme, B.K., 2010. *Sample Size Issues for Conjoint Analysis*, in: Getting Started with Conjoint Analysis: Strategies for Product Design and Pricing Research. Research Publishers LLC, Madison, Wisconsin, USA, pp. 57–66.

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science **325**, 419–422. https://doi.org/10.1126/science.1172133

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., Zeller, D., 2002. Towards sustainability in world fisheries.

Nature. **418**, 689-695. https://doi.org/10.1038/nature01017

Pauly, D., Zeller, D., 2017. Comments on FAOs State of World Fisheries and Aquaculture (SOFIA 2016). *Mar. Policy* **77**, 176–181. https://doi.org/10.1016/j.marpol.2017.01.006

Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007. Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci*. **11**, 1633–1644. https://doi.org/10.5194/hess-11-1633-2007

Perry, R.I., Boutillier, J.A., Foreman, M.G.G., 2000. Environmental influences on the availability of smooth pink shrimp, *Pandalus jordani*, to commercial fishing gear off Vancouver Island, Canada. *Fish. Oceanogr*. **9**, 50–61. https://doi.org/10.1046/j.1365-2419.2000.00121.x

Petursdottir, G., Hannibalsson, O., Turner, J.M.M., 2001. *Safety At Sea As an Integral Part of Fisheries Management Safety At Sea*, FAO Fisheries Circular. Rome, Italy. http://www.fao.org/3/x9656e/X9656E00.htm (accessed 01.11.20)

Pfeiffer, L., 2020. How storms affect fishers' decisions about going to sea Lisa. *ICES J. Mar. Sci*. https://doi.org/10.1093/icesjms/fsaa145

Pinnegar, J.K., Engelhard, G.H., Norris, N.J., Theophille, D., Sebastien, R.D., 2019. Assessing vulnerability and adaptive capacity of the fisheries sector in Dominica: long-term climate change and catastrophic hurricanes. *ICES J. Mar. Sci*. **76**, 1353–1367. https://doi.org/10.1093/icesjms/fsz052

Plagányi, É., 2019. Climate change impacts on fisheries. *Science* **363(6430)**, 930–931. https://doi.org/10.1126/science.aaw5824

Poggie, J., Pollnac, R., 1988. Danger and Rituals of Avoidance among New England Fishermen*. Marit. Anthropol. Stud*. **1**, 66–78. http://www.marecentre.nl/mast/documents/DangersandRitualsofAvoidanceamongNewEnglandFishermen.pdf (accessed 14.02.20)

Poggie, J.J., Pollnac, R.B., Gersuny, C., 1976. Risk as a basis for taboos among fishermen in southern New England. *J. Sci. Study Relig*. **15**, 257–

262. https://doi.org/10.2307/1386089

Poggie, J., Pollnac, R., Jones, S., 1995. Perceptions of vessel safety regulations: a southern New England fishery. *Mar. Policy* **19**, 411–418. https://doi.org/10.1016/0308-597X(95)00015-X

Poggie, J.J., Pollnac, R.B., Van Dusen, C., 1996. Intracultural variability in the cognition of danger among southern New England fishers. *Mar. Resour. Econ*. **11**, 23–30. https://doi.org/10.1086/mre.11.1.42629140

Politis, P.J., DeAlteris, J.T., Brown, R.W., Morrison, A.T., 2012. Effects of sea-state on the physical performance of a survey bottom trawl. *Fish. Res*. **123–124**, 26–36. https://doi.org/10.1016/j.fishres.2011.11.017

Poloczanska, E.S., Brown, C.J., Sydeman, W.J., Kiessling, W., Schoeman, D.S., Moore, P.J., Brander, K., Bruno, J.F., Buckley, L.B., Burrows, M.T., Duarte, C.M., Halpern, B.S., Holding, J., Kappel, C. V., O'Connor, M.I., Pandolfi, J.M., Parmesan, C., Schwing, F., Thompson, S.A., Richardson, A.J., 2013. Global imprint of climate change on marine life. *Nat. Clim. Chang*. **3**, 919–925. https://doi.org/10.1038/nclimate1958

Pollnac, R.B., Poggie, J.J., Cabral, S.L., 1998. Thresholds of danger: Perceived risk in a New England fishery. *Hum. Organ*. **57**, 53–59. https://www.jstor.org/stable/44126619 (accessed 03.11.20)

Poulard, J.C., Trenkel, V.M., 2007. Do survey design and wind conditions influence survey indices? *Can. J. Fish. Aquat. Sci.* **64**, 1551–1562. https://doi.org/10.1139/F07-123

Power, N.G., 2008. Occupational risks, safety and masculinity: Newfoundland fish harvesters' experiences and understandings of fishery risks. *Heal. Risk Soc*. **10**, 565–583. https://doi.org/10.1080/13698570802167405

Puckett, S.M., Hensher, D.A., 2008. The role of attribute processing strategies in estimating the preferences of road freight stakeholders. *Transp. Res. Part E Logist. Transp. Rev.* **44**, 379–395. https://doi.org/10.1016/j.tre.2007.01.002

QSR International Pty Ltd, 2018. *NVivo qualitative data analysis software version 12*.

Queirolo, D., Straley, J., Connell, V.O., Liddle, J., Thode, A., Wild, L., Behnken, L., Falvey, D., Lunsford, C., 2015. Effects of environmental conditions and fishing operations on the performance of a bottom trawl. *ICES J. Merine Sci*. **69**, 293–302. https://doi.org/10.1093/icesjms/fsr211

Radio Monsoon, 2020. Radio Monsoon, https://twitter.com/radiomonsoon (accessed 5.30.20).

Rasmussen, H.B., Ahsan, D., 2018. Injuries and fatalities in Danish commercial fishing fleet in 1998–2016. *Safety* **4**, 1–15. https://doi.org/10.3390/safety4020013

R CoreTeam, 2019. R: *A language and environment for statistical computing*.

Rezaee, S., Brooks, M.R., Pelot, R., 2017. Review of fishing safety policies in Canada with respect to extreme environmental conditions and climate change effects. WMU *J. Marit. Aff*. **16**, 1–17. https://doi.org/10.1007/s13437-016-0110-z

Rezaee, S., Pelot, R., Finnis, J., 2016a. The effect of extratropical cyclone weather conditions on fishing vessel incidents' severity level in Atlantic Canada. *Saf. Sci*. **85**, 33–40. https://doi.org/10.1016/j.ssci.2015.12.006

Rezaee, S., Pelot, R., Ghasemi, A., 2016b. The effect of extreme weather conditions on commercial fishing activities and vessel incidents in Atlantic Canada. *Ocean Coast. Manag*. **130**, 115–127. https://doi.org/10.1016/j.ocecoaman.2016.05.011

Riebesell, U., Gattuso, J.P., 2015. Lessons learned from ocean acidification research. *Nat. Clim. Chang*. **5**, 12–14. https://doi.org/10.1038/nclimate2456

Roalf, D.R., Mitchell, S.H., Harbaugh, W.T., Janowsky, J.S., 2012. Risk, reward, and economic decision making in aging. *Journals Gerontol. - Ser. B Psychol. Sci. Soc. Sci.* **67**, 289–298. https://doi.org/10.1093/geronb/gbr099

Roberts, S.E., 2010. Britain's most hazardous occupation: Commercial fishing.

Accid. Anal. Prev. **42**, 44–49. https://doi.org/10.1016/j.aap.2009.06.031

Robinson, E., Cipullo, M., Sousounis, P., Kafali, C., Latchman, S., Higgs, S., Maisey, P., Mitchell, L., 2009. *UK windstorms and climate change*, ABI Research Papers. Boston, USA. https://www.abi.org.uk/Globalassets/Files/Publications/Public/Property/2017/Abi_Final_Report.Pdf (accessed 20.09.20)

Rose, J.M., Bliemer, M.C.J., Hensher, D.A., Collins, A.T., 2008. Designing efficient stated choice experiments in the presence of reference alternatives. *Transp. Res. Part B Methodol*. **42**, 395–406. https://doi.org/10.1016/j.trb.2007.09.002

Sainsbury, N.C., Genner, M.J., Saville, G.R., Pinnegar, J.K., O'Neill, C.K., Simpson, S.D., Turner, R.A., 2018. Changing storminess and global capture fisheries. *Nat. Clim. Chang*. **8**, 655–659. https://doi.org/10.1038/s41558-018-0206-x

Sainsbury, N.C., Turner, R.A., Townhill, B.L., Mangi, S.C., Pinnegar, J.K., 2019. The challenges of extending climate risk insurance to fisheries. *Nat. Clim. Chang*. **9**, 896–897. https://doi.org/10.1038/s41558-019-0645-z

Saulter, A., Bunney, C., Li, J., 2016. *Application of a refined grid global model for operational wave forecasting, Forecasting Research Technical Report No: 614*. Exeter, UK. https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/weather-science/frtr_614_2016p.pdf (accessed 04.10.19)

Scarpa, R., Rose, J.M., 2008. Design efficiency for non-market valuation with choice modelling: How to measure it, what to report and why. *Aust. J. Agric. Resour. Econ.* 52, 253–282. https://doi.org/10.1111/j.1467-8489.2007.00436.x

Scarpa, R., Zanoli, R., Bruschi, V., Naspetti, S., 2013. Inferred and stated attribute non-attendance in food choice experiments. *Am. J. Agric. Econ*. **95**, 165–180. https://doi.org/10.1093/ajae/aas073

Schnier, K.E., Horrace, W.C., Felthoven, R.G., 2009. *The Value of Statistical*

Life: Pursuing the Deadliest Catch. Centre for Policy Research, 49. https://doi.org/10.1017/CBO9780511843938.018

Scholes, P., 1982. The Effect of Wind Direction on Trawl Catches; an Analysis of Haul-by-haul Data. *ICES J. Mar. Sci.* **40**, 81–93. https://doi.org/10.1093/icesjms/40.1.81

Scoccimarro, E., Fogli, P.G., Reed, K.A., Gualdi, S., Masina, S., Navarra, A., 2017. Tropical cyclone interaction with the ocean: The role of high-frequency (subdaily) coupled processes. *J. Clim*. **30**, 145–162. https://doi.org/10.1175/JCLI-D-16-0292.1

Secor, D.H., Zhang, F., O'Brien, M.H.P., Li, M., 2019. Ocean destratification and fish evacuation caused by a Mid-Atlantic tropical storm*. ICES J. Mar. Sci.* **76**, 573–584. https://doi.org/10.1093/icesjms/fsx241

Sharma, A., Sethulakshmi, C.S., 2019. Assessment of Occupational Hazards and Usage of Sea Safety Devices by Fishers of Kerala, India. *J. Agromedicine* **24**, 374–380. https://doi.org/10.1080/1059924X.2019.1646684

Shepperson, J., Murray, L.G., Mackinson, S., Bell, E., Kaiser, M.J., 2016. Use of a choice-based survey approach to characterise fishing behaviour in a scallop fishery. *Environ. Model. Softw*. **86**, 116–130. https://doi.org/10.1016/j.envsoft.2016.09.013

Shibu, S., D, A., N, S., Satish, A., Navaneeth, M., 2019. Autonmatic antenna reorientation system for affordable marine internet service. *J. Chem. Inf. Model*. **53**, 1689–1699. https://doi.org/10.1109/ICCIC.2018.8782343

Smith, M.D., Wilen, J.E., 2005. Heterogeneous and correlated risk preferences in commercial fishermen: The perfect storm dilemma. *J. Risk Uncertain*. **31**, 53–71. https://doi.org/10.1007/s11166-005-2930-7

Simpson, G.L., 2020. *gratia: Graceful 'ggplot'-Based Graphics and Other Functions for GAMs Fitted Using "mgcv"*. R package version 0.4.1.

Solomon, S., Plattner, G.K., Knutti, R., Friedlingstein, P., 2009. Irreversible climate change due to carbon dioxide emissions. *Proc. Natl. Acad. Sci. U. S. A*. **106**, 1704–1709. https://doi.org/10.1073/pnas.0812721106

Somerton, D.A., 2003. Bridle efficiency of a survey trawl for flatfish: Measuring the length of the bridles in contact with the bottom. *Fish. Res*. **60**, 273–279. https://doi.org/10.1016/S0165-7836(02)00178-9

Somerton, D.A., Munro, P., 2001. Bridle efficiency of a survey trawl for flatfish. *Fish. Bull*. **99**, 641–652. https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/2001/994/som.pdf (accessed 04.12.2019)

Spencer, D.M., Doubell, M.J., Brown, I.W., Redondo Rodriguez, A., Lee, S.Y., Lemckert, C.J., 2019. Environmental indices for spanner crab (*Ranina ranina*) catch rates depend on regional oceanographic features. *Estuar. Coast. Shelf Sci.* **228**, 106361. https://doi.org/10.1016/j.ecss.2019.106361

Sternberg, R.W., Larsen, L.H., 1975. Threshold of Sediment Movement By Open Ocean Waves: Observations. *Deep Sea Res* **22**, 299–302. https://doi.org/10.1016/0011-7471(75)90071-6

Stewart, I.J., Keller, A.A., Fruh, E.L., Simon, V.H., Horness, B.H., 2010. Throwing in the towel: When do adverse conditions dictate a weather day during a bottom trawl survey? *Fish. Res*. **102**, 130–140. https://doi.org/10.1016/j.fishres.2009.11.001

Stobart, B., Mayfield, S., Carroll, J., 2016. Influence of wind and swell on catch rates in a dive fishery: a case study from the south Australian abalone fishery. *J. Shellfish Res.* **35**, 685–694. https://doi.org/10.2983/035.035.0315

Stead, S., Daw, T., Gray, T., 2007. Uses of fishers' knowledge in fisheries management. *Anthropol. Action* **13**, 77–86. https://doi.org/10.3167/aia.2006.130308

Stramma, L., Schmidtko, S., Levin, L.A., Johnson, G.C., 2010. Ocean oxygen minima expansions and their biological impacts. *Deep. Res. Part I Oceanogr. Res. Pap*. **57**, 587–595. https://doi.org/10.1016/j.dsr.2010.01.005

Stobart, B., Mayfield, S., Carroll, J., 2016. Influence of wind and swell on catch rates in a dive fishery: a case study from the south Australian abalone fishery. *J. Shellfish Res*. **35**, 685–694. https://doi.org/10.2983/035.035.0315

Sullman, M. J. M., Hill, T. & Stephens, A. N., 2018. Predicting intentions to text and call while driving using the theory of planned behaviour. *Transp. Res. Part F Traffic Psychol. Behav.* **58**, 405–413. https://doi.org/10.1016/j.trf.2018.05.002

Surminski, S., Bouwer, L.M., Linnerooth-bayer, J., 2016. How insurance can support climate resilience. *Nat. Clim. Chang*. **6**, 333–334. https://doi.org/10.1038/nclimate2979

Tadesse, M.A., Shiferaw, B.A., Erenstein, O., 2015. Weather index insurance for managing drought risk in smallholder agriculture: lessons and policy implications for sub-Saharan Africa. *Agric. Food Econ*. **3(26)**. https://doi.org/10.1186/s40100-015-0044-3

Thiery, W., Davin, E.L., Seneviratne, S.I., Bedka, K., Lhermitte, S., Van Lipzig, N.P.M., 2016. Hazardous thunderstorm intensification over Lake Victoria. *Nat. Commun*. **7**, 1–7. https://doi.org/10.1038/ncomms12786

Thorvaldsen, T., 2013. The importance of common sense: How Norwegian coastal fishermen deal with occupational risk. *Mar. Policy* **42**, 85–90. https://doi.org/10.1016/j.marpol.2013.02.007

Thorvaldsen, T., 2015. Managing risk in the Norwegian fishing fleet*. Policy Pract. Heal. Saf*. **13**, 17–30. https://doi.org/10.1080/14774003.2015.11667809

Thorvaldsen, T., Kaustell, K.O., Mattila, T.E.A., Høvdanum, A., Christiansen, J.M., Hovmand, S., Snorrason, H., Tomasson, K., Holmen, I.M., 2018. What works? Results of a Nordic survey on fishers' perceptions of safety measures. *Mar. Policy* **95**, 95–101. https://doi.org/10.1016/j.marpol.2018.06.022

Tolman, H.L., 2014. *User manual and system documentation of Wavewatch III version 4.18*, National Oceanic and Atmospheric Administration Technical

Note. Maryland, USA. https://polar.ncep.noaa.gov/waves/wavewatch/manual.v4.18.pdf (accessed 04.10.20)

Trenberth, K.E., 2012. Framing the way to relate climate extremes to climate change. *Clim. Change* **115**, 283–290. https://doi.org/10.1007/s10584-012-0441-5

Trenberth, K.E., Fasullo, J.T., Shepherd, T.G., 2015. Attribution of climate extreme events. *Nat. Clim. Chang.* **5**, 725–730. https://doi.org/10.1038/nclimate2657

Turner, R.A., Sainsbury, N.C., Wheeler, B.W., 2019. The health of commercial fishers in England and Wales: Analysis of the 2011 census*. Mar. Policy* **106**, 103548. https://doi.org/10.1016/j.marpol.2019.103548

Tushemereirwe, R., Tuhebwe, D., Cooper, M.A., D'ujanga, F.M., 2017. The most effective methods for delivering severe weather early warnings to fishermen on Lake Victoria. *PLoS Curr*. **1**, 1–16. https://doi.org/10.1371/currents.dis.d645f658cf20bc4a23499be913f1cbe1

UK Government, 1997. *The Merchant Shipping and Fishing Vessels (Health and Safety at Work) Regulations 1997*. UK. http://www.legislation.gov.uk/uksi/1997/2962/contents/made (accessed 5.29.20)

UK Government, 2017. *The Fishing Vessels (Codes of Practice) Regulations 2017*. UK. http://www.legislation.gov.uk/uksi/2017/943/contents/made (accessed 5.29.20)

UK Government, 2019. *ILO work in fishing convention*. https://www.gov.uk/government/collections/ilo-work-in-fishing-convention (accessed 5.29.20).

UK Marine and coastguard agency, 2015. *Fishermen's Safety Guide: A guide to safe working practices and emergency procedures for fishermen*. Southampton, UK. https://assets.publishing.service.gov.uk/government/uploads/system/upload s/attachment_data/file/882707/Fishermans_safety_guide_2020_amendment_1.pdf (accessed 5.29.20)

UK Marine and coastguard agency, 2020. *Single handed fishing*. Southampton, UK. https://www.gov.uk/government/publications/single-handed-fishing (accessed 5.29.20)

UK Meteorological Office, 2020. *UK climate extremes*. https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-extremes (accessed 10.12.20).

UK Office for National Statistics (ONS), *2017. CT0724_2011 Census - Age by General Health by Industry (2 Digits)* https://www.ons.gov.uk/employmentandlabourmarket/peoplenotinwork/economicinactivity/adhocs/007524ct07242011censusagebygeneralhealthbyindustry2digits (accessed 11.20.18).

United Nations Framework Convention on Climate Change (UNFCCC), 2017. *'InsuResilience' to provide the poor with more financial protection against climate risks*. https://unfccc.int/news/insuresilience-to-provide-the-poor-with-more-financial-protection-against-climate-risks (accessed 9.1.19).

Urquhart, J., Acott, T., 2013. Constructing "The Stade": Fishers' and non-fishers' identity and place attachment in Hastings, south-east England. *Mar. Policy* **37**, 45–54. https://doi.org/10.1016/j.marpol.2012.04.004

Urquhart, J., Acott, T., 2014. A Sense of Place in Cultural Ecosystem Services: The Case of Cornish Fishing Communities. *Soc. Nat. Resour*. **27**, 3–19. https://doi.org/10.1080/08941920.2013.820811

Urquhart, J., Acott, T., Reed, M., Courtney, P., 2011. Setting an agenda for social science research in fisheries policy in Northern Europe. *Fish. Res*. **108**, 240–247. https://doi.org/10.1016/j.fishres.2010.12.026

Utne-Palm, A.C., 2002. Visual feeding of fish in a turbid environment: Physical and behavioural aspects. *Mar. Freshw. Behav. Physiol*. **35**, 111–128. https://doi.org/10.1080/10236240290025644 van der Pol, M., Shiell, A., Au, F., Jonhston, D., Tough, S., 2010. Eliciting individual preferences for health care: a case study of perinatal care. *Heal. Expect.* **13**, 4–12. https://doi.org/10.1111/j.1369-7625.2009.00551.x

van Houtven, G., Johnson, F.R., Kilambi, V., Hauber, A.B., 2011. Eliciting benefit-risk preferences and probability-weighted utility using choice-format conjoint analysis. *Med. Decis. Mak*. **31**, 469–480. https://doi.org/10.1177/0272989X10386116

van Nieuwkoop, J.C.C., Smith, H.C.M., Smith, G.H., Johanning, L., 2013. Wave resource assessment along the Cornish coast (UK) from a 23-year hindcast dataset validated against buoy measurements. *Renew. Energy* **58**, 1–14. https://doi.org/10.1016/j.renene.2013.02.033

van Putten, I.E., Kulmala, S., Thébaud, O., Dowling, N., Hamon, K.G., Hutton, T., Pascoe, S., 2012. Theories and behavioural drivers underlying fleet dynamics models. *Fish Fish*. **13**, 216–235. https://doi.org/10.1111/j.1467-2979.2011.00430.x

Vora, M.H., Bekaroo, G., Santokhee, A., Juddoo, S., Roopowa, D., 2018. JarPi: A low-cost raspberry pi based personal assistant for small-scale fishermen. 2017 *4th IEEE Int. Conf. Soft Comput. Mach. Intell*. 159–163. https://doi.org/10.1109/ISCMI.2017.8279618

Weinberg, K.L., 2003. *Change in the performance of a Bering Sea survey trawl due to varied trawl speed.* Alaska Fishery Research Bulletin. Seattle, USA. http://www.adfg.alaska.gov/FedAidpdfs/AFRB.10.1.042-049.pdf (accessed 10.03.20)

Weinberg, K.L., Kotwicki, S., 2015. Reducing variability in bottom contact and net width of a survey trawl by restraining door movement and applying a constant ratio of warp length to depth. *Fish. Bull*. **113**, 180–190. https://doi.org/10.7755/FB.113.2.6

Weinberg, K.L., Somerton, D.A., Munro, P.T., 2002. The effect of trawl speed on the footrope capture efficiency of a survey trawl. *Fish. Res*. **58**, 303–313. https://doi.org/10.1016/S0165-7836(01)00395-2

Wickham, H., 2016. *ggplot2: Elegant Graphics for Data Analysis*.

Wieland, K., Olesen, H.J., Pedersen, E.M.F., Beyer, J.E., 2011. Potential bias in estimates of abundance and distribution of North Sea cod (Gadus morhua) due to strong winds prevailing prior or during a survey. *Fish. Res.* **110**, 325–330. https://doi.org/10.1016/j.fishres.2011.04.023v

Wood, S.N., 2003. Thin plate regression splines. *J. R. Stat. Soc. Ser. B Stat*. *Methodol*. 65, 95–114. https://doi.org/10.1111/1467-9868.00374

Wood, S.N., 2017. *Generalized Additive Models: An Introduction with R, 2nd edition*. Chapman and Hall/CRC. Florida, USA.

Wood, S.N., Pya, N., Säfken, B., 2016. Smoothing Parameter and Model Selection for General Smooth Models. *J. Am. Stat. Assoc*. 111, 1548–1563. https://doi.org/10.1080/01621459.2016.1180986

World Meteorological Organization, 2016. *19-meter wave sets new record - highest significant wave height measured by a buoy*. https://public.wmo.int/en/media/press-release/19-meter-wave-sets-new-record-highest-significant-wave-height-measured-buoy (accessed 01.10.20)

Woodruff, J.M., 2005. Consequence and likelihood in risk estimation: A matter of balance in UK health and safety risk assessment practice. *Saf. Sci*. **43**, 345–353. https://doi.org/10.1016/j.ssci.2005.07.003

Wu, Y., Pelot, R., Hilliard, C., 2005. The effect of weather factors on the severity of fishing boat accidents in Atlantic Canada. *Risk Manag*. **7**, 21–40. https://doi.org/10.1057/palgrave.rm.8240217

Wu, Y., Pelot, R.P., Hilliard, C., 2009. The influence of weather conditions on the relative incident rate of fishing vessels. *Risk Anal*. **29**, 985–999. https://doi.org/10.1111/j.1539-6924.2009.01217.x

Zhou, S., Shirley, T.C., 1997. Behavioural responses of red king crab to crab pots. *Fish. Res*. **30**, 177–189. https://doi.org/10.1016/S0165-7836(97)00005-2