Essays on Adaptation and Behavioural Responses to Abrupt Changes

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Abstract

English Abstract

Humanity is currently facing a range of interconnected socio-ecological challenges, including climate change, economic instability, social crises, and pandemics. These issues often lead to abrupt changes, demanding the development of effective adaptation mechanisms to mitigate their impacts, particularly when they threat human survival. Hence, it is important to improve the understanding of adaptation, and identify the mechanisms driven its process. This thesis aims to advance the knowledge in this area by developing methodologies for assessment and exploring the influence of culture and risk preferences on the adaptation process.

Chapter 2 introduces an analytical framework to assess adaptation. This framework develops a metric to assess adaptation in a coupled human-ecological system. It derives driver-specific adaptation responses and disentangles the concepts of adaptation, sensitivity and total impact. The framework is applied to a calibrated bio-economic model focusing on the North Sea flatfish fishery. The case study demonstrates how fishers adapt through effort to three different changes in drivers and illustrates their differentiated effects on quantities supplied in the market.

Chapter 3 adopts an interdisciplinary approach to assess adaptation, using the conceptual representation of a socio-ecological system and the Ostrom Framework. The case study examines German flatfish fisheries and identifies the strategies they employed to persist despite the numerous challenges they encounter. Among the strategies, cultural traditions and self-identification as a fisher, rather than an entrepreneur, play and important role to foster adaptation.

Recognizing the importance of culture in adaptation, chapter 4 examines the role of cultural heritage from a consumer perspective. This chapter 4 focuses on the German

brown shrimp fishery, the most important coastal fishery in Germany. Using a discrete choice experiment, this chapter estimates the willingness to pay of tourists and locals to preserve the cultural heritage of the shrimp fishery. The target population is drawn from four towns in Germany -Ditzum, Busum, Cuxhaven, and Gretsiel- recognized for preserving the traditional practices. The findings reveal that individuals in these areas value maritime cultural heritage, along with other attributes of this fishery, such as its environmental sustainability.

The final chapter explores the role of risk preferences on the adaptation process, focusing on the post-impact phase following an abrupt change. Using the 2023 Turkey earthquake as a case study, this chapter investigates how individual risk preferences shift in response to the disaster. Through a combination of surveys and lab-in-the-field experiments involving over 600 participants - including both survivors of the earthquake and residents of unaffected cities in Turkey - the study reveals that individuals heavily impacted by the earthquake tend to become more risk-tolerant, with gender and damage level as significant factors influencing their responses.

In summary, this thesis investigates adaptation by integrating analytical and experimental methodologies. It develops metrics for assessing adaptation and examines the influence of culture and risk preferences on the adaptation process. By employing a variety of methodologies across different human-environment systems, this thesis contributes to a more comprehensive understanding of the complex and interdisciplinary nature of adaptation.

German Abstract

Die Menschheit steht derzeit vor einer Vielzahl miteinander verbundener sozio-ökologischen Herausforderungen, etwa dem Klimawandel, wirtschaftlicher Instabilität, sozialer Krisen und Pandemien. Diese Herausforderungen führen oft zu drastischen Veränderungen und erfordern die Entwicklung wirksamer Anpassungsmechanismen, um deren Folgewirkungen abzumilden, insbesondere wenn sie das Überleben der Menschen in Frage stellen. Daher ist es wichtig, das Konzept der Anpassungsfähigkeit und die dafür verantwortlichen Mechanismen starker herauszuarbeiten. Diese Dissertation zielt darauf ab, das vorhandene Verständnis auf diesem Forschungsgebiet durch die Entwicklung von Bewertungsmethoden und durch die erweiterte Forschung des Zusammenhanges zwischen den menschlichen kulturellen Aspekten und deren Risikobereitschaft auf verschiedene Adaptationsprozesse zu vertiefen.

Kapitel 2 stellt einen analytischesn Referenzrahmen zur Bewertung der Anpassungsfähigkeit vor. Dabei wird ein Maß für die Bewertung der Anpassungsfähigkeit in einem gekoppelten menschlich-ökologischen System entwickelt. Dadurch werden treiberspezifische Anpassungsreaktionen abgeleitet und die Konzepte der Anpassung, der Empfindlichkeit [sensitivity] und der Gesamtauswirkungen voneinander entkoppelt. Der Referenzrahmen wird auf ein kalibriertes bioökonomisches Modell angewendet, das sich auf die Plattfischfischerei im Nordseegebiet bezieht. Die Fallstudie zeigt, wie sich die Fischer durch ihren Fischereiaufwand an drei verschiedene Veränderungen der Antriebsfaktoren angepasst haben, und veranschaulicht die unterschiedlichen Auswirkungen auf die Liefermengen für den Fischmarkt.

Im Kapitel 3 wird zur Bewertung der Anpassungsfähigkeit ein interdisziplinärer Ansatz gewählt, der sich auf die konzeptionelle Darstellbarkeit eines sozio-ökologischen Systems sowie auf das Ostrom-Framework stützt. Die Fallstudie untersucht die norddeutschen Plattfischfischereien und zeigt die Strategien auf, die sie eingesetzt haben, um trotz der zahlreichen Herausforderungen, denen sie ausgesetzt sind, zu überleben. Zu den Strategien gehören beispielsweise kulturelle Traditionen und die Selbstidentifikation als Fischer und nicht als Unternehmer, wodurch die Anpassungsfähigkeit wesentlich beeinflusst wird.

Unter Berücksichtigung der Rolle der Kultur bei der Anpassungsfähigkeit untersucht das Kapitel 4 die Bedeutung des kulturellen Erbguts aus der Perspektive der Endverbraucher. Mithilfe eines diskreten Auswahlexperiments wird in diesem Kapitel die Investi-

tionsbereitschaft von Touristen und Einheimischen im Zusammenhang mit dem Erhalt des kulturhistorischen Erbes ermittelt, dabei wird auf die Krabbenfischerei eingegangen, die wichtigste und einer der ältesten Kulturtechniken der Fischerei an der Nordsee. Die untersuchte Population stammt aus vier Ortschaften – Ditzum, Büsum, Cuxhaven und Greetsiel –, im deutschen Bundesland Niedersachen in welchen die Erhaltung der traditionellen Praktiken eine feste Überzeugung ist. Die Ergebnisse zeigen, dass die Menschen in diesen Gebieten das maritime Kulturerbe ebenso schätzen wie andere Eigenschaften dieser Fischerei, wie zum Beispiel ihre ökologische Nachhaltigkeit.

Im letzten Kapitel wird die Rolle der Risikoeinstellung für den Anpassungsprozess untersucht, wobei der Fokus auf der Nachwirkungsphase abrupter Veränderungen liegt. Wie sich die individuellen Risikopräferenzen als Reaktion auf die Katastrophe verändern, wird in diesem Kapitel anhand des Erdbebens in der Türkei im Jahr 2023 als Fallstudie beschrieben. Die Studie zeigt auf der Basis einer Kombination aus Umfragen und Labor-Feldstudien mit über 600 Teilnehmern – darunter sowohl Überlebende des Erdbebens als auch Bewohner nicht betroffener Städte in der Türkei – , dass Personen, die vom Erdbeben stark betroffen waren, tendenziell risikotoleranter werden, wobei das Geschlecht und das Ausmaß der Schäden wesentliche Faktoren sind, die ihre Reaktionen beeinflussen können.

Das Projekt entwickelt einen Maßstab für die Bewertung von Anpassungsfähigkeit und untersucht den Einfluss von Kultur und Risikobereitschaft auf den Anpassungsprozess. Zusammenfassend lässt sich sagen, dass diese Forschungsarbeit die Anpassungsfähigkeit durch die Integration von analytischen und experimentellen Methoden abbildet. Mit der Einbeziehung einer Bandbreite an Methoden für verschiedene Mensch-Umwelt-Systeme trägt diese Arbeit zu einem umfassenderen Verständnis der komplexen und interdisziplinären Natur der Adaptation bei.

Contents

List of Abbreviations

CFP	Common Fisheries Policies
CPUE	Catch Per Unit Effort
EU	European Union
EEZ	Exclusive Economic Zone
FTE	Full Time Equivalent
GDP	Gross Domestic Product
HDI	Human Developmnet Index
IBTS	International Bottom Trawl Survey
ICES	International Council for the Exploration of the Sea
IOM	International Organization for Migration
MSC	Marine Stewardship Council
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSP	Marine Spatial Planning
MSY	Maximum Sustainable Yield
SES	Social Ecological System
SSB	Spawning Stock Biomass
SST	Sea Surface Temperature
STECF	Scientific, Technical and Economic Committee for Fisheries
TAC	Total Allowable Catch
TP	Tipping Point
WTP	Willigness To Pay

List of Figures

List of Tables

Chapter 1

Introduction

Continuous change has been a persistent challenge for humans throughout their evolution, compelling them to adapt in order to ensure their survival. Nowadays, humanity is facing multiple changes coming from the economic, social, cultural, technological, and environmental aspects, such as climate change, economic crises or pandemics. The frequency and simultaneity of these changes is increasing, demanding faster adaptation strategies (Ratajczak et al., 2018; Turner et al., 2020). The development of these strategies requires a better understanding of the factors affecting adaptation, including improved assessment mechanisms to take appropriate action. The aim of this thesis is to contribute to the understanding of adaptation in social and social-ecological systems, in particular to the improvement of quantification techniques, and to examine the role that individual risk preferences and culture play in the adaptive process.

Adaptation, due to its interdisciplinary nature, encompasses different definitions, approaches and perspectives. Generally, adaptation involves deliberate changes made in anticipation of, or in reaction to, external stimuli, typically hazards or threats with a negative impact on the system or individuals (Hufschmidt, 2011). Many studies focus on abrupt changes and aim to find adaptation mechanisms to deal with the negative impact of events such as: natural disasters, extreme climate events, or economic crises (Islam et al., 2020; Kousky, 2014). Depending on the approach, adaptation is analysed from a social or socio-ecological systems perspective. The ecological resilience approach analyses adaptation from a socio-ecological scale, studying the dynamics of the intertwined social-ecological systems, particularly when perturbations or abrupt changes move them away from equilibrium[1]. In this context, adaptation refers to human actions that sustain development of the system on current pathways, and abrupt changes are related to rapid changes in external drivers or non-linear responses to gradual changes. In contrast, the human or political ecology approach focuses on social systems, where the adaptation process is based on characteristics of individuals or communities that determine their capacity to adjust or react to threats (Berrouet et al., 2018). The adaptive capacity of these individuals or communities is determined by their access to resources, which translates into the process of adaptation. On the temporal scale, the adaptation process embeds the pre-impact (mitigation or absorptive adaptation), during impact (react) and post impact (recovery) phases of a threat, hazard or abrupt change (Hufschmidt, 2011).

Despite the multiple efforts to disentangle the concept of adaptation, confusion persists regarding metrics and indicators. This is due to the inherit complexity of the social or socio-ecological system under analysis. Most studies use general indicators such as access to assets, livelihoods, or governance and institutional aspects to measure adaptive capacity (Reed et al., 2013; Serfilippi and Ramnath, 2018; Whitney et al., 2017). While these indicators provide valuable insights, they primarily describe the availability of resources rather than the extent to which they are utilized, or whether they will be effectively utilized during an abrupt change. Moreover, these indicators describe general adaptive capacity concealing specific adaptations to particular threats.

The first goal of this thesis is to enhance the understanding and measurement of adaptation in the context of coupled human-environment systems, particularly focusing on the mechanisms humans use to adapt. Chapter 2 shows an analytical framework that conceptualizes the definition of adaptation chosen for this thesis, using mathematical modelling and economic theory as a background. This framework is exemplified through a calibrated bio-economic model applied to the North Sea flatfish fishery as a case study. Using an analytical model is advantageous because it allows us to derive optimal adaptive responses to various system drivers. The application of the framework allows for comparison of the effect of adaptation among drivers of the system, and derive driver-specific adaptations. It also quantifies and distinguishes adaptation before, during and after an impact for each driver, as well as the outcomes of adaptation to positive and negative impacts on a

[1]Social-ecological systems are complex adaptive systems. Complex adaptive systems possess critical thresholds, multiple drivers of change, and reciprocal feedback mechanisms between social and ecological components (Levin et al. 2013).

system. Chapter 3 further contributes to improve the measurement of adaptation in the German North Sea flatfish fishery. Through the use of the Ostrom framework and the analysis of spatio-temporal dynamics, it quantifies the autonomous adaptation strategies of a German fishery socio-ecological system to environmental and socio-economic change over the last two decades.

In the context of the North Sea flatfish fishery, chapter 3 shows that culture is an important factor affecting the process of adaptation, particularly in the context of socio-ecological systems. Cultural systems, composed of symbolic forms and means of communication, shape the worldviews and create links connecting the human and ecological system (Folke, 2016). Cultural identity is essential for structuring socio-ecological relationships, playing a significant role in adaptation strategies and maintaining the resilience of a system (Rotarangi and Stephenson, 2014). While the value of culture has been explored in many socio-ecological systems, studies in the fisheries domain are scarce (Khakzad and Griffith, 2016). In the EU, fishing activity provides more than 124.000 direct jobs, and contributes significantly to the personal protein intake, with an average person consuming 3.3kg more than the world average per year (STEFC, 2022). Despite the contribution of fishing in Europe, there is a scarcity of studies exploring the value of maritime cultural heritage in this region (Durán et al., 2015; Martino et al., 2023). Specifically, in Germany, there is an absence of assessments related to maritime cultural value. Hence, the second goal of this thesis is to explore the value of the maritime cultural heritage in Germany.

Chapter 4 explores the value of maritime cultural heritage for the North Sea Shrimp fishery in Germany. I investigate the cultural importance of this fishery by assessing people's attitudes toward maritime cultural heritage and examining how these attitudes affect their stated preferences. I implement a choice experiment to assess the cultural value of the fishery through sea food consumption preferences, and a face-to-face survey of more than 400 participants in four of the most important shrimp fishing ports in Germany. By determining the willingness to pay of five attributes of a shrimp dish, the results show that participants are willing to pay a positive value to maintain the German shrimp cultural heritage. However, the heritage attribute ranks lowest in willingness to pay among the five attributes evaluated. The results of this chapter contribute to increase the understanding of the role that culture plays in preserving one of the oldest cultural fishing techniques in the North Sea. Although the chapter does not explore the link between maritime cultural heritage and the adaptation process of this fishery explicitly, it provides insights into the potential role of culture in maintaining this fishery despite the multiple socioeconomic and ecological pressures it has faced over the years and still experience.

Together with culture, an important aspect influencing adaptation behavior is the perception of risk by individuals. Hufschmidt (2011) highlights that risk perception plays a crucial factor in the process of adaptation; the perceived level of risk influences the adaptation strategies implemented in practice. Risk preferences are part of individual characteristics that change after an abrupt impact, and this change is encompassed into the adaptation process during the post-impact phase of an abrupt change. In empirical studies, the effect of changes on risk perception due to abrupt changes leads to contradictory findings in the literature. Some studies find that individuals become more risk-taking in response to natural disasters, while others observe the opposite effect (Abatayo and Lynham, 2019). Imas (2016) offers a potential reconciliation of these contradictory findings, suggesting that individuals become less risk-taking when they experience realized losses, whereas unrealized losses lead to increased risk-taking. However, this expectation is unproven in the context of natural disasters. There is still a lack of research explicitly exploring the impact of realized losses and their magnitude on risk preferences in the context of natural disasters. Additionally, higher-order risk preferences, such as prudence, could also influence individuals' responses after a natural disaster, yet there is an absence of studies examining these higher-order risk preferences in such contexts.

The third goal of this thesis is to improve the understanding of the relationship between changes in risk behaviour and the adaptation process, particularly the post-impact phase of adaptation after a natural disaster. In chapter 5 I show a case study of changes in risk preferences after the Turkeys' 2023 . This study aims to address the research gaps in the literature on risk and natural disasters. It reports on field work involving incentivized experiments, and a survey on risk elicitation, income and asset losses, conducted with over 600 individuals in Turkey. The study is divided into three parts: The first part examines changes in risk preferences between the heavily affected individuals and a suitable control group, using the global preference risk module (Falk, 2018). The second part investigates the effect of realized losses, proxied by the magnitude of house damage, on individuals' risk preferences. The third part explores the relationship among higher-order risk preferences, specifically prudence, on post-earthquake behaviours , i.e., precautionary savings and self-protective behaviour. The results reveal that individuals who experienced the earthquake tend to exhibit more risk-taking behaviour, while those with greater house damage show increased risk aversion. The findings also show that prudence is positively associated with self-protective behaviours after the earthquake.

In this thesis I employ various methodologies encompassing two of the most prevalent approaches in the literature: ecological resilience and human/political economy. Chapter 2 addresses adaptation from the ecological resilience perspective, utilizing a coupled human-environment model to analyse the socio-ecological system of the German flatfish fishery of the North Sea. Chapter 3 analyses the same flatfish fishery combining the human/political approach, the Ostrom framework, the socio-ecological systems perspective and an empirical analysis of socio-spatial data. Chapter 4 assesses cultural preferences also using the human/political approach, but, focusing on the social system instead of the socio-ecological system. Chapter 4 analyses cultural preferences employing a choice experiment methodology to derive the stated preferences of society, chapter 5 focuses on the social system aiming to elicit individuals' risk preferences using field experiments and surveys. By using various approaches and methodologies to analyse adaptation in different contexts, this thesis I aim to bring a better understanding of adaptation, ranging from the quantification of adaptive capacity to the potential effects of individuals' risk preferences and culture on the adaptation process.

In summary, this thesis aims to answer the following questions:

1. How to assess and quantify the adaptation to different drivers in a coupled human-environment system?
2. What drivers affect the adaptation of North Sea flatfish Fisheries the most?
3. What is the value of the maritime cultural heritage of the German shrimp fishery?
4. How do risk preferences change after an abrupt change natural disaster?

Chapter 2

A Framework to Quantify Adaptation to Multiple Drivers

Authors: Emily Quiroga and Benjamin Blanz

Abstract: We develop an analytical framework to assess the adaptations in a coupled ecological-economic system and apply it to a bio-economic model. Our framework allows us to quantify the impact of multiple drivers on a coupled ecological-economic system, while distinguishing between adaptation and sensitivities to positive and negative exposures. This distinction allows us to differentiate between drivers that improve and decrease well-being. Our findings provide insight into how to focus resources to counteract negative or enhance positive impacts. We apply this framework to a bio-economic model calibrated to the North Sea flatfish fishery. We quantify the adaptations, sensitivities and total impact of fishers' profits to multiple drivers and identify among which of them fishers adapt the most. We also identify the effect of fishers adaptation to each driver on the quantities of fish offered in the market. This work forms a bridge between the multidisciplinary area of adaptability and the bio-economic modelling domain, increasing the understanding and knowledge regarding the measure of adaptation.

Keywords: Adaptation, fisheries, North Sea, flatfish fishery, sensitivity, exposure.

2.1 Introduction

The interaction between humans and nature involves multiple complexities and feedbacks affected by numerous sets of socioeconomic and ecological drivers. The impacts of these drivers on the coupled system happen in expected and unexpected ways. Here we focus on human behaviour and how groups of individuals adapt to these challenges coming from the environment or society. The analysis of adaptation is rooted in a interdisciplinary field with various approaches guided by their respective scientific background. These are the risk hazard approach, human/political ecology approach, and the ecological resilience approach (Berrouet et al., 2018). The political ecology view measures adaptation based on resources and social variables such as capital, education, income, and, social capital. The ecological resilience view argues that adaptation is not only about resources but about actions that sustain pathways of a socio-ecological system (Folke, 2016). In this study, we offer an alternative view of adaptation using economic theory as a background. This alternative offers us a way to derive the optimal adaptive response for each driver and to distinguish the adaptation response among positive and negative impacts allowing comparison among multiple drivers.

Adaptation can be separated into three stages, adaptation before, during, and after an impact. The first is called absorptive adaptation usually reducing the risk and exposure to drivers, while the latter is related to long-term responses, where adjustments become habitual (Hufschmidt, 2011). The adaptive capacity is considered a potential adaptation, i.e., before an impact. In the human/political ecology approach the adaptive capacity is measured using indicators such as access to assets, livelihoods, or governance and institutional aspects (Reed et al., 2013; Serfilippi and Ramnath, 2018; Whitney et al., 2017). While these indicators provide valuable insights, they primarily describe the availability of resources rather than the extent to which they are utilized, or whether they will be effectively utilized when changes in drivers are encountered. Moreover, these indicators describe general adaptations to deal with any harm and conceal driver-specific adaptations (McDowell and Hess, 2012; Thiault et al., 2019c). Here we present a framework that estimates the impacts of multiple drivers on a coupled ecological-economic system allowing for a comparison among them.

A contribution of our framework is to describe the optimal adaptive response for each driver in a coupled ecological-economic system. We operationalize the concept by Ionescu et al. (2009) where an adaptive capacity is an action in which the performance of the system is preferable to the performance without it. Sometimes the the effectiveness of general adaptation measures before an impact can vary during the impact itself. For instance, communities, entities, or individuals may have access to resources such as subsidies, insurance, or education. However, due to institutional or governmental factors, these resources may only be partially or not at all utilized in the midst of an impact. Our framework focuses on adaptation instead of adaptive capacity. The first refers to an actual or expected behaviour, and the second to the potential of adaptation. Our framework elicits the system's performance regarding a change in adaptation before, during, and after a change in drivers. This distinction allows us to disentangle the optimal adaptive response during an impact, and the performance of the system after it. We are interested in the degree to which the optimal adaptive response could mitigate an impact, rather than the time the response takes. These responses, however, can take a shorter or longer time depending on the phenomena of the system analyzed.

As a proof of concept, the framework is applied to a calibrated bio-economic multi-species model of the North Sea flatfish fishery. We determine the optimal adaptive effort responses of fishers' profits to changes in returns to effort, stock harvesting efficiency and wages. We show the impacts of adaptation through effort on the quantities harvested in the system. Our work adds to the existing models of this mixed flatfish fishery by focusing on the adaptation through effort to changes in multiple drivers (Nielsen et al., 2018; Prellezo et al., 2012). The stylised nature of the model we use allows us to understand the mechanisms underlying the adaptation and how these affect the quantities produced in the market. Our results indicate that fish quantities are mostly affected by adaptation due to changes in returns to effort followed by stock harvesting efficiency and wages. By considering multiple drivers our framework allows us to identify trade-offs among impacts on a given property of the system.

2.2 Adaptation across analytic approaches

Definitions of adaptation have been analysed among a diversity of disciplines. Analytic approaches such as ecological resilience, human/political ecology, and risk-hazard have different definitions of adaptation and adaptive capacity [1]. The ecological resilience approach conceives resilience as a system property. It is the system's capacity to self-organize and adapt in the face of ongoing change in a way that sustains the system in certain stability (Folke, 2016). In the 'Human/Political Ecology' approach a difference between 'adjustment' and 'adaptation' is made. Adjustments are purposeful actions, such as building a dam or structure to resist earthquakes. Adaptation is regarded as a process of co-evolution between an organism and its environment in a long-term response (Hufschmidt, 2011). In the approach combining hazards and human/political ecology definitions such as the one given by the Intergovernmental Panel of Climate Change (IPCC) define adaptation as "the process of adjustment to actual or expected climate and its effects to moderate harm or exploit beneficial opportunities" (**p.43**; IPCC, 2022). Also, Whitney et al. (2017) "refers to the latent ability of a system to respond proactively and positively to stressors or opportunities" (ibid.).

The definitions of adaptation above all cover both actions to moderate harms and to exploit benefits, however, their measures do not always show this distinction. Measures following the human/ecology approach are mostly directed to reduce harm, they use socio-ecological indicators, institutional analysis, social experiments, and community-based approaches as a way to measure adaptations (ibid.). The ecological resilience approach presents measures of adaptation, that usually contemplate the existence of thresholds. For instance, Luers et al. (2003) quantify adaptive capacity as the difference in vulnerability under existing conditions and modified conditions. Here, a system is described as a function of well-being (W), threshold (W_0), and a stressor (X). Vulnerability is then measured as the sensitivity regarding a threshold ($V = f(\frac{|\partial W/\partial X|}{W/W_0})$). Furthermore, Grafton et al. (2019) shows a measure of resilience with three main characteristics resistance, recovery, and robustness. Resistance is the system's ability to actively change while maintaining its system performance following one or more adverse events. Recovery is the time a system's performance needs to recover a desired functionality after an adverse event, and robustness is the system's probability to maintain its identity and not cross an undesirable threshold after an adverse event. These measures, however, do not cover

[1] This classification of schools of thought is based on Berrouet et al. (2018), however, Adger (2006) show other distinctions such as 'the vulnerability as an absence of entitlements', 'Natural Hazards', and 'Human/Political Ecology'. Hufschmidt (2011) also classifies the 'human ecologist school', 'structural view', and 'resilience school'.

adaptation with a positive impact and do not distinguish adaptation with both positive and negative impacts.

The measures described by Luers et al. (2003) and Grafton et al. (2019) require a definition of a threshold in a system, however, in many systems, this threshold can not be defined or simply does not exist. Our framework adds to the literature by quantifying not only negative impacts (that may drive the system close to a threshold) but also positive impacts which enhance the system's performance. We focus on quantifying the optimal adaptive response. We operationalize the concept of adaptation defined by Ionescu et al. (2009) and show how this optimal adaptive response may change with a positive and negative impact. Ionescu et al. (ibid.) define a framework in which a system is described as a function of the state of the system (x), a given input (e), and an adaptive action (u). They define an optimal action ($u \in U$) such that $f(x, e, u)$ is optimal. However, sometimes there is no complete knowledge of f and they define adaptation as an action where the performance of the system within that action is preferred to the performance of the system without it. This is important because the optimal action serves as a point of reference for the best scenario to be achieved during an impact, so that efforts and resources can be well directed.

In general, most of the definitions focus on adaptation as an ongoing process. The states of this process are defined differently according to the approach[2], but in general, they refer to actions before, during, and after an impact. Here we focus on adaptation during an impact, also called 'reacting action', 'response', or 'coping capacity' as an action during crisis (Hufschmidt, 2011). In practice, we only observe the state of the system before and after an impact, the latter already embeds the adaptive response, i.e., the effective resources or abilities used to cope with the impact. Our framework aims to quantify and disentangle this impact. We add to the literature by identifying the magnitude that the adaptive response can mitigate harmful impacts or can enhance beneficial impacts on the system. We describe four types of adaptive response the first

[2] Hufschmidt (2011) mentions the term 'adaptation' as the process of learning, anticipating, modifying, preparing, and planning. She distinguishes adaptive activities for households in a stage of mitigation, preparation, or recovery. Béné et al. (2012) departing from the resilience approach distinguishes absorptive, adaptive, and transformative capacities. The absorptive capacity reduces the risk of exposure to shocks absorbing the impact in the short term. While adaptive and transformative capacities are long-term responses to socio-economic and environmental challenges (Serfilippi and Ramnath, 2018).

two evaluate the absolute and marginal changes in the system's well-being function driven by a change in endogenous adaptation response. The third measures the rate at which the adaptive response changes due to marginal changes in the driver. The fourth measures how the adaptive response changes itself given marginal changes in the driver.

2.3 Framework to Quantify Impacts and Adaptation in an coupled ecological-economic system

Our approach to assess adaptation is based on the approach developed by Ionescu et al. (2009), who developed a formal framework of vulnerability to climate change. Vulnerability is defined using mathematical concepts independent of any knowledge domain and applicable to any system under consideration. Their vulnerability definition is based on the Intergovernmental Panel on Climate Change (IPCC, 2022). This definition states that the vulnerability to climate change is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity" (Ionescu et al., 2009). The vulnerability depends on the differences in exposure to the various direct effects of climate change which lead to different sensitivities and hence generating differential potential impacts on the system. The adaptive capacity is defined as the ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities or to cope with the consequences.

We consider the term adaptation in a broad sense, i.e, actions within the system taken not only to mitigate harmful impacts but also to enhance the positive impacts. A coupled ecological-economic system is exposed to multiple drivers that generate an increase/decrease of the performance in the system and adaptation aims to mitigate/enhance those impacts. In the human/political approach the differentiation between 'adjustment' and 'adaptation' lies in the temporal distinction, where the first are purposeful actions to adapt and the latter refers to long-term response, where adjustments become a part of society's habitus (Hufschmidt, 2011) [3]. In our framework the term adaptation refers to the long term response and addresses the issue of identifying the degree to which this response mitigates/enhances the impact of a driver.

Following the human/political ecology approach and using economic theory our frame-

[3]There is a temporal distinction between adjustments and adaptation which is difficult to define since the point where adjustments evolve into society's habitus is hazy (Hufschmidt, 2011)

work aims to quantify the best case potential adaptation response of a system to a specific driver. This measurement can help decision-makers to have a reference point of the magnitude of the adaptive response that could be achieved by performing certain activities to mitigate/enhance the impact of multiple drivers. Our framework is designed to answer the question *the adaptation of what to what?*. Ionescu et al. (2009) state that vulnerability and adaptive capacity are relative properties, it is the adaptation *of* something *to* something. Hence, our methodology encompasses two steps. Identification of (i) the system property under analysis (*of what*), and (ii) the driver (*to what*). The system property refers to the specific aspect of the coupled ecological-economic system considered. For example, in our case study, we investigate the *adaptation of fisher profits to changes in e.g. wages* and other drivers. In the following, we present the formal definitions of drivers, exposure, sensitivity, adaptation, and total impact (TI).

2.3.1 Formalisation

Drivers

We define $\theta = (\theta_1, \ldots, \theta_D)$ as the vector of D drivers of the coupled ecological-economic system, for which the researcher wishes to investigate the impacts on a specific system property. For instance, θ_d can represent the value of an input in a certain process affecting the system property. All drivers are considered to be exogenous depending on the boundaries of the system investigated.

System Property

We define $\psi(\theta)$ as the property of the system under investigation. This property can be related to the economic, ecological or social side of the system depending on the research question given by the researcher. Multiple properties can be also evaluated separately, case in which $\psi(\theta)$ becomes a vector valued function with P properties .

Adaptation

In addition to the drivers, the system property (ψ) also depends on $\tau(\theta)$, which corresponds to the endogenous behaviours in response to the drivers θ. We define $\tau(\theta) = (\tau_1(\theta), \ldots, \tau_M(\theta))$ as the M adaptation variables of actors within the system. A system can have a single or multiple adaptation variables. The optimal $\tau^*(\theta)$ is the value that maximizes the system property $\psi(\theta)$.

$$\tau^*(\theta) = \operatorname*{argmax}_{\tau} \psi(\tau, \theta) \tag{2.1}$$

2.3.2 Exposure

Exposure to changes in drivers, or simply exposure, is the magnitude of change in any drivers affecting the system property. For determining adaptions, the source of these events is not relevant, only their magnitude. This can either be evaluated for the entire vector of drivers or individual drivers. Usually, exposure is dependent on impacting a particular part of a system. In our definition a system property can be exposed but not affected, case in which the sensitivity (how affected the system property is by changes in drivers) would be zero. For instance, if the system property of a coupled ecological-economic system is a measure of a community's well-being, there could be changes in drivers which do not affect the community's well-being.

$$E(\theta, {}^0\theta) = \theta - {}^0\theta \tag{2.2}$$

$$E_d(\theta_d, {}^0\theta_d) = \theta_d - {}^0\theta_d \tag{2.3}$$

Each $E_d(\theta_d, {}^0\theta_d)$ depends on the magnitude of change in the driver d, where ${}^0\theta_d$ is the original value of the driver, and θ_d is the new state (Eq. (2.3)). The vector ${}^0\theta$ contains the initial values of all drivers. θ_d can be higher or lower than the initial state, resulting in a positive or negative exposure. If changes in a single driver, e.g. θ_d, are evaluated the vector of exposure contains zeros in all positions except for the change in θ_d in the dth position ($E(\theta, {}^0\theta) = (0, \ldots, \theta_d - {}^0\theta_d, \ldots, 0)$).

2.3.3 Sensitivity

The sensitivity is the degree to which the system property is affected either adversely or beneficially by exposure to changes in drivers (IPCC, 2001), given their initial values and excluding any adaptation. The sensitivity to a given level of exposure may vary depending on the system property under analysis. We interpret this as the change on the system property given by a change in the driver (Eq.(2.4)).

We define continuous and absolute sensitivities regarding the impact on the system property. The absolute measure is useful when investigating the total impact considering the range of exposure levels of the driver. Marginal sensitivities show the rate of change in the system property given by a marginal change in driver.

Absolute

In Eq.(2.4) we evaluate the system property (ψ) in two points, at the initial state of the drivers $\psi({}^0\theta, \tau({}^0\theta))$ and at the new state $\psi(\theta, \tau({}^0\theta))$, with no change in adaptation $\tau({}^0\theta)$. Depending on the data availability Eq. (2.4) can be evaluated in many values for each driver considered. For each property the sensitivity ψ_p is measured by the difference in the system property induced by the exposure, without adaptation. The absolute sensitivity can have positive or negative values, it depends on the effect of the driver on the system property. I.e., if $\psi_p(\theta)$ is greater than the value of the system property at the initial state ($\psi_p({}^0\theta)$) then the sensitivity with respect to that property $S_p(\theta, {}^0\theta)$ is positive, otherwise it is negative. If the change of the driver affects the system property adversely θ_d is considered a stressor, otherwise a benefactor.

$$\begin{aligned} S(\theta, {}^0\theta) &= \psi(\theta, \tau({}^0\theta)) - \psi({}^0\theta, \tau({}^0\theta)) \\ &= (S_1(\theta, {}^0\theta), \ldots, S_P(\theta, {}^0\theta)) \\ &= (\psi_1(\theta, \tau({}^0\theta)) - \psi_1({}^0\theta, \tau({}^0\theta)), \ldots, \psi_P(\theta, \tau({}^0\theta)) - \psi_P({}^0\theta, \tau({}^0\theta))) \end{aligned} \tag{2.4}$$

Marginal

The marginal sensitivities evaluate impacts on the system property from marginal changes in a driver at a given point. It measures the impact of a marginal increase in exposure from this point disregarding non-linearities in responses to larger exposure levels. This is relevant when making policy choices that are robust to random shocks [4]. In the case that multiple properties and drivers are evaluated simultaneously, the marginal form is the Jacobian of Eq. (2.4). The entries s_{pd} give the marginal sensitivity of property p to a change in driver d. In the case when a single property is considered $P = 1$ the Jacobian matrix collapses to a vector of partial derivatives.

[4] We follow Gallopín (2006) who defines sensitivity as change in the transformation of the system with respect to a change in the perturbation.

$$s(\theta, {}^0\theta) = \begin{pmatrix} \dfrac{\partial S_1(\theta, {}^0\theta)}{\partial \theta_1} & \cdots & \dfrac{\partial S_1(\theta, {}^0\theta)}{\partial \theta_D} \\ \vdots & \ddots & \vdots \\ \dfrac{\partial S_P(\theta, {}^0\theta)}{\partial \theta_1} & \cdots & \dfrac{\partial S_P(\theta, {}^0\theta)}{\partial \theta_D} \end{pmatrix} \tag{2.5}$$

$$s_{pd}(\theta, {}^0\theta) = \frac{\partial S_p(\theta, {}^0\theta)}{\partial \theta_d} = \frac{\partial \psi_p(\theta, \tau({}^0\theta))}{\partial \theta_d} \tag{2.6}$$

2.3.4 Adaptation

We define adaptation as an element within a coupled ecological-economic system that adjust to changing external drivers. Adaptation moderates harm or exploits beneficial opportunities (IPCC, 2014). The system properties (ψ) also depend on $\tau(\theta)$, which corresponds to the endogenous behaviours in response to the drivers θ. The adaption measures how much an optimal response to a change in the drivers can improve the system property, compared to the outcome without an adaptation (Eq. (2.7)). Additionally, we also measure the amount of change in the endogenous behaviour that is necessary to achieve the optimal adaptation.

Absolute

Eq.(2.7) shows the difference between the system property evaluated with an endogenous response to the drivers $\tau(\theta)$, and the initial behaviour $\tau({}^0\theta)$ with no response. In the case of multiple behaviour variables $\tau(\theta)$ is a vector. For instance, to assess the adaptive response *of* a community's well being *to* climate change, $\psi_p(\theta, \tau(\theta))$ corresponds to the system property under evaluation, i.e., community's well-being, a measure of the outcome. θ are drivers affected by climate change, and $\tau(\theta)$ reflects the community's actions affecting their well-being. $\tau(\theta)$ changes in response to the drivers θ. The community's well-being $\psi(\theta)$ can be some measure of utility, socio-economic or financial characteristics. The adaptive capacity is the benefit to the community of adapting to climate change, determined as the difference in well-being in the community before and after adaptation. ψ is evaluated at the new value of the driver θ, and there is only change in τ. If $\psi(\theta, \tau(\theta))$ is a vector of multiple properties being evaluated ${}^aA(\theta, {}^0\theta)$ is a vector valued function, where each entry corresponds to the changes in one of the properties.

$$\begin{aligned} {}^{a}A(\theta, {}^{0}\theta) &= \psi(\theta, \tau(\theta)) - \psi(\theta, \tau({}^{0}\theta)) \\ &= ({}^{a}A_1(\theta, {}^{0}\theta), ..., {}^{a}A_P(\theta, {}^{0}\theta)) \\ &= (\psi_1(\theta, \tau(\theta)) - \psi_1(\theta, \tau({}^{0}\theta)), ..., \psi_P(\theta, \tau(\theta)) - \psi_P(\theta, \tau({}^{0}\theta))) \end{aligned} \tag{2.7}$$

The change in behaviour in order to adapt is the difference in $\tau(\theta)$ due to the change in θ (Eq.(2.8)).

$$\begin{aligned} {}^{c}A(\theta, {}^{0}\theta) &= \tau(\theta) - \tau({}^{0}\theta) \\ &= (\tau_1(\theta) - \tau_1({}^{0}\theta), ..., \tau_M(\theta) - \tau_M({}^{0}\theta)) \end{aligned} \tag{2.8}$$

Marginal

We consider three marginal measures for adaptive capacity. First, the marginal version Eq. 2.7 is the Jacobian with the elements ${}^{a}a_{pd}(\theta)$. The entry ${}^{a}a_{pd}(\theta)$ represents the change in the mitigation of sensitivity of the system property p given by a change in the adaptation behaviour (τ) due to a marginal change of the driver d (Eq. 2.9). Second, as the marginal adaptive capacity of Eq. (2.9) is zero in the zero exposure case we also consider the second derivatives of Eq. (2.7). The elements ${}^{b}a_{pd}(\theta)$ present the second partial derivatives of Eq. 2.7. This is the curvature of the adaptive capacity, the rate at which ${}^{a}a_{pd}(\theta)$ changes due to a marginal change in θ_d. Third, ${}^{c}a_{md}(\theta)$ is the marginal measure of ${}^{c}A(\theta,{}^{0}\theta)$. It shows the marginal optimal change of adaptation behaviour in τ_m, given a marginal increase in driver d(Eq. 2.12). Notice that ${}^{c}a_{md}(\theta)$ measures changes in the ability of adaptation while ${}^{a}a_{pd}(\theta)$ and ${}^{b}a_{pd}(\theta)$ are about changes in the benefit of adaptation.

$$
\begin{aligned}
{}^{a}a_{pd}(\theta) &= \frac{\partial A_p(\theta, {}^{0}\theta)}{\partial\, \theta_d} \\
&= \frac{\partial \psi_p(\theta, \tau(\theta))}{\partial\, \theta_d} - \frac{\partial \psi_p(\theta, \tau({}^{0}\theta))}{\partial\, \theta_d} \qquad (2.9) \\
&= ti_{pd}(\theta) - s_{pd}(\theta) \qquad (2.10)
\end{aligned}
$$

$$
\begin{aligned}
{}^{b}a_{pd}(\theta) &= \frac{\partial^2 A_{pd}(\theta, {}^{0}\theta)}{\partial^2\, \theta_d^2} \\
&= \frac{\partial^2 \psi_{pd}(\theta, \tau(\theta))}{\partial\, \theta_d^2} - \frac{\partial^2 \psi_{pd}(\theta, \tau({}^{0}\theta))}{\partial\, \theta_d^2} \\
&= \frac{\partial ti_{pd}(\theta)}{\partial \theta_d} - \frac{\partial s_{pd}(\theta)}{\partial \theta_d} \qquad (2.11)
\end{aligned}
$$

$$
{}^{c}a_{md}(\theta) = \frac{\partial \tau_m(\theta)}{\partial\, \theta_d} \qquad (2.12)
$$

For instance, to assess the adaptive capacity *of* a community's well being *to* climate change, $\psi(\theta, \tau(\theta))$ represents a single measure of community's well being affected by climate change $(P = 1)$. Consider θ_1 a measurement of temperature and θ_2 precipitation $(\theta = (\theta_1, \theta_2))$. Let $\tau(\theta)$ be the adaptive actions that the community performs to affect their well being. Then ${}^{a}a_d(\theta)$ shows how the well being is affected by this change in the adaptive action given a marginal change in the driver θ_d. ${}^{b}a_d(\theta)$ represents the change of well being changes, due to adaptive behavioural changes with temperature or precipitation. If ${}^{b}a_2(\theta) < {}^{b}a_1(\theta)$, then adaptive capacity builds up quicker for temperature than for precipitation. Finally, ${}^{c}a_{md}(\theta)$ shows how a marginal change in the driver affects these adaptive actions, i.e, the optimal change in action given by a marginal change in temperature or precipitation. If ${}^{c}a_{m2}(\theta) > {}^{c}a_{m1}(\theta)$ then adaptation to precipitation requires a larger change in behaviour with respect to action m in order to adapt to precipitation than temperature. If there are multiple actions that can be adjusted to changing drivers these relationships may vary per action.

2.3.5 Total Impact (TI)

The Total Impact (TI) combines exposure, sensitivity, and endogenous adaption. It is the overall change of the system property once exposed to the change in drivers and endogenous adaptation occurs. TI measures changes in drivers on the system property. It is equal to sensitivity plus adaptive capacity. The latter is always positive. If sensitivity reduces the outcome of the system property, adaptive capacity counteracts this effect, otherwise enhances it.

Absolute

The system property is evaluated at the initial value of the drivers with no adaptation $\psi({}^0\theta, \tau({}^0\theta))$, and at the new values with adaptation $\psi(\theta, \tau(\theta))$. The difference between both is defined as TI (Eq. (2.13)).

$$\begin{aligned} TI(\theta, {}^0\theta) &= S(\theta, {}^0\theta) + {}^aA(\tau(\theta, {}^0\theta)) \\ &= \psi(\theta, \tau(\theta)) - \psi({}^0\theta, \tau({}^0\theta)) \\ &= (\psi_1(\theta, \tau(\theta)) - \psi_1({}^0\theta, \tau({}^0\theta)), \ldots, \psi_P(\theta, \tau(\theta)) - \psi_P({}^0\theta, \tau({}^0\theta))) \end{aligned} \tag{2.13}$$

Marginal

The marginal TI is the Jacobian of Eq. 2.13. The entries of the Jacobian are defined by Eq. 2.14. These show the change in the system property p with an optimal adaptation $\tau(\theta)$, given a marginal increase in driver θ_d. The marginal TI evaluated at the zero exposure levels of the drivers ${}^0\theta$ will be equal to the marginal sensitivity, as the marginal adaptive capacity is zero at that point.

$$\begin{aligned} ti_{pd}(\theta) &= \frac{\partial TI_p(\theta, {}^0\theta)}{\partial\, \theta_d} = \frac{\partial \psi_p(\theta, \tau(\theta))}{\partial\, \theta_d} \\ &= s_{pd}(\theta) + {}^aa_{pd}(\theta) \end{aligned} \tag{2.14}$$

2.4 Case Study: North Sea flatfish fishery

We apply the framework to fishers' profitability in the North Sea flatfish fishery. The EU derives 32% of the total landings from the North Sea and the Eastern Arctic, accounting for the highest total landed value in Europe (STECF, 2019b). Historically, the most harvested species in this region by value are Atlantic cod, Atlantic mackerel, and Atlantic herring (ibid.). However, a variety of other species such as European plaice, Common sole, and Common shrimp account for one third of the economic value generated in the North Sea. Fishing pressure caused shifts in the ecosystem composition historically and further shifts are expected due to climate change. This region is identified as one of the 20 hot-spots of climate change globally (Pinnegar et al., 2016). Quante and Colijn (2016) show projections regarding increased sea level, ocean acidification, ocean temperature, and a decrease in primary production. This causes migration of the species, affecting the availability of resources to local fishing fleets, and reducing the overall ‘carrying capacity’ of the stock (Pinnegar et al., 2016).

The North Sea flatfish fishery is a multi-species fishery catching plaice, sole, cod, and other flatfish. The economic importance of fisheries in the North Sea led to over-fishing of some flatfish species. In this paper we focus on European Plaice (*Pleuronectes platessa*) and Common Sole (*Solea solea*), because they are the two principal flatfish species targeted by European fisheries (Etherton, 2015). Sole grows up to a length of 30cm, and plaice up to 33cm (Knijn et al., 1993). These species have endured the consequences of climate change, over-fishing, and pollution (Engelhard et al., 2011a; Gattuso et al., 2018).

To promote the sustainability of the stock a policy was adopted regulating Total Allowable Catches (TACs), conservation areas, and mesh size (Engelhard et al., 2011a; European Commission, 2014; Keeken et al., 2007). TACs are in place since 1979 mostly restricting harvest of sole, while TACs for plaice have often been so large as to be non binding (Figure 2.1) (Daan, 1997). During the second half of the 20th century, the TACs decreased for plaice, in line with a recommended reduction in fishery mortality (ibid.). In 1989, to allow the plaice population to recover, a protected area, the ‘Plaice Box’, is closed to trawling fisheries (an area on the Dutch and German coast). The Spawning Stock Biomass (SSB) for plaice decreases after this measure, attributed to a distribution shift caused by long term climate change and an increase in discards outside of the ‘Plaice Box’ (Engelhard et al., 2011a; Keeken et al., 2007) (Figure 2.1). The drop in the SSB for sole since 1990 was also caused by shifted distributions but strongly attributed to fishing pressure. The high price of sole makes it the preferred targeted fish compared to plaice (Engelhard et al., 2011a), however, it is not possible to catch sole independently of plaice. In recent years the plaice stock (SSB) has recovered while sole shows a constant tendency (ICES, 2019a,b)

In the last decade, the average landings (harvests) of plaice by weight are approxi-

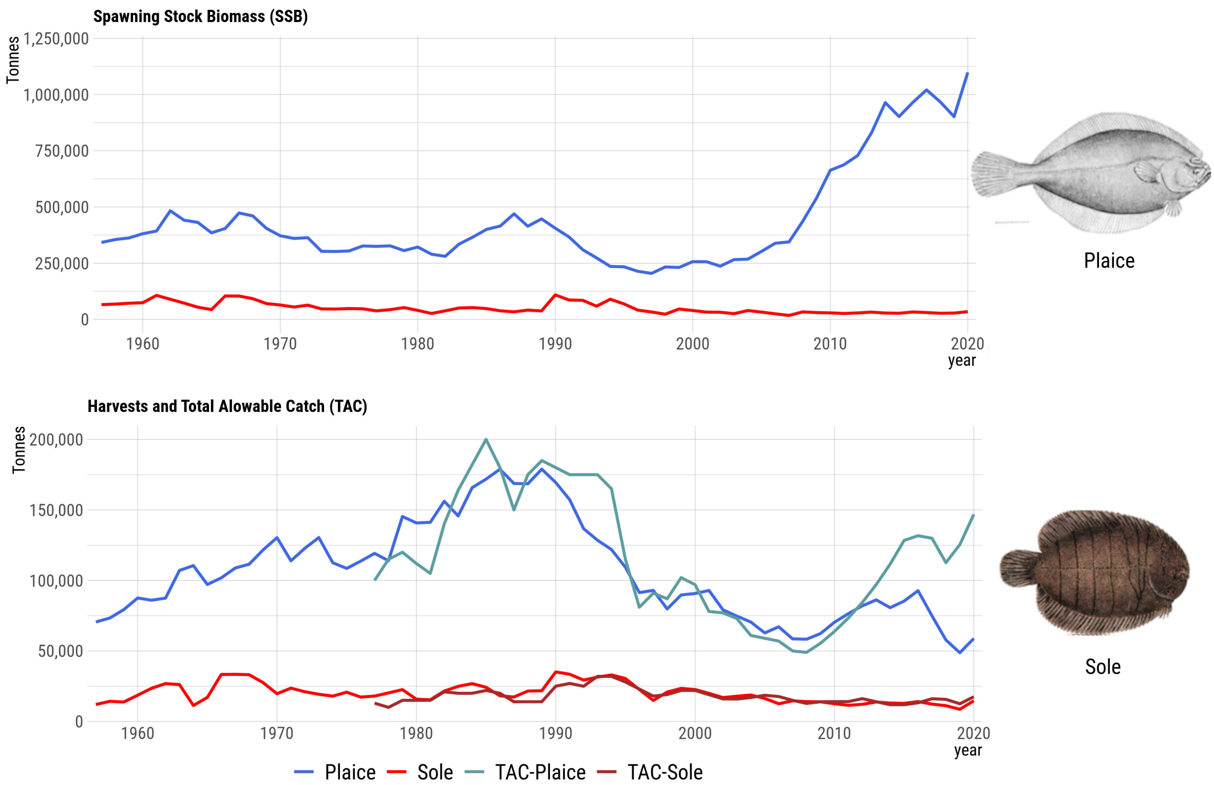

Figure 2.1: Spawning Stock Biomass (top), Harvests (Landings) and Total Allowable Catch (bottom) for plaice and sole between 1957-2020.

mately seven times larger than those of sole. However, because the price of sole is six times that of plaice, the two species' landings are roughly equal in value (STECF, 2019b). In this region the price is controlled by companies in The Netherlands because it is the larger producer of European plaice in the world (EUMOFA, 2013). The main actors in this fishery are The Netherlands, Denmark, UK, Belgium, France, and Germany. Despite increases in costs net profits remain positive, except for the Belgian and German fleets between 2010-2017 (STECF, 2019b).

In this paper we focus on three main aspects affecting this fishery. First, changing in technical measures affecting returns to effort. In 2023 the European commission called on members states to increase the monitoring and data collection of fishers to reduce the impact on the sea bed by bottom trawlers. By the end of 2024 member states are called to submit a national plan with the specific measures directed to data collection and monitoring programmes to improve observations and reporting of incidentally by-catch species (EC, 2023). These measures could include the installation of cameras on board or additional requirements on the fishing measurement process. Such measures have the potential to reduce returns per unit of fishing effort in this fishery.

Second, increasing regulations regarding the coverage of Marine Protected Areas (MPA) and Off-shore Windfarms (OWF) affecting the stock harvesting efficiency. The objective of the EU 2030 Biodiversity Strategy is to protect 30% of the European sea, and mobile bottom fishing in all MPA's by 2030. To achieve this objective the European commission calls the member states to create new MPAs and start adopting national measures by the end of March 2024. Offshore wind is also increasing, the European Commission estimates that by 2050 30% of future global electricity demand could be supplied by offshore wind. Both, MPAs and OWF, reduce the space available for fisheries and in the short term, the stock accessible to fish, reducing the stock harvesting efficiency.

Third, the ageing of the fishing population presents an additional pressure on this fishery. The STECF (2020) mentions that there is an inter-generational deficit which represent an important threat to the sustainability of this fishery. More than 60% of the fishers are between 40-65 years old and only 22% are between 25-39 years old. In 2019 this fishery experienced a sharp decrease (-18%) in employment compared to 2018 (STECF, 2021). This could be the result of adaptation to simultaneous stressors, such as stocks moving towards another region, increasing fixed costs, reduction in active vessels, and reduced harvesting efficiency.

2.4.1 Bio-Economic model

To apply the framework to our case study we use an existing bio-economic model (Blanz, 2019). In the context of an interconnected coupled ecological-economic system the bio-economic model is the most parsimonious product that incorporates the interconnections in a quantified way. We then calibrate the bio-economic model as it can serve as an intermediate complexity step between a fully conceptual model example and a pure data-based statistical analysis. Our framework, however, can be also used with another mathematical models or contexts.

In our application we modify the model described by (ibid.) to embody the peculiarities of the North Sea flatfish fishery (See the detailed description of the model in section 4.A). We replace the logistic growth function, used to model stock change, with a Ricker-recruitment type growth function (Ricker, 1975), as it better represents the stock data (Spawning Stock Biomass). We also introduce weighting factors for each fish species in the household utility function to better reflect consumer preferences. A feature of the model is the introduction of simultaneous multi-species harvesting, i.e., fisheries target one species but in doing so catch other species. In our case study, the fishers behaviour is market-driven. Fishers mostly target sole because of its higher price, but in doing so they also catch plaice (Aarts and Poos, 2009). The model includes parameters that account for these characteristics to resemble observations.

The bio-economic model has three elements: (i) The ecosystem component includes harvests and the stock change, represented by the species growth function for plaice and sole. The stock levels are the system's state variables. The system's stable and non-stable steady-states depend on the stock change which results from ecosystem growth and harvests. (ii) The harvesting component includes an endogenous amount of fisheries firms comprising the fleets of two métiers[5]. The first targets plaice and the second sole with imperfect selectivity. The harvesting function depends on effort and stock availability. Firms maximize profits, derived from harvests, prices, variable and fixed costs. (iii) The household component consists of a representative household obtaining utility from fish consumption and manufactured goods. The household maximizes utility subject to a budget restriction and thereby determines the optimal quantities demanded and willingness to pay for each fish species.

The model assumes market-clearing, all goods produced are consumed (Eq. A.10). In the long run a competitive market with free entry and exit, firms compete such that prices and total costs are equal. This leads to the zero profit assumption described in Eq. (A.5). The size of the fleets is determined satisfying the zero profit assumption and the optimal effort choice by fishing firms. There is no fishery rents since effort adjustment is much faster than fleet adjustment, so we consider fleet fixed when investigating effort. Another assumption of the model is that processors set prices to take any rents irrespective of consumer demand and do not adjust prices. This assumption is based on qualitative information of reality because German fishers are price takers given the monopoly of the price established by companies from The Netherlands (EUMOFA, 2013). The steady-states for stocks of each species in an open-access scenario with quotas are determined numerically. Our model resembles particular aspects of the North Sea flatfish fishery mainly catching plaice and sole. The model presents an abstraction of the multiple complexities embedded

[5]Métier refers to a combination of vessel and gear type. In this paper we use a model with two species where the species sub-index i takes the value of 1 for plaice and 2 for sole. Similarly the sub-index k refers to the two fleets, where k=*1* refers to the fleet targeting plaice and k=*2* the fleet targeting sole.

in this fishery, but still useful providing insights regarding the adaptations we analyse. Although the model includes by definition many assumptions, these are not required to apply the framework.

2.4.2 Calibration of the model

We calibrate the model to time series of stocks, harvests, and prices for the whole North Sea. For stocks and harvests, we use data on spawning stock biomass (SSB) and landings from 1957 to 2019 provided by the International Council for the Exploration of the Sea (ICES, 2019a,b). We use price data from the European Market Observatory for Fisheries and Aquaculture Products (EUMOFA) database for the years from 2000 to 2020. The ecosystem component is calibrated independently of the economic parts using the observed stock growth and harvests. Within the model, harvests and consumer demand are calculated based on the stock levels of each period. To account for this the economic parameters of the model are calibrated to harvests and prices of each period simultaneously. A detailed description of the calibration method is provided in section 2.B.

Tables 2.1 and 2.2 present the calibrated and output values of the model elements in steady-sate. Figure 2.2 shows the output of the calibration for SSB (stock), harvest, and prices. The predicted values for SSB resemble the real tendency of the stocks during the last forty-five years. The harvest predictions of plaice before the TAC was introduced are higher than the real time-series. This is because the modelled fleet adjusts automatically to the new levels of stocks and prices, while in reality, the enter-exit movement of the firms occurs over a longer time frame. The predicted values of plaice show a decreasing price from 1982 to 1986 followed by a decreasing harvest. After the introduction of the plaice box in 1989 the plaice price increased together with plaice harvest until the TAC becomes binding in 1995. The predicted values of sole harvest follow the binding TAC. Since 1987 the predicted sole price starts increasing followed by a slight increase in harvest until 1999 when the TAC decreases again. For the last ten years, the predicted sole harvest and prices resemble the real values. However, the predicted plaice harvest follows the path of the TAC because the real fishing capacity do not keep up with the TAC and the plaice industry do not profit much from it since the plaice price is low.

Symbol	**Value**	**Description**	**Exposure**	
Ecosystem drivers			Absolute (Min, Max)	Percentage (Min, Max)
x_i	$x_1 = 148.589$ $x_2 = 85.936$	Steady-state output for stocks of plaice and sole in tonnes.		
Harvesting drivers				
ϵ	0.5	Returns to effort. A higher value of ϵ refers to less returns per unit of effort.	0.48, 0.52	$-3.09\%, +4.26\%$
χ_i	$\chi_1 = 0.308$ $\chi_2 = 0.308$	Stock harvesting efficiency of the species i. Represents the ability to catch a species depending on stocks availability (catchability).	$\chi_1 : 0.093, 0.607$ $\chi_2 : 0.230, 0.549$	$\chi_1 : -69, 7\%, +96.8\%$ $\chi_2 : -25, 2\%, +78.0\%$
$\nu_{ik}^{\ddagger}$	$\nu_{11} = 1.00$ $\nu_{12} = 0.75$ $\nu_{21} = 0.00$ $\nu_{22} = 0.25$	Métier specific harvesting efficiency (ν_{ik}) of the species i targeted with the métier k.		
Market drivers				
p_i	$p_1 = 5.6$ $p_2 = 6.6$	Market prices in (Euros/Kg) for plaice p_1 and sole p_2 in steady-state.		
$\omega^{\ddagger}$	1	Wages. The model wage is normalized to one, and households receive a unit to spend in either other goods or fish.	0.65,1.37	$-35\%, +37\%$
ϕ	1.0 x10^{-8}	Fixed costs of harvesting firms. Costs of owning the harvesting vessel and equipment independent of use.		
Household preferences drivers				
α	6.77 x 10^{-5}	Relative importance of fish consumption for households.		
β_i	$\beta_1 = 2.69$ $\beta_2 = 4.14$	Weight of the species i in the household utility function.		
η	1.10	Elasticity of demand for fish consumption.		
σ	2.01	Substitution elasticity between plaice and sole.		

Table 2.1: Calibration results for each parameter, and steady-state values for prices, and stocks. ‡These parameters are not included in the calibration and are taken from the theoretical results in Blanz (2019).

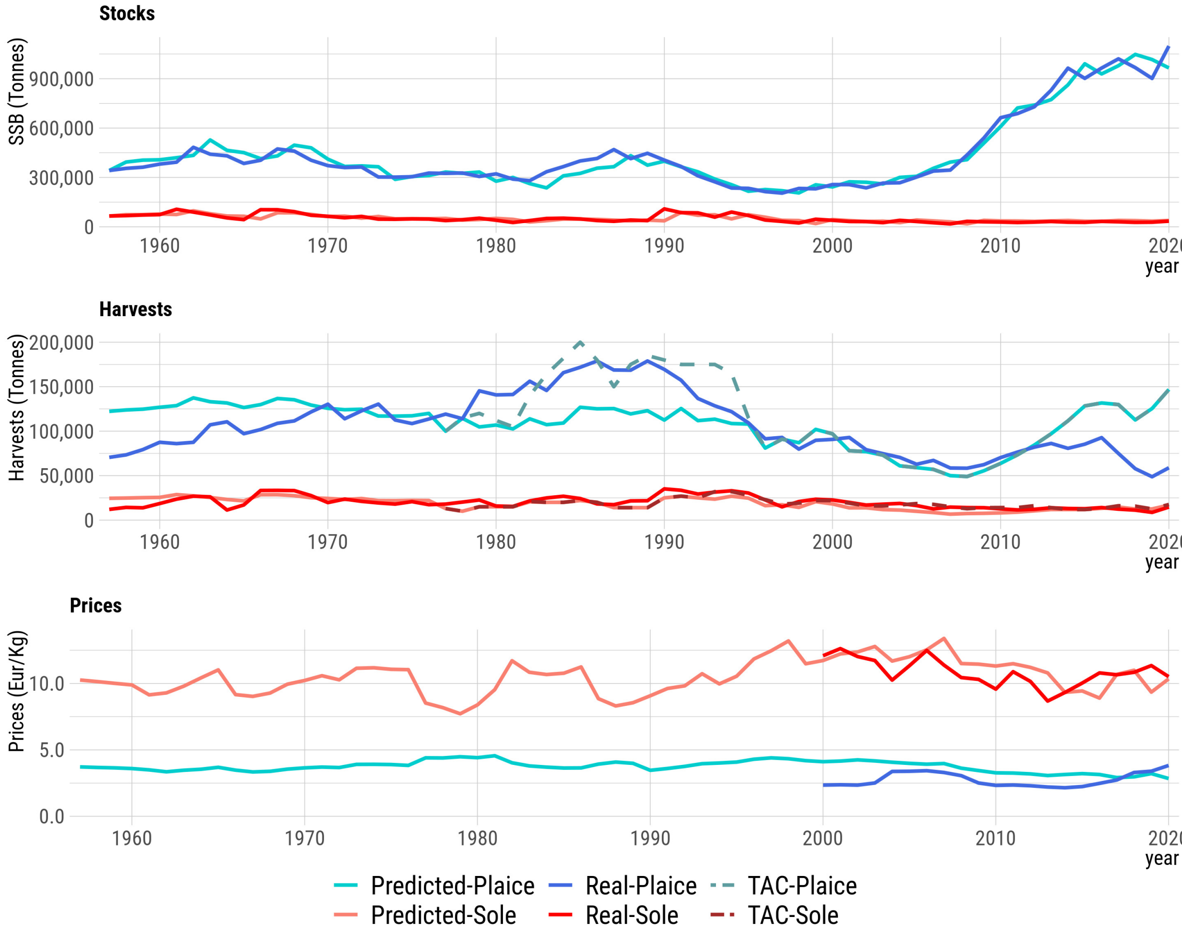

Figure 2.2: The difference between the real data and predicted levels of stocks (top), harvests (centre), and prices (bottom). Predicted stock levels are the result of predicted growth, given the real data in the previous period. The shown predicted levels of harvests and prices are based on the real stock levels of each period. Theil Inequality Coefficient: Stocks: Plaice = 0.049, Sole = 0.1507 Harvest: Plaice = 0.1506, Sole = 0.1389 Prices: Plaice = 0.1615, Sole = 0.0516

2.4.3 Application of the analytical framework to the bio-economic model

The framework presented above enables us to find the adaptations of many system properties to many drivers. Hence, the main question to answer before proceeding with the case study is the adaptation *of* what *to* what?. We select fishers' economic viability to answer the first "what" as the most critical aspect in this sector (Schuhbauer and Sumaila, 2016). For the second "what" we assess drivers derived from changes in policies affecting the harvesting process (θ). After identifying the best adaptation of fisheries' profits to the drivers considered we identify the effect of this adaptation on the quantities produced.

In our application, we replace $\psi(\theta)$ by $\pi(\theta)$, which corresponds to the fishers' profits. There are two fishers' métiers ($k \in \{1, 2\}$) that fish two species ($i \in \{1, 2\}$). We evaluate profits of two métiers, hence $\pi(\theta) = (\pi_1(\theta), \pi_2(\theta))$. Profits are a function of the set of

Symbol	Value	Description
Steady state values		
n_i	$n_1 = 383$, $n_2 = 2315$	Optimal number of firms for each species.
h_{ik}	$h_{11} = 13.752$, $h_{12} = 62.317$, $h_{21} = 0.00$, $h_{22} = 17.545$	Optimal harvests (h_{ik}) of species i per metiér k in tonnes. The fleet targeting plaice ($k = 1$) only catches plaice.
e^*_k	$e_1 = 1.0\text{x}10^{-8}$, $e_2 = 1.0\text{x}10^{-8}$	Optimal effort in steady-state for the metiér k. This is the effort that results from the zero profit condition and profit maximization(Eq. A.13).
Scaling parameters		
κ	$533.459, 8$	Scaling parameter for stocks. The real values of SSB and landings were divided by this parameter to scale to model values.
$wScale$	$10.052.180\text{x}10^6$	Scaling parameter for the income of the economy. This value correspond to the whole economy GDP of the North Sea countries for the year 2015.

Table 2.2: Calibration results for steady-state values of firms, harvests and effort. κ and $wScale$ are used to scale the real data to model values.

drivers (θ) and depend on harvests (h_{ik}) of species i with métier k, prices (p_i) of species i, effort (e_k) of the métier k, wages (ω), and fixed costs (ϕ) (Eq. 2.15). We analyse profits before the 'zero profit condition' holds to allow profits to deviate from zero (Eq. A.5). We investigate the short term effects on individual fishing companies. Market forces will drive profits to zero by entries and exits of firms in the long term. Our analysis precedes these adjustments. I.e., if profits are likely to decrease/increase due to changes in a driver, this forms the incentives for firms to enter or exit the market in the longer term. In our case study we replace the adaptation mechanism $\tau^*_m(\theta)$ by effort $e^{**}_k(\theta)$ [6].This effort represents the optimal adaptation strategy for fishers to maximize profits, prior to reaching the zero-profit condition. The modelled fisher adapts to changed conditions by modifying fishing effort (Eq. 2.17). We name (e^{**}_k) the adaptive effort to distinguish from the equilibrium effort ($e^*_k(\theta)$) which is derived once the zero profit condition holds (Eq. A.13).

$$\pi_k(\theta) = \sum_{i=1}^{\bar{i}} h_{ik}(e^{**}_k, x_i)p_i - \omega e^{**}_k - \phi \qquad (2.15)$$

In Eq. 2.15 harvest (h_{ik}) and adaptive effort (e^{**}_k) are defined in Eq. (2.16, 2.17) where x_i is the available stock, ν_{ik} is the métier harvesting efficiency, χ_i the stock harvesting

[6] In our application we evaluate two properties $K = 2$ and use two adaptation behaviours for each property that correspond to the effort of each métier ($M = 2$). Because each property corresponds to an adaptation behaviour we use the same index k for both. Our framework allows multiple adaptation mechanisms for one system property, but in this application we use only one.

efficiency, and ϵ the returns to effort.

$$h_{ik}(e_k^{**}, x_i) = \nu_{ik}(e_k^{**})^{\epsilon} x_i^{\chi_i} \tag{2.16}$$

$$e_k^{**}(\theta) = \left(\frac{\epsilon}{\omega} \sum_{i=1}^{\bar{i}} \nu_{ik} x_i^{\chi_i} p_i) \right)^{\frac{1}{1-\epsilon}} \tag{2.17}$$

Drivers

We evaluate three drivers according which are considered to be the most critical in this fishery. In section 2.4 we show three most important drivers affecting this fishery: changing in technical measures affecting returns to effort, increasing regulations regarding the coverage of the MPA, and the ageing of the fishing population (V. Stelzenmüller et al., 2022). First, we evaluate returns to effort (ϵ). We argue that regulation changing the monitoring of fishing and requirements on data collection, as mentioned in section 2.4, affects the returns to effort by changing fishers' working conditions. Second, we assess changes in the stock harvesting efficiency for each species (χ_i). χ_i is affected by regulations changing the space available to fish such as, MPAs and OWF. In the short term fishers experience less accessible fish affecting the harvesting efficiency. Third, we assess changes in wages (ω). This fishery ageing represents a threat to its sustainability, we identify the effect of changes in wages on the optimal adaptation through effort. We consider that an increase in wages could attract the new generation, such that it can keep the fishery active. The set of all drivers is given by $\theta = \{\omega, \chi_1, \chi_2, \epsilon\}$.

Exposures

Exposure is defined as changes in values for each element of θ (Eq. 2.3). The magnitude of exposure for each driver is based on historical variations of harvests, stocks, prices, wages, and fixed costs observed in the data. We use the harvest variations to identify the exposure limits for the returns to effort (ϵ), and stock harvesting efficiency (χ_i). Using Eq. (2.16) we obtain the maximum and minimum intervals of each driver that result in the same harvesting range. Exposure levels of wages (ω) are taken from maximum variations in the data [7]. We use the wage values of the North Sea countries with the

[7] The sample of maximum and minimum variations are within the 95% of confidence intervals.

maximum deviations of the mean as a reference for exposures. The selected exposures for each driver are described in the last column of Table 2.1. They are interpreted relative to the steady-state values, i.e., the status-quo of the system from which the changes in drivers and corresponding adaptations are analysed.

Sensitivities

We characterize the sensitivities of fishers' profits to drivers from the harvesting,and market components (Table 2.1). Sensitivities are described using Eq. (2.4). We analyse individual sensitivities of profits for each driver, holding other drivers constant. An example of the absolute sensitivity of profits to changes in stock harvesting efficiency (χ_i) is Eq. (2.18). χ_i is the new level of exposure and ${}^0\chi_i$ the original value, keeping stock and prices constant at steady-state levels. We apply the same exercise for returns to effort (ϵ) and wages (ω).

$$S_k(\theta, {}^0\theta) = \pi_k(\theta, e_k^{**}({}^0\theta)) - \pi_k({}^0\theta, e_k^{**}({}^0\theta)) \tag{2.18}$$

$$\theta = (0, \ldots, \chi_i, \ldots, 0)$$
$${}^0\theta = (0, \ldots, {}^0\chi_i, \ldots, 0)$$

The sensitivities of profits for the métier k to a marginal change in the driver d are defined by Eq. (2.19). Profits are evaluated with the adaptive effort (e_k^{**}) embedded, not the equilibrium effort (e_k^*), hence this derivative is different than zero.

$$s_{kd}(\theta) = \frac{\partial \pi_k(\theta, e_k^{**}({}^0\theta))}{\partial \theta_d} \tag{2.19}$$

Adaption

We determine the adaptation by evaluating the difference in profits in two cases. We calculate profits when fishers first experience the change in the driver $\pi_k(\theta, e_k^{**}({}^0\theta))$, without yet modifying their effort. Then, we identify profits after adaptation $\pi_k(\theta, e_k^{**}(\theta))$, once the effort is adjusted to the new level of the driver $e_k^{**}(\theta)$. The difference in profits between these two values yields the absolute benefit of adaptation per métier k for each driver (θ_d). We assess individual adaptive capacities for each driver θ_d holding others constant following the same procedure as with the sensitivities.

$$^{a}A_k(\theta, {}^{0}\theta) = \pi_k(\theta, e_k^{**}(\theta)) - \pi_k(\theta, e_k^{**}({}^{0}\theta)) \tag{2.20}$$

The marginal benefit of adaptation for fishers' profits using the adaptation effort with métier k to the driver d are in Eq. (2.21), (2.22). Eq. (2.20) shows the optimal change in adaptive behaviour due to a change in the driver. Eq. (2.20),(2.21) evaluated at steady state (${}^{0}\theta$) are zero. In our framework adaptation is always positive, through an optimal response to a changing situation.

$$^{a}a_{kd}(\theta) = \frac{\partial A_k(\theta, {}^{0}\theta)}{\partial\, \theta_d} \tag{2.21}$$

$$^{b}a_{kd}(\theta) = \frac{\partial^2 A_k(\theta, {}^{0}\theta)}{\partial\, \theta_d^2} \tag{2.22}$$

$$^{c}a_{kd}(\theta) = \frac{\partial e_k^{**}(\theta)}{\partial\, \theta_d} \tag{2.23}$$

Total Impacts

We use Eq. 2.13 to derive the Total Impacts (TIs) of profits to multiple drivers. TIs are determined as the overall difference in profits at the initial level of the driver (${}^{0}\theta_d$) and at the new level (θ_d). Profits at the initial level of the driver and without adaptation yield: $\pi_k({}^{0}\theta_d, e_k^{**}({}^{0}\theta_d))$. Profits at the new level of the driver and with adaptation included yield: $\pi_k(\theta_d, e_k^{**}(\theta_d))$. We assess the TIs using Eq. (2.24), for each driver independently.

$$TI_k(\theta, {}^{0}\theta) = \pi_k(\theta, e_k^{**}(\theta)) - \pi_k({}^{0}\theta, e_k^{**}({}^{0}\theta)) \tag{2.24}$$

The marginal TIs contemplate the derivative of profits once there is an optimal adaptation to the change in the driver (Eq. 2.25).

$$ti_{kd}(\theta_d) = \frac{\partial TI_k(\theta, {}^{0}\theta)}{\partial\, \theta_d} \tag{2.25}$$

After identifying how fishers adapt to maximize profits we identify the effect of this adaptation on the quantities of fish available in the market.

2.5 Results

In our case study we investigated the sensitivity, adaption, and total impact (TI) *of* fishing profits, *to* changes in four drivers and investigate the effect of adaptation on quantities available in the market. The TIs, adaptations, and sensitivities of profits to drivers are presented in figure 2.3 for wages (ω) and returns to effort (ϵ). The figures corresponding to the harvesting efficiency (χ_i) are in the appendix C.1. The horizontal axes represent the magnitude of exposure for each driver (θ_d) within the levels established in Table 2.1. The change on the vertical axes is calculated relative to steady-state. We perform the analysis from the steady-state to facilitate interpretation, however, within framework any other reference can be used. Profits are scaled relative to the household income (ω). As exposures are relative to the starting value, the initial level of exposure, adaptation, sensitivity, and TI is zero.

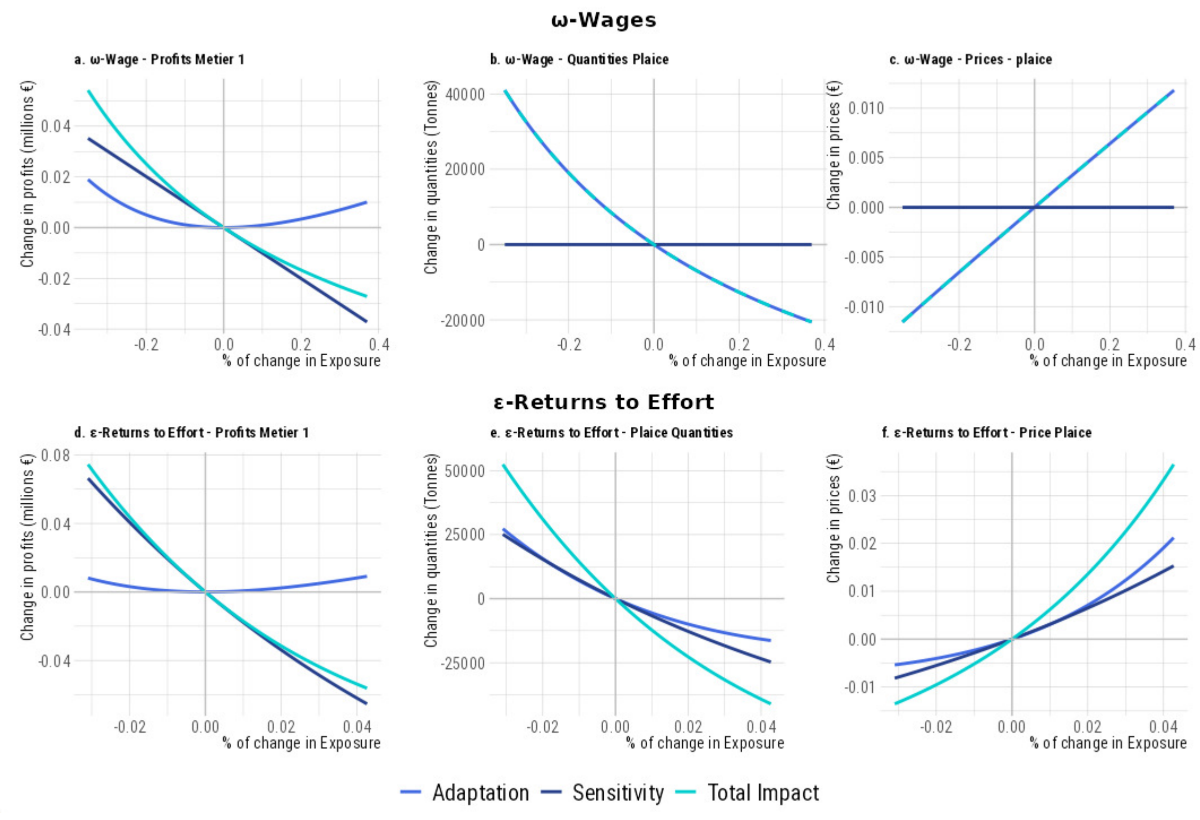

Figure 2.3: Changes in profits, quantities and prices due to changes in wages and returns to effort.

The first row of figure 2.3 shows the impact of wages on profits of métier 1, quantities and prices. The impact of changes in wages on profits is linear. The sensitivity in figure 2.3.a shows that for an increase in wages profits decrease. Fishers have a greater adaptive capacity to decreasing wages than to increase. If the exposure is negative (reducing wages), fishers can maintain the same effort at a lower cost or even increase their effort. In contrast, if the exposure is positive (increase in wages) fishers' costs increases and force them to decrease their effort, generating lower adaptation than to decrease in wages. Hence, total impact increases more if wages decrease than if they increase. The quantities do not instantaneously change with wages (2.16), when the change in the driver is experienced. After fishers adapt the quantities change with effort. The prices show the willingness to pay of households given the quantities available in the market following equation A.19.

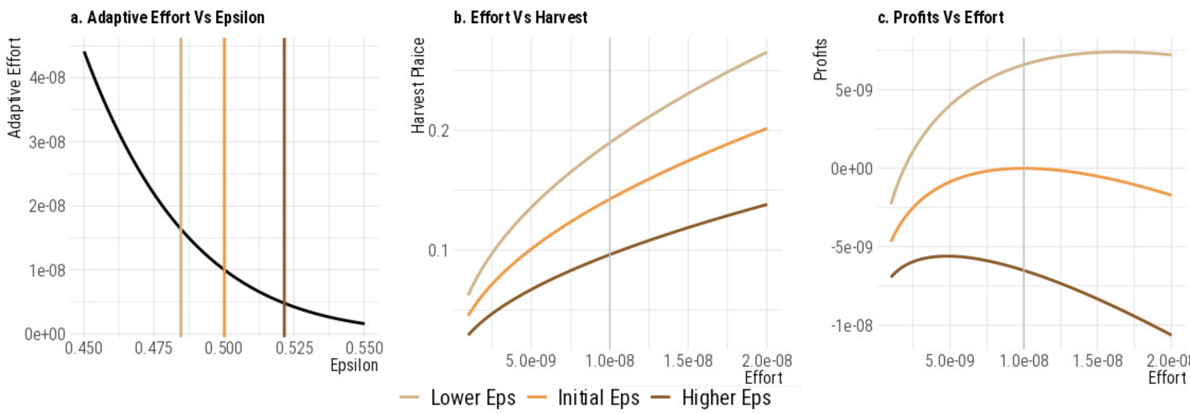

Figure 2.4: Changes in effort, harvest and profits for initial, higher and lower values of ϵ

The bottom row of figure 2.3 presents the changes in profits, quantities and prices due to a change in returns to effort (ϵ). If returns to effort increase the effective effort (e_k^ϵ) decreases, and profits also fall (Equation 2.15). This is because the effort in steady-state is less than one. A reduction in harvesting efficiency corresponds to an increase in ϵ. A higher ϵ decreases effort, followed by a reduction in the harvest, i.e., the quantities available in the market. To adapt, fishers reduce effort, which reduces their costs, counteracting the sensitivity and increasing profits. Note that the effect of adaptation on profits is always positive. The reduction in effort due to the increase in ϵ reduces fish quantities, increasing prices. A decrease in ϵ increases effort, adaptive effort (e^ϵ) and hence harvest (see Figure 2.4). Lastly, changes in the availability of stocks modify χ_i. A higher χ shows a lower availability of stocks for fishers. The analysis for χ_i resembles the reasoning of ϵ (see fig. C.1).

To compare the effect of adaptation on profits among different drivers, figure 2.5 allows us to determine the drivers to which fishers adapt the best. Figure 2.5 shows the fishers' effort adaptation to positive and negative exposures. Fishers adapt the best in absolute terms to changes in wages than any other driver, especially when they decrease. Lower wages allow fishers to maintain the same effort at lower costs or even increase their effort. Furthermore, fishers' profits are mostly impacted by returns to effort, the total impact is highest among the drivers evaluated.

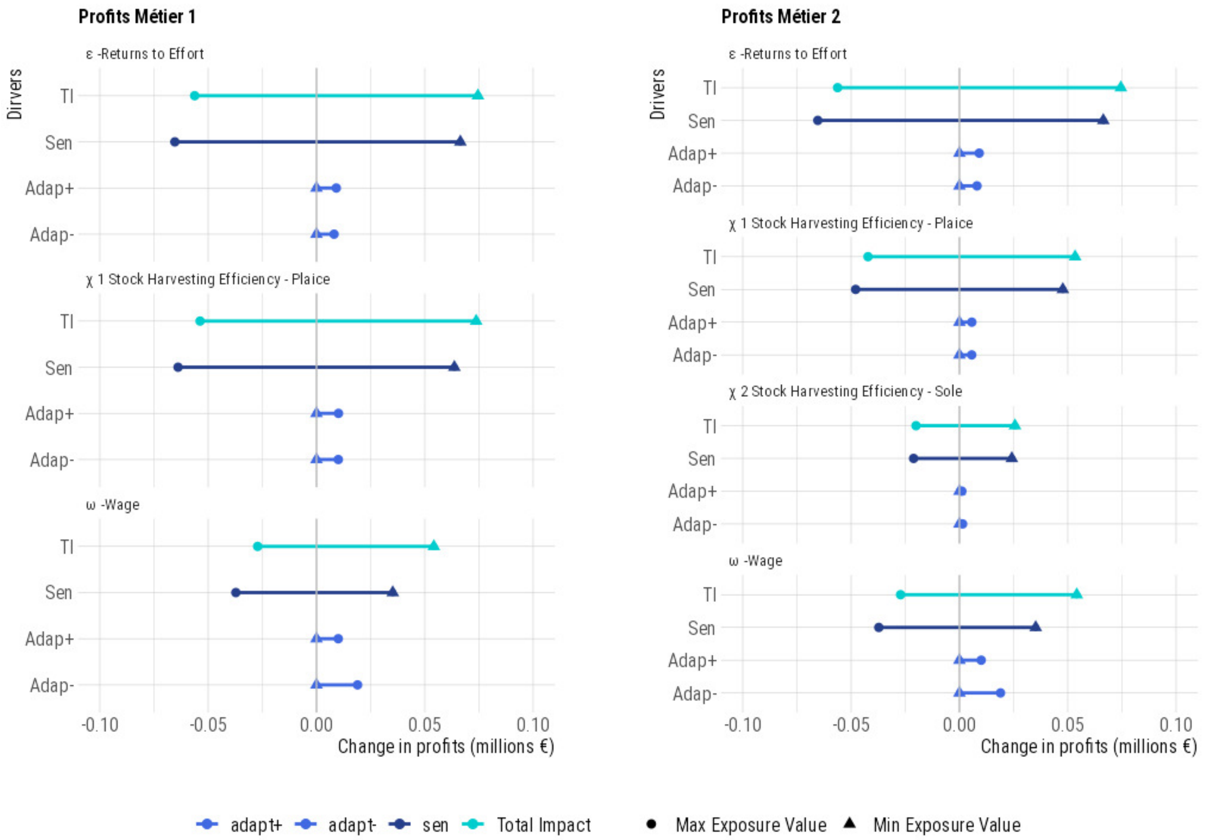

Figure 2.5: Absolute changes in profits due to changes in drivers for each métier. The horizontal axes show the change in profits in millions of euro. Métier 1 only harvests plaice, hence it has no sensitivity to changes in χ_2. 'adapt-' shows the adaptation when there is a decrease in the driver and 'adapt+' when there is an increase. The boundaries of the drivers are set according to the levels of exposure based on historical variations of harvests, stocks, prices, wages and fixed costs observed in the data.

The marginal adaptation ${}^a a_{kd}(\theta)$ in steady state ${}^0\theta$ is zero for all drivers (see Fig. 2.3. Hence, we present ${}^c a_{kd}(\theta)$ in figure 2.6. ${}^c a_{kd}(\theta)$ shows the change in adaptive effort given by a marginal change in the driver (Eq. 2.23). The adaptive effort is mostly affected by returns to effort (ϵ) followed by stock harvesting efficiency (χ_1) and wages (ω).

The absolute and marginal measures of total impacts complement each other. Absolute values depend on the level of exposure and evaluate adaptation and effects regarding abrupt changes in drivers. Marginal measures show the effect of marginal changes in drivers and are independent of the level of exposure. This is useful when the level of exposure is uncertain. The marginal measures correspond to the slope of the respective

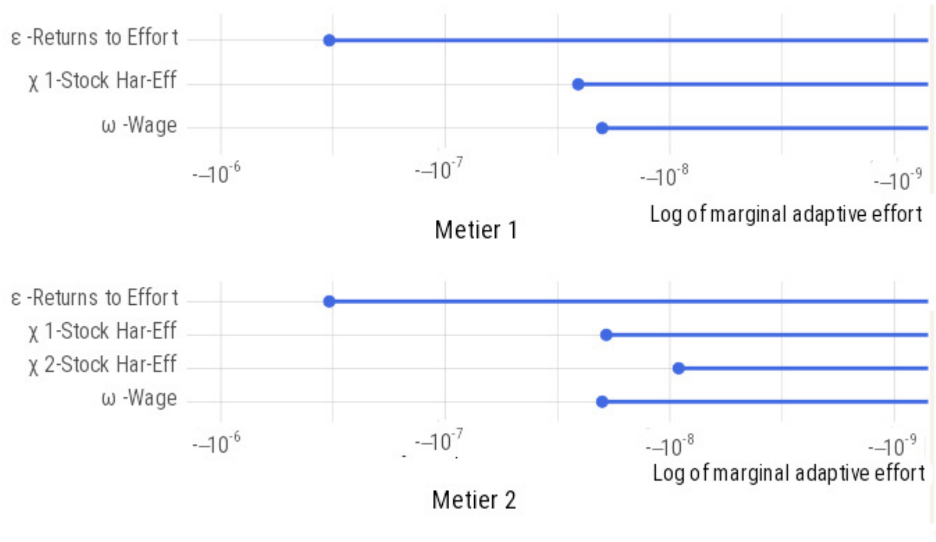

Figure 2.6: Changes in adaptive effort given by a marginal change in the drivers considered for Métier 1 and 2. The horizontal axes show the log scale of the adaptive effort and the horizontal axes the drivers evaluated.

absolute measures. Marginals also provide an overview of trade-offs among drivers' effects on profits and adaptations.

Figure 2.7 shows the comparison of the effect for each driver on quantities for the extremes of the established exposures. The horizontal axis displays the minimum and maximum vertical values of quantities presented in figure 2.3. 'Adapt+' represents the effect of adaptation on changes in quantities when exposure increases, and 'Adapt-' when exposure decreases. The symbols represent the maximum and minimum values of each driver.

The driver with the largest impact on quantities is returns to effort. For changes in ϵ adaptation has a large effect counteracting the sensitivity. Changes in χ_1 mostly affect the quantities of plaice and χ_2 those of sole quantities. The effect of χ_1 on sole is larger than the effect of χ_2 on plaice. Decrease in wages have a larger impact in the quantities of plaice than sole. This is mainly because in initial steady state sole is restricted by quota while plaice is not.

Figure 2.8 shows the effect of changes in fishers' adaption, sensitivity and total impacts on quantities given marginal changes in drivers. They are the result of the equation 2.9 for quantities with the drivers considered. Marginal increases in ϵ decrease the quantities of plaice more than sole, this is because in the initial steady state the quantities of plaice harvested are more than four times those of sole Marginal changes in the stock harvesting efficiency affect quantities of plaice more than sole. Changes in quantities due to marginal

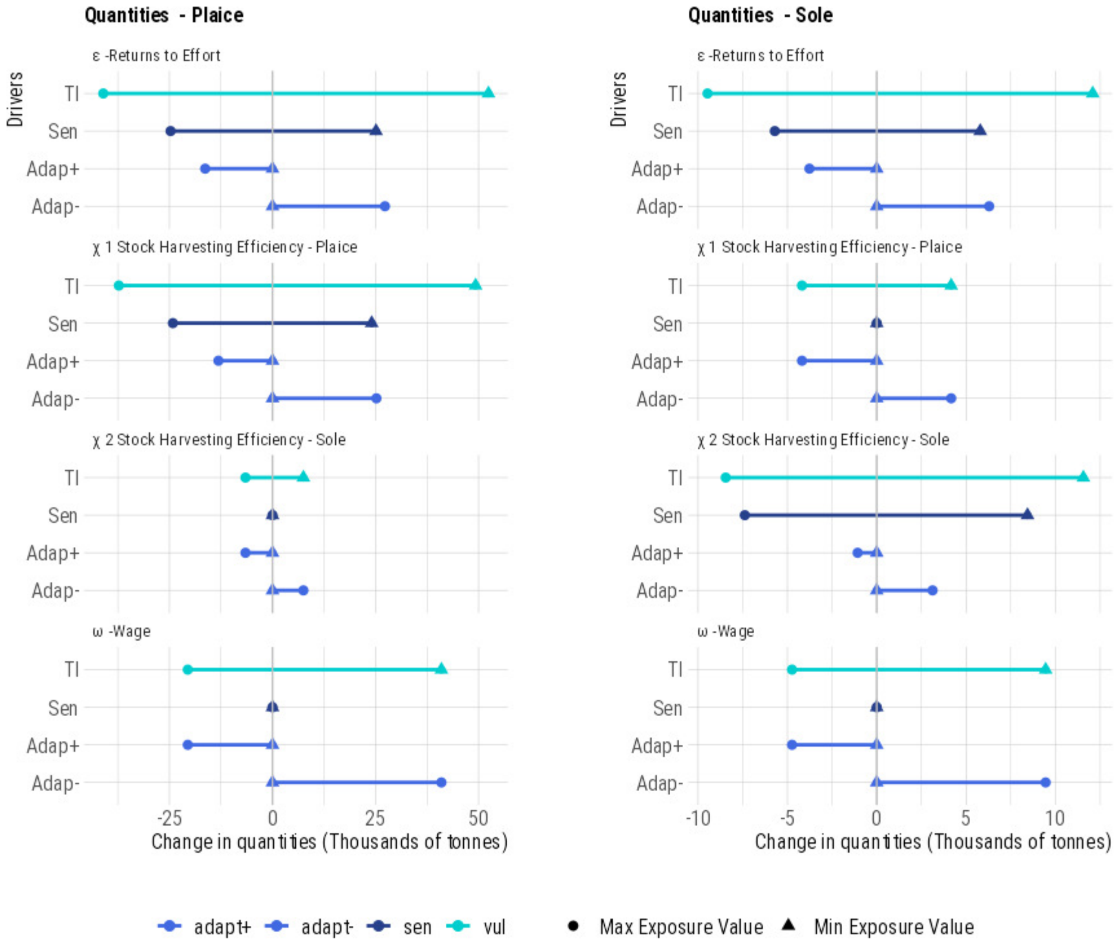

Figure 2.7: Absolute changes in quantities due to fishers adaptation to changes in drivers.

increase in wages (ω) are only due to adaptation in effort, hence the sensitivity is zero.

Using the dynamics of the bio-economic model, we identify the new steady states for changes in the considered drivers. Table 2.3 shows the new interior steady states for changes in wages (ω), returns to effort (ϵ), and stock harvesting efficiency (χ_i). We find the interior steady states for the upper and lower values presented in Table 2.1. The first row shows the initial values of stock, quantities, prices, and fleet size for the initial analysis in steady state. The values of the table are in percentage relative to the initial values. For changes in any of the drivers the stocks and quantities of sole remain at the same level of initial values (100%), this is due to the restricting quota levels for this species.

The lower bound of wages corresponds to a decrease of 4% from the initial value. This marks bifurcation point such that, for lower values of ω, there is no interior steady state. Decreases in wages lead to a reduction in fishing costs and an increase in the quantities harvested of plaice, consequently lowering prices. Further reductions in wages result in a

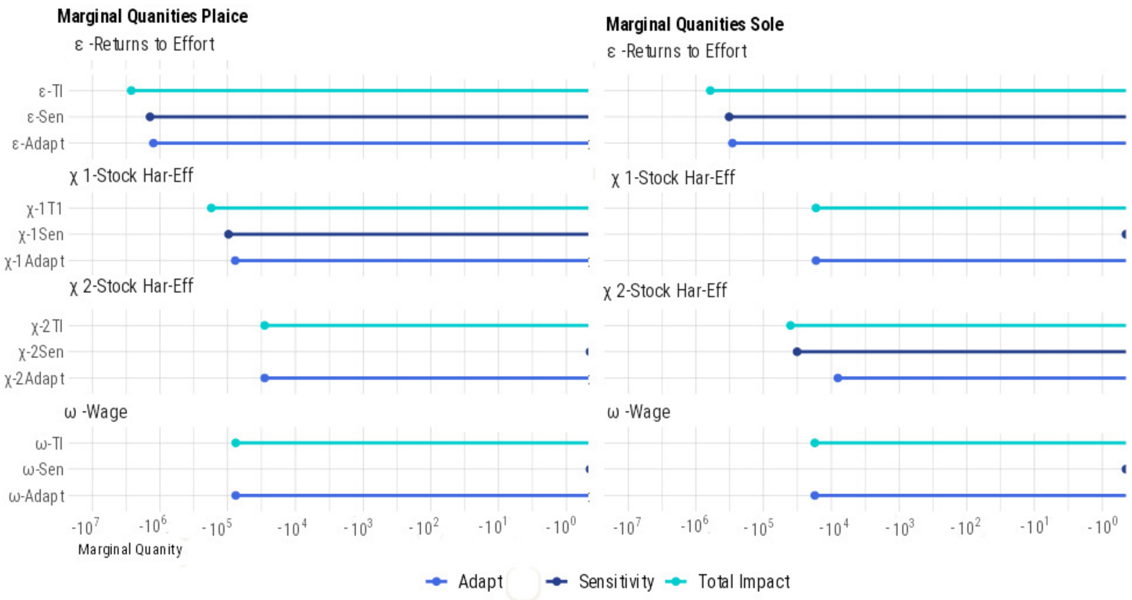

Figure 2.8: Marginal changes in quantities to fishers adaptation to a marginal change in drivers. Horizontal axes show changes in marginal quantities and horizontal axes show the total impact, sensitivity and adaptation for each of the drivers considered.

	Stocks		**Quantities**		**Prices**		**Fleet Size**	
Driver	Plaice	Sole	Plaice	Sole	Plaice	Sole	Métier1	Métier2
Initial	586,709 Tonnes	85,937 Tonnes	132,122 Tonnes	17,545 Tonnes	3.67 Eur/Kg	6.63 Eur/Kg	674	2315
Wages-Low	95%	100%	100.4%	100%	99.70%	97.98%	106%	98%
Wages-Up	135%	100%	91.9%	100%	106.76%	117.05%	49%	117%
ϵ_{Lw}	43%	100%	80.5%	100%	118.26%	91.19%	107%	92%
ϵ_{Up}	159%	100%	83.1%	100%	114.58%	195.56%	0%	142%
χ_1-Lw	108%	100%	98.9%	100%	100.84%	71.33%	173%	71%
χ_1-Up	110%	100%	98.5%	100%	101.16%	100.00%	99%	100%
χ_2-Lw	25%	100%	57.6%	100%	152.74%	86.78%	91%	87%
χ_2-Up	80%	100%	99.6%	100%	98.58%	184.11%	0%	148%

Table 2.3: Steady states values of stocks, quantities and prices for changes in the drivers considered. The values are relative to the initial steady state.

collapse of the fishery, given the current quota levels. The decreased fishing costs create incentives to expand the plaice fishery, as current quotas are not binding for this species.

The lower boundary of returns to effort also presents a bifurcation. The decrease in ϵ presented in Table 2.3 corresponds to 1% of the initial value, and with lower values, there is no interior steady state. An increase in ϵ in the long run increases the harvest of plaice and leaves the fishery with only meétier 2. Changes in χ_i resemble similar dynamics to ϵ. Cases in which χ_2 increases also leave the fishery practising only métier 2.

2.6 Discussion

Some studies assess adaptive capacities of a whole socio-ecological system (SES) (Carpenter and Brock, 2008; Cottrell et al., 2020), and others of a social community embedded in the SES (Cabral et al., 2015; Chen et al., 2020; Cinner et al., 2013). When assessing adaptive capacities in most cases the unit of analysis is unclear, i.e., "the adaptive capacity of what to what?" (Whitney et al., 2017). Our framework answers this question for multiple drivers. We develop a framework that can distinguish various types of adaptation and the degree to which the adaptation counteracts/enhances the impacts of drivers on the system property. The application of this framework to a bio-economic model calibrated to the flatfish German North Sea fishery served as proof of concept to exemplify the use of it. The analysis of the case study demonstrates that the degree of mitigation or enhancement of harmful or beneficial impacts on the system property is driver-dependent. We specifically focus our analysis on fishers' adaptation through effort, illustrating how this adaptation increases profits. We also present the effects of adaptation on supplied quantities in the market.

Our adaptive effort measure represents the full-time equivalent (FTE) units necessary to perform the fishing activity. It provides an indication of employment changes that this adaptation would cause. With our framework, we distinguish the level of adaptation to different drivers, focusing on returns to effort, wages and stock harvesting efficiency. We identify that in absolute terms fishers adapt the most to changes in wages, particularly to a decrease in wages. In 2019 this fishery experienced a sharp increase in employment of 18% compared to 2018. The decrease in adaptive effort can be the result of adaptation to multiple drivers. We show, in particular, that the effect on employment due to a change in wages can be offset by modifying other drivers such as returns to effort or stock harvesting efficiency (Fig. 2.6).

In the short term, we show that quantities are mostly affected by absolute and marginal changes in returns to effort, followed by stock harvesting efficiency and wages. Regulations aimed at controlling fishing activities have a more substantial impact on quantities compared to regulations directed at changing the accessibility to the resource, i.e, stock harvesting efficiency. Monitoring or increasing requirements on reporting the fishing activity have higher decrease in marginal quantities than marginal changes in stock harvesting efficiency. Changes in the latter result from increasing coverage of MPAs (Russi et al., 2016), and off-shore wind farms (OWF) (Stelzenmüller et al., 2020). These aspects increase the time at sea, making the fishing process less efficient. In absolute terms, the effect of fishers' adaptation on quantities depends on the level of exposures considered. Larger reductions of the available space to fish can have differentiate effects than changes in fishing monitoring.

Our analysis show that, in the long term, policies decreasing the available space to fish (increasing χ_i) could cause the lost of firms targeting plaice (métier 1). Yet, this is the result of our model assuming current quota levels and free entry-exit of firms. The latter is an strong assumption because in reality, fishers are constrained by higher costs of new vessels and investments. These costs are strongly influenced by vessel size and age (Lam et al., 2011). The increasing regulations could cause a decrease in the number of fishing firms. Further research, including restrictions in the fleet size in the model, can lead to a better understanding of the system once it is expose to changes in drivers.

The application of our framework also contributes to distinguish effects of drivers on multiple system properties. We assess the impacts of fishers' profits adaptation to drivers on quantities within the system. Our findings reveal that adaptation to wages has one of the largest effect on absolute and marginal quantities.A marginal increase in wages results in a reduction in adaptive effort almost proportionate to an increase in stock harvesting efficiency (see Fig 2.6). This decrease in effort leads to lowers costs, subsequently increasing quantities. These findings suggest that changes in effort due to a marginal decrease in the space available to fish (increasing χ_i) could potentially be counteracted by a marginal increase in wages. Although, we do not explicitly test trade-offs among drivers, our study provides an indication of potential trade-offs effects among drivers. This perspective provides policymakers with insights into potential trade-offs among policies, enabling them to consider further reductions in effort (Full-Time Equivalent) without generating harmful effects on employment in the fisheries sector.

Our framework operationalizes the concept of Ionescu et al. (2009) by eliciting the magnitude of the optimal adaptation that mitigates or enhances harmful/beneficial impacts in an ecological-economic system. In our case study, we show that optimal adaptation for some drivers involves increasing effort, while for others, it requires decreasing it. This stands in contrast to general measures of adaptation that typically only consider adaptation to a single driver. Thiault et al. (2019a) mention that adaptation strategies aimed to reduce the total impact to one driver may inadvertently influence impacts on others.

The design of our framework allows us to distinguish adaptations to changes in drivers that cause harm or benefit to a system. In this study we exemplify this by evaluating the impacts of changes in drivers from an steady state for positive and negative directions. This distinction is important because the adaptations and impacts on the system can vary according to the direction of the effect. For instance, in our case study we show that the magnitude of change in profits when wages decrease is higher than the magnitude of change for an increase in wages, i.e, adaptation is higher for a decrease in wages than for an increase. It is relevant to identify these mechanisms because positive impacts caused by a driver can mitigate the harmful impacts of others. Gallopín (2006) also mentions that disturbances in a system can also cause beneficial transformations which need to be addresses in order to have a improved measure of the total impact in the system [8].

2.7 Limitations

We develop a framework that allow us to assess and disentangle adaptations, sensitivities and total impacts of multiple drives on a coupled ecological-economic system. We use a bio-economic model to apply this framework because it is the minimum viable product that incorporates the key interconnectedness among economic and ecological sub-systems. In the application of the bio-economic model there are some assumptions inherent to these type of models, however, they are not required to apply the framework. The assumptions of the bio-economic model have an effect on the implications and results of the application.

Although our model is a oversimplification of the multiple dynamics embedded in this fishery, still provides an understanding of the underlying mechanisms of adaptation

[8] The total impact in the system is refereed by Gallopín (2006) as vulnerability.

affecting quantities and profits. Due to the stylish nature of the model and the complexity of the reality, it limits the results. In this sense results are also stylized.

2.8 Conclusion

In the multidisciplinary field of adaptation and adaptive capacity, various definitions and concepts exist, contributing to confusion and imprecise policy advice. We have developed a framework that aims to clarify and disentangle sensitivity, total impacts, and adaptation through mathematical modelling. Our framework enables the assessment of adaptations to multiple drivers affecting a system property, facilitating the distinction between the benefits and harms of these drivers on the coupled ecological-economic system.

As a proof of concept, we apply our framework to a calibrated bio-economic model of the North Sea flatfish fishery. We investigate the adaptations of fisheries profits to multiple drivers and elicit the optimal adaptation effect in quantities. Among the three drivers evaluated, we identify those that fishers can adapt the best through effort. We find that adaptation to marginal changes in returns to effort generate higher changes in quantities than marginal changes in stock harvesting efficiency. The fact that our framework allows us the comparison of adaptation impacts among multiple drivers serves as a departure point to identify trade-offs or counteracting effects among policies.

Our results exemplify the extent to which various drivers harm or enhance well-being in this fishery and to what extent the fishery can mitigate these effects endogenously. This framework can be applied to other fisheries regions and be used with different bio-economic models. We consider that the generality of the definitions makes the application of our framework easy to implement.

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2.A Model Description

We present a bio-economic model based on Blanz (2019). It provides us with tools to understand the North Sea fishery complexity. We add to this bio-economic model two main components. First, a variable that accounts for the weight of each species in the household' utility function (β_i). Second, the logistic growth function was replaced by the Ricker-recruitment function that, to our knowledge and data, provides a better fit to the stock growth for plaice and sole in the North Sea.

Figure A.1 shows the components of the model. An ecosystem component describing the current state and dynamics, harvesting firms maximizing profits, and consumers maximizing contemporaneous utility. The market between the harvesting firms and households allows to sale harvested ecosystem stocks to consumers. The prices on this market and corresponding harvested quantities are determined endogenously. A second labor market allows firms to employ the labor provided by households in the harvesting or manufacturing of a numeraire commodity. Hence, it provides income to households to pay for the fish and other products consumed.

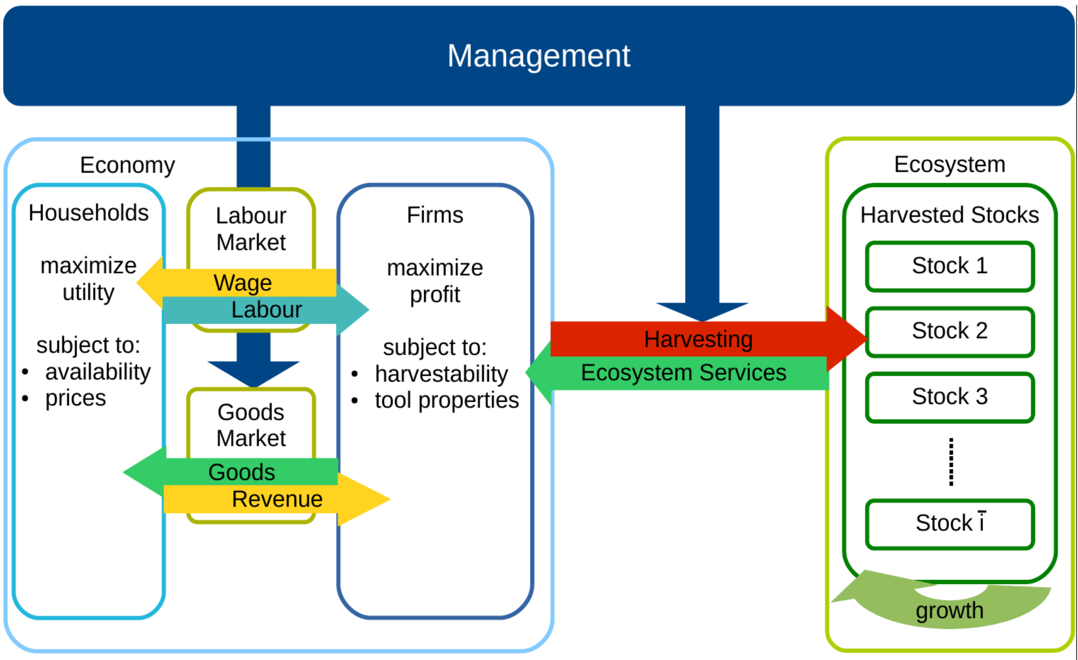


Figure A.1: Components of the bio-economic model and their interactions

Ecosystem Properties

This sub-system is composed of $\bar{i}$ species. Stocks are denoted by x with indexes for species $i \in I$, where I is the set of all species $I = [1, i] \cap Z$. Species are assumed to grow each period t due to intrinsic growth g_{it} and are diminished by harvests H_{it}. This change in stocks is modeled by differential equations, determining the dynamics of the model. This is the only component of the model that account for time dependency.

$$\dot{x_{it}} = g_{it}(\mathbf{x}_t) - H_{it} \tag{A.1}$$

In equation A.1 g_{it} is the biomass growth function represented by the Ricker-recruitment growth A.2. It depends on the entire vector of stocks, and the parameters a_i and b_i. 'a_i' is density independent parameter proportional to fecundity and 'b_i' is a density-dependent parameter. If density-dependence in the stock-recruitment (growth) relationship does not exist, then $b = 0$.

$$g_i(\mathbf{x}) = a_i(x_i)e^{-b_i x_i} \tag{A.2}$$

Harvesting Properties:

Once the stock for each period is assessed, fisheries make their harvest choices based on the stock available x_i. The harvest component includes $\bar{k}$ mètiers, which encompasses all that is necessary for the fisher to harvest and is not dependent on the effort i.e. all upfront investments that are necessary to start operating.

Métiers are indexed by $k \in K$, where K is the set of all mètiers $K = [1, k] \cap Z$. Each métier has a target species, but may also catch other species, as by-catch. While individual firms may not change their métier, the economy-wide fleet size for each métier is dynamic. The change of gear in use occurs through the market entry and exit of firms performing different métier. where $\bar{i} = \bar{k}$.

Total harvest in the economy H_i of species i is determined by the number of firms n_k practicing métier k and the sum of the harvested quantity by each firm h_{ik} targeting the species i with métier k.

$$H_i = \sum_{k=1}^{\bar{k}} n_k h_{ik}(e_k, x_i) \tag{A.3}$$

The harvest per firm is defined following the generalized Gordon–Schaefer production function (Clark, 1990). Using the métier k the fisher can target the species i, but can also harvest other species. The fisher can not control the fish species that she catches. Therefore, the total amount of harvest H_i depends on the effort e_k practicing all the mètiers k capable of catching that species ($k \in K|\nu_{ik} > 0$). The effort experiences diminishing returns to effort ϵ and is determined under the assumption of perfect markets for harvesting goods and labor. The gear effect is governed by the gear matrix ν_{ik}. The elements of ν_{ik} specify the catchability for each species i by mètier k. Species abundance influences the harvest returns per effort through the harvestability function $\chi_i(x_i)$. It captures changes in harvest yield due to changing stocks. Less abundant species are more difficult to catch compared to species with high stock levels $\chi_i(x_i) = x_i^{\chi_i}$. In the following $\chi_i(x_i)$ will be abbreviated as χ_i. It specifies a square matrix containing the χ_i along the diagonal and zeros off the diagonal.

$$h_{ik}(e_k, x_i) = \nu_{ik} e_k^{\epsilon} \chi(x_i) \tag{A.4}$$

The profits of each firm are defined as the difference between income and costs. The income is derived from the quantity of fish harvested h_{ik} times the price of the species i, p_i. Costs include wages ω times the effort e_k, which is measured in units of labor, keeping the structure given by Quaas and Requate (2013). Fixed costs ϕ_k are defined per mètier k and represent fees for entering the markets, fixed price for quotas or also initial capital. In order to maximize profits each firm takes stock levels x_i, prices p_i and wages ω as given to define their effort e_k.

$$\max_{e_k} \ \pi_k = \sum_{i=1}^{\bar{i}} h_{ik}(e_k, x_i) p_i - \omega e_k - \phi_k \tag{A.5}$$

The maximization of these profits and the assumption of perfect markets leads the firms' profits to zero. Under an open-access scenario it derives to the optimal effort level, given by (A.13). Then, the firms' mètier specific equilibrium harvest is obtained from replacing e_k^* in the harvesting production function:

$$h_{ik}(x_i) = \nu_{ik} e_k^{*\epsilon} \chi(x_i) \tag{A.6}$$

Household Properties:

The household preferences involve the fish' consumers who have preferences for fish Q, and a numeraire commodity y. The utility is described by the function:

$$U(Q,y) = \begin{cases} y + \alpha \frac{\eta}{\eta-1} Q^{\frac{\eta-1}{\eta}} & \text{for } \eta \neq 1. \\ y + \alpha \ln Q & \text{for } \eta = 1. \end{cases} \tag{A.7}$$

The parameter η indicates the constant demand elasticity of fish, $\alpha \geq 0$ characterize the importance of fish consumption in overall consumption. Regarding the preferences over the fish species, they are modeled using a Dixit-Stiglitz utility function (Dixit and Stiglitz, 1977).

$$Q = Q(\mathbf{q}) = \left(\sum_{i=1}^{\bar{i}} (\beta_i q_i)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{A.8}$$

In equation A.8, q_i corresponds to the quantity of the fish species i consumed by the household. β_i represents the weight of each species in the utility function. This allows us to account for differences in demand quantity for a specific type of fish species. $\sigma > 0$ measures the elasticity of substituting between consumption levels of different species. Hence, perfect substitution is achieved when σ tends to infinity ($\sigma \to \infty$), and lower values illustrate the limited substitutability of fish species in consumption.

The households maximize their utility subject to the budget constrain. They allocate their wages ω received from providing labor to the fisheries and manufactured sector. The first part of ω is spent in a manufactured good y, which price is normalized to one. A second part is spent in fish, with the amount consumed q_i given the weight of each species in the utility function β_i and the price per species p_i.

$$\omega = y + \sum_{i=1}^{\bar{i}} (\beta_i q_i) p_i \tag{A.9}$$

To keep the analysis tractable, no savings or other capital accumulation is possible in the model. Additionally, Further to what is presented in Quaas and Requate (2013) and following Blanz (2019), household demand presents an additional restriction called the market-clearing condition. It states that whatever is harvested will be consumed for each species, such that the number of firms are non-negative $n_k \geq 0$

$$q_i = H_i = \sum_{k=1}^{\bar{k}} n_k h_{ik}(x_i) \tag{A.10}$$

Firm Optimization Problem

The firms maximize their profit and therefore find their optimal effort, resulting in the first order condition, from (A.5):

$$\frac{\delta \pi_k}{\delta e_k} = \epsilon \left(\sum_{i=1}^{\bar{i}} \nu_{ik} \chi(x_i) p_i \right) e_k^{\epsilon - 1} - \omega = 0 \tag{A.11}$$

$$e_k^{**} = \left(\frac{\epsilon}{\omega} \sum_{i=1}^{\bar{i}} \nu_{ik} x_i^{\chi_i} p_i) \right)^{\frac{1}{1-\epsilon}} \tag{A.12}$$

Given the assumption of perfect markets in the model, the market pressure on each firm drives profits to zero, what leads into the zero profit condition $\pi_k = 0$. Replacing (A.12) in the zero profit condition, we have:

$$e_k^{*} = \frac{\phi_k}{\omega} \frac{\epsilon}{(1-\epsilon)} \tag{A.13}$$

This zero profit condition also allows to derive the prices. For this purpose the assumption of $\bar{i} = 2$ and $\bar{k} = 2$ holds, so that a theoretical solution can be determined. The specific step by step can be found in the appendix of Blanz (2019).

Hence, we have:

$$^{p}b_k = \phi_k \left(1 + \frac{\epsilon}{1-\epsilon} \right) \left(\frac{\phi_k}{\omega} \frac{\epsilon}{1-\epsilon} \right)^{-\epsilon} \tag{A.14}$$

$$p_1^{*} = (\chi_1)^{-1} (\nu_{11}\nu_{22} - \nu_{12}\nu_{21})^{-1} (\nu_{22}{}^{p}b_1 - \nu_{21}{}^{p}b_2) \tag{A.15}$$

$$p_2^{*} = (\chi_2)^{-1} (\nu_{11}\nu_{22} - \nu_{12}\nu_{21})^{-1} (\nu_{11}{}^{p}b_2 - \nu_{12}{}^{p}b_1) \tag{A.16}$$

Household Optimization Problem

The households maximize their utility and choose their quantities Q, and y.

$$\max_{Q,y} U(Q, y) \; s.t. \; \omega = y + \sum_{i=1}^{\bar{i}} (\beta_i q_i) p_i \tag{A.17}$$

Solving this maximization problem, lead us to the quantities q_i^{*} demanded by consumers, and p_i^{*} willingness to pay for the fish. This function relates the amount of each species demanded (and consumed) to the prices of all available species.

$$q_i^* = \alpha^\eta p_i^{-\sigma} \beta_i^{\sigma-1} \left(\sum_{i'}^{\bar{i}} (p_i \beta_i)^{1-\sigma} \right)^{\frac{\sigma-\eta}{1-\sigma}} \tag{A.18}$$

$$p_i^* = \alpha \beta_i (\beta_i q_i)^{\frac{-1}{\sigma}} Q^{\frac{\eta-\sigma}{\eta\sigma}} \tag{A.19}$$

From this optimization procedure we derive an equation that describes the demanded quantity of one species in terms of the consumption given by the other. From the first order condition we have:

$$q_2 = \left(\left(\frac{p_1}{\alpha \beta_1} (\beta_1 q_1)^{\frac{1}{\sigma}} \right)^{\frac{\eta(\sigma-1)}{\eta-\sigma}} - (\beta_1 q_1)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} (\beta_2)^{-1} \tag{A.20}$$

The fishers maximization of profits and the utilities from the household, allows us to find the optimal number of firms practicing each mètier k (Eq. A.21, A.22). The assumption of $\bar{i} = 2$ and $\bar{k} = 2$, holds in order to find a mathematical expression that can be generalized. With these components the model is described.

$$n_1^*(q(\mathbf{p})) = \frac{\nu_{22}\chi_2 q_1(\mathbf{p}) - \nu_{12}\chi_1 q_2(\mathbf{p})}{e_1^{*\epsilon}\chi_1\chi_2(\nu_{11}\nu_{22} - \nu_{12}\nu_{21})} \tag{A.21}$$

$$n_2^*(q(\mathbf{p})) = \frac{\nu_{11}\chi_1 q_2(\mathbf{p}) - \nu_{12}\chi_2 q_1(\mathbf{p})}{e_2^{*\epsilon}\chi_1\chi_2(\nu_{11}\nu_{22} - \nu_{12}\nu_{21})} \tag{A.22}$$

2.B Model Calibration

We calibrate stocks, harvests, and prices for the whole North Sea, using the data provided by the International Council for the Exploration of the Sea (ICES) regarding landings (harvests) and stocks (SSB)(ICES, 2019a,b). Prices are calibrated using data from the EUMOFA (European Market Observatory for Fisheries and Aquaculture Products) database. The calibration involves the following steps:

1. *Ecosystem component*: The function describing the stock growth is calibrated using data of SSB for plaice and sole from the years 1957 to 2019 (ICES, 2019a,b). The data are transformed to a scale of the model through a scale parameter (κ) that represents the Maximum Sustainable Yield (MSY). The initial values of the parameters 'a' and 'b' of the Ricker-recruitment function are found by linearizing the function and fitting a linear model to the observed data (Equation.A.2), using

the FSA (Simple Fisheries Stock Assessment Methods) library in R. Then, a non-linear least squares model based on those values of 'a' and 'b' is estimated. The fit between the model estimates and the real growth data is shown in figure 2.1.

2. *Household and Harvesting Components*: We calibrate household parameters using data prices for the years 2001-2020. We transform this prices to be relative to income to fit the scale of the model. We use the Gross Domestic Product (GDP) of the North Sea Countries as a proxy for the income used the model. Prices and GDP are adjusted for inflation to 2015 constant prices. To calibrate harvesting parameters, we use the same data as in the step one, combined with harvest data reported in landings for the whole North Sea by ICES (2021a,b)[9]. Using this data and the parameters already found in step one we construct an objective function to minimize the error between the predicted values of harvests and prices, and the real data (Equation A.23). We use the existing implementation of the *nlminb* procedure in R to minimize these errors (ζ) (Nash et al., 2019)(Equation. 2.16, A.19).

   To find the initial values of our final calibration procedure we use results of previous trials. During our calibration procedure we implement different trials to minimize the objective function. Using different weighted values, including more or less parameters or changing the time lapse for the calibration. The result of these trials gives many possible values for each parameter. Use choose the maximum and minimum values of each parameter and construct a matrix of 519 possible combinations that we use as initial values for our final calibration.

   Finally, we find the best fitting parameters for ϵ, χ_1, χ_2,ϕ, η, α, σ, β_1, and β_2 that ensure an interior steady-state and reflects the real relationships between quantities, harvest and prices. To identify the parameters that comply with an interior steady-state we set the quota as the last value of our data for the year 2020.

$$\min_{\hat{H}_i,\hat{p}_i} \zeta = \sum_{t=1957}^{2020}\sum_{i=1}^{2} m_i^h(\hat{H}_{it} - H_{it})^2 + \sum_{t=2001}^{2020}\sum_{i=1}^{2} m_i^p(\hat{p_{it}} - p_{it})^2 \tag{A.23}$$

   subject to:

$$\epsilon,\ \chi_1,\ \chi_2,\phi,\ \eta, \alpha, \beta_1, \text{ and } \beta_2 > 0.000001$$

[9]The ICES (2021a,b) reports include landings, discards and catches. For our purposes we set landings equivalent to harvest because these are the quantities that are traded on the market.

$$\sigma > 1.000001$$

where $\hat{H}_i$ is:

$$\hat{H}_{it} = \sum_{k=1}^{2} n_{kt} h_{ikt}(e_{kt}, x_{it}) = \sum_{k=1}^{2} n_{kt}(\nu_{ik} e_k^{\epsilon} x_{it}^{\chi_i})$$

$\hat{p_{it}}$ is:

$$\hat{p_{it}} = \alpha\beta_i(\beta_i q_{it})^{\frac{-1}{\sigma}} Q^{\frac{\eta-\sigma}{\eta\sigma}}$$

and m_i^h and m_i^p are weighted values for harvest and prices to normalize the calibration to the mean of the real values:

$$m_i^h = \frac{1}{\bar{H}_i} \text{ and } m_i^p = \frac{1}{\bar{p}_i}$$

2.C Changes in Profits

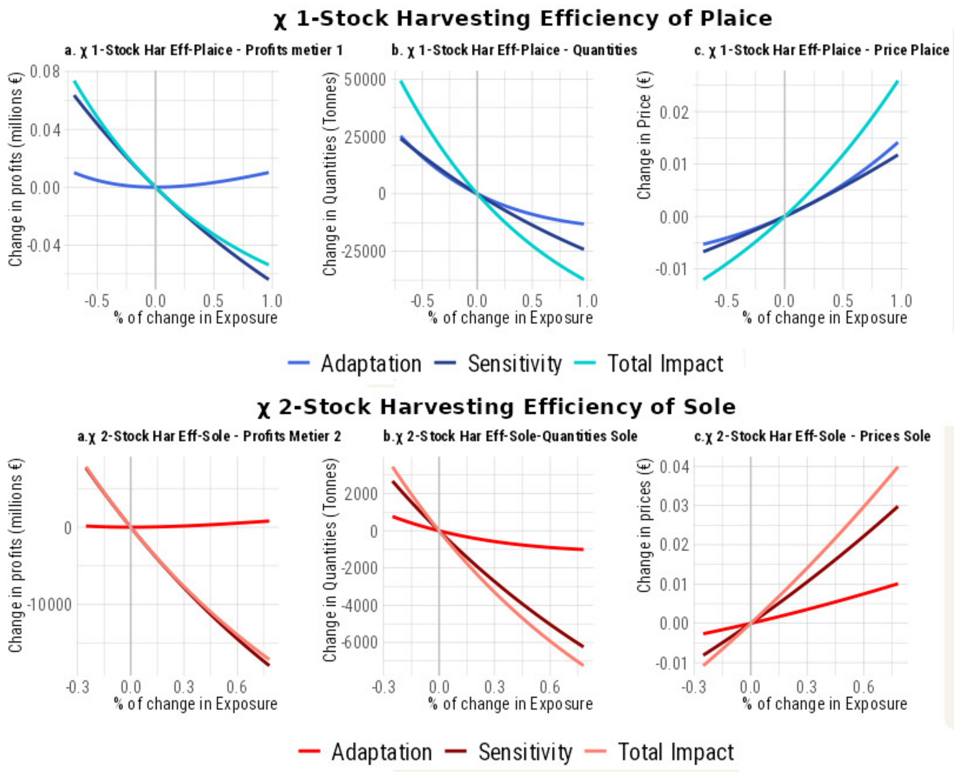


Figure C.1: Changes in profits, quantities and prices due to changes in stock harvesting efficiency. Horizontal axes show the change in exposure with respect to the initial steady state and horizontal axes the change in profits.

Chapter 3

A Fisheries Social-Ecological System at Risk of Losing Its Capacity to Adapt to Global Change

Authors: Stelzenmüller, Letschert, Blanz, Blöcker, Claudet, Cormier, Gee, Held, Kannen, Kruse, Rambo, Scharper, Sguotti, Quiroga, and Möllmann

Abstract: Global change challenges coupled human-nature-systems such as fisheries socio-ecological systems (SESs) because they are confined by spatial and functional ecosystem boundaries, and human livelihoods often depend on their stable environmental, socio-economic and socio-cultural states. Understanding the capacity of an SES to adapt to changing ecological or socio-economic conditions is complex and entails disentangling the system's properties such as resilience, vulnerability and adaptive capacity. Here, we quantified autonomous adaptation strategies of a German demersal fishery SES in the southern North Sea to environmental and socio-economic change at regional and local scales over the last two decades. Deploying the modified Ostrom framework allowed us to analyse spatio-temporal dynamics of SES attributes and their linkages. Our analysis revealed autonomous adaptations of the SES to environmental and socio-economic change, which entailed a shift in target species, fishing strategies, but importantly a distinct decrease in number of actors. We found that the ability of the SES to adapt decreased with time, with the SES being now on the brink of withstanding future environmental and socio-economic change. Key barriers to adaptation for the fisheries SES are related to fishing cultures, economic structures, political setting and increasing spatial use conflicts. We now find the SES is locked in an undesirable state reflecting a social-ecological trap where social and ecological feedbacks negatively reinforce one another. Our findings highlight the need for tailored and context specific co-management approaches for all decision-making processes to which the SES is exposed to. In-depth understanding of SES components and the linkages of SES attributes is a prerequisite to develop future management approaches to enhance SES adaptive capacity to global change [1].

Keywords: adaptive capacity, fishing métiers, marine spatial planning, network analysis, stakeholder interviews, North Sea, tipping point.

[1]This chapter is consists of the paper "Fostering the capacity of a fisheries social-ecological system to adapt to global change" in submission to Global Environmental Change by Stelzenmüller, Letschert, Blanz, Blöcker, Claudet, Cormier, Gee, Held, Kannen, Kruse, Rambo, Scharper, Sguotti, Quiroga, and Möllmann (2023).

3.1 Introduction

Global change fuels the social demand to strengthen the adaptive capacity of social-ecological systems (SESs) to resist everchanging ecological or socio-economic conditions. While SES definitions vary, there is consensus about SES components comprising the entities of common pool resources, resource users, and institutions (Colding and Barthel, 2019). In general, SESs can be characterised by the integration of biogeophysical and socio-cultural processes, their complexity and levels of self-organisation, as well as nonlinear and unpredictable dynamics with feedbacks between environmental, as well as socio-economic and socio-cultural processes (Colding and Barthel, 2019; Leenhardt et al., 2015).

Human-ocean interactions are particularly complex and emerging global threats such as climate change are challenging especially for fisheries SES (Visbeck, 2018). Fisheries SESs are confined by spatial or functional ecosystem boundaries and human well-being and livelihoods depend on the exploitation of marine resources and therefore the prevailing environmental, socio-economic and socio-cultural conditions (Partelow, 2018; Perry et al., 2011). In marine ecosystems, climate induced changes of environmental conditions comprise alterations of system productivity and food web dynamics, decline of habitat-forming species, shifts in species distributions, and greater occurrences of diseases (Boyce et al., 2022; Hoegh-Guldberg and Bruno, 2010). Shelf and coastal waters are especially exposed to socio-economical change due to the intensification of the blue offshore economy (Gourvenec et al., 2022) leading to an increase of environmental risks (Bugnot et al., 2021; Turschwell et al., 2022), uncertain cumulative impacts on various ecosystem components (Halpern et al., 2015), and steering the concern of socio-economic impacts on fisheries (V. Stelzenmüller et al., 2022). In Europe, fisheries SESs are governed by the EU Common Fisheries Policy (CFP; EU Regulation 1380/2013 and EU Regulation 2019/1241), but they are also exposed to local area-based management measures implemented for instance by EU environmental policies (Probst et al., 2021) or the EU Marine Spatial Planning Directive (MSPD; EU Directive 2014/89/EU) (Vanessa Stelzenmüller et al., 2021). While fisheries governance systems have accepted the complexity of fisheries SES (Hare, 2020), the challenge remains on how to embed SESs and their potential vulnerabilities in decision-making processes in a wider ecosystem approach to management (Lauerburg et al., 2019). Hence, a prerequisite for such decision-making processes is a profound knowledge on the abilities of fisheries SESs to adapt to ecological and social state changes (Salgueiro-Otero and Ojea, 2020).

Understanding the capacity of an SES to adapt to changing ecological or socio-economic conditions is complex and entails a clear differentiation between the system's properties such as resilience, vulnerability and adaptive capacity. SES resilience is often defined as an intrinsic system property with the understanding that a resilient system can respond to uncertainties and adapt toward transformative change (Refulio-Coronado et al., 2021). The vulnerability of a SES is often defined as a function of exposure to disturbance, sensitivity ("sensitivity of the SES to a particular disturbance"), and adaptive capacity ("ability to adapt/withstand to a particular disturbance") (Change, 2007). This concept has been adopted to assess for instance the vulnerabilities of fisheries SES to specific stressors (Johnson et al., 2016; Payne et al., 2021; Thiault et al., 2019b, 2018). Adaptive capacity is defined as the SES characteristic that determines whether and to which degree an SES can adjust. Hereafter, adaptive capacity is related to the well-being of the social and ecological elements rather than avoiding large changes (Refulio-Coronado et al., 2021).

SES adaptation can be proactive or reactive (also referred to as autonomous (Pecl et al., 2019), spontaneous or planned, and can be strengthened through adaptive management entailing elements of monitoring, reporting, and refining. In the past, fisheries SESs have shown short term or rapid adaptations to changing environmental or socio-economic conditions through, e.g., intensification and diversification of fishing, migration and 'riding out the storm' as well as long-term changes through respective adaptations in policy and governance (Kluger et al., 2020; Perry et al., 2011). Thus, their adaptation strategies can span across ecological (MPA designations, reduction of stressors, etc.), socio-economic (investments, catch diversification of livelihoods, etc.) or institutional (adaptation programmes, coordination and organisation, etc.) realms (Woods et al., 2021).

Here we unravel and quantify autonomous adaptation strategies of the German mixed demersal fishery in the southern North Sea SES to environmental and socio-economic change at regional and local scales over the last two decades. The German plaice related fishery, mainly targeting beside plaice (Pleuronectes platessa) also sole (Solea solea) (Letschert et al., accepted), is a minor actor in the wider North Sea fishery; but an important local resource (Letschert et al., 2021). We here considered all German plaice related fisheries in the southern North Sea as being part of our target SES (ibid.) which operates in an area prone to climate change (Engelhard et al., 2014; Fock et al., 2014; Frelat et al., 2017; Murgier et al., 2021; Sguotti et al., 2022). Furthermore, the SES is being confronted with a rapid spatial expansion of offshore renewables (V. Stelzenmüller et al., 2022) and marine conservation measures (Probst et al., 2021), forcing many fishing vessels to relocate their effort or adapt the fishing practices in the future (Vanessa Stelzenmüller et al., 2021).

The general use of models in SES research is compromised both by the degree of realism and the degree of knowledge integration (Schlüter et al., 2012). We identified SES components with the help of the modified Ostrom framework for institutional analysis and development (McGinnis and Ostrom, 2014). We analysed the spatio-temporal dynamics of SES attributes using quantitative statistics and semi-structed interviews to finally untie past adaptive capacities to environmental and socio-economic change. Eventually we conclude on barriers to future SES adaptation within this multi-level governance system and identify future management needs to strengthen adaptive capacities of fisheries SES at risk due to global change.

3.2 Methods

3.2.1 Socio-Ecological System Context and Assessment Framework

Following the rationale described in Lauerburg et al., 2019 we identified the German plaice related fisheries in the southern North Sea as our resource system of interest. We conducted a stakeholder workshop to scope for key SES components, key resources, as well as perceived tipping points that have affected resource exploitation in the past or might do so in the future. The workshop was held on 5th of October 2017 with 21 attendees comprising representatives of the fishing sector (n=6), marine conservation (n=1), academia (n=10), as well as offshore renewable representatives (n=1), and authorities responsible for MSP in the German Exclusive Economic Zone (EEZ) (EU Maritime Spatial planning Directive; (EU Regulation 2014/89/EU) and implementation of EU environmental policies (e.g. Marine Strategy Framework Directive; EU Directive 2008/56/EC) (n=3). Stakeholders identified the rapid expansion of offshore renewables in the southern North Sea, the implementation of fisheries management measures in Natura2000 networks (Mazaris et al., 2019), and climate change as the main drivers of future socio- economic and ecological change. Importantly, stakeholders representing the fisheries sector identified the shift from an Atlantic cod (Gadus morhua) dominated to a flatfish dominated fishery in the early 2000s as an ecological tipping point which had knock-on effects on the actors and the resource system as a whole. The loss of cod as a major resource has forced the fisheries to focus more on a plaice related fishery, itself an adaptation to change.

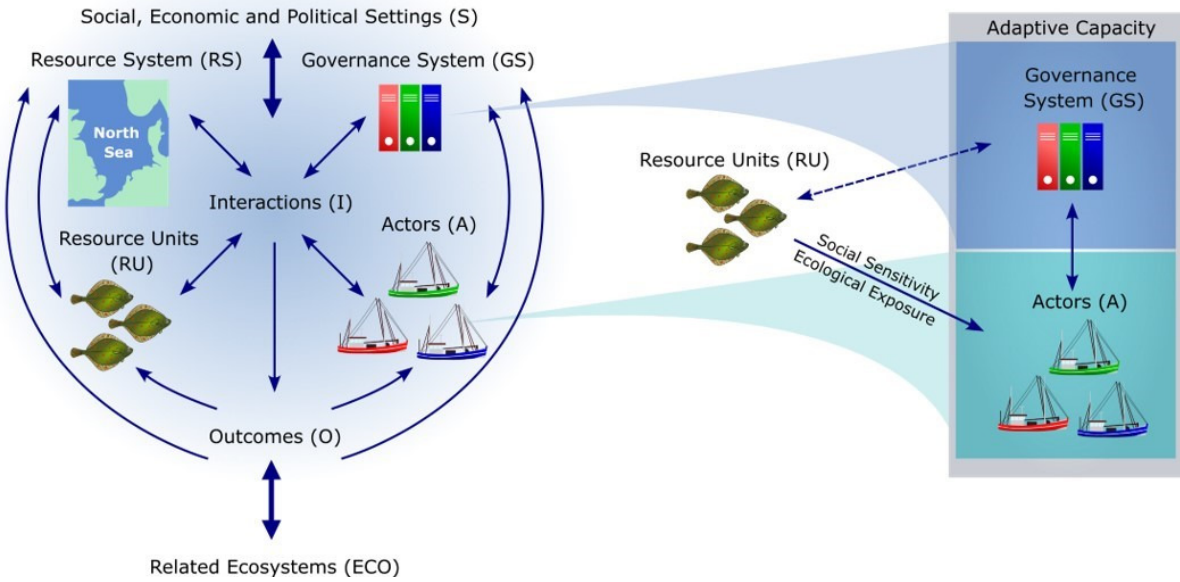


Figure 3.1: Conceptual representation of the social-ecological system structure and illustration of the focus on analysing adaptive capacities related to actors and governance systems (modified from McGinnis and Ostrom, 2014). Resource system (RS) refers to the mixed demersal fisheries in the southern North Sea; Resource units (RU) refers to European plaice; Actors refer to fleets targeting the RU; Governance system (GS) refers to set of institutional arrangements (such as rules, policies, and governance activities) that are used by one or more actors to interact with and govern the RU (see also Table 3.1).

We assessed the adaptive capacity of the SES with the help of the modified Ostrom framework for institutional analysis and development (McGinnis and Ostrom, 2014). This diagnostic tool has been applied in fisheries, forestry, agriculture or watershed management (McGinnis and Ostrom, 2014; Partelow, 2018) and helps to identify SES components comprising resources, actors, governance systems and their linkages and causalities (Colding and Barthel, 2019; Schlüter et al., 2012). We explored the spatio-temporal dynamics of the SES attributes during the past two decades, after the occurrence of the ecological tipping point identified by the stakeholders. Adopting the definitions of previous work (Ban et al., 2017; Cox, 2014), we assumed that the capacity of an SES to adapt depends on actor responses to environmental change and their interaction with the governance system (Figure 3.1). Table 3.1 details the tier 1 and 2 variables of the Ostrom framework with the associated indicators comprising the elements of resource system, resource unit, actors, and governance system. In the following sections we describe the analyses of the respective SES components and attributes in more detail.

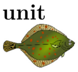
Tier1	**Tier 2**	**Indicators**
Resource system 	Clarity of system boundaries	Spatio-temporal allocation of fishing activities; Location of landing ports
	Predictability of system dynamics	Yearly SST (C°)
	Productivity of system	Annual landings (t) by species
Resource unit 	Growth or replacement rate	Annual spawning stock biomass (SSB) of plaice (t)
	Interaction among resource units	Annual total catches of plaice (t), Fishing mortality (F)
	Spatial and temporal distribution	Relative spatio-temporal changes of plaice catches in the southern North Sea
Actors 	Number of relevant actors	Annual catch compositions per métier, number of fishing trips per year and métier, number of vessels per year and métier
	Socio-economic attributes	Average length (m) of fishing vessels per fleet; Average annual income (€), costs (€), profit per vessel (€); Average annual price (€) of target species, Average annual price of oil ($), Average annual number of engaged crew and Full Time Equivalent (FTE) per vessel; Age of the fleet (y); Number of companies and producer organisations to which the vessels were associated to
	Spatial and temporal distribution	Relative spatio-temporal changes of plaice catches in the southern North Sea
	Importance of resource (dependence)	Spatiotemporal changes in centre of gravity of plaice catches of German vessels
	Socio-cultural attributes	Description of fishing culture and culture barriers to adaptation
Governance System 	Description of fisheries assessment and management system	Mapping governance structures and decision-making process

Table 3.1: Domains (Tier 1) and components (Tier 2) of the German plaice related fisheries social-ecological system in the southern North Sea following the specifications of (McGinnis and Ostrom, 2014) together with the respective indicator, metric and assessment methods.

3.2.2 Spatio-Temporal Trends of SES Components and Attributes

Resource System and Unit

We characterised climate-related environmental changes at the scale of the entire North Sea and the German EEZ and coastal waters by analysing trends in annual average sea surface temperatures (SST). We focus also on the EEZ and coastal waters since this scale refers to the boundaries of the governance systems described below (see Table 3.1). We used SST data from hindcast runs derived from a coupled atmosphere-ocean model Kay et al., 2018 and computed annual averages for ICES (International Council for the Exploration of the Sea) statistical rectangles in the North Sea region that have a spatial resolution of one-degree longitude and 0.5-degree latitude.

Further, we explored temporal stock dynamics of plaice in the North Sea based on time series (1957 – 2019) of spawning stock biomass (SSB) and fishing mortality (F) derived from routine stock assessments (P. ICES, 2018). With the help of catch per unit of effort (CPUE) data, collected by the International Bottom Trawl Survey (IBTS), we analysed spatial stock dynamics in the entire German EEZ and separately for inshore and offshore areas. We refined the SES spatial boundaries in more detail through the spatial analysis of logbook data with available information on landing ports (2009 – 2019).

Actors

Plaice is mainly caught by two German fleets, one using beam and pulse trawls to catch demersal fish, i.e. plaice, sole or turbot (Scophthalmus maximus), and a second using otter bottom trawls to catch mixed demersal species such as plaice, Norway lobster (Nephrops norvegicus), and turbot (STECF, 2019). Some fishing vessels switched target species and respective gears within a year making the categorisation of fishing fleets difficult. For this reason, we categorised all German vessels as fishing métiers based on logbook data for individual fishing trips (between 2000 to 2019). Logbook data included landings (tonnes), deployed gear, date and time, as well as the geographical location at ICES rectangle resolution (0.5○ lat × 1○ lon) (provided by the German Federal Office for Agriculture and Food). For each vessel we determined the relative catch composition per fishing trip. Based on the ten most caught species, we created a Euclidean distance matrix and performed hierarchical agglomerative clustering using the complete linkage approach (P. Legendre and L. Legendre, 2012). Due to the large number of fishing trips (n = 140633), we divided the data and clustering into three randomly selected subsets. For each random set we named the respective cluster after the dominant species and explored its spatial distribution. After visually examining the catch composition and geographical distribution for each cluster we merged matching clusters (i.e. the métiers) resulting in seven final clusters. We calculated the number of SES actors as the number of vessels associated with each métier and analysed the temporal trends of the relative catch composition of all seven métiers.

Furthermore, we extracted socio-economic attributes of the actors from logbook data and the German vessel register (not publicly available) comprising the length of vessels (m) and the companies or producer organisations to which vessels belonged that catch at least 50% of plaice and sole.

For the two types of vessels (beam or otter trawlers) that could be associated with the here defined métiers, we extracted from the Scientific, Technical and Economic Committee for Fisheries (STECF) data base (www.stecf.jrc.ec.europa.eu) (2008 – 2018) the average income (€), cost (€), investment (€), engaged crew members, and full time equivalent (FTE) per vessel. We furthermore assessed temporal trends of average annual prices (€) of target species from STECF and Brent crude oil prices ($) from world bank data base (www.data.worldbank.org).

We described the SES actor's attribute "importance of the resource or dependence on the resource" (see Table 3.1) by assessing spatio-temporal changes of plaice landings of German vessels by means of centre of gravity analysis (He et al., 2011). This is used as a proxy of the technical capability of German vessels to adjust their operations to the resource distribution. We calculated the centre of gravity as the mean (geographic) centre of ICES rectangle midpoints weighted by the landings derived from annual logbook data (2000 – 2019) (Engelhard et al., 2011b).

Maintaining a socio-economically and socio-culturally viable fishery within spatially refined boundaries requires the SES actors to adapt their fishing strategies to changing environmental and socio-economic conditions. Therefore, we analysed such changes in strategies of the German plaice related fisheries by using network analysis. We use network metrics to quantify the yearly averaged connectivity between fishing trips of individual vessels being associated to a specific métier (Frawley et al., 2021) (Appendix 3.A). The degree of connectivity is higher the more a vessel participates in a pair of métiers, which additionally indicates higher resilience against changes in a SES (Frawley et al., 2021; Fuller et al., 2017).

Finally, we conducted a qualitative interview-based study with fisheries representatives to understand both the nature and changes of socio-cultural attributes of fishers and the fishing community, as well as barriers to adaptation as perceived by the German North Sea fisheries. Initial background interviews provided a first overview of issues from the perspective of people involved in the sector. Subsequently, detailed qualitative semi-structured interviews were conducted with a set of individual fishers (N=18) and trainee fishers (N=30). Due to the Covid-19 pandemic most of these interviews were online. Their focus was on key aspects of self-perception and understanding of fishing as a job and a lifestyle, comprising: 1) values, lifestyle, knowledge and traditions; 2) the practice of fishing and what makes a person a "good fisher"; 3) perspectives of older and younger generations and changes over time; 4) past and future challenges to fishers from the perspective of those active in fishing; and 5) self- organisation, political representation and fishers' view on policies affecting them in their fishing activities.

Governance Structures and Decision-Making Processes

Fisheries management in a European context is a multi-level governance system with legislative and executive bodies implementing policies and decision-making processes. These in turn are driven by European directives and policies based on the Common Fisheries Policy (Belschner et al., 2018; van Hoof and Kraus, 2017) and implemented by EU Member States through national and local legislation and policies. In addition, other policies, formulated independent from fisheries policy (e.g. MSPD, MSFD), are highly relevant for spatially allocating fishing activities, in particular those leading to spatial constraints such as the development of offshore renewables or implementations of European environmental policies entailing marine protected areas (Probst et al., 2021). To illustrate the multi-level hierarchy in the decision-making processes to which the SES is exposed, we translated the EU process on defining quota and catch limits by the EU (https://www.consilium.europa.eu/en/infographics/fishing-opportunities-infographics) together with the additional governance components into a swimlane diagram of the decision- making process. With the help of the above described interviews we mapped stakeholder's perception of the prevailing governance processes. These formed the basis to discuss barriers to SES adaptation in relation to management decision making processes.

3.3 Results

3.3.1 Spatio-Temporal Dynamics of Resource System and Unit

The resource system as such, comprising also the wider North Sea, has experienced a clear warming trend of approximately 0.5 ◦C since the mid-1990s (Appendix 3.B). Highest annual average temperatures were observed in the 2010s in the middle of the study area (Appendix 3.B). The key resource unit, North Sea plaice, experienced a strong recovery from a depleted state during the late 1990s to record high spawning stock biomass in recent years, exceeding all recently applied biomass reference points (Fig. 3.2 a). Plaice recovery is clearly a result of a drastic reduction in fishing mortality from above 0.6 in the 1990s to below all reference points and especially the management target of FMSY=0.21 (Fig. 3.2 b) (Blöcker et al., 2023). However, the increase in the North Sea plaice stock is not spatially homogeneous (Fig. 3.2 c). Stock components strongly increase in the north of Scotland as well as in the offshore areas of the Netherlands, Germany and Denmark. Within the German EEZ and surrounding waters the increase was observed until 2011 only, while afterwards the offshore stock component declined to the low levels of the 1990s (Fig. 3.2 d). Importantly, the coastal stock component of the German EEZ did not increase but decreased (Fig. 3.2 e, f). The observed spatio-temporal trends suggest a general decoupling of the plaice stock dynamics between the greater North Sea and within the German EEZ, and a drastic decrease in the coastal stock component. The spatial boundaries of the resource system, based on plaice landings by the German fisheries, were stable over time and most productive coastal fishing grounds were observed within the Dutch, German and Danish waters (see Appendix 3.C). German vessels landed plaice primarily in the Netherlands and Denmark, with Dutch ports such as Harlingen, Den Helder, and Louwersoog. Louwersoog is the most important port because since 2009 at least 75% of the German catches have been landed there.

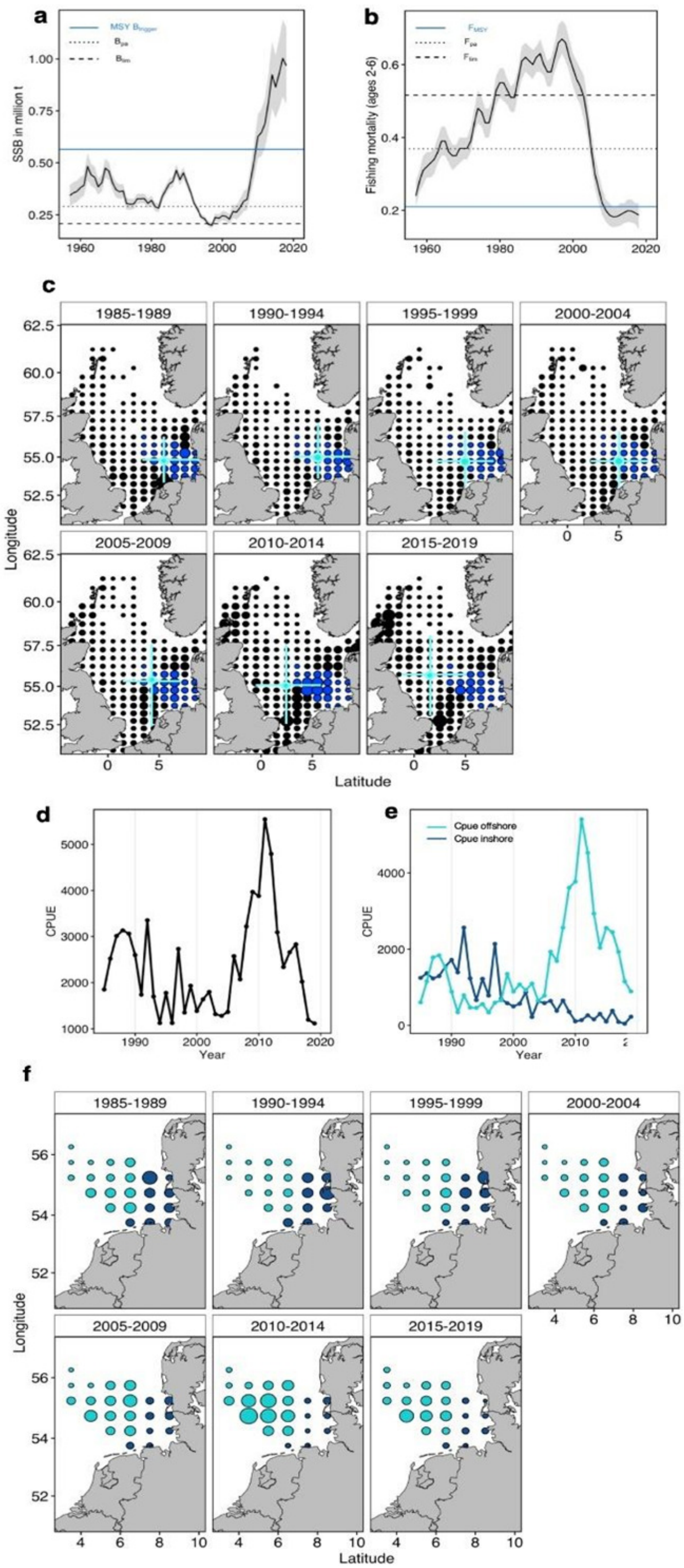


Figure 3.2: Temporal development of the North Sea plaice a) spawning stock biomass (SSB) and b) fishing mortality - grey shaded areas represent confidence intervals; horizontal lines indicate management reference points. Spatial changes in 5-year average cpue in the entire North Sea - the turquoise cross indicates the centre of gravity of the stock; blue dots represent cpue in the German EEZ (see f); temporal development of plaice stock in the entire German EEZ and coastal waters (d), and divided in inshore (blue) and offshore (turquoise) areas (e); spatial changes in 5-year average plaice cpue in the German EEZ.

3.3.2 Spatio-Temporal Trends of Actor Attributes

Catch Composition of Defined Métiers and Number of Actors

The temporal trends of the productivity of the system, i.e., the annual changes in catch composition of each métier, is shown in Appendix 3.D. Three North Sea métiers were characterised by plaice catches, namely the Nephrops & Plaice (NP), the Plaice (P), and the Plaice & Sole (PS) métiers, respectively. The NP métier is composed of demersal trawlers catching mainly Norway lobster and plaice. The P métier is also dominated by demersal trawlers catching plaice. In contrast, the PS métier refers to beam trawlers catching mainly plaice and sole (Figure 3.3). In all métiers plaice catches dropped significantly in 2007, increased slightly afterwards and decreased again since 2016 (Appendix 3.D). At the same time sole catches increased. For the NP métier, plaice catches were rather low between 2000 and 2006 and increased to a relative contribution of roughly 30% to the total catch in 2019. In contrast, Norway lobster catches increased continuously over the past twenty years contributing now up to approx. 50% of the total catch (Appendix 3.D).

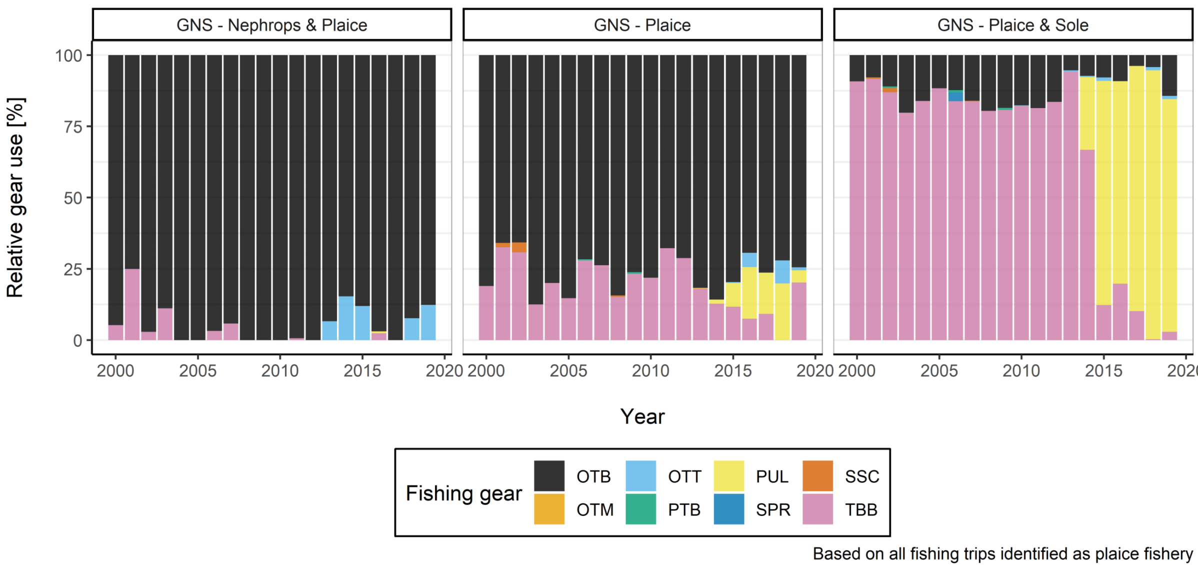


Figure 3.3: Relative composition (%) of gears deployed across all annual fishing trips in the greater North Sea (GNS) associated to the GNS - Nephrops & plaice, GNS - Plaice & Sole, and GNS - Plaice métiers. OTB: bottom otter trawl; OTM: Midwater otter trawl; OTT: twin bottom otter trawl; PTB: bottom pair trawl; PUL: pulse bottom trawl; SPR: Danish seine (anchored); SSC: Danish seine (without anchor); TBB: beam trawl.

The number of actors actively engaging in fishing, and hence the number of fishing trips and vessels associated with the plaice-related métiers, has changed greatly over the past two decades (Figure 3.4). From 2000 to 2006 the overall number of vessels decreased from

180 to approx. 100 and the related number of annual fishing trips declined continuously from 1800 to 800. In line with the observed decreasing trends in plaice catches (Appendix 3.D), the total number of fishing trips dropped sharply in 2007 and remained stable afterwards. Annual fishing trips and vessel numbers of the NP métier increased from 2006 onwards, however not compensating for the decline of the overall fleet size.

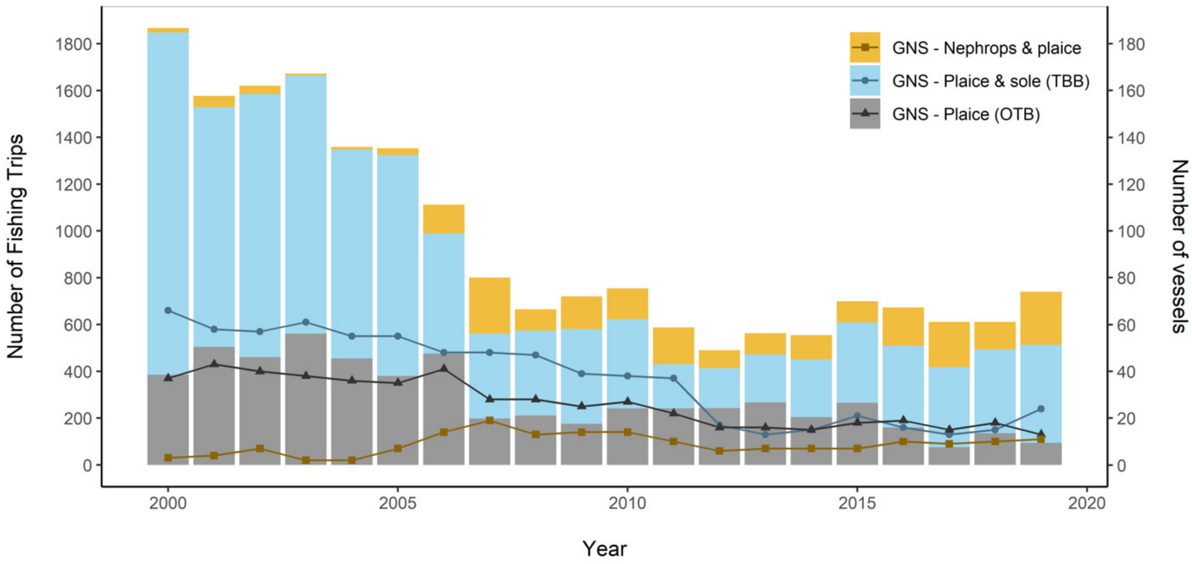


Figure 3.4: Annual number of fishing trips (bars) and number of vessels (lines) associated to the métiers Nephrops & plaice (yellow), Plaice & sole (blue) and Plaice (grey). Note that within one year a single vessel might have been associated to more than one métier since the allocation is based on individual fishing tips and catch compositions.

Socio-Economic Actor Attributes

Over time we found a constant average vessel length of 24m for the NP métier, while the vessel length increased from 2015 onwards for the PS and P métier (Appendix 3.E). This increase coincided with the successive replacement of beam trawls by pulse trawls (Figure 3.3). The number of ship owners decreased over the past 20 years from 35 to 10. In terms of producer organisations, the majority of vessels belonging to some form of organisation are members of just one fishery cooperative. Its membership increased by roughly 30% since 2000, while membership in all other organisations markedly decreased over the same period. To date, there are no other organisations and only a minority of the vessels are self-organised (owner operators).

The average income, costs and profit of beam and demersal trawlers engaging in the plaice related fisheries increased from 2008 to 2018 (Figure 3.5). A key characteristic for these vessels, which mostly operate offshore, is that their income has been almost exclusively generated from landings, while other sources of income such as owning restaurants or conducting charters seemed not relevant. The observed increase of the average annual income and profit has mainly two reasons. Firstly, these vessels could be associated to more than one of the métiers defined here which means a changing catch composition (Appendix 3.D) over time with reduced plaice catches but increasing Norway lobster or sole catches. Since the prices per kilo for sole and Norway lobster were 3 to 5 times higher than that of plaice (Figure 3.5), the overall income and profit increased. In addition, the drop of oil prices in 2008 and 2016 contributed to increased profits (Appendix 3.F). As opposed to the annual average working hours and number of engaged crew per vessel, which remained relatively stable over time (Figure 3.5).

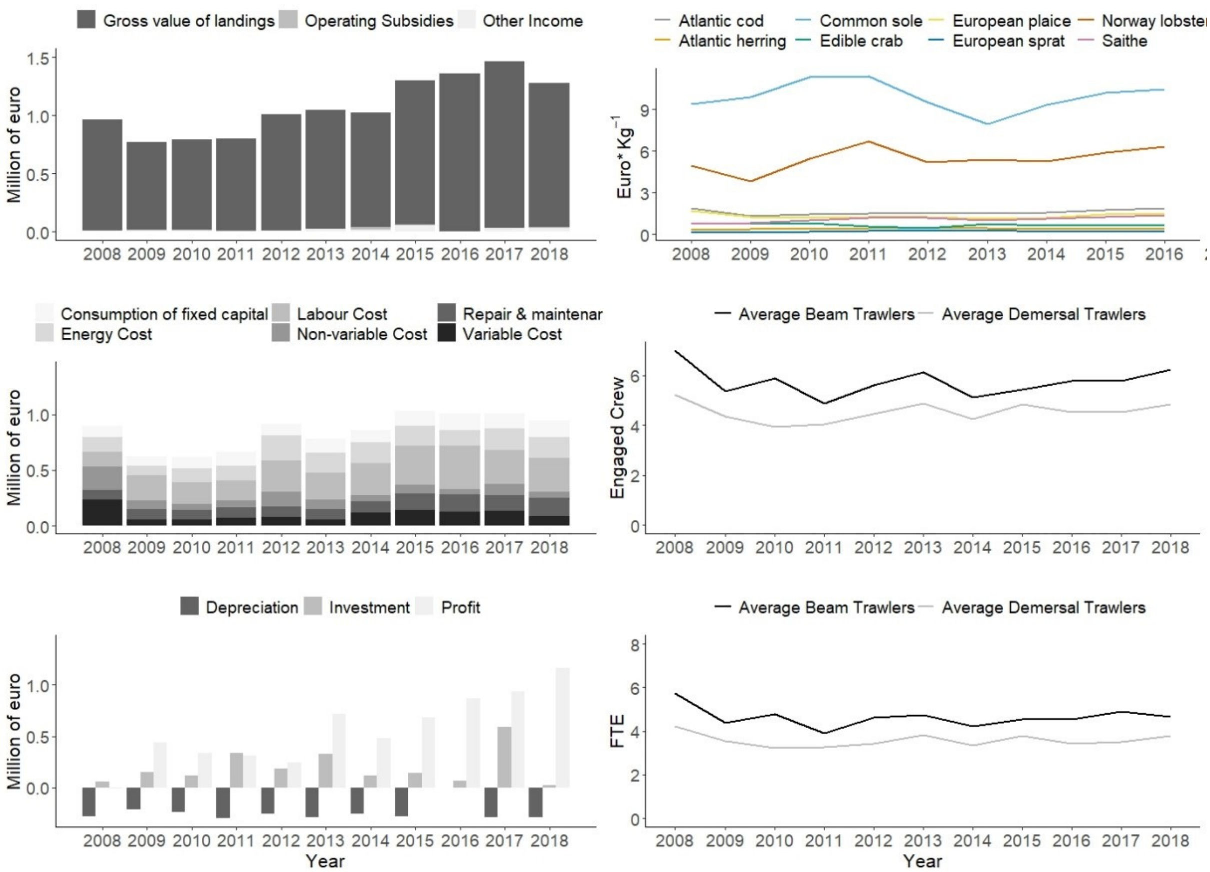


Figure 3.5: Socio-economic attributes of actors. The upper panel shows the average annual income (upper left), costs (upper middle), and profits (upper right) of German beam and demersal trawlers engaging in the plaice related fisheries; the lower panel shows the annual average fish prices (lower left), number of engaged crew (lower middle) and the full-time equivalents (FTE; lower right)

Besides the observed changes in catch composition and socio-economic attributes the overall importance of plaice as a key SES resource unit is reflected in the persistent spatial patterns of German plaice catches (Appendix 3.C). The annual centre of German plaice catches remained mostly within the German EEZ of the North Sea, while the centre of gravity of UK plaice catches followed the northward shift of the resources. The greatest distance between two centres was observed to be 95 km between 2005 and 2014.

Changes in Fishing Strategies

We explored changes of fishing strategies for the fishing métiers defined here in the Greater North Sea and Baltic Sea with the help of network connectivity metrics based on individual fishing trips (Figure 3.6). The higher the connectivity between a pair of métiers, the more often a respective vessel participated in both métiers. Vessels participating in a métier with a high level of connectivity can be described as generalists whereas a low level of connectivity refers to a more specialised fishery. Overall, we found a general decrease of connectivity over time, indicating a potential decrease of the adaptive capacity of vessels to switch between fishing practices (Appendix 3.A). Our results showed a declining level of connectivity between the Baltic Sea and Greater North Sea fisheries between 2005 and 2014, which grew stronger again only in recent years. The five-year averaged networks of the different métiers showed that the plaice métier (P) and PS métiers both played a central role in connecting fisheries within the Greater North Sea, whereas the P métier was also connected to the cod fisheries in the Baltic Sea. In the later years, the NP métier moved towards the centre of the Greater North Sea network and even played a cross-regional role from 2010 onwards. A comparison of individual métiers revealed that before 2006 connectivity was highest for the PS métier (Appendix 3.A, Figure 3.9). Thereafter the connectivity of the three métiers (PS; NP; P) showed comparable orders of magnitude. On the contrary, the relative connectivity strength of the NP métier increased over time, although it always remained below the connectivity strength of the PS métier. This indicates that in recent years the NP métier seemed to have the highest potential to adapt, hence to change fishing strategies.

3.3.3 Governance Structures and Decision-Making Processes

The EU linear decision process for setting quota is shown in Figure 3.7 together with the multi- level governance system to which the SES is exposed. Thus, most fish stocks such as plaice in the North Sea are mainly managed through a quota system based on total allowable catches (TACs) for participating countries. Annual TACs of plaice are

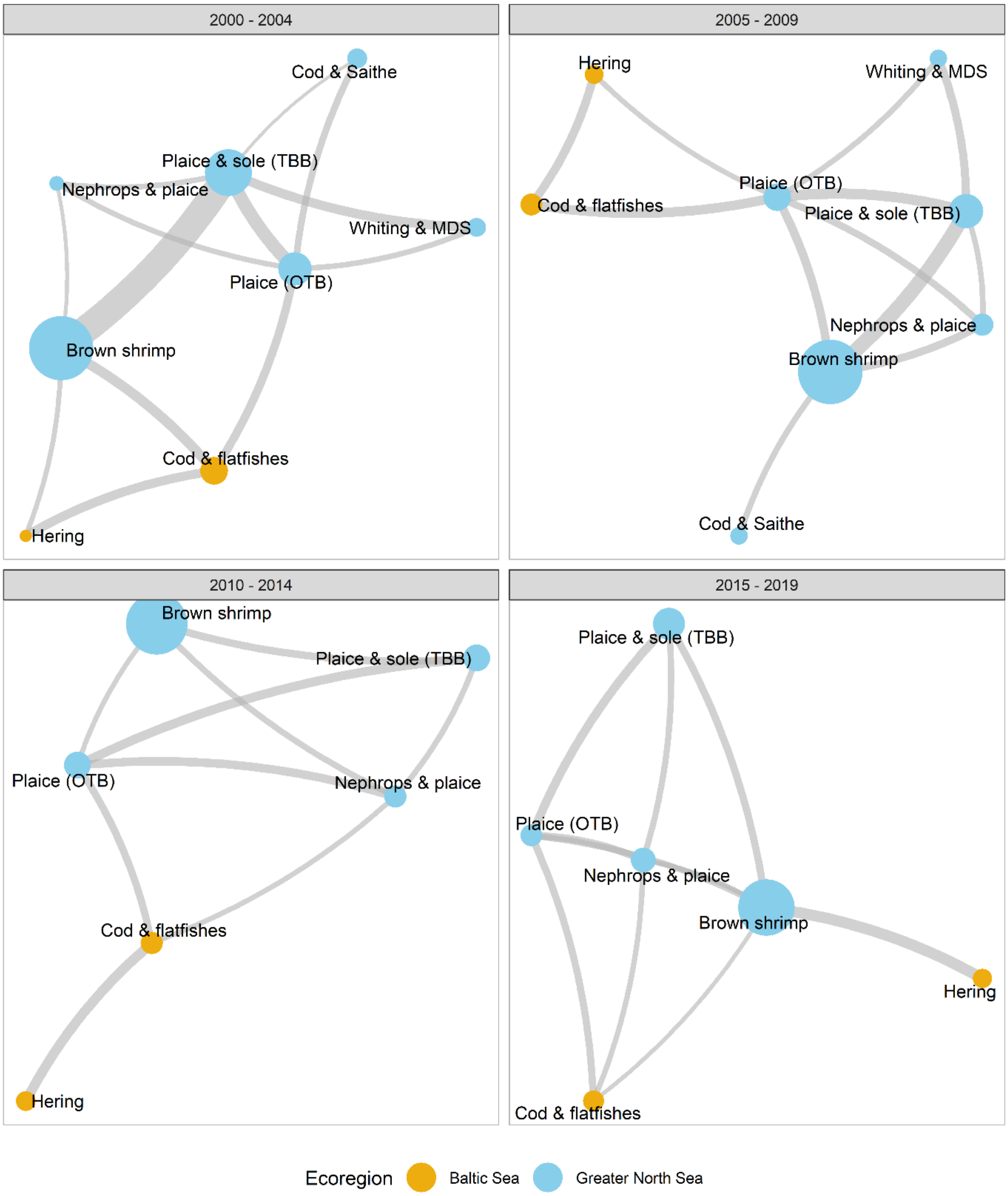


Figure 3.6: Undirected networks showing the connectivity between the different métiers in the North Sea and Baltic Sea. Node size represents the average number of annual fishing trips of the respective métier and edge size represents the connectivity between métiers based on averages of annual edge weights. The larger the node, the more numbers of fishing trips. Thicker edges indicate both more vessels participating in the respective pair of nodes, as well as more even distribution of their fishing effort among the pair of nodes.

based on stock assessments carried out within ICES by international fisheries experts as well as advices from STECF. Final decisions on TACs, prepared by the European commission based on input from ICES and STECF, are made annually through negotiations in the European Council of the fisheries ministers (see Figures 3.7 and 3.8). The lower part of Figure 3.7 depicts the national process where the quota allocations are further managed and distributed on a national basis by the respective ministry. Further spatial fisheries restrictions are also related to governance processes, which are not related to the EU fisheries policy implementation. Spatial restrictions are rather related to EU environmental policies and national MSP processes which govern for instance the spatial expansion of offshore renewables. Our stakeholder interviews confirmed the “receiver” position of the fishing sector in this decision process (Figure 3.8). With respect to quota allocation our interviews highlighted that the national allocation of TACs in Germany, based on tradition and historical catches per vessel is as often regarded as unfair and restricting. Furthermore, the EU discard ban complicates their planning because TACs for bycatch species might be required in addition to the main species. The discard ban aims at balanced harvest and should support a more selective fishery (Borges, 2020). The same is the case for the so- called choke species problem, where a species with a low quota can cause a vessel to stop fishing even if they still have quota for other species. Overall, fishers and fisheries sector representatives perceive spatial exclusion from their traditional fishing grounds due to competing marine uses such as offshore renewables and the implementation of fishing restrictions in marine protected areas as the most significant future challenges. These policies affecting the SES are developed independently from the CFP in separate processes stimulated by EU Directives and are completely under national planning jurisdiction (Figure 3.7). While fishery representatives are involved as stakeholders in these policy processes, fisheries interests do not feature prominently in their legislative objectives. Interviews with fisheries representatives and public and parliamentary debates on the future development of the German EEZ furthermore highlight that fishing is neither a major nor powerful actor compared to shipping, energy, and nature conservation (Figure 3.8).

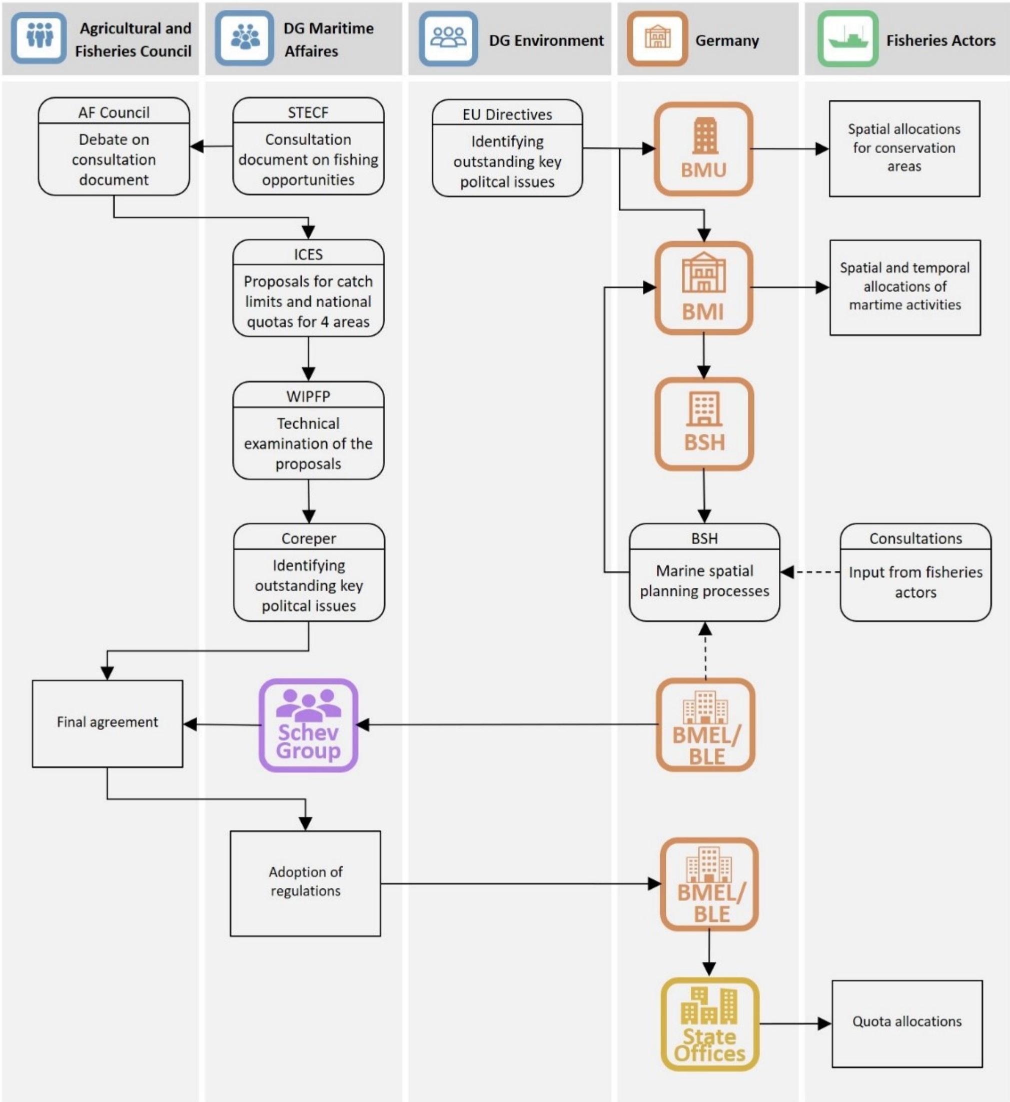


Figure 3.7: Linear representation of the multi-level hierarchy in the decision-making process relevant for the SES.

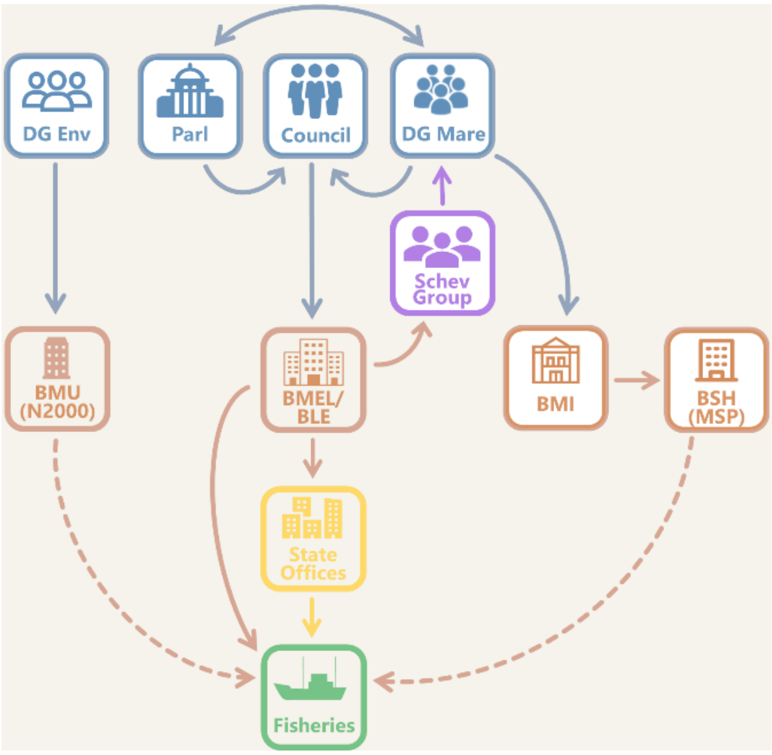


Figure 3.8: General structure of the governance system related to the German fishery sector.

3.4 Discussion

3.4.1 Unravelling Autonomous SES Adaptation

Fisheries SESs must continuously adapt to both environmental and socio-economic change that impact the structure and function of the SES in which they are embedded (Frawley et al., 2021). Only recently, research on fisheries SESs quantified adaptive capacities towards, e.g., environmental change (Bograd et al., 2019; Brattland et al., 2019; Silva et al., 2019; Thiault et al., 2019b). Many empirical studies analysed fisheries SESs at rather small geographical scales describing the state, regulation and use of a single biological resource (Lauerburg et al., 2019). Our study is one of the first that quantified the spatio-temporal dynamics of SES attributes at larger spatial scales involving more than one resource. Combining the Ostrom framework with quantitative and analytical approaches (Schlüter et al., 2012) enabled an in-depth understanding of the factors that determine SES dynamics.

The decrease in plaice catches in 2005 caused a direct socio-economic change, such as an increased activity of the Nephrops & Plaice métier and a shift of the main gear deployed by the Plaice & Sole métier. Hence, interviews confirmed that many coastal fishers have abandoned near-shore flatfish fisheries (switching to brown shrimp fishery) in response to the shift of plaice to more northern offshore waters, where the resource is now out of reach for their small vessels. In summary, we found a rather rapid autonomous adaptation of the SES actors to declining plaice catches over the past 20 years based on technical innovation such as pulse trawls leading to increased sole catches, catch diversification and a change in fishing strategies. The deployment of pulse trawls, which are known for a higher sole catch efficiency (Rijnsdorp et al., 2020), allowed the SES actors to move to different areas previously not accessible by the heavy beam trawl (Hintzen et al., 2018). However, pulse trawling in EU waters was banned in 1998 and re-introduced in 2006 (Le Manach et al., 2019), but has been banned again from 2021 onwards. Our results confirmed a general increase of higher priced sole and Norway lobster catches over the past ten years. In part, the combination of low fuel costs, decreasing number of vessels and fishing trips caused an increase of profits for the remaining vessels. The decreasing connectivity of métiers over time, revealed a trend towards specialisation and a likely reduction of the ability to switch fishing strategies, emphasising a potential diminution of the overall capacity of the SES to adapt to global change.

3.4.2 Barriers to Adaptation

Our analysis revealed consistent SES system boundaries over the past 20 years and a strong link between the resource unit plaice and the SES actors. Target species and the respective catch compositions showed clear fluctuations, with a constant decline of plaice catches over time within the system boundaries. Interviews revealed that the observed spatial persistence of fishing patterns, despite decreasing catches, might be rooted in the fishing culture and self- perception of fishers. Hence, our observations confirm the fact that professional fishing can appear to persist against the odds (Christy et al., 2021), which is linked to the choice of fishing as a lifestyle rather than an ordinary job. Success and standing within the community are closely linked to the size of the catch, making competition and a degree of rivalry between the fishers a key element of the prevailing fishing culture. Our interviews confirmed that independent of specific fisheries and métiers, most German fishers tend to define themselves as fishers in the sense of actively fishing rather than economic entrepreneurs; most are not interested in engaging in the marketing or selling of fish.

We recognised that the main barriers to adaptation arose from the commercial environment of the fishers and their concerns over future spatial and environmental policy. Fishers know the inherent need to be flexible and that the profession has always adapted to change, but current uncertainties (e.g. Brexit, increasing competition with the fleets of neighbouring countries or the effects of rising fuel prices) resulted in a low affinity to "risk appetite" (such as investing in new boats or gear). Our findings show that business structures per se and more so in neighbouring countries have changed from small family businesses to more organised cooperatives and more industrialised fleets. Given that German fishers are mostly interested in fishing, there is little interest in forming cooperatives or developing alternative, more localised marketing strategies that could help increase profitability.

There is also no real intent to become involved politically, although existing structures are criticised for their lack of effectiveness in giving fishing in Germany a greater voice. In summary, fishers do regard their current situation as requiring change. The greatest barrier to adaptation seems to be a mindset that sees fishers as trapped by compounding factors – by an unfavourable regulatory environment, by spatial shifts in the resource, by the perceived lack of political support, the inability to make the necessary financial investments (in vessels and gear), and the inability to organise the necessary changes (obtaining support for risk-taking, self-organisation, professionalisation of tasks such as marketing) from within the community itself.

The CFP is the key policy driving the governance processes regarding fisheries at the EU and German scales. However, we conclude that national interpretation and process of implementation defines the specific outcome for fishers. For the here studied SES, it is primarily the MSPD and associated sectoral policies that regulate the introduction of spatially exclusive maritime activities such as offshore renewables, hence creating vulnerabilities in terms of displacement and limiting the access of the fishers to fishing grounds (V. Stelzenmüller et al., 2022). A detailed impact assessment of the multi-level governance system described here for the adaptive capacity of the German southern North Sea fisheries to e.g. environmental and socioeconomic change, is largely beyond the scope of our study. However, we took a first step towards a better understanding of the role of governance in enhancing the adaptive capacity of our SES by mapping the complexity of governance structures and its major components.

3.4.3 Future Management Needs to Support SES Adaptation to Global Change

Our study strongly supports the conclusion that SES adaptive capacity builds on the experience and knowledge of community members (traditional ecological knowledge) to characterise pertinent conditions, community sensitivities, adaptive strategies, and decision-making processes (Cinner et al., 2018; Smit and Wandel, 2006). An in-depth assessment of adaptive capacities requires not only collaboration across traditionally distinct disciplines and sectors (Friedman et al., 2020). More importantly, it necessitates access to the knowledge of the communities associated with the resource system and the subsequent selection of indicators and data (Lauerburg et al., 2019; Sterling et al., 2017).

Applying the multi-tier framework required the integration of a multitude of data sources and analytical approaches ranging from stock assessment, network analysis to qualitative interviews. Our analysis does not allow us to conclude on optimal, robust, or adaptive management strategies that take uncertainty, different time scales, and nonlinear behaviour of SESs into account. The evaluation of management and policy strategies would require ecosystem models (Steenbeek et al., 2021), modelling frameworks (Oliveira et al., 2022) or integrative probabilistic modelling approaches such as Bayesian belief networks (Rambo et al., 2022). Nevertheless, our approach does allow for a general characterisation and deeper understanding of autonomous SES adaptive capacities.

With the help of the multi-tier Ostrom framework we have described the autonomous or reactive adaptation of the SES and extracted the barriers of adaptation for SES actors comprising also the multi-level governance system to which the SES is exposed. SES actors or fishers are in the "receiver" position at the bottom of the decision-making process. Hence, they do not play a direct role in the decision-making process, limiting the potential to adapt. This shows that one of the key design principles illustrated by long-enduring common-pool resource institutions - "Individuals or households with rights to withdraw resource units (e.g. fishers) are clearly defined" (Basurto and Ostrom, 2019) is neglected. We argue that when environmental change is coupled with external and socio-economic change and when governance does not acknowledge design principles of common-pool resources (Gari et al., 2017), the SES adaptive capacity potential decreases and may reach its limits. This situation corresponds to a social-ecological trap in which social and ecological feedbacks reinforce one another locking a SES into an undesirable state

(Eriksson et al., 2021; Villasante et al., 2022). According to Boonstra et al. (2016), social-ecological traps emerge from multi-scalar processes, and structural drivers which often originate outside the local scale or community reflecting the values and influence by other interests. Among the three pathways for disrupting socio-ecological traps described in Eriksson et al., 2021, co-management is the one that would have the highest potential to strengthen the SES adaptive capacity.

Within the spatial boundaries of the SES, co-management needs and approaches should be tailored to the local context. We postulate that co-management should relate to all decision- making processes affecting the SES: fisheries management, marine conservation and MSP. For instance, tailored co-location solutions for offshore renewables and fisheries could mitigate the loss of fishing opportunities and should be explored and facilitated through MSP and licensing (V. Stelzenmüller et al., 2022). Such co-location solutions could contribute to diversification of catches, fishing practices and possibly livelihoods (Vanessa Stelzenmüller et al., 2021). Strengthening co-management approaches would also follow the growing recognition that fisheries should be managed for all three pillars of sustainability: economic, social and environmental sustainability (Garlock et al., 2022), implying a proper recognition of fishers' self-perception and socio-cultural as well as economic conditions. Recent studies suggested measures to enhance SES adaptive capacity, comprising fisheries diversification, access to resources, alternative management or licencing systems as well as general coping strategies of fishing communities (Frawley et al., 2021; Jara et al., 2020; Silas et al., 2020; Thiault et al., 2019d). To strengthen SES adaptive capacity in the southern North Sea, where coastal communities and fishing fleets have generally a higher risk of adverse consequences due to climate change (Payne et al., 2021), we in particular stress the necessity of alternative management from the above list of measures. A shift from a multi-level governance system to a more bottom-up community centric decision-making process is needed for SES to withstand external factors such as climate change induced ecological tipping points, market trends and strong fluctuations of operating costs.

3.A Network Connectivity

First, we calculated the total and relative sums of trips per métier, vessel, and year. To focus on the dominant métiers, we removed data points with less than ten trips, as well as less than 10 % of the total trips per vessel and year. We measured the connectivity between two fisheries for each year using an adapted formula of (Fuller et al., 2017) in which we replaced revenue of vessels by number of trips, since revenue data were only available from 2009 onwards. Hence, we computed annual undirected networks and weighted edges according to connectivity values between two fisheries. We assessed our networks by calculating node strength and edge density. Node strength (the sum of numbers of fishing trips per métier of all edges pointing to one node) is a proxy of how métiers are connected to each other. Edge density is an indicator for the connectedness of a network, which is calculated as the sum of all edge weights divided by the sum of all node weights and (Frawley et al., 2021; Fuller et al., 2017). Further we averaged node strength to represent the weighted connectedness of a network. Both metrics are indicators for the connectedness of the network, and, in networks of participatory fisheries, may be used to determine the resilience of fishery (Frawley et al., 2021; Fuller et al., 2017). A higher connectedness usually means a higher adaptive capacity of the fishers, because, in case of rapid change leading to an exacerbation of a fishery, they can more easily switch to another fishery.

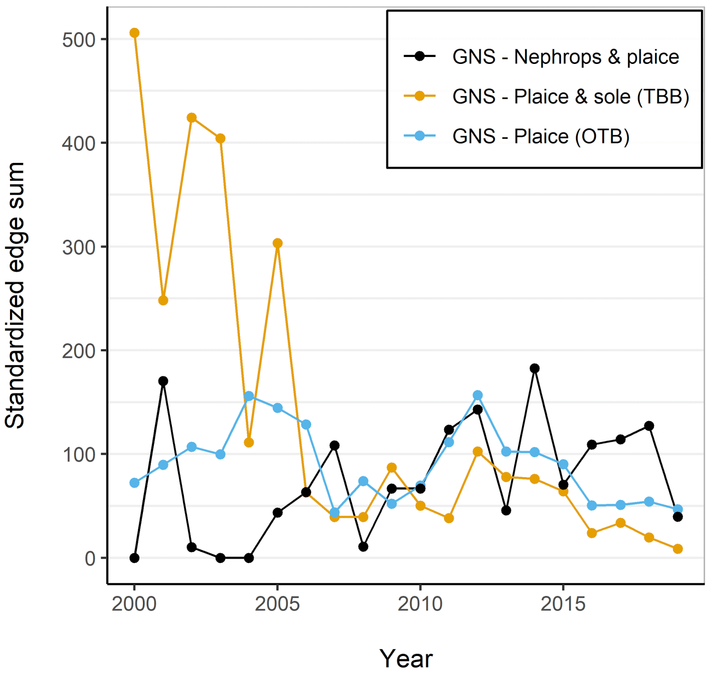


Figure 3.9: The sums of all edge weights connected to respective métier nodes standardised by the number of vessels participating in that respective fishery each year.

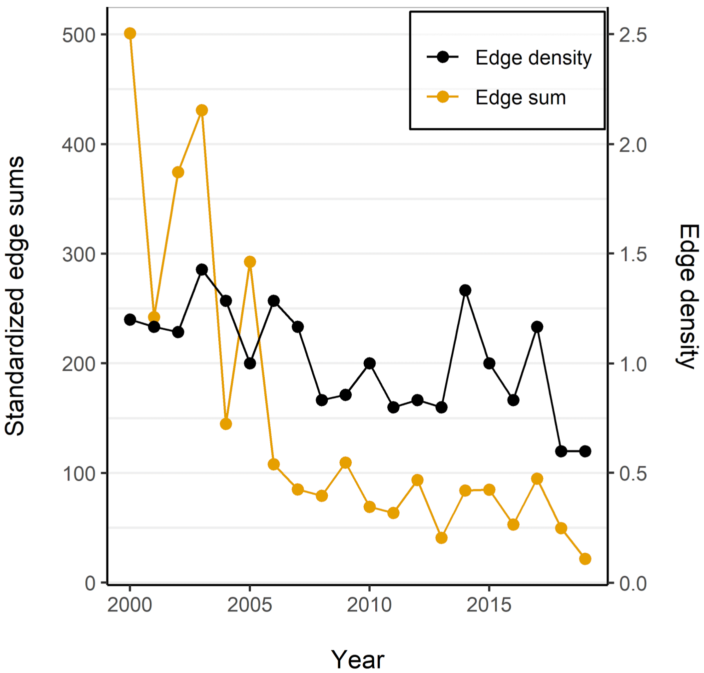


Figure 3.10: Standardised edge sum and edge density are network metrics and proxies for the connectivity of the network. Standardised edge sum depicts the yearly sum of all edge weights divided by the number of vessels active in that respective year. Edge density is the number of edges divided by the number of nodes (fisheries).

3.B Sea Surface Temperature

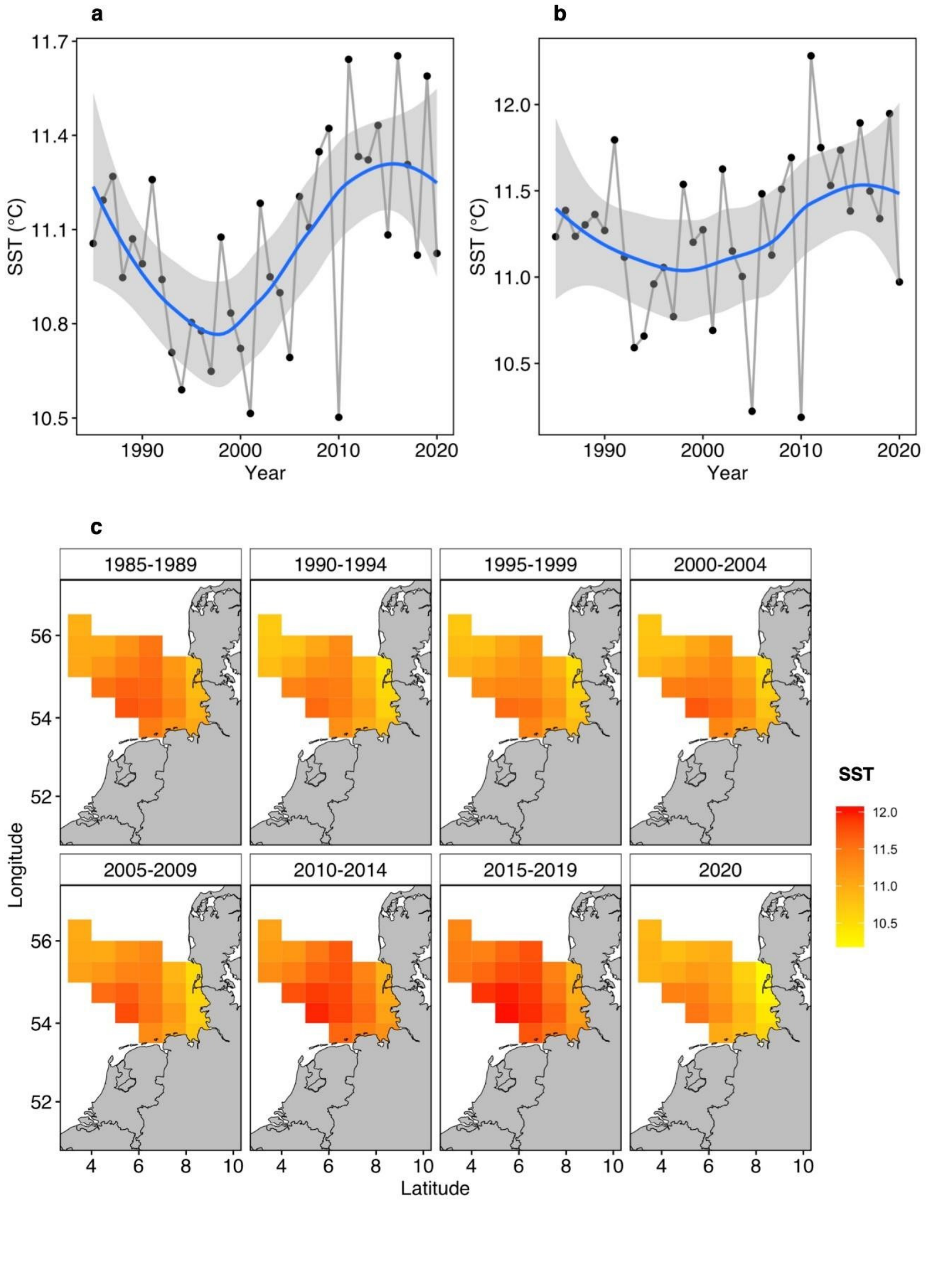


Figure 3.11: Temporal changes in average sea surface temperature (SST) in the greater North Sea (a) and in the German Exclusive Economic Zone (EEZ) and coastal waters (b) - blue lines represent loses smoother; spatial changes in 5-year average SST in the German EEZ and coastal waters (c).

3.C Plaice Landings

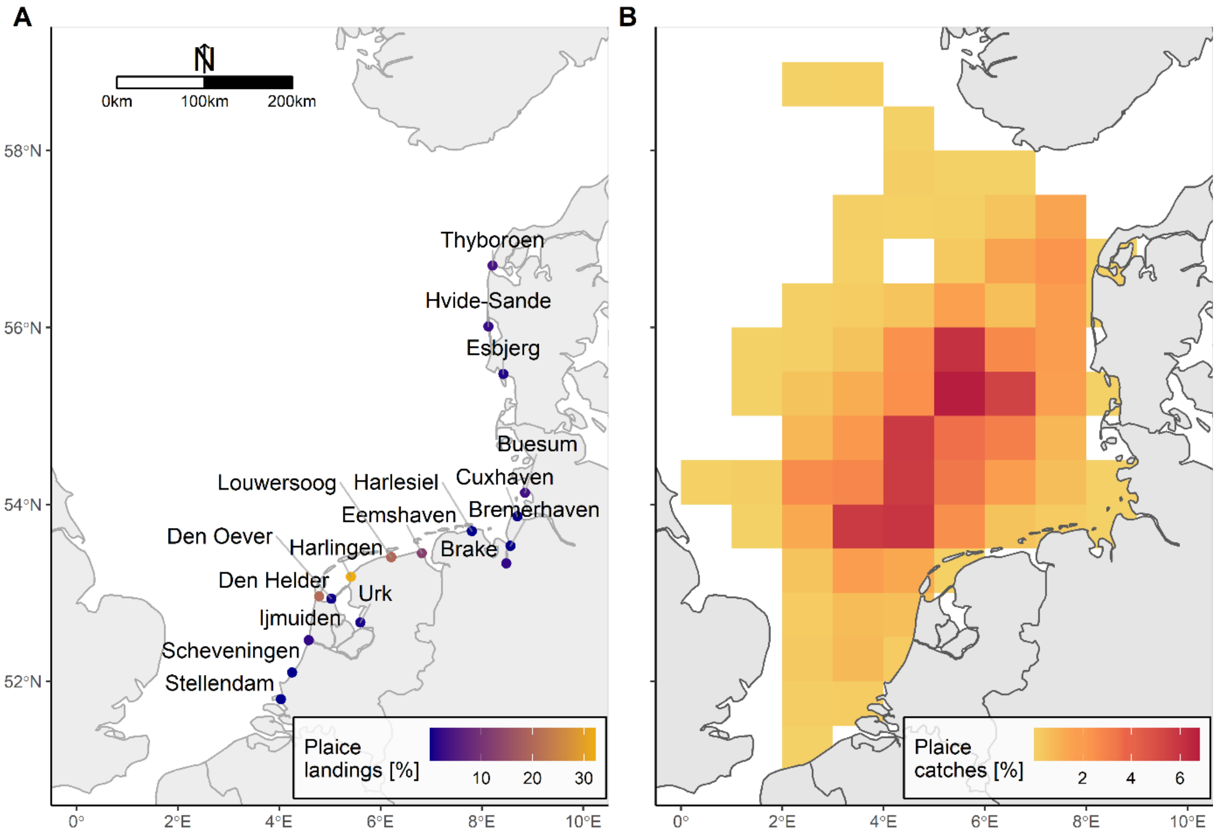


Figure 3.12: Relative proportion of aggregated plaice landings (2009-2019) of the German fleet in North Sea ports (A) and relative proportion of plaice catches (2000-2019) of the German fleet per ICES rectangle (B). Both data sets were cropped to ports and ICES rectangles with at least 0.01 % landings or catches.

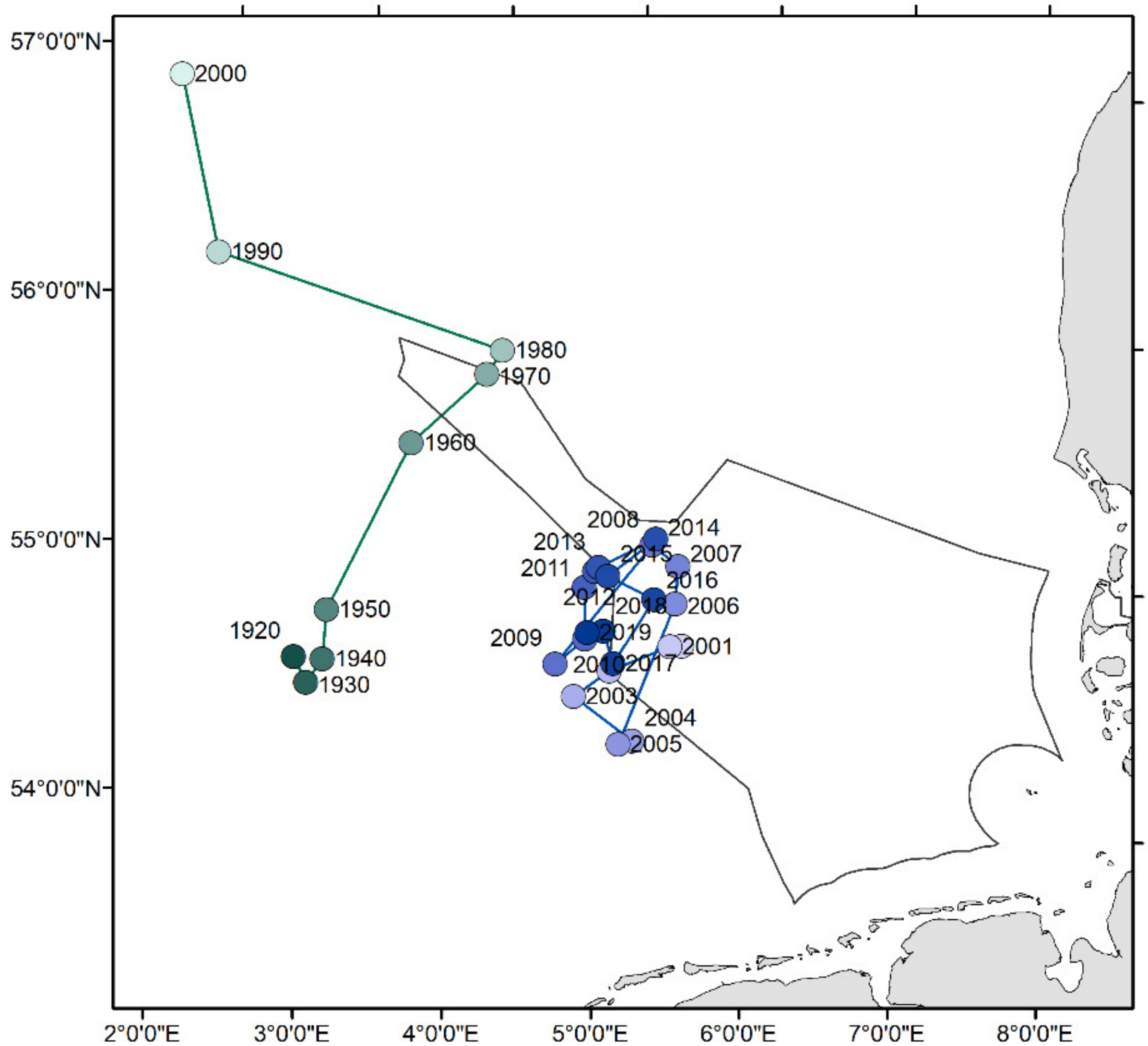


Figure 3.13: Centre of gravity of German plaice landings between 2000 and 2019 (from dark to light blue) and centre of gravity of British trawl plaice landings between the 1920s and the 2000s (from dark to light green) redrawn from Engelhard et al. 2011.

3.D Catch Composition

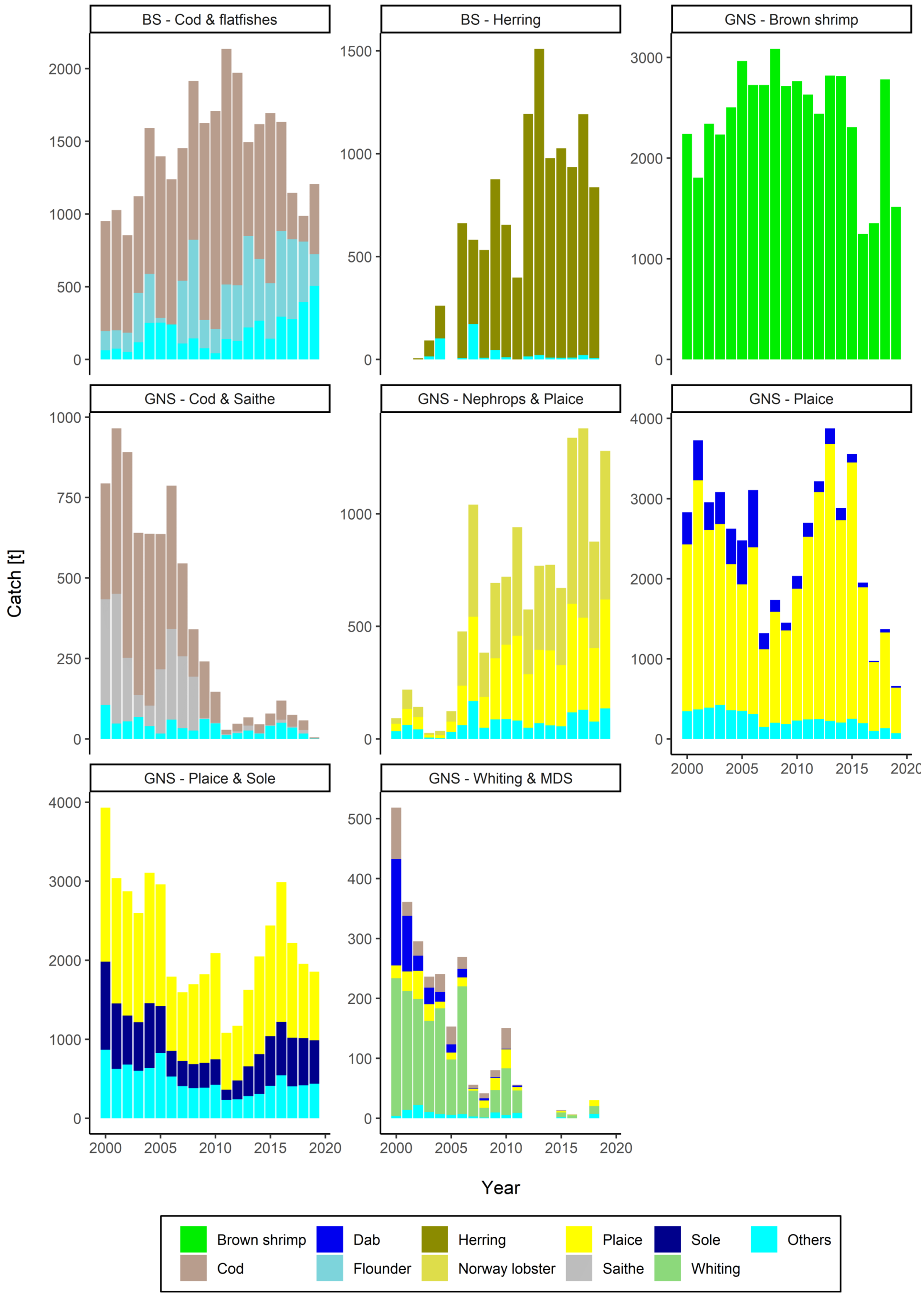


Figure 3.14: Relative catch composition of the seven métiers defined for the plaice related fishery.

3.E Vessel Length

The annual distribution of vessel length (m) for the three plaice dominated métiers are shown in Figure 1. The vessel length for the Nephrops & plaice métier seemed to be relatively constant as the median value settled around 24m for most years. The vessel length of the Plaice & sole métier increased from 2010, hence the distribution shifted to larger vessels (28 m). We observed the same trend for the plaice métier. This might be due to the case that less smaller vessels participated in the fishery or because several large vessels joined the fishery. Figure 2 shows the relative composition of deployed gears (%) for the three métiers. Until 2014, the composition of gears used by German vessels of plaice métiers is mainly composed of beam trawls (TBB), otter bottom trawls (OTB). In 2015 beam trawls became successively replaced by pulse trawls (PULS).

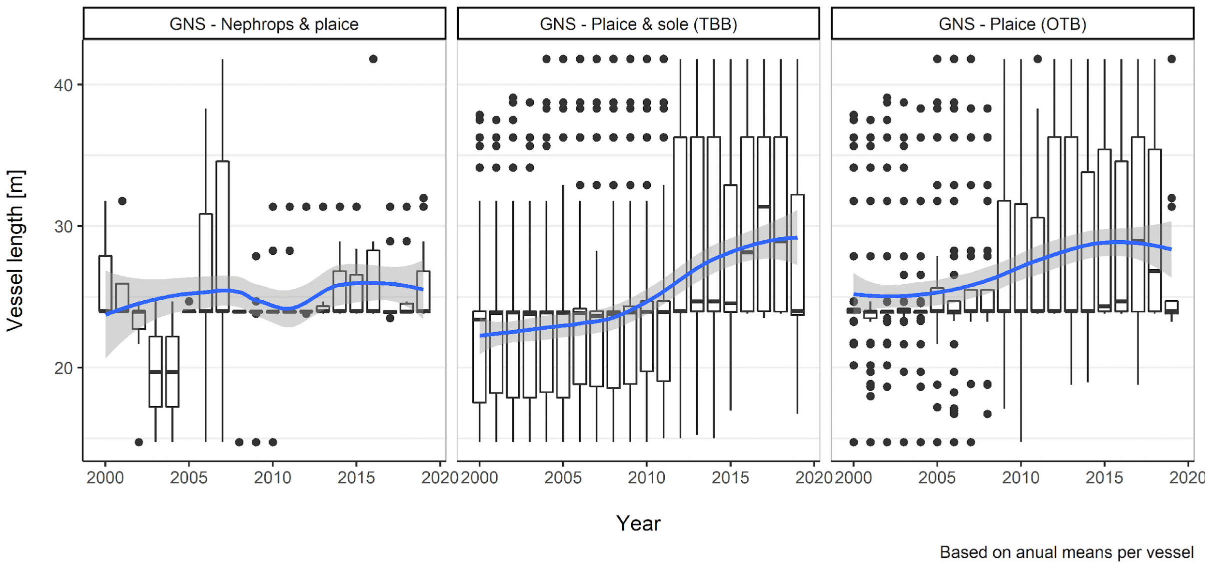


Figure 3.15: The boxplot represents the distribution of annual lengths of vessels participating in plaice related fishing activities. The blue line represents a smoother function using a general additive model (GAM).

3.F Oil Price

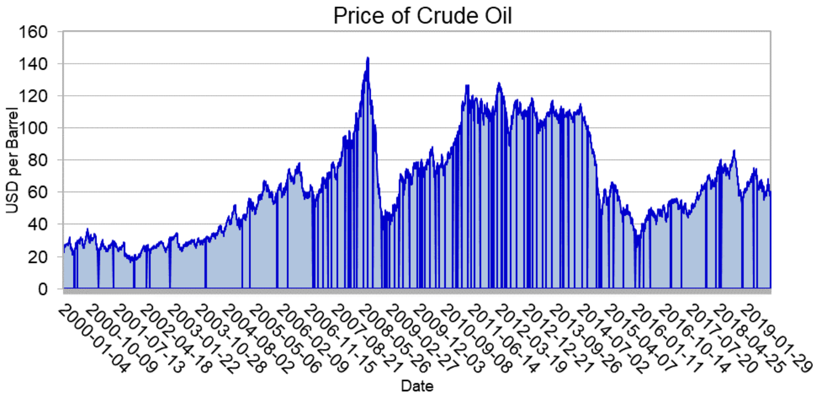


Figure 3.16: Daily oil price. Source: The World Bank 2020.
(https://data.worldbank.org/indicator/EP.PMP.DESL.CD. ID: EP.PMP.SGAS.CD. License: CC BY-4.0)

Chapter 4

Beyond Fishing: The Value of Maritime Cultural Heritage in Germany

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Abstract: The importance of maritime heritage in providing benefits such as a sense of place and identity has been widely discussed. However, there remains a lack of comprehensive quantitative analysis, particularly regarding monetary valuation and its impact on people's preferences. In this study, I present the results of a choice experiment that assesses the value of the cultural heritage associated with shrimp fishing through seafood consumption preferences in Germany. Additionally, I investigate people's attitudes toward cultural heritage and examine how these attitudes affect their stated preferences. I find that these attitudes are significantly stronger in towns where local fishermen led a prominent awareness campaign on fishing culture during the study period. Moreover, I observe a positive willingness to pay for a cultural heritage attribute in shrimp dishes, which varies depending on individuals' attitudes toward cultural heritage.
Keywords: Maritime cultural heritage, German shrimp fishery, Discrete Choice Experiment.

4.1 Introduction

Fishing is a practice dating back to ancient times. It contributes as a source of food, income and pride. In the European Union (EU), the fishing activity provides 124.000 direct jobs, with nearly the half belonging to the small-scale coastal fleet (STECF, 2019a). Fishing activity also contributes to the personal protein intake, where an average person consumes 3.3kg more sea food than the world average (STEFC, 2022). Besides an economic benefit, fishing, particularly in coastal areas, has an inherit cultural heritage characterized by the creation of a sense of place in terms of place attachment and cultural-social memory for residents. Furthermore, it serves as a touristic attractions for visitors (Khakzad and Griffith, 2016). The fishing cultural heritage is a public good characterized by fishing traditions, maritime cultural landscape and traditional waterfronts, all of which create place attachment to residents and visitors in these areas (ibid.)[1]. Maritime cultural heritage maintains a sense of place in fishing communities and contributes to preserving socio-cultural memory, as well as social and psychological benefits (Durán et al., 2015; Khakzad and Griffith, 2016; Martino et al., 2023; Urquhart and Acott, 2013; Xiao et al., 2023).

In Germany, this maritime cultural heritage is at risk. The brown shrimp fishery, currently the most important coastal fishery, has experienced a constant decrease in the number of vessels over the last two decades. Despite not being constrained by quotas, this fishery is subject to the European Common Fishery Policy (CFP) regulations, and national restrictions such as mesh size and the number of licenses issued (Döring et al., 2020). The adaptation of the fishing tradition over the decades is remarkable given historic and economic facts such as the World War II, the reunification of Germany, the declaration of Exclusive Economic Zones (EEZ) after 1977 (Schacht and Voss, 2023), the increase in fuel prices, increasing imports of products at a lower price, and changes in demand among others (STEFC, 2022). This fishing tradition embeds a set of cultural customs and knowledge that have remained despite these multiple challenges.

The public good nature of maritime cultural heritage implies that some elements would

[1]Place attachment refers to connections to physical and social settings that provide social and psychological benefits to residents and visitors in these fishing areas (Brown et al., 2003). Cultural heritage, in particular, is a form of asset belonging to an individual, community, a region, a nation or to humankind as a whole (Throsby, 2007).

not survive without some form of collective action, as the market does allocate resources properly, with a provision lower than socially optimal (Durán et al., 2015). Yet, the challenge of determining the optimal provision together with insufficient data, particularly on the demand side, may result in the under-provision of this public good (Throsby, 2007). Given the importance of maritime cultural heritage and the risk of its disappearance, this study is aims to assess the Willingness To Pay (WTP) of residents and non-residents for shrimp cultural heritage in Germany. I analyse the maritime heritage aspect of sea food choices encompassing vibrant traditional working waterfronts with operational boats and bustling fish markets. These elements significantly impact people's decisions to consume seafood (Khakzad et al., 2015; Symes and Phillipson, 2009).

This paper adds to the literature by exploring the link between food consumption and maritime cultural heritage. It also exploits the influence of an awareness-raising campaign towards shrimp cultural heritage on people's cultural attitudes and WTP. To my knowledge, only Martino et al. (2023) explored the link between food consumption and cultural heritage. The present study is the first in Germany assessing consumers preferences for maritime cultural heritage and exploring the correlation of an awareness-raising campaign on these preferences. I also contribute by examining people's attitudes that influence consumers preferences towards maritime cultural heritage. I implement a modified survey based on the attitudinal scale developed by Choi et al. (2007). This scale measures cultural attitudes of people using factor and hierarchical cluster analysis. I identify aspects that influence pro-cultural attitudes towards maritime heritage.

I also exploit a campaign that unfolded on-site during the study period. The campaign promoted by local shrimp fishers, aimed to raise awareness about the shrimp cultural heritage. The campaign was more visible in two of the four towns where this study was conducted. I found a significant correlation among the presence of the campaign with higher pro-heritage attitudes, and an increased WTP for maritime cultural heritage. I found that people have a positive WTP for shrimp cultural heritage but also for a local, fresh and sustainable shrimp dish. In the next section I describe the German North Sea shrimp fishery, in section three I describe the methodology, in section fourth I present the results, in the fifth section I show a discussion, and the final section offers the conclusion.

4.2 North Sea shrimp cultural heritage

The Brown shrimp is mostly harvested by Germany and the Netherlands, which together account for 79% of the EU brown shrimp production (Goti-Aralucea et al., 2021). In Germany, this fishery comprises 195 vessels with a beam trawler as a gear by 2020. These fisheries are organized as producer organizations grouped either by size of the vessel or the geographical location (ibid.). The majority of these fisheries are certified by the Marine Stewardship Council (MSC), which entails a certification process initially developed for a consortium of German fisheries. This plan encompasses 421 vessels from the Netherlands, Germany, Denmark, and Belgium, detailing specifications for gear, mesh size, and beam length, as well as guidelines for reducing catch per unit of effort in accordance with ICES criteria (Addison et al., 2023; Goti-Aralucea et al., 2021).

In the last years brown shrimp fisheries face increasing regulations and socio-economic pressures that endanger their existence. The increasing area for Marine Protected Areas (MPA) leave fisheries with less available space to fish (Stelzenmüller et al., 2021), higher temperatures could cause migration of the species to other areas (Schulte et al., 2020), and the recently COVID pandemic drop drastically the prices and landings decreased (STEFC, 2022). It is challenging to maintain profitability despite some efficiency factors such as, externalization of shelling and marketing tasks, together with capital cost reduction (Goti-Aralucea et al., 2021). Various resilience strategies are contemplated to improve the business, including mechanical shelling, instead of the outsourcing shelling in Morocco, and internalization of the marketing and sale of the shrimps. Additionally, a strategy involves integrating greater diversity within both the fleet and administrative teams to foster innovation within the shrimp business (ibid.).

Besides the mentioned pressures on fisheries, during March of 2023 in Büsum, the Agriculture Ministers announced the ban of the fishing method of bottom trawls, which should take place from March 2024. The action is taken because this fishing method can damage the seabed. The ban is extended to all Marine Protected Areas (MPA) by 2030 at the latest. Two-thirds of the sea area where shrimp fishermen currently legally operate falls within protected areas. These include the Wadden Sea National Park and areas of the European protected areas “Natura 2000”. The mayor of Greetsiel mentioned that this measure could lead to the disappearance of cultural heritage, tourism would be negatively affected, and business could lose their existence. Fishers association claim that this regulation would leave them with hardly any area to fish[2]. However, this measure was not still in place at the moment of this study, this is an action plan that the European Commission has to negotiate which each member state.

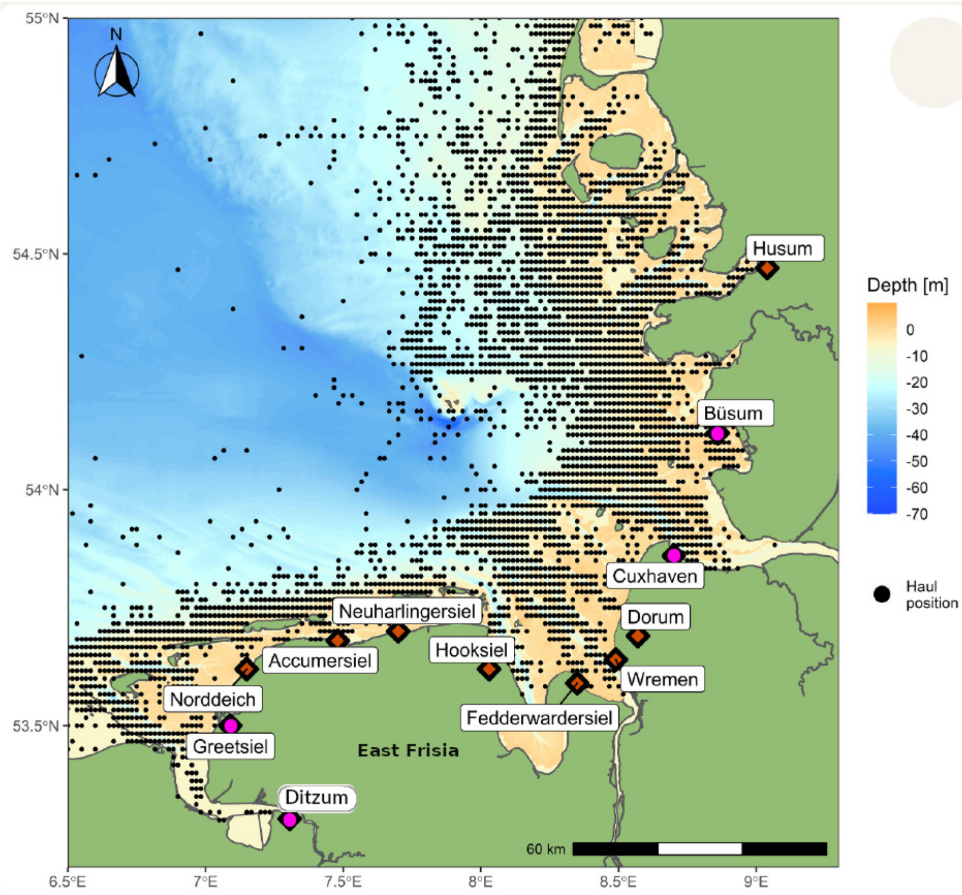


Figure 4.1: Brown shrimp ports in Germany. The pink dots represent the ports (towns) where this study was carried out.

After the announcement, fishers started a campaign to support the existence of the brown shrimp trawlers. The campaign consists of symbols such as crosses symbolizing the death of the vessels, and includes a letter explaining the causes they support (See annex figures 4.6 and 4.7). Fishers mention that the prohibition of the fishing method and the decreasing space available to fish means the end of brown shrimp fishing, fishing companies, and the tourism industry. This letter was displayed in most restaurants and touristic key points such that it was highly visible to locals and tourists. The campaign

[2]https://www.ndr.de/nachrichten/niedersachsen/oldenburg_ostfriesland/Krabbenfischer-fuerchten-wegen-geplantem-EU-Verbot-um-Existenz,krabbenfischer420.html, https://www.ndr.de/nachrichten/niedersachsen/Krabbenfischer-demonstrieren-gegen-Verbot-von-Grundschleppnetzen,krabbenfischer422.html

was more visible in the towns (ports) of Greetsiel and Ditzum, due to the small area in comparison to Cuxhaven and Büsum (See figure 4.1).

The consequences of the possible disappearance of the Brown Shrimp fishery could have significant economic implications. It is the the most important coastal fishery for Germany in economic terms, given by its large volume and high prices that yield the highest revenues of all coastal fleets (Goti-Aralucea et al., 2021). However, the consequences of loosing this fishery go beyond the mere act fishing, encompassing potential impacts on cultural heritage. Fisheries in Germany started in the Middle Ages (Döring et al., 2020), and the tradition of fishing Shrimp is one of the oldest cultural fishing techniques in the North Sea[3]. However, the current form of fishing with Beam Trawls is not older than approximately 120 years old. The cultural heritage includes the historical ports. The figure 4.1[4] shows important ports where the German brown shrimp is landed and the fishing area. In Greetsiel, for instance, the port is older than 600 years, making the town still preserving the "magic of old times"[5]. The North Sea shrimp is also one of the symbols of the East Frisia region (See figure 4.1), as it contributes to build the identity of many people from the coastal region of the North Sea.

4.3 Methodology

I use a Discrete Choice Experiment (DCE) to identify the value of the cultural heritage of the shrimp fishery. DCE is an economic valuation method that through a simulated market scenario enables the analysis of stated preferences for non-markets goods. This methodology is based on the premise that an individual's utility for a particular good is comprised of both sum of its use and non-use values. The purpose is to obtain a monetary measure of the change in utility levels as consequence of a change in the provision or characteristics of this good (Mariel et al., 2021). This methodology is extensively used in the context of cultural heritage, for instance, museums or places that are unique by definition (Bedate et al., 2004; Bertacchini et al., 2011; Choi et al., 2010). In the maritime cultural heritage contexts DCE has been recently explored (Martino et al., 2023; Tanner et al., 2021; Xiao et al., 2023). Durán et al. (2015) present one of the leading papers in

[3] $https : //www.ostfrieslandkrimi.de/greetsiel - hafen - mit - der - groessten - krabbenkutterflotte - ostfriesland/$

[4] Figure based on the study by Goti-Aralucea et al. (2021)

[5] $https : //www.greetsiel.de/sehenswuerdigkeiten/hafen - greetsiel$

applying DCE in the context of maritime cultural heritage.

I conducted a survey in four of the towns with the highest number of shrimp landings in Germany to assess the value of the maritime cultural heritage. The ports with the highest average proportion of landings in the last seven years are: Büsum, has the highest amount of total landings with a share at 26%, followed by Cuxhaven at 12%, and Greetsiel at 10%. Following Greetsiel there are six towns with similar share of shrimp landings (ranging between 3.5% and 4.5%). Therefore, the fourth town was selected based on its cultural significance for the fishery. Following the guidance of experts from the research institute of the German Ministry of Food, Agriculture, and Consumer Protection (Thünen Institute), Ditzum was chosen as the fourth town for the survey implementation, with a share of landings amounting to 3.9%.

The study area comprises the towns of Ditzum, Greetsiel, Büsum, and Cuxhaven. This study was performed in the summer of 2023 during the last weeks of August and first days of September during 20 consecutive days. These towns have few locals, and they live mainly from tourism. The local population in these places is 570, 1410, 4876 and 199.603 habitants respectively[6]. The quantity of visitors exceeds by a high magnitude the quantity of locals. During 2021 in Emden, region where Ditzum is located, there was 101.167 visitors. Krummhörn, region, where Greetsiel belongs, had 76.039 tourists. Büsum received 228.036 and Cuxhaven 358.728 tourists [7].

The visibility of the campaign in the towns depends on factors such as the spatial connection of the historical center with the harbour, the availability of an open sea area (beach), and a the purpose of visit by the tourists. In Ditzum and Greetsiel the location of the historical center, harbour and tourists routes are interconnected, attracting visitors primarily interested in nature, fishing, and local food. Due to the compact size of their historical centres and the absence of an open sea area, tourist routes are concentrated around key locations where campaign advertisements are prominently displayed (See figure 4.6). In contrast, Busum and Cuxhaven have an open sea area (beach), that often serve as the main attraction for visitors. In Cuxhaven, for instance, the historical center is situated 5km away of the beach and the harbour is disconnected from both the city center and the beach. These factors contribute to the campaign being more visible in Ditzum and Greetsiel compared to Büsum and Cuxhaven.

[6]Data from https://www.citypopulation.de/en/germany/admin/niedersachsen

[7]Statistics for 2021 data from https://stadtistik.de/stadt

4.3.1 Survey design

I designed and implemented a face-to-face survey involving 409 individuals to assess preferences towards the shrimp cultural heritage in the North Sea. The recruitment process is random to tourist and residents in these areas. The survey comprises five sections (1) Background information of the respondent. (2) Attitudinal scale towards shrimp cultural heritage. (3) Connection with fishery (4) The choice experiment and (5) socio-demographic information.

The first section corresponds to the background of the interviewer, reasons to travel, the federal state where they come from and, for tourists, the duration of their stay. The second section refers to an attitudinal sale to asses shrimp cultural heritage values. This scale is based on Choi et al. (2007), they identified variables to explain the multidimensional nature of cultural values. I adapted their attitudinal scale to the shrimp cultural heritage context, and added important aspects mentioned in Martino et al. (2023) regarding socio-economic dimensions. The attitudinal scale comprises (a) Intercommunity and intergenerational linkages (b) Recognition of diverse cultural values (c) Awareness of cultural loss (d) Preservation of traditions and customs (e) Economic, environmental and social dimensions. All statements are assessed in a scale from 1 (strongly disagree) to 5 (strongly agree). Before starting the section regarding attitudinal scale, the participant received information about the meaning of shrimp marine cultural heritage. The definition, derived from Khakzad and Griffith (2016), refers to tangible and intangible values associated with shrimp fishing. To ensure clarity, examples of these intangible values were given to the participant. The third section refers to the reasons to visit or live in the town, connections to fishery, and importance of the harbour. The four section corresponds to the DCE and the fifth addresses to socio-demographic information. The survey is available in the section 4.A.

4.3.2 Discrete choice experiment

The DCE is designed to estimate the expected price premiums that consumers are willing to pay for specific characteristics of a shrimp food meal with a side. The goal is to model consumer preferences from a set of value chain attributes of a good. Choice sets are presented to the respondents with exclusive combination of attributes, requiring them to make trade-offs among alternatives. The consumers then chose the alternative that maximized their utility, allowing for the identification of attributes influencing consumer decisions. This process enables the inference of Willingness To Pay (WTP) for changes in those attributes. In this situation, the consumer faces a utility maximization problem over attributes, with individuals allocating their income to attain the optimal combination of attributes. This methodology enables a relevant comparison between various goods and state an unbiased metric for gauging preferences over attributes. Consequently, it is widely utilize as a tool for evaluating the value of non-marketed goods and services and determining product prices (Mariel et al., 2021).

In this study a shrimp meal with a side is the vehicle trough which the value of cultural heritage is assessed. The attributes of the shrimp meal that participants evaluate in the CE are: 1) *the origin of the shrimp*, if it is locally produced or imported. 2) *The processing of the fish* if it is fresh or frozen. 3) *The harvesting process* distinguishes between small-scale inshore fishing, carried out by local traditional vessels or foreign vessels. 4) *The certification* refers to the sustainable fishing label as an environmental protection measure, with a comparison between certified and non-certified fisheries (Cerjak et al., 2014). 5) *The heritage* refers to the visual aspect of inshore shrimp fishing, exploring the cultural experience of access to visibly active fishing boats at docks versus limited access due to waterfront development for residential and non-fishing commercial purposes. 6) *The payment vehicle* used to calculate monetary trade-offs concerning a shrimp meal with a side. The payment attribute is based on the market price of a shrimp meal with a side for 23 euros. Two higher levels includes 30 and 35 euros, and a lower level of 15 euros. The increase of 30% and 50% is based on Menozzi et al. (2020) regarding a study for preference of sea food with environmental labels in Europe[8].

These attributes were based on previous studies by Durán et al. (2015), Martino et al. (2023) and Verbeke et al. (2016). Certain attribute combinations posed challenges for participants who lacked familiarity with shrimp fishery. For instance, a product which is imported and fresh. In such cases participants were explained that the shrimp could be imported from The Netherlands and still arriving fresh to Germany. Another combination was a product locally produced with a foreign vessel, possible case with a local/national company that employs vessels from The Netherlands. These cases were clarified so that

[8]Menozzi et al. (2020) include an increase of 30% of the average price market for an environmental sea food label. The increase up to 50% corresponds to the case of a product also produced locally.

participants could make informed decisions.

The participants were informed that the baseline or status quo (option C) does not mirror the present cultural heritage associated with shrimp consumption. It was explained as a hypothetical scenario intended to serve as a baseline, portraying the least favoured combinations of characteristics of a shrimp dish. In comparison to the baseline, I expect that the alternative levels exhibit positive and significant values. Each choice card present the levels in table 4.1. The design consists of 16 choice cards divided into 4 blocks (each with four cards). Participants were assigned randomly to one of these blocks, enabling each respondent to make four choices, each one among three alternatives (A, B or C). The design of the choice cards was performed using R software following Aizaki and Nishimura (2008) ensuring a D-efficient design and non-dominated solutions (See Figure 4.2). I assessed the D-efficiency value, indicating a minimal degree of correlation among attributes in the design.

Attribute	Description	Levels
Origin	Country where the shrimp is harvested	Locally produced or Imported
Processing	State of the shrimp before cooking	Fresh or frozen
Harvesting	The practice that relates catching with local vessels (*krabenkutter*) operating inshore versus foreign vessels.	Local vessel or foreign vessel
Environmental certification	Shrimp harvested with a environmental conditions and received a eco-label	Sustainable certified or no-sustainable
Heritage	Visual attribute of inshore fishing that relates to the possibility to enjoy cultural aspects such as access to visibly active shrimp fishing vessels operating at docks compared to a situation where access to the waterfront is restricted to areas redeveloped for residential and non-fishing commercial uses.	Waterfront development or fishing heritage
Price	The willingness to pay for a shrimp meal with a side at a restaurant.	€15, €23, €30, €35

Table 4.1: Attributes for each choice card with description and levels.

Figure 4.2: Choice Card for the participant in the experiment

4.3.3 The logit model

The DCE is analysed using the Random Utility Theory. The conceptual theory is based on a scenario in which a person or decision-maker faces a choice (or choices) over a set of alternatives, each characterized by certain attributes. A decision-maker n faces a choice among J alternatives. The decision-maker n derives a specific level of utility from each alternative j, denoted U_{nj}, $j = 1, ..., J$. The decision-maker chooses the alternative that provides the greatest utility, choosing an alternative i if and only if $U_{ni} > U_{nj} \forall j \neq j$.

This utility is known to the decision-maker but not to the researcher; therefore, it comprises an observed component V_{nj} and a random stochastic component ϵ_{nj}. Hence:

$$U_{nj} = V_{nj} + \epsilon_{nj} \tag{4.1}$$

Often, the observed part of the utility is specified in linear parameters, where x_{nj} is a vector of variables that relate to alternative j as faced by the decision maker n, and β is a vector of coefficients for these variables. The error term, ϵ_{ni}, is assumed to be independent of β and x_{nj} :

$$U_{nj} = \beta x_{nj} + \epsilon_{nj} \forall j \tag{4.2}$$

The key assumption is that each decision maker will chose the alternative that provides the highest utility. The probability that the decision-maker n chooses the alternative i is:

$$P_{ni} = Prob(U_{ni} > U_{nj} \forall i \neq j)$$
$$P_{ni} = Prob(V_{ni} + \epsilon_{ni} > V_{nj} + \epsilon_{nj} \forall i \neq j)$$
$$P_{ni} = Prob(\epsilon_{nj} - \epsilon_{ni} > V_{nj} - V_{ni} \forall i \neq j)$$

Multinomial logit Model (MNL)

The MNL model assumes that consumers are homogeneous in terms of taste in the population. The error term is independently and identically distributed (i.i.d) with an extreme value distribution, such that $\epsilon_{nj} - \epsilon_{ni}$ follows a logistic distribution. Hence, the probability that a decision maker n chooses the alternative i is:

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_j e^{V_{nj}}} \tag{4.3}$$

This probability is usually estimated using the Maximum likelihood method. The MNL, however, has some limitations such as: (1) the proportional substitution among alternatives implied by the Independence of Irrelevant Alternatives (IIA) assumption; (2) Assumption of preference homogeneity in the sample, implying that coefficients of attributes in the utility function remain the same across all respondents; and (3) assumption of independent errors over time.

Random Parameter Mixed Logit (RPML)

The RPML overcomes the limitations of the MNL, especially when heterogeneity in preferences within the population is expected. The RPML allows for a continuous form of preference heterogeneity, such that the utility coefficients can vary across individuals according to a probability distribution function. This model allows variability of preferences for attributes across individuals and random taste variation, identifying how preferences vary within a population. Unlike the MNL, the RPML is unrestricted of the IIA assumption, i.e, it does not imply proportional substitution across alternatives. The RPML defines a density for the β coefficients with θ referring to parameters of the density function, such as the mean and variance. The unconditional choice probability under this density is the integral of equation 4.3 over all possible values of β_n (See equation 4.4). Where β_n is the vector of coefficients for each x_{nj} varying over decision-makers n rather than being fixed. The utility is specified as: $U_{nj} = V_{nj} + \epsilon_{nj} = \beta_n x_{nj} + \epsilon_{nj}$.

$$P_{ni} = \int \left(L_{ni}(\beta)\right) f(\beta \mid \theta) d\beta \tag{4.4}$$

Where

$$L_{ni}(\beta) = \frac{e^{\beta' x_{ni}}}{\sum_j e^{\beta' x_{nj}}} \tag{4.5}$$

There are no closed form solutions for equation 4.4; hence, the probabilities are approximated through simulation techniques for any given value of θ. The simulation involves three steps: (1) Draw R values of β from $f(\beta \mid \theta)$, labelled as β^r; (2) Calculate the logit formula (Equation 4.5) with each draw; (3) Repeat first and second step many times and average the results. The simulated probability is the average of these calculations, given by $\check{P}_{ni} = (1/R) \sum_{r=1}^{R} L_{ni}(\beta^r)$. This $\check{P}_{ni}$ is then entered into the log-likelihood function, resulting in a simulated log-likelihood (SLL):

$$SLL = \sum_{n=1}^{N} \sum_{j=1}^{J} d_{nj} ln \check{P}_{nj} \tag{4.6}$$

Where $d_{nj} = 1$ if n chooses j and zero otherwise. The maximum simulated likelihood estimator is the value of θ that maximizes SLL. A generalized version of this specification accounts for repeated choices by each respondent. In this study, each respondent n faces t number of choice situations. The utility is then represented as $U_{njt} = \beta_n x_{njt} + \epsilon_{njt}$, with ϵ_{njt} being i.i.d extreme value over choice situation t, respondents n and alternatives j.

Conditional on β, the probability that the person makes this sequence of choices is the product of logit formulas:

$$\mathbf{L}_{n\mathbf{i}}(\beta) = \Pi_{t=1}^{T} \left[\frac{e^{\beta_n x_{ni_t t}}}{\sum_j e^{\beta_n x_{njt}}} \right] \tag{4.7}$$

The unconditional probability is the integral of this product over all values of β: $P_{n\mathbf{i}} = \int \mathbf{L}_{n\mathbf{i}}(\beta) f(\beta) d\beta$. Where $\mathbf{i}$ represents a sequence of alternatives, one for each choice situation t ($\mathbf{i} = \{i_1, .., i_T\}$). The parameters of the model are estimated using a maximum likelihood estimation technique.

The marginal Willingness To Pay (WTP) for each attribute is determined by the change in price (considering price as an attribute) associated with a unit increase in that attribute. WTP represents the value that the average respondent n is willing to pay for an increase of one unit in the given attribute. Recall that the coefficient of the attribute corresponds to each element in the β_n's vector.

$$WTP = \frac{\beta_{attribute}}{\beta_{price}} \tag{4.8}$$

The utility function used in this design is defined by:

$$\begin{aligned} U_{njt} = \beta_0 + \beta_1 + \beta_3 Price_{njt} + \beta_4 Origin_{njt} + \beta_5 Processing_{njt} + \\ \beta_6 Harvesting_{njt} + \beta_7 Certification_{njt} + \beta_8 Heritage_{njt} + \epsilon_{njt} \end{aligned} \tag{4.9}$$

The coefficients β_0 and β_1 represent Alternative Specific Constants (ASC), which are dummy variables indicating the selection of alternative B or C relative to alternative A. The willigness to pay (WTP) values are subsequently derived by implementing the MNL and the RPML models using the utility function described in equation 4.9. These models are implemented in R software, following Croissant (2020).

4.4 Results

4.4.1 Descriptive Statistics

Most of the participants in the survey were tourists, with over 80% from the towns of Büsum and Greetsiel (Table 4.2). The sample included ninety five locals, of whom fifty three were from Cuxhaven. Sixty-five participants did not provide information about their income, while among those who did, an average of 49% reported earning more than €40.000 per year. Less than 13% of respondents, on average, reported a connection to the fisheries sector, either through relatives or contacts in the fishing industry; however, this connection was more prevalent in Ditzum and Cuxhaven. In the hypothetical scenario with no more shrimp fishing and neither vessels on the harbour, over 70% of participants reported they would *come back* to these towns, with Ditzum showing the lowest proportion and Cuxhaven the highest. Most respondents came from the states of Niedersachsen and North Rhine-Westphalia, accounting for 38% of the sample (See section 4.8).

	All	Büsum	Ditzum	Greetsiel	Cuxhaven
Age	54.414	52.752	58.852	54.971	53.301
Female %	0.550	0.523	0.419	0.600	0.594
Tourist %	0.765	0.872	0.774	0.857	0.602
Education	13.459	12.596	14.918	13.942	13.120
Income	3.603	3.876	3.784	3.670	3.692
Connection %	0.125	0.083	0.194	0.076	0.165
Come Back %	0.778	0.844	0.452	0.724	0.917
Sample Size	409	109	62	105	133

Table 4.2: Descriptive statistics of the sample per town. *Age* displays the average values per town. *Female* indicates the percentage of women, while *Tourist* represents the percentage of people who were tourists. The variable income is a categorical variable ranging from 1 to 6 increasing by €10.000 starting in €20.000 as income per year before taxes. *Education* represents the years of education. *Connection* illustrates the percentage of people who claim to have a connection with fisheries, either through relatives or work-related contacts in the fishing industry. The variable *connection* takes the value of 1 if the person had some connection with fishing and zero otherwise. *Come back* reflects the percentage of people who intend to return to the town even if there is no longer any shrimp fishing cultural heritage available for tourists.

Participants' reasons for living in or visiting these towns varied between towns (Table 4.3). Nature emerged as the most important reason for the participants, encompassing activities such as hiking, biking, walking, and sightseeing. Cuxhaven and Büsum recorded the highest averages, with a statistically significant difference between the towns. Water activities followed a similar trend to nature, largely due to the beach proximity of Cuxhaven and Büsum, which serves as a major attraction for tourists. Additionally, Work-related reasons showed significant differences among towns with Cuxhaven having the highest proportion of participants who live or visit for work purposes.

Visit	Ditzum	Greetsiel	Cuxhaven	Büsum	F Value	P value
Work	1.45	1.34	1.96	1.34	4.823	0.029
Family	2.93	1.56	2.47	1.68	0.097	0.756
Fishery	3.53	3.70	3.51	3.60	0.391	0.532
Food	3.63	3.37	3.38	3.39	0.263	0.608
Nature	3.95	4.81	4.69	4.87	7.874	0.005
Water Activities	2.20	2.29	3.02	3.35	38.790	0.000

Table 4.3: The rows show the purpose of the visit per town. The numbers indicate the average from the scale 1 (not important) to 5 (very important). Last two columns show the F-test and P-Value regarding significant differences among towns.

4.4.2 Cultural heritage preferences

Table 4.4 presents the results of the attitudinal scale towards the shrimp cultural heritage across five factors. Factor one, intercommunity and inter-generational linkages, showed significant higher values for towns with the campaign. Similarly, factor two, recognition of diverse cultural values, reported higher values for campaign towns, though only three of the four items were statistically significant. Factors three and four reported no statistical difference among towns with and without the campaign, with Büsum reporting the highest average for preserving cultural traditions in factor four. Finally, factor five showed significantly higher values for towns with a visible campaign, with Ditzum scoring the highest average regarding environmental and soci-economic dimensions.

Among all items, the highest average score was regarding the affirmations: (1) "Local shrimp fishing is important to be done sustainably respecting living and non-living resources in the sea", (2) "It is important to maintain maritime cultural heritage", and (3) "We do need to conserve the shrimp cultural heritage for future generations". This result showed that respondents gave the highest importance to sustainability of the fishing practice, as well as to maintaining this practice for future generations.

#	item	All	Ditzum	Greetsiel	Büsum	Cuxhaven	F-Test-All	F-Test-Campaign
1	It is important to maintain maritime cultural heritage	4.69	4.77	4.72	4.71	4.62	1.454	2.462
	Factor 1: Intercommunity and intergenerational linkages							
2	I am glad because shrimp cultural heritage is available to me	4.31	4.56	4.45	4.27	4.11	5.417**	13.456***
3	We do need to conserve the shrimp cultural heritage for future generations	4.50	4.73	4.59	4.45	4.37	3.914**	9.772**
4	The cultural values present in the Shrimp fishery heritage of our forefathers are important to me.	4.00	4.15	4.07	3.99	3.87	1.424	3.105*
	Factor 2: Recognition of diverse cultural values							
5	Shrimp fishing heritage helps me to identify myself	2.44	3.02	2.50	2.27	2.26	5.242**	9.755**
6	We need to take care about shrimp cultural heritage	4.25	4.53	4.32	4.28	4.04	4.901**	8.169**
7	We have the right to destroy the shrimp cultural heritage to suit our needs	1.33	1.48	1.36	1.17	1.35	1.970	2.454
8	I recognize the existence of shrimp cultural heritage in this town (in food, vessels, architecture)	3.98	4.15	4.28	4.07	3.59	10.176***	16.139***
	Factor 3: Awareness of cultural loss							
9	If things continue on their present course, we will soon experience a major loss in shrimp fishery cultural heritage.	3.97	3.84	3.97	4.09	3.94	1.011	0.793
10	The shrimp fishery cultural heritage is disappearing	3.25	3.42	3.17	2.99	3.45	3.347*	0.052
	Factor 4: Preservation of traditions and customs							
11	I want to know the traditions of our grand parents who practice the shrimp fishery	3.30	3.37	3.12	3.47	3.28	0.741	0.725
	Factor 5: Economic, environmental and social dimensions							
12	Local shrimp fishing it is economically important for the fishers	4.45	4.63	4.63	4.44	4.24	7.614***	17.829***
13	Local shrimp fishing is a tourist attraction, i.e. instrument for local economic development	3.95	4.37	4.20	4.14	3.41	19.794***	25.049***
14	Local shrimp fishing reminds me about the connection with the sea/environment	4.00	4.52	4.06	3.97	3.73	8.347***	13.613***
15	Local shrimp fishing influences the character of the place through buildings, symbols, traditions, etc. It is part of the cultural heritage.	4.12	4.43	4.39	4.09	3.79	11.443***	27.259***
16	Local shrimp fishing is important to be done sustainably respecting living and non-living resources in the sea.	4.76	4.84	4.82	4.80	4.63	3.303*	4.500*

Note: *p<0.1; **p<0.05; ***p<0.01

Table 4.4: Average values of the survey regarding the attitudinal scale towards the shrimp cultural heritage. The scale from one to five, where (1) means: "I do not agree at all with the statement" and (5) means "I agree totally with the statement". The column F-Test-All shows the F-test for significant differences among towns. The last column (F-Test-Campaign) indicates significant differences regarding the presence of the campaign, high visible and low visible campaign (Ditzum and Greetsiel vs Büsum and Cuxhaven).

Based on the attitudinal scale results, I conducted a Hierarchical Cluster Analysis (HCA) to categorize individuals based on their preferences for shrimp cultural heritage, as outlined by Choi et al. (2007). I employed the Ward method that produces the high-

	Dependent variable:	
	Preferences for cultural heritage (Pro-Heritage)	
	(1)	(2)
Female	-0.088	-0.090
	(0.214)	(0.235)
Age	0.013*	0.018**
	(0.007)	(0.007)
Education	-0.072**	-0.084**
	(0.034)	(0.039)
Income		-0.029
		(0.073)
Campaign	0.626***	0.461*
	(0.225)	(0.250)
Fix Income	0.385	0.292
	(0.298)	(0.321)
Tourist	-0.247	0.018
	(0.254)	(0.276)
Constant	0.213	0.219
	(0.708)	(0.760)
Observations	395	334
Log Likelihood	-257.973	-215.587
Akaike Inf. Crit.	529.945	447.174
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 4.5: Logit estimation regarding preferences for cultural heritage. Female takes the value of one for women. Campaign has the value of one for towns with a visible campaign. Tourists the value of one if the respondent is a tourist. Fix income, corresponds to one if the person either is retired or employed ans zero otherwise.

est agglomerative coefficient, resulting in a better fit than other methods. The squared Euclidean distance served as the measurement of the distance matrix. According to the clustering gap statistic, the optimal number of clusters was five; however, the gap statistic was very similar for two or five clusters. For ease of analysis, I divided the sample in two clusters: Individuals with (a) High preferences (pro-heritage) and (b) Low preferences for shrimp cultural heritage (No pro-heritage) attitudes.

I performed a logistic regression to identify individual explanatory characteristics related with pro-heritage attitudes (Table 4.5). The dependent variable is coded as one if the individual belongs to the cluster with a high preference for shrimp cultural heritage (pro-heritage) and zero otherwise. The results indicate a significant correlation between older individuals and those less educated with higher cultural preferences. In the sample, the variables of age and years of education were negative and significantly correlated, i.e, on average, older people were less educated (correlation=-0.21, p-value = 1.433e-05). Additionally, individuals located in towns with a visible campaign showed a positive correlation with a higher attitude towards shrimp cultural heritage, indicating a higher probability of belonging to the pro-heritage group. This finding suggests that the campaign visibility may influence cultural preferences.

4.4.3 Choice experiments results

The Multinomial Logit Model

The results of the MNL model show that the null hypothesis that the coefficients are zero is rejected, and all the coefficients of the multinomial model are statistically significant at the 1% level (Table 4.6). The alternative specific constants for choices A and B indicate changes in utility relative to alternative C. Results indicate that, on average, respondents prefer choices A or B over alternative C. This implies that, overall, people prefer a shrimp dish with at least one of the attributes over having none of them. The coefficient of the price is negative, as expected, indicating that an increase in price leads to lower utility and a decreased likelihood of purchase.

	Estimate	Std. Error	z-value	Pr(>$\mid z \mid$)
Choice A	1.053	0.159	6.622	0.000
Choice B	1.184	0.152	7.744	0.000
Price	-0.07	0.008	-8.832	0.000
Origin	0.721	0.069	10.44	0.000
Processing	0.489	0.08	6.135	0.000
Harvesting	0.694	0.076	9.139	0.000
Certification	0.814	0.085	9.573	0.000
Heritage	0.312	0.079	3.963	0.000
N	4896			
Log likelihood	-1435.233			
R^2	0.096			

Table 4.6: Multinomial Logit Model estimates

Random Parameters Mixed Logit (RPML)

In contrast to the MNL, the Random Parameters Mixed Logit (RPML) model allows for heterogeneity of preferences among consumers. In this application, the coefficients estimated in the RPML are assumed to follow a normal distribution. A comparison of the two models reveals that RPML fits the data better. Specifically, the log likelihood of the RPML is lower than that of the MNL, indicating that the RPML model more accurately predicts the respondents' choices. Additionally, the McFadden R^2 value for the RPML is higher than that of the MNL, further supporting the better fit of the RPML. Notably, the standard deviations of each attribute in the RPML are significantly different from zero, suggesting that respondents exhibit preference heterogeneity with respect to these attributes. This finding also implies that the assumption of Independence of Irrelevant Alternatives (IIA) does not hold for the observed population.

	Estimate	Std. Error	z-value	Pr(>| z |)
Choice A	1.170	0.223	5.238	0.000
Choice B	1.404	0.212	6.622	0.000
Price	-0.085	0.011	-7.489	0.000
Origin				
Mean	0.973	0.109	8.938	0.000
St. dev.	1.034	0.209	4.947	0.000
Processing				
Mean	0.611	0.115	5.318	0.000
St. dev.	0.793	0.297	2.670	0.008
Harvesting				
Mean	0.904	0.119	7.570	0.000
St. dev.	1.066	0.245	4.348	0.000
Certification				
Mean	1.244	0.155	8.046	0.000
St. dev.	1.156	0.254	4.557	0.000
Heritage				
Mean	0.400	0.108	3.701	0.000
St. dev.	0.831	0.241	3.442	0.001
N	4896.000			
Log likelihood	-1405.118			
R^2	0.115			

Table 4.7: Random Parameters Mixed Logit Model Estimates

The means and standard deviations per attribute stated in table 4.7 provide information about the share of respondents with a positive probability value for each attribute. Overall, 83% percent of the respondents have a positive likelihood for choosing a shrimp dish produced locally (origin), 77% with a fresh attribute (processing), 80% with a local vessel attribute (harvesting), 86% with a certification attribute (certification), and 68% with a heritage attribute (heritage). This implies that their utility increases when choosing a shrimp dish with any of these attributes.

Willingness to Pay for each attribute

The WTP estimates for the MNL and the RPML shows that certification is the attribute for which consumers are willing to pay the most, followed by local shrimp (origin=1), harvested by a local vessel (Harvesting=1) (Table 4.8). Conversely, the heritage attribute has the lowest WTP in both models, suggesting that, consumers are willing to pay €4.5 more for a shrimp dish with a heritage attribute.

	MNL	RPML
Origin	10.288	11.431
St. dev.		12.146
Processing	6.975	7.184
St. dev.		9.322
Harvesting	9.904	10.617
St. dev.		12.527
Certification	11.625	14.612
St. dev.		13.585
Heritage	4.458	4.704
St. dev.		9.764

Note: All values are statistically significant at 1% level.

Table 4.8: Mean and standard deviation of WTP estimates of the MNL and RPML model (Unit €)

The RPML model results show high standard deviations for the WTP per attribute, indicating a high variance in the data (Table 4.8). This suggests that individual preferences or the influence of the campaign may play a role in the WTP per attribute.

Heterogeneity Analysis

I divided the sample into sub-groups to gain a deeper understanding of the WTP (Table 4.9). The first split categorized participants based on pro-heritage and no pro-heritage attitudes, while the second split the respondents from towns with and without the campaign. Among all the sub-groups, the certification attribute demonstrated the highest WTP, except for the campaign group, where it ranked second after the origin attribute. Respondents from campaign towns showed the highest WTP for all attributes, followed by those with pro-heritage attitudes. Overall, participants had the lowest WTP for a shrimp dish with a heritage attribute, except for the campaign group, where it ranked second to last. This indicates that people with pro-heritage attitudes and located in camping towns are willing to pay more for any shrimp dish attribute than people with low heritage preferences and located in towns with less campaign visibility.

	Pro-Heritage	**No Pro-Heritage**	**Campaign**	**No-Campaign**
Origin	18.347	5.923	24.511	7.194
Processing	9.123	5.402	9.462	6.278
Harvesting	19.344	5.099	19.685	6.624
Certification	19.418	9.940	21.441	11.599
Heritage	8.634	1.946	9.643	2.547
Observations	227.000	169.000	166.000	242.000

Table 4.9: Mean estimates of WTP for sub-groups (Unit €) using the RPML model. The first two columns show the WTP with the whole sample divided in pro and no-pro heritage groups. The last two columns show the results of the WTP with the sample divided in respondents located in campaign and no-campaign towns.

The composition within the groups can affect the WTP. From the respondents located in campaign towns 62% were classified with pro-heritage attitudes, a fact that could explain the highest WTP for the heritage attribute in the campaign towns. Furthermore, within the no-campaign group, 51% belonged to the pro-heritage group, i.e, half of the participants in no-campaign towns exhibited pro-heritage attitudes. This is in line with results from table 4.5 showing the positive significant correlation between the presence of the campaign and the pro-heritage attitudes.

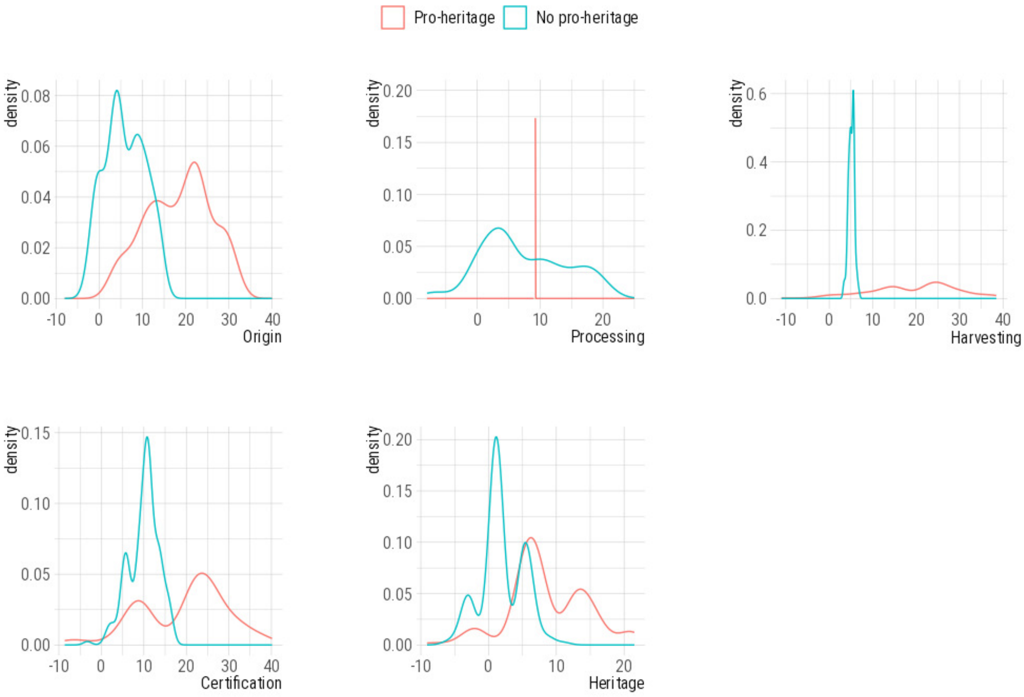


Figure 4.3: Kernel density functions for individual WTP per attribute with pro-heritage and No pro-heritage groups.

The kernel density functions illustrate the distributions for individual WTP for each attribute (Figures 4.3 and 4.4). Individuals with pro-heritage attitudes exhibited higher WTP with more density in the tails for almost all attributes, compared to the no pro-heritage group. The processing attribute was an exception, all people with pro-heritage attitudes were willing to pay a similar amount for a shrimp dish characterized by freshness. In contrast, the harvesting, certification and heritage attributes showed a WTP with more density in the center for individuals in the no pro-heritage group, who were willing to pay less and similar amounts for shrimp harvested with a local vessel, with a sustainable certification and cultural heritage attributes.

Similarly to the pro-heritage group, participants from campaign towns had a WTP with higher density in the tails compared to those from no-campaign towns. Interestingly, respondents in campaign towns were willing to pay a similar amount for a shrimp dish with a heritage attribute, which contrast with the pattern in the pro-heritage group, where the density of the WTP was higher in the tails. The processing attribute showed a WTP with higher density in the center for the non-campaign group, contrasting with the no

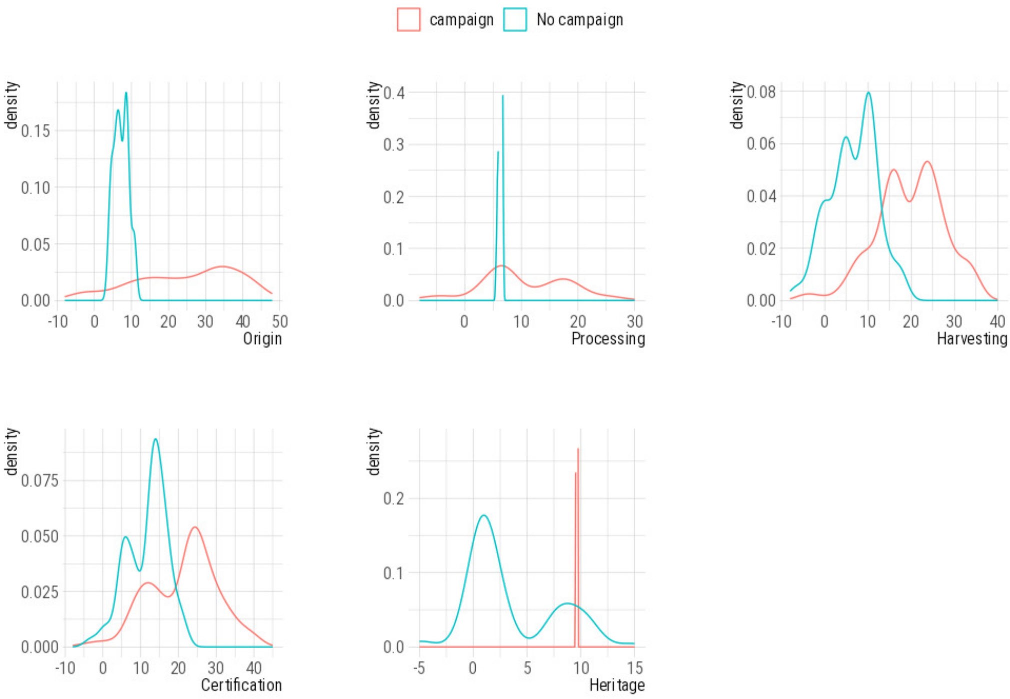


Figure 4.4: Kernel density functions for individual WTP per attribute with Campaign and no-campaign groups.

pro-heritage group, where the density was higher in the tails.

	Pro-heritage	No pro-heritage	p-Value	Campaign	No Campaign	p-Value
Female %	0.535	0.562	0.626	0.531	0.557	0.662
Age	56.722	51.385	0.001	56.208	53.262	0.069
Education	13.084	13.827	0.028	14.165	12.890	0.000
Income	3.572	3.688	0.548	3.707	3.571	0.478
Fix Income	0.873	0.787	0.020	0.838	0.835	0.846
Tourist %	0.768	0.769	0.969	0.831	0.726	0.011

Table 4.10: Descriptive statistics for differences between sub-groups. The p-value show the statistics results of the t-test mean differences between sub-groups.

The demographic heterogeneity between sub-groups can explain differences in WTP (Table 4.10). Respondents in the campaign and no-campaign towns were significantly different in age, education, and percentage of tourists. The age difference was driven by Ditzum, with the highest average among all towns (See table 4.2). Education was significantly different between sub-groups, but between the campaign and no-camping group it was higher than the pro and no-pro-heritage group. The significant difference of percentage of tourists between campaign and no-campaign groups was driven by Cuxhaven, where nearly 40% of respondents were locals.

4.5 Discussion

This study provides insights into consumer preferences for shrimp seafood in Germany through a choice experiment. The findings reveal that the cultural heritage of the German brown shrimp fishery increases the utility of consumers when purchasing a shrimp dish. On average, respondents are willing to pay an additional amount of €4.7 for a shrimp dish that includes a heritage attribute. Moreover, consumers increase their utility by choosing a shrimp dish with any of the evaluated attributes compared to none of them. The results are novel, since this is the first study in Germany evaluating the value of shrimp cultural heritage, one of the oldest fishing techniques in the North Sea.

Additionally, I found a significant correlation between willingness to pay and pro-heritage attitudes, particularly in relation to the high visibility of an awareness-raising fishing campaign conducted by local fishers during this study. The visibility of the campaign differed between the towns of Greetsiel and Ditzum compared to Cuxhaven and Büsum. As a result, respondents in the former two towns exhibited stronger attitudes towards cultural heritage than those in the latter. While causality is not established (i.e., respondents valuing the brown shrimp cultural heritage might have chosen to visit these areas), this study, is the first to demonstrate the correlation of a cultural heritage campaign with the willingness to pay for a heritage attribute in seafood consumption.

The campaign started after the speech of the Agriculture Minister in March 2023. Although this study was performed four months after, the campaign was still active for the summer period, the most touristic time in the year. The visibility of the campaign was mainly concentrated in the harbours of the towns and was influenced by factors such as town size and purpose of tourists' visits. Ditzum and Greetsiel are small towns, each covering an area of less than $15km^2$ and populations under 1.500 inhabitants. Both towns are feature harbours located in the city center, which area among the most visited spots for tourists. In Ditzum and Greetsiel the campaign was located in front of the harbours, having a high visibility by tourists. Neither of these towns has an open sea or beach highly visited by the tourists. Conversely, Büsum and Cuxhaven are known for their beaches and water activities, which serve as major tourist attractions and are statistically different from the campaign towns (see Table 4.3). In Cuxhaven the beach is located $7km$ away from the harbour, which could decrease the probability of visitors going to that area. These factors may influence the visibility of the campaign by tourists.

Campaigns are well-known to increase consumers' WTP. Companies often use marketing campaigns to promote products and attract more customers, inducing them to increase their WTP. Some campaigns use moral causes such as ethical narratives related to fair trade, sustainable/green, local product or charity causes, which can impact purchasing probabilities (Park KC, 2018). Additionally, non-profit organizations like UNESCO conduct campaigns to raise awareness about the world cultural heritage sites, thereby enhancing peoples' willingness to engage in conservation activities(Mastura Jaafar and Rasoolimanesh, 2015). The results of this study align with existing literature, as they reveal a significant correlation between responses in campaign sites and higher WTP. Pro-heritage attitudes likely serve as the mechanism through which the campaign influences WTP, given the significant correlation between these attitudes and the campaign's visibility.

The heterogeneity analysis aims to identify the differentiated effects of the campaign versus the attitudes of the participants, although both effects are significantly correlated. Yet, the analysis give insights into differences in WTP per sub-groups. The size of the sub-samples, however, is considered small. Given the characteristics of the design, the minimum sample size for this study is $N = 125$ and the sub-groups size range between 166 and 242 participants[9]. The small sample size can explain the high variability in WTP's densities when comparing campaign and no-campaign versus pro-heritage and no-pro-heritage subgroups. Although the differentiated effect of the campaign on WTP is not exactly established, in this study I show that the campaign may influence the WTP since respondents in campaign towns have the highest WTP among all sub-groups, and yet 60% of the participants in these towns reported having high pro-heritage attitudes.

The results of the attitudinal scale show that older and less educated individuals are significantly correlated with higher preferences for shrimp cultural heritage. In the sample,

[9]The minimum sample size rule widely accepted in choice experiments is given by $N \geq 500\frac{L^{max}}{JS}$, where L^{max} is the largest number of levels for any of the attributes, J the maximum number of alternatives, and S the number of choice sets each respondent receives (Assele et al., 2023). The values in this study are: $L^{max} = 4$,$J = 3$, and $S = 4$.

older people are generally less educated than younger generations. The correlation among age and years of education is negative and significant (corr= - 0.21 p-value=0.00001). The mean age of the sample in these towns is 54 years with a median of 58 (SD=16). A possible explanation for older people to be more pro-heritage is that they may have more memories, through magazines or media, about this fishery, a plausible reason to visit these areas. However, besides this preference for heritage, the primary reason for visiting these areas is nature, followed by fishery in Greetsiel, Cuxhaven, and Büsum (See Table 4.3). This suggests that while heritage plays a role in attracting visitors, it is not the primary motivation. Interestingly, these findings align with those of Martino et al. (2023), whose study also revealed a higher preference for fishing cultural heritage among local and older individuals compared to younger ones.

Among the attributes evaluated, certification is the attribute for which the people is willing to pay the highest, followed by a product produced locally. This result is in line with (ibid.), where these two attributes also played the most important role in the WTP. Bronnmann et al. (2021) in a DCE with sea food in the Baltic Sea also found that the certification label in fish products has the highest WTP among other attributes analysed.Similarly, Menozzi et al. (2020) found that for herring, seabass and seabream, Germany is where environmental labels are more relevant among European countries. Zander and Feucht (2018) also found that European residents appreciate a fish produced locally and are willing to pay a price premium to compensate for the potentially higher production costs. These findings collectively highlight the importance of certification and local production in influencing consumer preferences and WTP for seafood products.

In this study, I show that brown shrimp cultural heritage is important for consumers, as they are willing to pay a premium price to preserve it. Although this WTP is the lowest among other attributes evaluated, yet it does not undermine its importance. This intangible good is currently overlooked in public opinion and policy reports. For instance, the reports by the European Parliament (Wilson, 2020) about the impact of Offshore Wind Farms (OWF) and other marine renewable on European fisheries. These reports discuss possibilities for the co-existence of Offshore Renewals (OR) and fisheries but lack awareness about the impacts on cultural heritage resulting from diminishing fishing activity. Stelzenmüller et al. (2021) mention that the effect of OWF could result in economic losses and socio-cultural impacts in fisheries, but they do not consider the loss in magnitude of cultural heritage.

There is an increasing awareness about the role of maritime cultural heritage, however, the studies are limited and fishing is still considered as a mere economic activity where accounted impacts are mainly in terms of profits or jobs. Urquhart and Acott (2013) mentions that fishing is a way of life that goes beyond the means to earn a living. Fishing contributes to a sense of place, i.e building historic environment and cultural heritage, it is a source of tourism and a way to keep old traditions alive. In this context, this research serves as a starting point to dive into the value of maritime cultural heritage in Germany. This study also aims to contribute to the public debate bringing a light on the possible consequences of cultural loss if there is an end of the brown shrimp fishery. Overfishing and climate change may lead to the extinction of a species, and similarly, the loss of maritime cultural heritage could reach a point of no return where the old fishing traditions are only preserved in books. These findings highlight the need for increased recognition and consideration of maritime cultural heritage in policy discussions and decision-making processes.

Future research can assess the influence of awareness-raising campaigns on the change of consumers preferences and also on the cultural resilience of fishers. The campaign can represent an adaptation method to keep the fishery alive despite the multiple challenges faced recently and in the past. Rotarangi and Stephenson (2014) mentions that cultural resilience refers to the ability of individuals to positively adapt despite adversity. Yet, the resilience and adaptation strategies can have further consequences in social and ecological systems. Further research can investigate the relationship between cultural attitudes, both by the society and fishers, and their consequence on the ecological and social systems. While (Quaas and Requate, 2013) already investigated the relationship between consumer preferences and ecological consequences, still the cultural aspect, specifically in fisheries socio-ecological systems remains under-investigated.

4.6 Conclusion

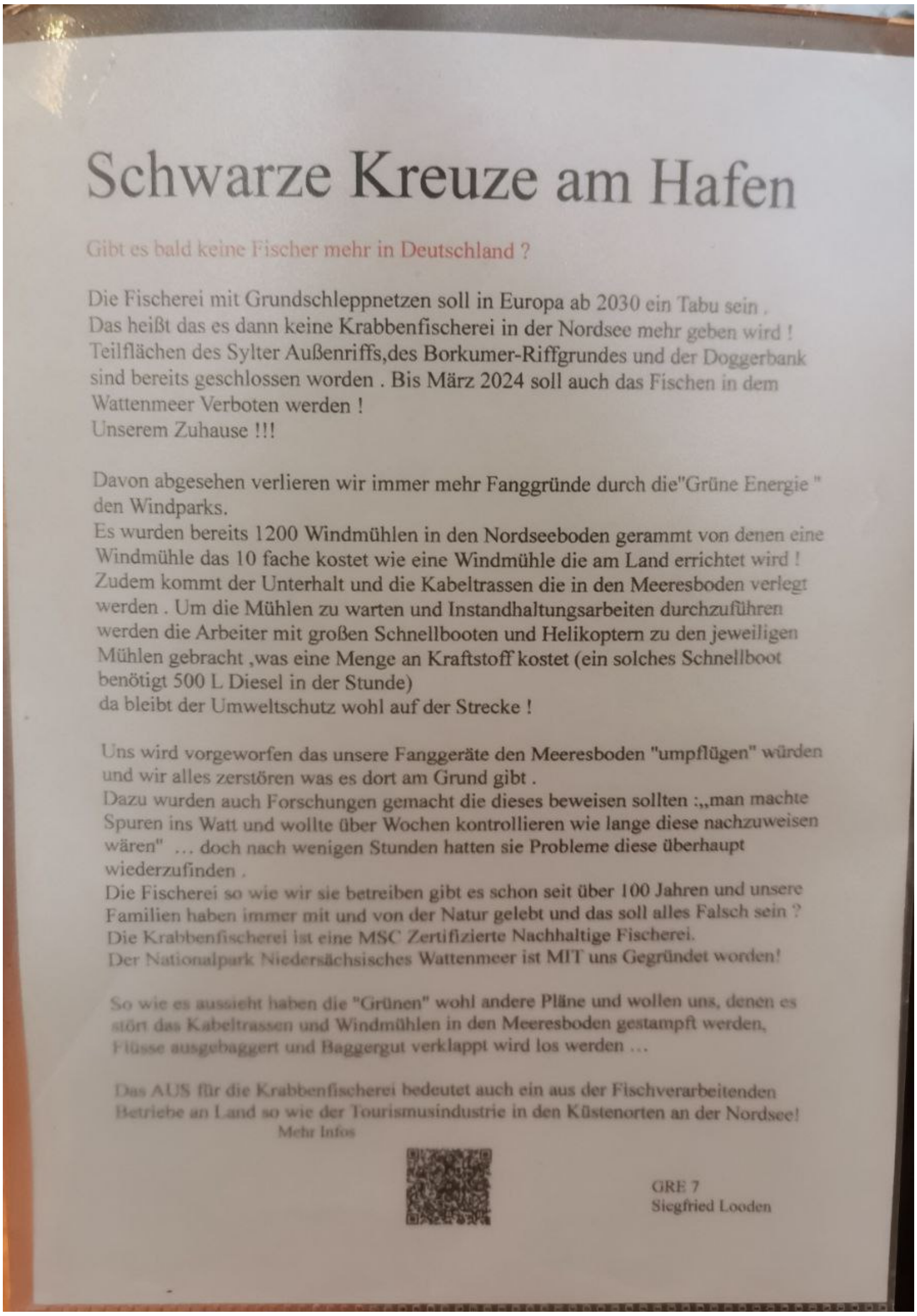
This study contributes to increase the socio-cultural knowledge of the brown shrimp fishery in Germany. The results show that, besides an economic benefit the existence of this fishery has a cultural heritage value, being one of the oldest fishing techniques in the North Sea. Residents and non-residents value the cultural heritage and are willing to pay a positive value to sustain it. Factors correlated with pro-heritage attitudes are age, education and the presence of a strong visual fishing campaign on the towns studied. Older and less educated people have higher pro-heritage attitudes towards maritime cultural heritage than younger participants. Notably, consumers exhibit the highest Willingness To Pay (WTP) for a sustainable certification attribute on the shrimp dish, aligning with existing literature, particularly in the European seafood market. The results of this is study shed light on the broader implications of fishing policies that go beyond the fishing activity. This study provides a wider picture to policy makers so that more informed decisions can take place.

4.A Field Work

Figure 4.5: Field work: Surveys during the summer of 2023.

4.B Awareness-raising campaign

Figure 4.6: Campaign of the shrimp fisheries in Ditzum and Greetsiel



Schwarze Kreuze am Hafen

Gibt es bald keine Fischer mehr in Deutschland ?

Die Fischerei mit Grundschleppnetzen soll in Europa ab 2030 ein Tabu sein .
Das heißt das es dann keine Krabbenfischerei in der Nordsee mehr geben wird !
Teilflächen des Sylter Außenriffs,des Borkumer-Riffgrundes und der Doggerbank sind bereits geschlossen worden . Bis März 2024 soll auch das Fischen in dem Wattenmeer Verboten werden !
Unserem Zuhause !!!

Davon abgesehen verlieren wir immer mehr Fanggründe durch die"Grüne Energie " den Windparks.
Es wurden bereits 1200 Windmühlen in den Nordseeboden gerammt von denen eine Windmühle das 10 fache kostet wie eine Windmühle die am Land errichtet wird !
Zudem kommt der Unterhalt und die Kabeltrassen die in den Meeresboden verlegt werden . Um die Mühlen zu warten und Instandhaltungsarbeiten durchzuführen werden die Arbeiter mit großen Schnellbooten und Helikoptern zu den jeweiligen Mühlen gebracht ,was eine Menge an Kraftstoff kostet (ein solches Schnellboot benötigt 500 L Diesel in der Stunde)
da bleibt der Umweltschutz wohl auf der Strecke !

Uns wird vorgeworfen das unsere Fanggeräte den Meeresboden "umpflügen" würden und wir alles zerstören was es dort am Grund gibt .
Dazu wurden auch Forschungen gemacht die dieses beweisen sollten :„man machte Spuren ins Watt und wollte über Wochen kontrollieren wie lange diese nachzuweisen wären" … doch nach wenigen Stunden hatten sie Probleme diese überhaupt wiederzufinden .
Die Fischerei so wie wir sie betreiben gibt es schon seit über 100 Jahren und unsere Familien haben immer mit und von der Natur gelebt und das soll alles Falsch sein ?
Die Krabbenfischerei ist eine MSC Zertifizierte Nachhaltige Fischerei.
Der Nationalpark Niedersächsisches Wattenmeer ist MIT uns Gegründet worden!

So wie es aussieht haben die "Grünen" wohl andere Pläne und wollen uns, denen es stört das Kabeltrassen und Windmühlen in den Meeresboden gestampft werden, Flüsse ausgebaggert und Baggergut verklappt wird los werden …

Das AUS für die Krabbenfischerei bedeutet auch ein aus der Fischverarbeitenden Betriebe an Land so wie der Tourismusindustrie in den Küstenorten an der Nordsee!

Mehr Infos

GRE 7
Siegfried Looden

Figure 4.7: Campaign letter of the shrimp fisheries in Ditzum and Greetsiel

4.C Origin of the respondents in the sample

Figure 4.8: Quantity of tourist respondents per origin of federal state. The number outside of the map (11) corresponds to foreigners from Netherlands, Denmark, Belgium and Switzerland.

4.D Survey Implemented in the study

MARITIMES KULTURERBE – UMFRAGE: #_____ Ort___________Kart______

Mein Name ist Emily Quiroga, ich bin Studentin an der Universität Hamburg. Ich führe ein Forschungsprojekt durch, in dem ich die Bedeutung des kulturellen Erbes der Nordseekrabbenfischerei untersuche. Ich würde gerne wissen, ob Sie Zeit haben, an einer Umfrage teilzunehmen. Die Umfrage wird etwa 15 bis 20 Minuten Ihrer Zeit in Anspruch nehmen. Die Fragen sind anonym und Sie können die Beantwortung jeder Frage verweigern und Ihre Teilnahme jederzeit beenden. Würden Sie gerne teilnehmen?

Abschnitt 1: Ihr Hintergrund

Sind Sie?

a) Ortsansässig, d. h. in dieser Stadt wohnhaft oder in einer Stadt/einem Dorf in der Nähe dieser Stadt wohnhaft, die/der regelmäßig (z. B. wöchentlich) in diese Stadt fährt?
b) ein Besucher
   - Aus welchem Bundesland kommen Sie? _____________
   - Warum sind Sie heute gekommen?
     (1) Berufliche Gründe
     (2) Familien Gründe
     (3) Sonstiges
c) Tourist, der hier einen Teil seines Urlaubs verbringt
   - Aus welchem Bundesland kommen Sie? _____________
     (Wenn es sich um Tourismus handelt, fahren Sie mit der nächsten Frage fort)
   - Wie viele Nächte bleiben Sie insgesamt hier? ____
   - Kommst du hierher als:
     (1) Alleine
     (2) Ehepaar
     (3) Familie
     (4) Gruppe von Freunden

Abschnitt 2: Verbindung zur Fischerei und Wissen über die Fischerei als kulturelles Erbe
Kulturelles Erbe der Nordseekrabben: Eine Reihe von materiellen und immateriellen Gütern, die mit der Krabbenfischerei verbunden sind und historische menschliche Aktivitäten in Küsten- und Meeresgebieten in der Vergangenheit, Gegenwart und Zukunft umfassen. Materiell: traditionelle Hafenanlagen, traditionelle Boote und Schiffe, die Fertigkeiten zu deren Bau und andere traditionelle Handwerkskünste sowie die Fischereiarchitektur wie Häuser, Docks und Lagerhäuser. Immateriell: Einheimische und das Wissen der Fischer.

Bitte wählen Sie bei den folgenden Aussagen den Grad der Zustimmung aus: 1 (stimme überhaupt nicht zu), 2 (stimme nicht zu), 3 (ich bin mir nicht sicher), 4 (ich stimme zu), 5 (ich stimme sehr zu).

	Aussagen	**1 stimme überhaupt nicht zu**	**2 stimme nicht zu**	**3 nicht sicher**	**4 stimme zu**	**5 stimme sehr zu**
	Allgemeine Aussagen zum maritimen Kulturerbe					
1	Es ist wichtig, das maritime Kulturerbe zu erhalten					
	Faktor 1: Interkommunale und generationenübergreifende Verbindungen 1					
2	Ich bin froh, dass das kulturelle Erbe der Nordseekrabben für mich verfügbar ist.					
3	Wir müssen das kulturelle Erbe der Krabbenfischerei für künftige Generationen bewahren?					
4	Die kulturellen Werte, die im Erbe der Krabbenfischerei unserer Vorfahren stecken, sind mir wichtig.					
	Faktor 2: Anerkennung der verschiedenen kulturellen Werte					
5	Füllen sie sich mit dem Erbe der Krabbenfischerei identifiziert					
6	Man darf nicht zulassen dass das kulturelle Erbe der Krabbenfischerei verloren geht.					
7	Wir haben das Recht, das kulturelle Erbe der Krabbenfischerei zu zerstören, um es unseren wirtschaftlichen Bedürfnissen anzupassen.					
8	Ich erkenne das kulturelle Erbe der Krabbenfischerei in dieser Stadt (in Form von Lebensmitteln, Gefäßen, Architektur)					
	Faktor 3: Bewusstsein für den kulturellen Verlust					
9	Glauben Sie, dass das kulturelle Erbe der Krabbenfischerei in der Zukunft, verloren gehen könnte.					
10	Das kulturelle Erbe der Krabbenfischerei verschwindet					
	Faktor 4: Bewahrung von Traditionen und Bräuchen					
11	Ich habe Interesse daran, die alte Tradition des Krabbenfangs näher kennenzulernen (Ich möchte die Traditionen unserer Großeltern kennenlernen, die den Krabbenfang betrieben.)					

	Faktor 5: Wirtschaftliche, ökologische und soziale Dimensionen	**1 stimme überhaupt nicht zu**	**2 stimme nicht zu**	**3 nicht sicher**	**4 stimme zu**	**5 stimme sehr zu**
12	Der lokale Krabbenfang ist für die Fischer wirtschaftlich wichtig					
13	Die lokale Krabbenfischerei ist eine Touristenattraktion, d.h. ein Instrument für die lokale wirtschaftliche Entwicklung					
14	Der lokale Krabbenfang erinnert mich an die Verbundenheit mit dem Meer/ und der Umwelt					
15	Die lokale Krabbenfischerei prägt den Charakter eines Ortes durch Gebäude, Symbole, Traditionen, Essen usw. Sie ist Teil des kulturellen Erbes.					
16	Es ist wichtig, dass der lokale Krabbenfang nachhaltig betrieben wird und die lebenden und nicht lebenden Ressourcen im Meer respektiert werden					

Nur für Einheimische
Hat einer der folgenden Punkte Ihre Entscheidung beeinflusst, hier zu leben oder weiter zu leben? Bitte bewerten Sie die folgenden Antworten nach dem Grad ihrer Bedeutung für Sie: 5 bedeutet am wichtigsten, 1 am unwichtigsten.

	1 wichtigsten	**2**	**3**	**4**	**5 unwichtigsten**
Arbeiten in diesem Gebiet					
Familie/Freunde					
Fischerei/maritimes Kulturerbe (Häfen, Schiffe, Häfen, Museen usw.)					
Lokales Essen, Meeresfrüchte etc.					
Natur im Allgemeinen/ Landschaft (Wandern/Entspannen)					
Freizeitaktivitäten im Wasser					
Sonstiges					

Nur für Besucher/Touristen
Hat einer der folgenden Punkte Ihre Entscheidung, diesen Ort zu besuchen, beeinflusst? Bitte wählen Sie die Antworten aus, die für Sie am wichtigsten sind, 5 bedeutet am wichtigsten, 1 am unwichtigsten.

	1 wichtigsten	**2**	**3**	**4**	**5 unwichtigsten**
Arbeiten in diesem Gebiet					
Familie/Freunde					
Fischerei/maritimes Kulturerbe (Häfen, Schiffe, Häfen, Museen usw.)					
Lokales Essen, Meeresfrüchte etc.					
Natur im Allgemeinen/ Landschaft (Wandern/Entspannen)					
Freizeitaktivitäten im Wasser					
Sonstiges					

1. Haben Sie eine direkte oder indirekte Verbindung zur Fischerei?
   (a) Ich habe keine Verbindung
   (b) Ich habe eine Verbindung, bitte angeben_____________
2. Wussten Sie, bevor Sie hierher kamen, dass es in der Stadt Fischerei gibt?
   a) Ja
   b) Nein
3. (*Wenn ja*), Was bringt die Fischerei Ihrer Meinung nach für die Stadt und ihre Umgebung?
   a) Frische Krabben besorgen
   b) Erhaltung von Arbeitsplätzen in der Region
   c) Beitrag zur lokalen Wirtschaftstätigkeit
   d) trägt zur Schönheit der Landschaft bei
   e) Beitrag zum kulturellen Erbe und zur Tradition
   f) Sonstiges__________
4. Für Sie sind der Hafen und die Krabbenfischerboote in dieser Stadt ...
   a) eine wichtige touristische Attraktion, um diese Stadt als Reiseziel zu wählen
   b) eine Touristenattraktion wie jede andere, die nicht von touristischem Interesse ist
   c) Ich weiß es nicht.
5. Waren Sie schon einmal in dieser Stadt, um die Krabbenfischerboote und die Aktivitäten im Hafen zu sehen?
   a) Ja
   b) Nein
6. Wenn es in dieser Stadt keine Krabbenfischerei mehr gäbe und keine Fischerboote im Hafen liegen würden, würden Sie dann in diese Stadt zurückkehren wollen?
   a) Ja
   b) Nein

Abschnitt 3: Auswahl

Jetzt zeige ich Ihnen eine Reihe von Karten zum Thema Krabbenfischerei als Kulturerbe. Ich möchte, dass Sie sich für eine von drei Möglichkeiten entscheiden: Karte A, Karte B und Karte C. Die Karten A und B unterscheiden sich durch die Beschreibung des Fischfangs und durch den Betrag, der für ein Krabbengericht in einem Restaurant ausgegeben wird. Wenn Sie sich für Karte C entscheiden, zahlen Sie für eine Krabbengericht, die sich durch folgende Merkmale auszeichnet: importiert, tiefgefroren, mit einem ausländischen Schiff gefischt, nicht zertifiziert und ohne Bezug zum lokalen Fischereierbe (verloren gegangen und durch die Stadtentwicklung ersetzt), ohne kulturelles erbe. Wenn Sie Karte A und B wählen, entscheiden Sie sich für ein Produkt, das aus lokaler Produktion stammt, frisch ist, ökologisch nachhaltig und besser mit dem lokalen Fischereierbe verbunden ist, aber der Preis kann höher sein als bei Karte C.

Bei der Wahl Ihrer bevorzugten Karte sollten Sie die Kompromisse zwischen der Verarbeitung der Meeresfrüchte, der Herkunft, den Fischereipraktiken usw. und dem Geld, das Sie auszugeben bereit sind, berücksichtigen. Bitte versuchen Sie, so realistisch wie möglich zu sein und Ihr Haushaltsbudget sorgfältig zu berücksichtigen.

Karten	**Antworte (A, B or C)**
1	
2	
3	
4	

Herkunft: Die Garnelen werden vor Ort geerntet oder importiert.
Verarbeitung: Die Garnelen sind frisch oder gefroren.
Ernte: Die Praxis des Fangs mit lokalen Schiffen, die in Küstennähe operieren, gegenüber ausländischen Schiffen, die effizienter sind.
Umweltzertifizierung: Label für nachhaltigen Krabbenfang als Maßnahme des Umweltschutzes.
Kulturerbe: das visuelle Attribut der Küstenfischerei, das sich auf die Möglichkeit bezieht, kulturelle Aspekte zu genießen, eine lebendige fisherei, wie z. B. den Zugang zu sichtbar aktiven Krabbenfischerbooten, die an den Docks arbeiten, im Vergleich zu einer Situation, in der der Zugang zum Ufer auf Gebiete beschränkt ist, die für Wohnzwecke und nicht-fischereiliche kommerzielle Zwecke umgestaltet wurden.
Der Preis: Die Bereitschaft, für eine Krabbenmahlzeit in einem Restaurant zu zahlen.

Abschnitt 4: Soziale Präferenzen

1. (Hypothetische Situation:) Stellen Sie sich die folgende Situation vor: Sie haben heute unerwartet 1.500 Euro erhalten. Wie viel von diesem Betrag würden Sie für einen guten Zweck spenden? (Werte zwischen 0 und 1500 sind erlaubt.) ___________Euro
2. (Bereitschaft zum Handeln:) Wie groß ist Ihre Bereitschaft, für gute Zwecke zu spenden, ohne eine Gegenleistung zu erwarten? (1: keine Bereitschaft zu handeln 10: totale Bereitschaft zu handeln)

1 Keine- Breitschaft	2	3	4	5	6	7	8	9	10 Totale- Bereitschaft

Abschnitt 5: Soziodemografische Informationen

1. Geschlecht: Männer ___ Frau ____ Andere _____
2. Alter: ____
3. Was ist Ihre sozio-berufliche Kategorie?
   a) Arbeitnehmer
   b) Rentner
   c) Arbeitslos
   d) Selbstständig
   e) Andere Situation:
4. (Darf ich Sie fragen) Welche Ausbildung haben Sie?
   a) Staatsrechtlich bzw. landesrechtlich anerkannter Abschluss (Hauptschule, Berufsschule, Realschule, Fachhochschule, Abitur, Studienkolleg)
   b) Bachelor
   c) Master (Diplom, Magister)
   d) Staatsexamen/Staatsprüfung (Lehramt, Medizin, Rechtwissenschaften, Forst- oder Archivdienst)
   e) Ph.D. (Doktor)
   f) Ich möchte das lieber nicht sagen
5. Wie hoch ist Ihr Haushaltseinkommen vor Steuern in Euro/Jahr?
   a) Bis zu 20,000
   b) 20,000 bis 30,000
   c) 30,000 bis 40,000
   d) 40,000 bis 50,000
   e) 50,000 bis 60,000
   f) Mehr als 60,000
   g) Ich möchte lieber nicht sagen

Chapter 5

Revealing risk preferences: Evidence from Turkey's 2023 Earthquake

Authors:Emily Quiroga and Michael Tanner

Abstract: The study on risk preferences and its potential changes amid natural catastrophes has been subject of recent study, yet produced contradictory findings. An often proposed explanation specifically distinguishes between the opposite effect of realized and unrealized losses on risk preferences. Moreover, higher-order risk preferences and its relation to post-disaster behaviors remain unexplored, despite potential theoretical implications. We address these gaps in the literature by conducting experiments with 600 individuals post-Turkey's 2023 catastrophic earthquake, specifically heavily affected individuals who are displaced, those who are not and a control group. Results indicate higher risk-taking in heavily affected individuals when compared to unaffected individuals. Our results are specifically driven by affected females. We find no pre-existing differences in risk preferences between earthquake and control areas using 2012 data. Within the heavily affected group of individuals, higher house damage—our proxy for realized losses—increases risk aversion, with total destruction of a house inducing even higher aversion. Regarding higher-order risk preferences for individuals heavily affected by the earthquake, we find that prudence is positively associated with self-protective behaviors after the earthquake, specifically internal migration and/or displacement. While precautionary savings shows initially no correlation to prudence, a positive association emerges when considering that prudence is also related to occupational choices, with individuals with stable incomes and who save being more prudent. Our results contribute insights into how disasters influence risk preferences, specifically aiming to address contradictory findings in the literature, while presenting novel evidence on the relationship between prudence and post-natural disaster behaviors.

Keywords: Risk preferences, Turkey-Syria earthquake, natural disasters, prudence, gender, displacement.

5.1 Introduction

Risk and higher-order risk preferences play a crucial role in predicting individuals' decisions across various domains, including labor market outcomes, health, insurance and medical treatment choices, addictive behaviors, investment decisions, and migration-related choices. The study of these preferences holds fundamental importance for microeconomics and bears numerous practical implications (Schildberg-Hörisch, 2018).The stability of risk preferences has been of longstanding interest in economic theory (Stigler and G. S. Becker, 1977), with research increasingly addressing this as an empirical question. Natural catastrophes, such as earthquakes, typhoons, tsunamis and hurricanes, provide a unique opportunity to test for potential changes in risk preferences in the field, given the exogenous nature of such large shocks, which usually manifest in the realm of losses (Hanaoka et al., 2018; Ingwersen et al., 2023).

Studies consistently report changes in risk preferences in response to a natural catastrophe, however, there is a contradiction in the literature (Beine et al., 2021; Cassar et al., 2017; Eckel et al., 2009; Hanaoka et al., 2018; Li et al., 2011). Approximately 40% of these papers find that extreme events make individuals more risk-loving, while the remainder find the opposite effect (Abatayo and Lynham, 2019). Imas (2016) offers a potential reconciliation of these contradictory findings. He states that when individuals experience realized losses, they become less risk-taking, and when these losses are unrealized, the effect is the opposite. Yet, this does not align with the mixed results from the literature on catastrophes. Importantly, no research on catastrophes and risk preferences has explicitly set out to explore the role of realized losses and their magnitude in the context of natural disasters. Particularly, higher-order risk preferences such as prudence, which are linked to self-protective behaviors and precautionary savings, could potentially shape individual responses following a natural catastrophe. However, to our knowledge there a notable absence of research on high-order risk preferences in the aftermath of natural catastrophes.

We aim to address these research gaps by doing field work with over 600 affected and unaffected individuals in Turkey six to eight weeks after the catastrophic earthquake in Turkey and Syria during 2023. We conducted incentivized experiments, survey-based risk elicitation, alongside surveys on income, asset losses, and other variables of interest. The two earthquakes of 7.8 and 7.6 of magnitude led to the critical damage of an estimated

890,000 living units, with the World Bank assessing $34.2 billion in direct damages. Moreover, over 3 million people are estimated to have been internally displaced, according to the International Organization for Migration (IOM)[1].

To address our first research goal, we test for potential changes in risk preferences between heavily affected individuals and a suitable control group using the global preferences risk preferences module (Falk et al., 2018). We select this method as it is previously validated in Turkey, and we gain access to data of the year 2012 to test for potential pre-existing differences between treatment and control groups (as defined by the geography of the earthquake). We conduct experiments with internally displaced individuals in the emergency response centers in the city of Antalya. Our sample also includes non-internally displaced individuals in the affected cities of Gaziantep, Adana, and Osmanye. The control group comprises individuals from Antalya and its surrounding towns, attempting to exploit the setting as a natural experiment.

Our second research goal aims to disentangle the effect of realized losses, proxied by the magnitude of house damage, on risk preferences of individuals. We conduct incentivized experiments using the Gneezy and Potters (1997) method for risk elicitation, within our sub-sample of affected individuals only, both displaced and not. We also explore other potential proxies of realized losses that go beyond a strict understanding of material losses stemming from house destruction.

Our third goal entails assessing relation of higher-order risk preferences, specifically prudence, on post earthquake behaviours related to precautionary savings and self-protective behavior[2]. We conduct incentivized experiments with the subsample of affected individuals, both displaced and not. We utilize the prudence experiment developed by Eeckhoudt and Schlesinger (2006), using the modified version of Schaap (2021) for developing settings. We propose that internal displacement and/or internal migration can be understood as a form of self-protective behavior, and likewise, we test for precautionary savings after the earthquake.

Our findings align with expectations, revealing that individuals heavily affected by the earthquake display different risk-taking tendencies compared to our control group. Specifically, individuals affected by the earthquake are significantly more risk taking

[1]https://turkiye.iom.int/earthquake-response

[2]i.e., primary prevention, explained as behaviors/decisions reducing the likelihood of a loss occurring with the loss size being exogenous(Eeckhoudt and Gollier, 2005).

when compared to the control group. Additionally, our analysis using 2012 data from Falk et al. (2018) indicates no pre-existing differences in risk preferences between individuals from the earthquake and control areas. This further supports that observed differences can be attributable to the earthquakes effect. Gender-wise, we observe potential heterogeneous impacts, with our overall results primarily driven by changes in females' risk preferences. Evidence suggests that a negative income shock might underlie these gender-specific changes. For our second hypothesis, we find a positive association between the level of house damage and increased risk aversion among heavily affected individuals, consistent with Imas (2016). Moreover, the magnitude of realized loss matters, with total house destruction leading to higher risk aversion compared to lower levels of damage. Our results capture the broader contradiction evidenced in the literature, where the earthquake resulted in overall increased risk-taking compared to the control but induced heightened risk aversion within the affected group, especially for those experiencing catastrophic losses.

For our third research goal, we find that prudence has a significant and positive association with self protective behaviour, i.e the decision to migrate in our setting. For our exploration of precautionary savings and prudence, we find no initial correlation. However, considering that prudence also plays a role in occupational choice, i.e., prudent individuals might prefer less risky income paths (Fuchs-Schündeln and Schündeln, 2005), we control for occupational self-selection and find a positive association between savings and stable incomes and prudence.

Overall, our results are robust to various checks and regression specifications, including analyses with matched and unmatched samples. Our findings are align with previous research in different strands of the relevant literature, such as the stability of risk preferences, the effects of natural disasters, the impact of prior losses on risk attitudes, and empirical studies of prudence and related behaviors.

The remainder of the paper is organized as follows. Section (2) provides a brief literature review. Section (3) details our hypothesis, the field setting and our experimental design. Section (4) describes the data. Section (5) presents our analysis. Section (6) discusses results and concludes.

5.2 Risk Preferences and Natural Disasters

In recent years, economists increasingly delve into the examination of the stability of risk preferences, and the body of evidence on this subject is expanding rapidly. This heightened interest is, in part, a response to the recognition that the stability of preferences is, to some extent, an empirical question (Schildberg-Hörisch, 2018). Moreover, it challenges the long-standing assumption in economics that individual risk preferences remain constant over time, a concept argued by Stigler and G. S. Becker (1977). Examining the constancy of (risk) preferences is a fundamental aspect of microeconomics with significant practical implications. This investigation is crucial because an individual's inclination towards risk-taking can predict various aspects of labor market performance, health outcomes, addictive behaviors, investment choices, and decisions related to migration (Schildberg-Hörisch, 2018).

In existing empirical evidence, negative shocks such as financial crises and natural catastrophes could have persistent effects on risk preferences (Hanaoka et al., 2018). However, there is no consensus regarding the direction of the impact of extreme event, and little understanding about mechanisms through which these events change risk preferences (Abatayo and Lynham, 2019). For instance, Eckel et al. (2009) elicited risk preferences in a sample of hurricane Katrina evacuees twenty days after the hurricane and compare it with a sample of the same evacuees and non-evacuees ten months after the hurricane. They found that women were significantly more risk loving for the sample evacuees 20 days after the hurricane. Hanaoka et al. (2018) also studied whether risk preferences changed after the 2011 Great East Japan Earthquake. They used a representative survey that follows risk preferences on individuals before, and one and five years after the earthquake. They found that men who experienced a higher intensity of the earthquake become more risk tolerant. Beine et al. (2021) conducted a survey and a field experiment in Tirana, Albania before and (coincidentally) after two major earthquakes hit Albania during 2019. They found that there is a significant increase in risk aversion after the earthquakes. Abatayo and Lynham (2019) compared individuals from communities in the Philippines that were directly hit by a typhoon with those that were not, observing evidence that those affected by the typhoon are less risk averse. Additionally, they found strong evidence that females affected by the typhoon are more risk-loving than females unaffected by the typhoon. Ingwersen et al. (2023) found that survivors of the Indian Ocean tsunami from

Indonesia who were directly exposed to the tsunami made choices consistent with greater willingness to take on risk relative to those not directly exposed to the tsunami. Yet these differences were short-lived, a year later, there is no evidence of differences in willingness to take on risk between the two groups.

In a survey of the existing literature investigating the effect of extreme events on risk preferences Abatayo and Lynham (2019) showed that approximately 40% of these papers found that extreme events make individuals more risk-loving and the remainder found the opposite effect. Imas (2016) proposed a potential reconciliation of these contradictory findings, arguing that individuals with *realized* losses, i.e. those that are experienced, take on less risk. On the contrary, individuals with *paper* losses, i.e., holding a losing stock or not cashing out after a loss, take greater risk. Imas (ibid.) defined *realization* as an event in which money or another medium of value is transferred between accounts, where these accounts could be real, (e.g., broker- age, savings), or mental accounts. If losses stemming from a natural disaster are preponderantly realized losses, then relative risk aversion would dominate across the findings in the literature. However, the mixed evidence suggests that extreme events have inconsistent effects on risk preferences, hence timing and context matter, specifically in developing settings (Abatayo and Lynham, 2019).

In addition to risk preferences, some decisions also depend on higher order risk attitudes. Second order risk aversion leads individuals to opt for higher levels of prevention in the context of self-insurance. However, when it comes to self-protection, relying solely on risk aversion is insufficient to determine the optimal level of preventive effort. Third-order risk aversion, i.e. prudence, also affects the optimal level of prevention (Eeckhoudt and Gollier, 2005). The effect of prudence on preventive effort has been mostly approached theoretically, with conflicting arguments if prudence leads to more or less preventive effort (Eeckhoudt and Gollier, 2005; Menegatti, 2009a).

Third-order risk aversion affects precautionary saving due to changes in the distribution of a future income stream which are determined by individuals' prudence (Eeckhoudt and Schlesinger, 2006). The degree of prudence individuals exhibit has implications on a wide range of economic applications, from bargaining, rent seeking, behaviour in risky occupations to health related decisions. For example, Felder and Mayrhofer (2014) showed that prudent individuals test and treat earlier in the health domain. Moreover the degree of prudence on experimental measures is predictive for wealth, saving, and borrowing behavior (Noussair et al., 2014). Additionally, prudence preferences play a vital role in shaping decisions regarding preventive behavior. Eeckhoudt and Gollier (2005), along with Courbage and Béatrice Rey (2006), examined the impact of prudence preferences on preventive measures. They clarified the distinction between two types of prevention: (1) self-protection (primary prevention), which reduces the likelihood of a loss occurring (with the loss size being exogenous). (2) self-insurance (secondary prevention), which focuses on minimizing the magnitude of a loss (while the likelihood of occurrence is exogenous) (Ehrlich and G. Becker, 1972).

In light of the existing literature, our aim is to contribute specifically to the research on the effect of catastrophes on risk preferences, particularly focusing on the role of the magnitude of realized losses in influencing risk preferences. Additionally, we seek to explore prudence-related behaviors that might theoretically be linked to post-natural disaster responses, an area lacking in empirical evidence.

5.3 Hypothesis, Setting and Experimental Design

5.3.1 Hypothesis

In this section we present our hypotheses, which we derive from the literature and inform the experimental design and data analyses.

First, in line with the literature researching natural catastrophes and changes in risk preferences (Abatayo and Lynham, 2019; Hanaoka et al., 2018; Ingwersen et al., 2023) we expect:

Prediction. *1: The impact of the earthquake leads to changes on the risk preferences of individuals who were severely impacted as compared to our control group*

For the first hypothesis, we expect significant changes in risk preferences. However, given the conflicting results across the literature, we are agnostic about the direction of the changes. In light of those conflicting results, we set out specifically to test in the field the potential explanation that asset losses, in the form of realized assets as proposed by Imas (2016), might be a driver of results towards increased loss aversion. Therefore, for the second hypothesis we set out to look into risk preferences within the treated group (affected by earthquake) and the role of asset losses. These losses are understood as varying degrees of house damage of the respondents, as a proxy for realized losses. Therefore we propose:

Prediction. *2: Within individuals affected by the earthquake, realized losses proxied by house damage is correlated to increased risk aversion*

Finally, we address the relevance of higher order risk preferences, i.e. prudence, in our study setting from two potential angles. First, given the literature on precautionary savings, we aim to explore the differentiated effects on savings after the earthquake for heavily affected individuals. Second, we explore the association of self protective behaviour/primary prevention and prudence in our setting. We propose internal displacement is at least partially a mechanism to reduced the likelihood of a loss occurring (with the loss size being exogenous), and therefore we expect an association to prudence. For the latter, we are agnostic regarding the direction of the effect, as there are conflicting theoretical predictions that either lead to positive or negative association. Therefore we propose:

Prediction. *Within individuals affected by the earthquake, higher order risk preferences are correlated to*

3: post earthquake saving behaviour, as a form of precautionary savings, thus prudence should have a positive correlation with saving behaviour

4: Internal displacement, as a form of primary prevention/protective behaviour.

5.3.2 Field setting

On February 6, 2023, an earthquake of 7.8 (Richter Scale) struck southern and central Turkey, as well as northern and western Syria, marking the strongest seismic event in Turkey in over 80 years. Approximately 9 hours later a second earthquake with a 7.6 magnitude occurred to the north-northeast in Kahramanmaraş province. By the 20th of March of 2023, the total death toll of over 57,000 (50,000 in Turkey and 7,000 in Syria) (Hussain et al., 2023)

The 2023 earthquakes originated from the East Anatolian Fault (EAF), a major tectonic structure in the eastern Mediterranean, separating the Arabian and Anatolian tectonic plates. Only in Turkey, over 13 million people experienced moderate to high levels of ground shaking in a region already grappling with a high number of COVID-19-related illnesses (Dal Zilio and Ampuero, 2023), with over 9.1 million being directly affected[3].

Over 1.5 million people lived below the national poverty line in the affected provinces according to 2021 data. Moreover, 52% of homes in these provinces were constructed after 2001 when strict new building regulations were enforced following the destructive 1999 magnitude-7.4 Izmit earthquake (Hussain et al., 2023). Despite these regulations, over 230,000 buildings were damaged or destroyed. Later estimations approximate the number of destroyed or critically damaged units to be 890,000, with more than 1.8 million units being lightly damaged. However, those with light damage do not necessarily provide adequate living conditions[4].

Economic damages are estimated at $34.2 billion in direct damages in Turkey from the earthquakes, according to the World Bank's 2023 Global Rapid Post-Disaster Damage Estimation (GRADE) Report (Gunasekera et al., 2023). Additionally, the most-affected Turkish provinces hit by the 2023 earthquakes suffer from higher levels of poverty compared to western Turkey. Internal displacement is estimated at 3 million people, according to the International Organization for Migration (IOM) [5]. As a response, the government implemented distribution centers of goods for the earthquake victims to ensure access to critical goods and services. These centres were located in the main cities, where most of the victims were displaced.

5.3.3 Experimental Design

In this section we describe the research design for each hypothesis. Our first hypothesis aims to detect potential changes in risk preferences which are attributable to the earthquake. For this, we determine our treatment area and relevant control area, ensuring that the latter is of comparable nature to the affected regions. We first define treatment as individuals from the geographical area heavily affected by the earthquake, the allocation can be expected to be as good as random. To ensure an appropriate control area, we analyse unaffected geographical areas which could serve as plausible comparison group. We identify a region with similar economic and human development indicators as the affected

[3]https://reliefweb.int/report/turkiye/kahramanmaras-earthquakes-turkiye-and-syria-31-may-2023

[4]United Nations Office for the Coordination of Humanitarian Affairs (OCHA)

[5]https://reliefweb.int/report/turkiye/turkiye-2023-earthquakes-situation-report-no-11-23-march-2023-entr

region, but geographically distant from the epicenter of the earthquakes. We conducted this analyses looking at 12 statistical regions in Turkey and their specific Human Development Index (HDI). Figure 5.1 presents 12 regions in Turkey, with regions below the national mean of HDI in light coloring, and the regions with HDI above the national mean in darker. Cities which are defined as heavily affected are marked. Differences in HDI between the east and west of the country makes most of the western provinces not ideal controls. The Mediterranean Region is unique with affected and unaffected cities due to geographical distance, whilst also having an HDI which is comparable to all of eastern Turkey. We select the province of Antalya as potential control for the experimental design of hypothesis one. Table 5.1 presents the GDP per capita per province for both the most affected cities and our selected control province (in bold). The table also shows other provinces that were not affected and served as receivers for internally displaced/migrants (marked with a *), yet deemed unsuitable as a control region.

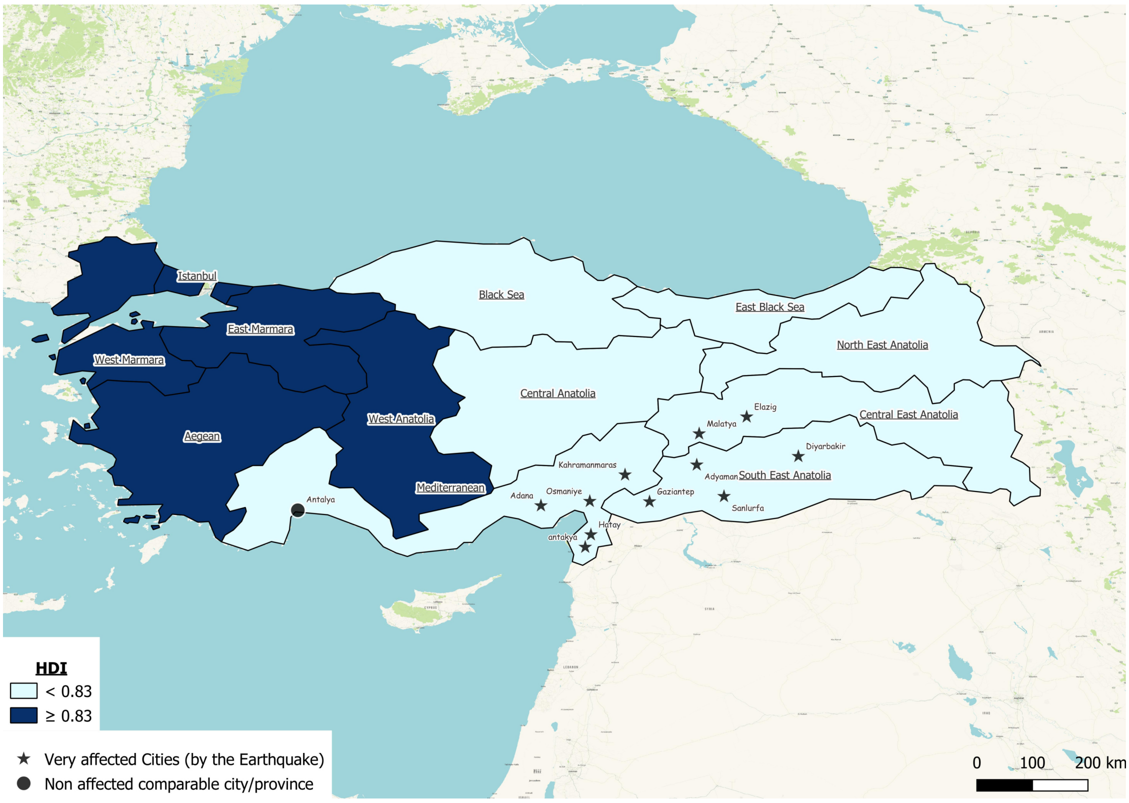


Figure 5.1: Map of Subnational Human Development Index (HDI) as of 2021 per Turkey's NUTs1 Statistical Regions with geographical location heavily affected cities and our selected control city. The Mediterranean region is located in the southern part and includes the province of Antalya and the affected cities.

Some victims of the earthquake were internally displaced from their homes in the heavily affected regions. Most of them established themselves in temporary housing and

Province	2020	2021
Adana	6,291	6,977
Ankara*	12,041	13,020
Antalya	7,252	8,983
Elazig	5,944	6,272
Gaziantep	6,763	7,819
Hatay	5,385	6,785
İstanbul*	13,931	15,666
İzmir*	9,967	11,668
Kahramanmaraş	5,601	5,997
Malatya	5,147	5,355
Osmaniye	5,133	6,256

Table 5.1: Gross Domestic Product (GDP USD) per Capita at the province level in Turkey. Selected control province in bold. * Unaffected provinces deemed unsuitable control areas.

camps on cities not affected by the earthquake. These individuals visited the centers where the government provided food and clothes for free to all affected. We perform most of our surveys and experiments in the centers located in the city of Antalya. In these centers the participants were waiting to receive their goods, time in which we carried out the survey elicitation of risk preferences. Beside the surveys of earthquake victims performed in Antalya, we also execute the study in situ in the regions of Gaziantep, Adana and Osmaniye. Therefore, we ensure to have a population of both, affected individuals internally displaced and not displaced in our sample. For our control individuals we surveyed individuals in the city of Antalya and surrounding areas, as these also serve as comparison given our priority for timely field work and the existing circumstances on the ground[6]. The risk elicitation surveys and experiments were carried out starting the 24th of March, to ensure capturing the effects of the earthquake as much as possible. Ethics approval for our design was provided by the University of Hamburg, additionally informed consent was obtained from participants.

[6]Movement to the Eastern regions was severely complicated due to the immediate effects of the earthquake, and travelling to the southern regions advised against due to security concerns.

We assess individual risk preferences for treated and control individuals using the risk module survey designed by Falk et al. (2018) to test our first hypothesis. The Global Preference Survey (GPS) designed by Falk et al. (ibid.) elicits economic preferences from 80.000 people in 76 countries, including Turkey. The measures include time preference, risk preferences, positive and negative reciprocity, altruism and trust. The risk preference module includes a lottery choice using the staircase method and a self assessment question about the willingness to take risks (See Annex 5.B). The results of the lottery stair case and the self assessment question were converted into a single *risk index* using the method and weights described in Falk et al. (ibid.). Aside from its robustness and wide application in developing settings, we select this method as we gained access to data by Falk et al. (ibid.) on Turkey prior the earthquake. Employing the identical risk elicitation method allows us to conduct checks to explore pre-existing differences in risk preferences between individuals from our treatment and control areas. All individuals also completed an accompanying survey designed to reveal loss of assets/Level of house damage, existing informal support networks, income changes and other variables of interest.

To test the second hypothesis we conduct incentivized experiments with individuals who were heavily affected by the earthquake, thus only the treated group from hypothesis 1. We conduct these experiments with both internally displaced individuals, and also in situ in heavily affected areas[7]. To elicit the the magnitude of realized losses our survey inquires levels of house damage, for individuals affected by the earthquake, loss of income, and existing networks. For our incentivized experiments we use the Gneezy and Potters (1997) experiment in risk taking. This experiment mimics an investment decision, where participants receive an endowment and decide which part of it is invested into a risky asset. This asset pays off three times the investment with a probability of 50%, and zero otherwise. The level of risk aversion in individuals is determined by their investment choices; higher investments reflect lower levels of risk aversion. The figure A-3 shows the structure of the experiment. The relative simplicity of the method, combined with the fact that it can be implemented in a single trial and basic experimental tools, makes it a useful instrument for assessing risk preferences in the field (Charness et al., 2013). Moreover, when compared to other experimental methods, the Gneezy and Potters (1997) approach

[7]Given field constraints only individuals from Adana and Osmaniye conducted incentivized experiments, individuals Gaziantep only conducted survey module by Falk et al., 2018

is more consistent in its findings, specifically in developing/rural settings (Charness and Viceisza, 2016), which is a matter of importance for the design.

We also design and implement a survey to elicit a measure of perception of asset loss, specifically information on the level of house damage by the earthquake. Within this survey we also gather data regarding income, savings, married status, education, migration and mathematical abilities among others.

For our third hypothesis, we implement a second incentivized experiment with the same group as hypothesis two. This experiment aims to assess higher order risk attitudes, specifically prudence, with the individuals affected by the earthquake. We implement the prudence experiment developed by Eeckhoudt and Schlesinger (2006) using the modified version for developing settings described by Schaap (2021). To assess participants' prudence, they were presented with 5 binary choices. These choices involved assigning a risk with a mean of zero to either the high or low outcome of a lottery. The lottery and the mean-zero risk were determined by independent coin-flips, represented in figure A-5. Allocating the mean-zero risk to the high (low) outcome indicated prudent (imprudent) preferences (Eeckhoudt and Schlesinger, 2006). The specific choices are detailed in Table 5.2. Participants considered one choice at a time and received no feedback until the end of the session. Only one of the choices was paid out at the end. The first choice is referred to as the baseline choice, in the subsequent four choices, the expected payout for opting either option A or option B in the baseline choice was increased. This adjustment created an incentive for choosing the imprudent or prudent option, respectively.

These choices are identified by the expected payout of the prudent option compared to that of the imprudent option. For instance, in the choice labeled "+10," the expected payout of the prudent option is ten lira higher than that of the imprudent option. This framework enables the detection of inconsistent behavior concerning payout maximization. For instance, if a participant initially chose the prudent option in the baseline but later opts for the imprudent option in the "+10" choice, this decision is considered inconsistent. Prudence is quantified based on the number of prudent choices made out of the five available options (Schaap, 2021).

Table 5.2 presents the list of lotteries with the respective frequency of individuals who choose the respective option. Each choice has an option A or B and is composed with two steps. For instance, in the first step of the option A at the baseline, if the coin falls

	Option A	Option B	Frequency A	Frequency B
Baseline	$60\|(+30\|-30)\|\|40$	$60\|\|40(+30\|-30)$	208	90
Prudence +10	$70\|(+30\|-30)\|\|50$	$60\|\|40(+30\|-30)$	210	88
Prudence -10	$60\|(+30\|-30)\|\|40$	$70\|\|50(+30\|-30)$	128	170
Prudence +20	$80\|(+30\|-30)\|\|60$	$60\|\|40(+30\|-30)$	222	76
Prudence -20	$60\|(+30\|-30)\|\|40$	$80\|\|60(+30\|-30)$	100	198

Table 5.2: Prudence experiment lottery

heads the individual gets 40 Lira otherwise they get 60 lira and proceed to the second step. Then the coin is flipped again, if the coin falls tails the individual will receive 60 lira plus 30 lira (total of 90 lira), otherwise they get 60 lira minus 30 lira (total of 30 lira). The corresponding notation of this procedure is "$60|(+30|-30)||40$". The same reasoning follows the rest of the choices (See figure A-5)

5.4 Data

In this section we present a description of the collected data prior to analyses. Figure 5.2 shows the treated area of our study (determined by the geographical location of the earthquake), and plots all surveyed individuals *N=602* (control, treated internally displaced and treated in situ). By randomly surveying heavily affected individuals at the goods collection center we are able to get a representative sample of the whole affected zone as show in Figure 5.2. Our sample holds individuals from all the most affected cities, with the circles on the figure representing the number of individuals surveyed and the city where they originally came from.

Table 5.3 shows the characteristics of the population surveyed. In total we collect data of 602 participants. To test the first hypothesis we use the non-incentivized survey based sample that aims to measure risk preferences following the procedure described in (Falk et al., 2018), compring of all individuals. For the second and third hypotheses

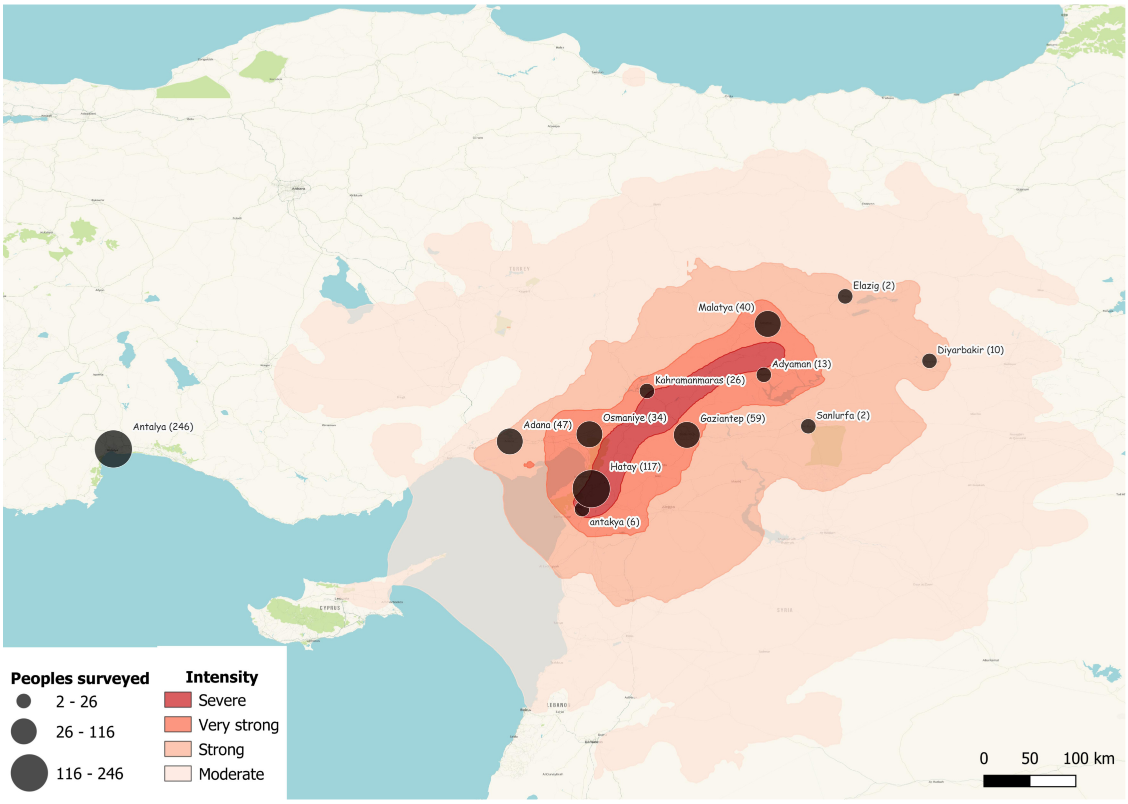


Figure 5.2: Map showcasing sample distribution and earthquake intensity using U.S Geological Survey Data[8] and scale based on Worden et al. (2012)

we use the sample composed of individuals who participated in incentivized experiments (302 participants). This sample is a subset of the "treatment group" (Third column in table 5.3). The variable *Savings* takes the value of 1 if the person has savings to support themselves for the next six months or zero otherwise. *Math* is a self assessment variable from zero to ten where zero means "not good at all in math" and ten "good at math". *Network* is a dummy taking the value of one if the person has family or friends who can support him/her for the next six months. *Displacement* has the value of one if the individual was internally displaced or zero otherwise. *House Damage* represents a self-assessment of the degree of damage of their house due to the earthquake, with five distinct categories of damage ranging from very low to total destruction of house. *Risk Index* is composed by a self assessment risk and a stair case response following Falk et al. (2018). The higher the value the more risk living the individual is.

	All Sample	Non-Incentivized		Incentivized
		Control	**Treatment**	(Experimental sample)
Female %	0.483	0.455	0.503	0.503
Married %	0.636	0.573	0.680	0.669
Mean Age	39.3	39.0	39.6	40.1
Education %				
Primary	0.307	0.268	0.307	0.338
Secondary	0.352	0.358	0.352	0.368
University	0.322	0.358	0.322	0.278
Graduate	0.018	0.016	0.018	0.017
Income %				
< 140 €	0.073	0.020	0.110	0.129
140 €- 339 €	0.123	0.187	0.079	0.079
340 €- 669 €	0.432	0.451	0.419	0.450
670 €- 999 €	0.204	0.224	0.191	0.195
> 1000 €	0.168	0.118	0.202	0.146
Savings%	0.216	0.297	0.160	0.123
Math	5.669	5.659	5.677	5.543
Network%	0.440	0.500	0.399	0.374
Displacement %	0.409	0.000	0.691	0.801
House Damage %				
Very low damage	0.281	-	0.281	0.166
Low Damage	0.197	-	0.197	0.232
Medium Damage	0.171	-	0.171	0.192
High Damage	0.264	-	0.264	0.311
Total Destruction	0.084	-	0.084	0.099
Risk Index	9.363	8.679	9.943	9.713
Sample Size	602	246	356	302

Table 5.3: Descriptive statistics. All sample that includes the control and treatment group. To test the first hypothesis the columns control and treatment were used. The last column corresponds to the sample used to analyse the second and third hypothesis.

5.5 Results

5.5.1 Balance tests and matching procedure

In this section we present the results pertaining our first hypothesis (Section 5.3.1), evaluating the effect of the earthquake on potential risk preferences via the GPS survey (Falk et al., 2018). Table 5.3 shows the summary statistics including the outcome variable, *risk index*. Table 2 presents all covariates for the control and treatment (earthquake) groups of the non-incentivized risk elicitation sample. As we exploit a natural experiment thorough our experimental design, we we use the Propensity Score Matching (PSM) as an additional robustness check[9]. Specifically, we follow the optimal method which finds the matched samples with the smallest average absolute distance across all the matched pairs Ho et al. (2011).

Table 5.4 presents the balance before and after the matching procedure. The column *F-Test* evaluates the significant difference between the control and treatment group before and after the matching[10]. We observe a variance in the average marriage variable between the treatment and control groups, which we deem not central to our research objectives, particularly considering recent experimental evidence regarding differences in risk preferences among married, unmarried couples, and individuals.[11].

Moreover, there is evidence that differences in marriage are pre-existing. Data from 2020 (before the earthquake), in the provinces of Adıyaman, Şanlıurfa, Hatay and Gazaintep, which are the origin of most of our affected population (and most severely affected by the earthquake), are amongst the ones with highest marriage rate when compared to the mean of the country[12]. After the matching process we detect no significant differences between groups, achieving balance across covariates. We have a sample of 492 individuals from both the treated and control groups, exhibiting similarity in the characteristics described in Table 5.4. We proceed to conduct all our analyses with both the matched

[9]We use the *matchit* package using the software R for the matching procedure(Ho et al., 2007)

[10]We also used the balance test described in Du and Hao (2022), the description is found in the Annex 5.E

[11]Bernedo Del Carpio et al. (2022) find that risk preferences of married couples and unrelated pairs are similar to the preferences of their constituent individuals.

[12]Marriage and Divorce Statistics for 2020, 25/02/2021 Statistical Press Report `https://data.tuik.gov.tr/Bulten/Index?p=Marriage-and-Divorce-Statistics-2020-37211&dil=2`. See Annex 5.F for details.

and unmatched samples to ensure robustness.

	Balance table Before					**Balance table After**				
	Control		**Treatment**			**Control**		**Treatment**		
	Mean	SD	Mean	SD	**F-test**	Mean	SD	Mean	SD	**F-test**
Age	39.03	13.93	39.65	13.68	0.29	39.03	13.93	39.87	14.68	0.42
Female	0.46	0.50	0.50	0.50	1.31	0.46	0.50	0.46	0.50	0.01
Married	0.57	0.50	0.68	0.47	7.20***	0.57	0.50	0.58	0.49	0.07
Education	2.12	0.82	2.01	0.86	2.62	2.12	0.82	2.08	0.85	0.29
Income	3.35	1.31	3.23	1.70	0.96	3.35	1.31	3.33	1.76	0.02
Math	5.66	2.22	5.69	2.50	0.03	5.66	2.22	5.52	2.59	0.40
N	246		356			246		246		

Note: *p<0.1; **p<0.05; ***p<0.01

Table 5.4: Balance Table for the matching procedure. SD represents the Standard Deviation for each variable. The F-test show the significant differences between the control and group sample.

5.5.2 Changes in Risk Preferences

We test the effect of the earthquake on risk preferences using our matched sample as per Hypotehsis 1. Regressions using the unmatched samples are presented in Annex 5.H. We implement an Ordinary Least Square (OLS) regression with *Risk Index* as a dependent variable (See Eq.5.1). Table 5.5 shows the results of the regression. The first column shows that individuals who experienced the earthquake are significantly 1.4 points more risk-taking than those who did not. This is line with hypothesis 1, i.e, there is changes in risk preferences due to the impact of the earthquake. Moreover, at a baseline women are significantly less risk-taking than men. As per previous findings in the literature we proceed to test for potential heterogeneous effects of the earthquake across genders. For this we include an interaction between gender and our earthquake dummy that defines treatment (earthQ) in the second column. We find that overall significance of the *earthQ* disappears and instead the interaction became highly significant. This implies that the effect of the earthquake on changes in risk preferences is driven by females. Women who experience the earthquake are 3.887 points significantly more risk taking than those who did not (sum of β_1 and β_3). Second, women are less risk taking than men in the earthquake area[13]. As a robustness check we replicate the same regression for the non-matched sample and our results hold (See Annex 5.G).

$$\begin{aligned}
Risk_i = \beta_0 + \beta_1 EarthQ_i + \beta_2 Female_i + \beta_3 earthQ_i * Gender_i + \beta_2 Income_i + \\
\beta_4 Married_i + \beta_5 Age_i + \beta_6 Education_i + \beta_7 Saving_i + \beta_8 Math_i + \\
\beta_8 Network_i + \epsilon_i
\end{aligned} \tag{5.1}$$

The significant differences in risk-taking among the earthquake and non-earthquake areas can potentially be attributed to systematic pre-existing differences between our treatment and control study areas. To assess pre-existing differences, we utilize data from Falk et al. (2018). We employ the same risk elicitation methodology as Falk et al. (ibid.), who gathered risk preferences in Turkey for the year 2012 in the same areas we used as control and treatment for our experimental design. We set up a regression using individual risk preferences collected in 2012 in Antalya as the control region. The treatment group is constructed using observations from Adana, Malatya, Hatay, and Gaziantep, gathering 136 observations and closely resembling the composition of our earthquake-treated sample in geographical distribution.

We conduct a OLS regression using the risk index as a dependent variable and available covariates such as gender, age, and math ability. With this we aim to check for the effect of pre-existing risk preferences across the regions or across gender among earthquake and non-earthquake areas in 2012. The results are presented in Table 5.6, showing no differences in risk preferences across geographical location (earthQ) and gender. We conclude that there are no pre-existing differences between samples in 2012, supporting our main thesis that the existing differences in risk preferences can be attributed to the

[13]The average difference of risk taking among women and men from the earthquake area is derived from equation5.1 adding the coefficients β_2 and β_3 which results in a negative coefficient of -0.668.

	Dependent variable:	
	Risk Index	
	(1)	(2)
EarthQ	1.448**	-0.577
	(0.599)	(0.796)
Female	-2.922***	-5.132***
	(0.615)	(0.841)
EarthQ*Female		4.464***
		(1.176)
Income	0.797***	0.778***
	(0.227)	(0.224)
Married	0.095	0.291
	(0.741)	(0.733)
Age	-0.041	-0.052*
	(0.027)	(0.027)
Education	-0.151	-0.211
	(0.443)	(0.437)
Savings	0.924	0.881
	(0.805)	(0.794)
Math	0.392***	0.413***
	(0.139)	(0.137)
Network	-0.555	-0.520
	(0.625)	(0.617)
Constant	6.949***	8.342***
	(1.653)	(1.671)
Observations	486	486
R^2	0.139	0.165
Adjusted R^2	0.123	0.147
Residual Std. Error	6.491 (df = 476)	6.402 (df = 475)
F Statistic	8.572*** (df = 9; 476)	9.374*** (df = 10; 475)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 5.5: OLS regression with matched sample. The second column includes interaction among earthquake and gender.

earthquake[14].

For Antalya, our control group, Falk et al. (2018) have 40 observations. Hence, as a robustness check, we extended the control group to cover the cities of Samsun, Kastamonu, and Trabzon. These cities are comparable in characteristics to Antalya, in such way the sample size increased to a total of 136 observations. Specifically, these places have the same HDI as the regions affected by the earthquake in 2023, making the sample comparable. Overall, our previous results hold, finding no difference in risk preferences between our treatment group and the expanded control group on 2012 (See Annex Table A-5).

	Dependent variable:
	Risk Index
EarthQ	-0.674
	(1.160)
Gender	-1.190
	(0.948)
Age	-0.104***
	(0.035)
Math	0.345*
	(0.178)
Constant	11.198***
	(2.252)
Observations	172
R^2	0.103
Adjusted R^2	0.081
Residual Std. Error	5.961 (df = 167)
F Statistic	4.786*** (df = 4; 167)
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 5.6: OLS regression using the risk index as a dependent variable. Differences in risk preferences between individuals treatment and control area in 2012. The variable EarthQ is equal to one if individuals belongs to the earthquake area and zero otherwise. Gender is equal to one for women.

Figure 5.3 presents histograms of the risk index variable by gender for the control and treatment groups,. The figure illustrates that changes in risk preferences are driven by

[14]Descriptive statistics about the data are found in Annex 5.H

the targeted impact of the earthquake on women. The histograms reveal that women who experience the earthquake in the heavily affected region become more risk-taking than those in the control group. To gain a better understanding of potential drivers of this result, we perform further regressions with a sample of treated females (N=161) and males(N=160), using our Risk Index as the dependent variable. Table 5.7 shows the results of the regression.

We explore several potential channels for our results. Firstly, we include a variable *Neg Income*, which has the value of one if there was a negative difference in income before and after the earthquake and zero otherwise. This variable aims to capture the effect of negative income shocks. Secondly, the variable *Change Members* is a dummy with the value of one if the household experienced a change in the quantity of members of the family before and after the earthquake[15]. We add this variable to account for the loss of a family member, or conversely, new members who are now a responsibility for the household which might be driving changes in female risk preferences.

The within-treatment regression reveals that a negative difference in income before and after the earthquake (income loss) is significantly correlated with more risk-taking for both men and women (See Table 5.7). This suggests that changes in risk preferences towards decreased loss aversion after the earthquake may stem from the generalized negative income shock. We find no statistical significance in the variable accounting for changes in the quantity of members of the family before and after the earthquake.

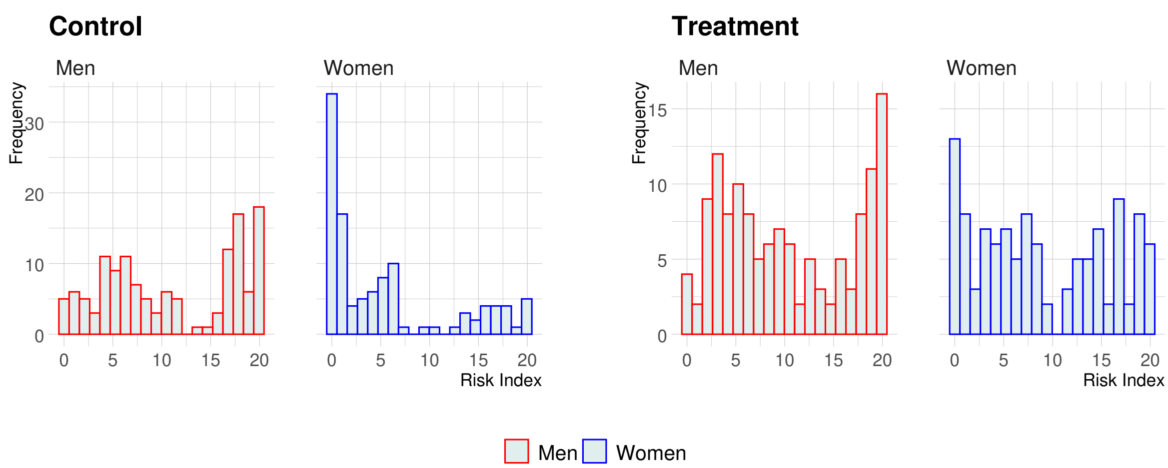


Figure 5.3: Histogram of the Risk Index variable for the matched sample in the control and treatment regions by gender.

[15]Some households experience an increase in the quantity of members because people who loss members of their family can join another household.

	Dependent variable:			
	Risk Index			
	Female		Male	
	(1)	(2)	(3)	(4)
Age	-0.072	-0.072	-0.015	-0.015
	(0.043)	(0.044)	(0.044)	(0.044)
Education	-0.598	-0.595	-0.318	-0.463
	(0.661)	(0.702)	(0.776)	(0.780)
Married	0.023	0.022	-1.353	-1.498
	(1.203)	(1.210)	(1.378)	(1.377)
Neg, Income	2.185*	2.185*	1.136	1.289
	(1.148)	(1.154)	(1.092)	(1.094)
Property House	0.165	0.164	0.854	0.937
	(1.087)	(1.091)	(1.069)	(1.067)
Savings	0.342	0.347	1.231	0.963
	(1.615)	(1.667)	(1.382)	(1.390)
Trust	-1.735	-1.733	-2.422**	-2.235*
	(1.082)	(1.102)	(1.158)	(1.161)
Change Members	0.205	0.204	-3.082	-3.107*
	(2.341)	(2.350)	(1.875)	(1.869)
Math	0.618***	0.617***	0.314	0.229
	(0.221)	(0.226)	(0.218)	(0.226)
Network		-0.015		1.612
		(1.164)		(1.138)
Constant	10.295***	10.297***	11.185***	11.306***
	(2.834)	(2.847)	(2.911)	(2.903)
Observations	160	160	160	160
R^2	0.132	0.132	0.088	0.100
Adjusted R^2	0.080	0.074	0.033	0.039
Residual Std. Error	6.279 (df = 150)	6.300 (df = 149)	6.371 (df = 150)	6.349 (df = 149)
F Statistic	2.545***	2.275**	1.601	1.651*
	(df = 9; 150)	(df = 10; 149)	(df = 9; 150)	(df = 10; 149)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 5.7: OLS regression results for the sub-sample of female and male of the earthquake area.

5.5.3 Risk Preferences and realized losses

In this section, we present the results from our incentivized experiments (Gneezy and Potters, 1997), focusing exclusively on individuals heavily affected by the earthquake. The variable of interest is the percentage of money that individuals chose to invest in the risky option (% invested in the bag. See A-4). This is a measure of risk-taking in this setting, as a higher proportion of investment indicates more risky behavior. We make use of a variable in our survey inquiring about the level of damage the house of the respondent perceived, measured from one to five, where five means total destruction. This variable is represented by *House Damage* in our regressions. We consider that this variable encapsulates a significant aspect of *realized losses* caused by the earthquake, at least constrained to the material domain. To test the effect of the magnitude of house damage on risk behavior, we also define medium damage and total damage as dummy variables, keeping the control group as the non-damage alternative. The medium damage encompasses the categories 2, 3, and 4 of the house damage variable, and total damage refers to the fifth category. With this set of variables and regressions, we aim to detect the relationship between realized losses, proxied by house damage, and risk preferences. We also aim to test if the loss magnitude has a differing effect among risk preferences in individuals affected by the earthquake. Annex 5.I provides a detailed description of house damage in our sample.

Table 5.5 shows the results of an OLS regression where the dependent variable is the percentage of endowment that individuals invest in the risky choice. Regression (1) shows that, on average , individuals who increase in one unit the house damage level invest less percentage of money in the risky option. When desegregating the house damage variable into categories proxying for the magnitude of the damage (Regression (2)), we find that people who experience a total destruction are significantly less risk taking than those who encounter no damage. Whereas, people who experienced medium damage exhibit less risk taking behavior than the baseline, however, this difference is not significant. This serves as tentative evidence that the magnitude of the realized loss may influence risk-taking behavior.

Realized losses, however, are not only restricted to the level of house damage or exclusive to the material domain, as per Imas (2016). In the context of an earthquake, realized losses comprise losing money but also any other medium of value. We argue that

	Dependent variable:			
	% Investment in the Bag			
	(1)	(2)	(3)	(4)
House Damage	-0.036**		0.003	
	(0.018)		(0.023)	
Medium Damage		-0.080		
		(0.062)		
Total Destruction		-0.182**		
		(0.090)		
Displacement			-0.205***	-0.198***
			(0.077)	(0.058)
Gender	-0.099**	-0.094**	-0.094**	-0.095**
	(0.044)	(0.044)	(0.044)	(0.043)
Age	-0.001	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Married	-0.035	-0.035	-0.010	-0.011
	(0.053)	(0.054)	(0.053)	(0.053)
Education	0.029	0.028	0.033	0.032
	(0.030)	(0.030)	(0.030)	(0.029)
Income	0.045***	0.043***	0.030*	0.030*
	(0.016)	(0.016)	(0.016)	(0.016)
Employed	-0.076	-0.075	-0.067	-0.067
	(0.054)	(0.054)	(0.053)	(0.053)
Retiree	-0.098	-0.100	-0.113	-0.113
	(0.079)	(0.079)	(0.078)	(0.078)
Unemployed	-0.256*	-0.250	-0.292*	-0.292*
	(0.154)	(0.156)	(0.153)	(0.153)
Constant	0.685***	0.665***	0.758***	0.762***
	(0.123)	(0.124)	(0.124)	(0.121)
Observations	298	298	298	298
R^2	0.123	0.122	0.144	0.144
Adjusted R^2	0.096	0.092	0.115	0.118
Residual Std. Error	0.367 (df = 288)	0.368 (df = 287)	0.363 (df = 287)	0.362 (df = 288)
F Statistic	4.489***	4.005***	4.841***	5.395***
	(df = 9; 288)	(df = 10; 287)	(df = 10; 287)	(df = 9; 288)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 5.8: OLS regression results realized losses on risk behavior

people who were internally displaced from the earthquake area most likely experienced a loss that goes beyond the strict definition of realized losses proxied by house damage (i.e., they might have physical assets which were a source of income such as an office, or machinery, or important sources of value that might go beyond the material realm). Hence, we include the variable *Displacement* in regressions (3) and (4) in Table 5.8 to control for a potentially broader understanding of realized losses.

	Dependent variable:	
	Displacement Behavior	
	(1)	(2)
House Damage	2.181***	2.193***
	(0.392)	(0.396)
Gender	0.156	0.185
	(0.419)	(0.416)
Age	-0.001	-0.002
	(0.016)	(0.016)
Married	0.384	0.446
	(0.471)	(0.490)
Education	0.577*	0.588*
	(0.325)	(0.326)
Income	-0.864***	-0.861***
	(0.188)	(0.188)
Math	-0.051	-0.047
	(0.086)	(0.086)
Property	0.068	0.108
	(0.428)	(0.441)
No -Network	0.835**	0.848**
	(0.412)	(0.411)
Savings	-0.140	-0.128
	(0.521)	(0.524)
Change Members		0.412
		(0.911)
Constant	-1.526	-1.656
	(1.070)	(1.120)
Observations	301	301
Log Likelihood	-30.880	-30.795
Akaike Inf. Crit.	83.761	85.590
Note:	*p<0.1; **p<0.05; ***p<0.01	

Table 5.9: Drivers of displacement

The displacement variable shows a significant and negative coefficient, meaning that people who were displaced are less risk-taking. This effect is highly significant and of higher magnitude than the house damage variable. This suggests that displacement captures a broader set of losses not exclusively defined by the individual's house damage. As a robustness check, we performed identical regressions in Table 5.8 using the risk index constructed from the GPS as dependent variable. The results still hold and are presented in Annex A-6.

We further test the idea that the displacement variable potentially captures a broader understanding of realized losses. We conduct a probit regression on the displacement/ migration decision to understand its drivers (See Table 5.9). We expect different aspects related to realized losses to be driving displacement for our previous statement to hold, i.e., displacement is driven by realized losses proxied by house damage and other lost of monetary mediums or values. Table 5.9 shows that the decision to internally migrate (or potentially being forced to leave, i.e., becoming internally displaced) is correlated with the level of house damage an individual experienced. Likewise, people who have no informal network (friends and family) to support them and have lower income are more likely to be displaced from their town of residence. Annex 5.J presents the histogram of displacement per house damage level.

5.5.4 High Order Risk Preferences

Prudence and Self protective behaviour

Our third hypothesis focusses on treated individuals, i.e from the area heavily affected by the earthquake both displaced and not. We are interested in potential self-protective behaviors[16]. We propose that internal displacement and/or internal migration can be understood as a form of self-protective behavior, and proceed to test this hypothesis using results from our incentivized experiments.

In the experiment, participants were presented with five choices, from which they could opt for either the prudent or imprudent option. We generate a prudence variable, *prudent choices*, which counts the number of prudent choices the individual makes. This variable is ordinal, ranging from one to five, with higher values indicating more prudent individuals. We employ an ordered probit regression. Table 5.10 presents four regressions where the variables displacement, network and house damage are added sequentially. These three

[16](i.e., primary prevention, explained as behaviors/decisions reducing the likelihood of a loss occurring with the loss size being exogenous)

variables exhibit high correlation, as evidenced by previous results demonstrating the relationship between lack of network and house damage with displacement behavior (See Table 5.9 and figure 5.4). Additionally, stable income is a dummy variable with a value of one for individuals formally employed with a salary or retirees, and zero otherwise (where zero corresponds to self-employment).

Results show a positive correlation between prudence and the decision to internally migrate/displacement, which is higher in both magnitude and significance than the house damage coefficient. This presents tentative evidence that the decision to internally migrate/displacement can be understood as a form of self protective behaviour, as it is most likely a way to ensure less exposure to current and future losses. We also observe little to no significance between prudence and variables related to displacement, albeit house damage exhibits a positive relatively weak association. Importantly, only age seems to be of importance when analysing prudence with individuals heavily affected by the earthquake.

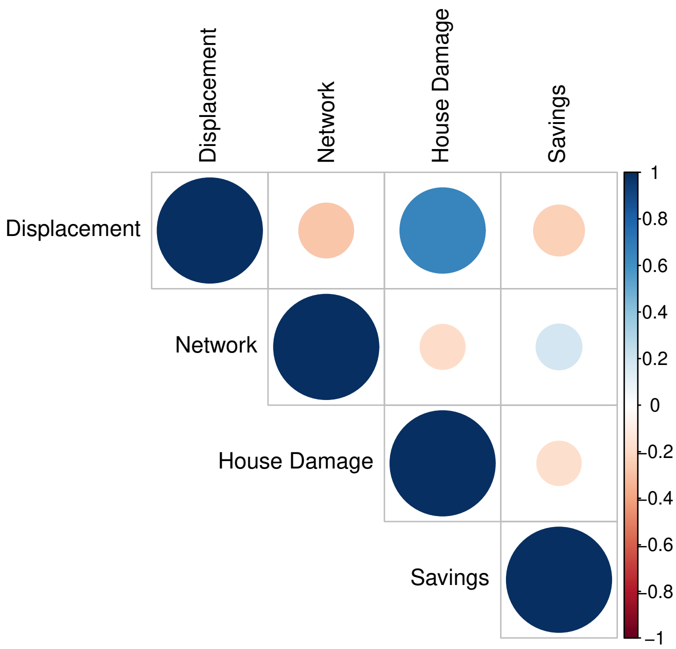


Figure 5.4: Summary correlations of covariates for prudence

	Dependent variable:		
	Prudent Choices		
	(1)	(2)	(3)
Age	0.022**	0.021**	0.020**
	(0.009)	(0.009)	(0.009)
Married	0.136	0.216	0.227
	(0.268)	(0.264)	(0.266)
Education	0.105	0.136	0.117
	(0.140)	(0.144)	(0.140)
Displacement	0.735**		
	(0.290)		
Network		-0.165	
		(0.233)	
House Damage			0.159*
			(0.089)
Gender	-0.140	-0.175	-0.131
	(0.218)	(0.220)	(0.220)
Income Before	-0.003	-0.057	-0.046
	(0.083)	(0.081)	(0.081)
Invest	0.004	0.001	0.003
	(0.006)	(0.006)	(0.006)
Savings	0.248	0.156	0.204
	(0.326)	(0.329)	(0.326)
Stable Income	-0.258	-0.252	-0.250
	(0.236)	(0.237)	(0.237)
Observations	291	291	291
Note:	*p<0.1; **p<0.05; ***p<0.01		

Table 5.10: Prudence and Self-protective behaviour

Prudence, Precautionary savings and self selection

To analyse precautionary savings and prudence, we use the number of prudent choices individuals made in the experiment as a dependant variable . The higher values correspond to individuals which are more prudent. We analyze our results with an ordered probit regression indicated in table 5.11.

In the initial specification, presented in table 5.10, we find no relation between prudence and savings. However, considering that prudence also plays a role in occupational choice, i.e., prudent individuals might prefer less risky income paths (Fuchs-Schündeln and Schündeln, 2005), we control for occupational self-selection using the variable stable income. We find that individuals who have stable incomes and savings are significantly more prudent. We repeat the regression across differing specifications with results being consistent. We also find significant negative association between prudence and having a stable income yet no savings. We believe our results indicate differentiated precautionary savings behavior in line with higher-order risk preferences, especially when accounting for self-selection into employment with riskier/less riskier income paths.

	Dependent variable:			
	Prudence Behavior			
	(1)	(2)	(3)	(4)
Age	0.022**	0.023**	0.022**	0.021**
	(0.009)	(0.009)	(0.009)	(0.009)
Married	0.136	0.096	0.180	0.189
	(0.268)	(0.270)	(0.266)	(0.268)
Education	0.105	0.129	0.162	0.140
	(0.140)	(0.141)	(0.145)	(0.141)
Displacement	0.735**	0.717**		
	(0.290)	(0.291)		
Network			-0.159	
			(0.233)	
House Damage				0.140
				(0.089)
Gender	-0.140	-0.152	-0.181	-0.144
	(0.218)	(0.218)	(0.219)	(0.219)
Income Before	-0.003	-0.015	-0.070	-0.059
	(0.083)	(0.083)	(0.081)	(0.081)
Invest	0.004	0.003	0.0003	0.001
	(0.006)	(0.006)	(0.006)	(0.006)
Savings	0.248	-0.316	-0.425	-0.339
	(0.326)	(0.429)	(0.430)	(0.432)
Stable Income	-0.258	-0.438*	-0.438*	-0.423*
	(0.236)	(0.253)	(0.254)	(0.254)
Savings:Stable Income		1.265**	1.328**	1.213*
		(0.632)	(0.638)	(0.637)
Observations	291	291	291	291
Note:		*p<0.1; **p<0.05; ***p<0.01		

Table 5.11: Results of ordered probit regression regarding prudence and precautionary savings after the earthquake for affected individuals. The dependent variable is the number of prudent choices individuals made in the experiment.

5.6 Discussion

By investigating risk and higher preferences among individuals heavily affected by an earthquake, whether displaced or not, alongside a relevant control group, our aim is to contribute to the literature on changes in risk preferences following natural disasters. We find individuals who were heavily affected by the earthquake more risk taking in comparison with those not affected. This aligns with similar studies conducted in Japan following earthquakes (Hanaoka et al., 2018), Indonesia post-tsunamis (Ingwersen et al., 2023), and the USA after hurricanes Eckel et al., 2009. Importantly, these studies stand out for their methodological robustness, with both Hanaoka et al. (2018) and Ingwersen et al. (2023) having access to observations across time.

We test for pre-existing differences using the approach outlined by Falk et al. (2018) and data collected on the studied regions on 2012. We find no significant differences between our control and treatment groups (as defined by geographical location). This supports the notion that the differences in observed risk preferences are attributable to the earthquake. Yet, despite this finding which aligns with our proposition, the fact that the Falk et al. (ibid.) data was collected in 2012, means that any potential impact between 2012 and 2023 could also be driving our results, which we consider as a limitation of this study.

Our results withstand various robustness checks, including expanding the control group beyond 2012 to include other similar regions, and conducting regressions for both matched and unmatched samples. Importantly, when checking for heterogeneous effects of the earthquake across genders we found that our general finding, i.e. increased risk taking after the earthquake, is driven by females. Women who experienced the earthquake exhibit significantly more risk-taking behavior compared to those who did not. This finding aligns with the work of Eckel et al. (2009) and Abatayo and Lynham (2019) who find similar effects for females. We attempt to investigate potential drivers of women's behavior, finding that a negative change in income is associated with significantly increased risk-taking among all affected individuals, including men and women. Moreover, our design benefits from preference elicitation in a very short time frame after the natural disaster, approximately two months, as opposed to other similar research in the literature. For example, Abatayo and Lynham (ibid.), elicited preferences 18 months after a typhoon, or Andrabi and Das (2017), Ahsan (2014) and Cassar et al. (2017) ran their experiments

3–4 years after a natural disaster struck.

A great part of papers focusing on risk preferences and natural disasters finds that extreme events make individuals more risk-loving, while the remainder find the opposite effect(Abatayo and Lynham, 2019). This existing contradiction in the literature on risk preferences after natural disasters is explained through Imas (2016) work, which is proposed as a reconciliation for the conflicting results. This is because Imas (ibid.) show that realized and unrealized losses lead to opposite effects on risk preferences. Yet, Abatayo and Lynham (2019) suggested that most effects of natural catastrophes are realized, thus, one would expect consistent results towards increased risk aversion. Moreover, Imas (2016)'s results might not be applicable to developing contexts, or perhaps not to fieldwork, as Imas (ibid.) primarily operates in controlled settings with stock traders.

We test if realized losses, in the form of house damage after the earthquake, indeed leads to risk aversion. Interestingly, we consistently found that realized losses lead to risk aversion, in line with Imas (ibid.). Furthermore, this effect appears to be particularly pronounced among individuals who experienced a total loss of their home, suggesting that the effect intensifies with the magnitude of total loss. This result in itself highlights the existing contradiction in the literature. Overall, we find that people who experienced the earthquake became more risk-taking than people who did not, however, heavily affected individuals who suffered catastrophic losses became more risk-averse.

We further examine the role of losses by investigating the decision for internal migration following the earthquake. We believe that internal migration encompasses losses that extend beyond the exclusive realm of material losses related to one's house. The decision to migrate (or being displaced) is likely correlated with other realized losses, which could also be non-monetary. We consistently found that internally displaced individuals tend to be more risk-averse than those who experienced the earthquake but did not migrate, further reinforcing this point.

To ensure the robustness of our assumption regarding internal migration and realized losses, we inquire into the drivers of internal displacement. We discover that a lack of informal networks, lesser income, and the level of house damage is correlated to internal migration. This suggests that internal displacement could serve as a suitable proxy for a broader understanding of realized losses in our setting. According to the Internation Organization for Migration (IOM), people who move voluntarily within a country can be regarded as internal migrants, including several reasons formally and informally. If their movement is forced, individuals are referred to as Internally Displaced Persons (IDP). We consider that a significant part of affected individuals in our sample are IDP, they were forced to move due to conditions, whilst others are most likely internal migrants, as their decision might be a choice.

To our knowledge, we present the first examination of higher-order risk preferences in the context of material losses and internal displacement following a natural catastrophe. This contributes to the very limited empirical literature on prudence Lugilde et al. (2019). We initially explored the concept of self-protective behavior and prudence, positing that the decision to internally migrate can be understood as a self-protective measure. I.e, leaving an earthquake-prone area likely reduces the likelihood of experiencing a future loss. We found that prudence is positively correlated with the decision to internally migrate, as stated above, this internal migration may be a forceful manner for a subgroup of our sample.

Eeckhoudt and Gollier (2005) demonstrated that a prudent individual expends less preventive effort than a risk-neutral one. Courbagea and Beatrice Rey (2006) extended this model into the health context, where prudence also leads to lower optimal prevention efforts. However, Menegatti (2009b) expands the original model from one to two periods, arguing that in many prevention situations, the preventive effort precedes its effect on the probability. In contrast to the results of one-period models, he found that prudence leads to more prevention. Our results show a positive correlation between prudence and migration/internal displacement, which we believe can be understood as a form of self-protective behavior. This is in line with Menegatti (ibid.)'s theoretical results. However, Peter (2017) showed that once saving decisions are incorporated (i.e., they are endogenous), results of the one-period models are restored. In other words, prudence should lead to less prevention in the sense of self-protection. Yet, for this to hold, individuals must be able to optimize both their savings (and, thus, also consumption) and prevention decisions. We believe this is not the case for individuals facing constraints imposed by a natural catastrophe, as our results align with Menegatti (2009b) theoretical findings.

Moreover, we explored the potential role of precautionary savings and higher order risk preferences in our study. Prudent individuals, expecting future income shocks, typically accumulate precautionary savings to smooth consumption. However, in our initial analysis, we found no clear correlation between savings and prudence. This seems counter-intuitive, as, in the absence of complete insurance, one would expect that expected future income shocks drive prudent individuals to build up precautionary savings to avoid wide fluctuations in consumption.

Nevertheless, it is essential to consider that risk aversion not only influences savings behavior but also plays a role in occupational choice. Prudent individuals might opt for occupations associated with less risky income paths, while less prudent may prefer occupations with higher income risk (Fuchs-Schündeln and Schündeln, 2005). In line with these findings on self-selection and precautionary savings (ibid.), we examine potential self-selection of prudent individuals into occupations linked with less risky income paths. Our analysis provided suggestive evidence of self-selection, indicating that individuals (heavily affected by the earthquake) who self-select into stable income jobs and have savings are significantly more prudent than those who are self-employed and lack savings. While our results regarding higher-order risk preferences in catastrophe settings cannot be regarded as causal findings, we believe to present novel suggestive evidence in the field of empirical research on prudence related behaviors (Lugilde et al., 2019), such as primary prevention and precautionary savings in the context of a natural disaster.

Importantly, there is evidence that conclusions derived from changes in risk preference from incentivized experiments have a relation with 'real-life' risk-taking behaviors. Cameron and Shah (2015) find that individuals in villages in Indonesia that suffered a flood or earthquake within the past three years display higher levels of risk aversion in comparison to individuals unaffected by such events. They examine the extent to which behavior in the risk experiments is correlated with such 'real-life' risk-taking as opening a new business or changing jobs. They provide evidence that more risk-averse individuals are less likely to take these types of risky decisions. This could potentially imply long run economic impacts that could be attributable to changes of risk preferences from natural disasters.

Timing is an important aspect to consider. A notable limitation of our study is the absence of continuous observations across time for the same individuals. As a result, we are unable to provide insights into the long-term effects of catastrophes on risk preferences or the permanence of our findings. In this aspect, the literature finds conflicting evidence on the permanence of changes in risk preferences across time due to natural disasters.

Hanaoka et al. (2018) finds persistent changes in risk preferences after an earthquake in Japan, whereas Ingwersen et al. (2023) in a tsunami context finds that changes in risk preferences are short-lived: starting a year later. To our knowledge there is no evidence of differences in willingness to take risk between the two groups. We believe that the permanence of changes in risk preferences after a natural disaster, and their correlation to economic behaviour are important avenues for future research.

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5.A Survey and experiment in distribution center

Figure A-1: Research assistants implementing the survey and experiment in the distribution center of goods for earthquake victims in Antalya.

5.B Risk assessment

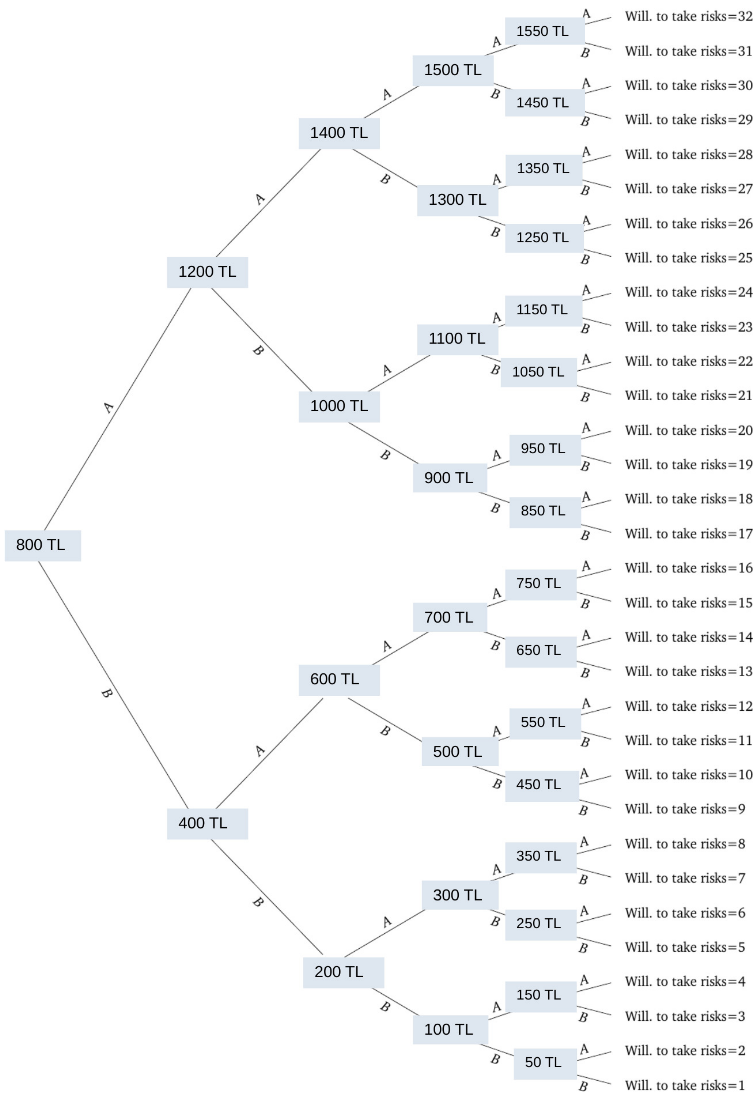

Figure A-2: Risk Tree used in the experiment to assess risk behavior. The staircase risk task involved a decision tree, where numbers represented guaranteed payments, "A" denoted the choice of a lottery, and "B" indicated the choice of a certain payment. The procedure operated as follows: participants were initially asked whether they preferred a guaranteed payment of 800 lira or a 50:50 chance of either receiving 1500 lira or nothing. If they chose the safe option ("B"), the subsequent guaranteed amount inquired decreased to 400 lira. Conversely, if they opted for the gamble ("A"), the assured amount was raised to 1200 lira. This pattern continued throughout the tree, following the same rationale. The risk tree values were based on those indicated in (Falk et al., 2018) taken in 2012. These values were converted in real values for the time of the experiment in 2023.

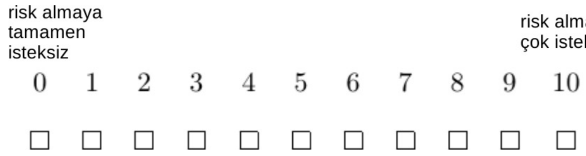

Figure A-3: Self assessment question about the willingness to take risk. Participants were inquired: Please tell me, in general, how willing or unwilling you are to take risks. Please use a scale from 0 to 10, where 0 means "completely unwilling to take risks" and a 10 means you are "very willing to take risks".

5.C Risk experiment based on Gneezy and Potters

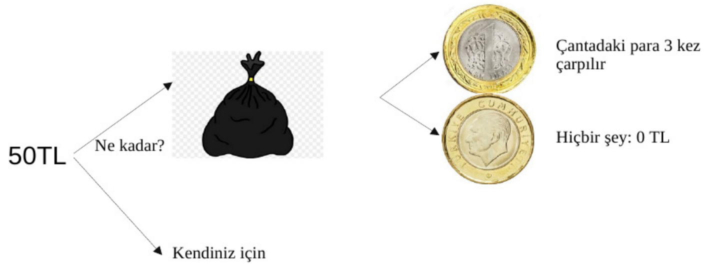

Figure A-4: Structure of the risk experiment based on Gneezy and Potters

5.D Prudence experiment

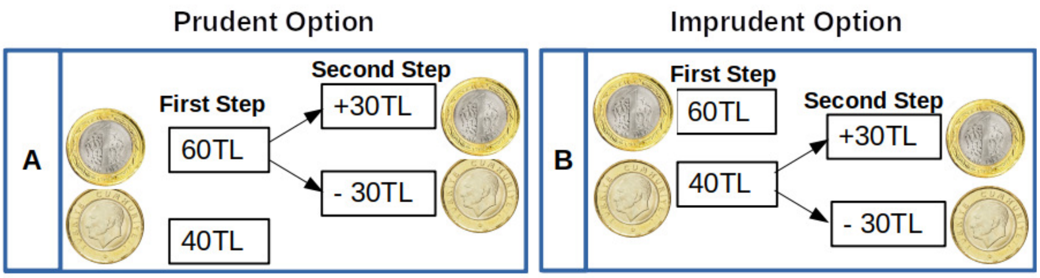

Figure A-5: Structure of the prudence experiment based on (Schaap, 2021). The figure shows the two options in the base line of the choice task.

5.E Balance Table

	Balance table Before					**Balance table After**				
	Control		**Treatment**			**Control**		**Treatment**		
	Mean	SD	Mean	SD	**Diff**	Mean	SD	Mean	SD	**Diff**
Age	39.03	13.93	39.65	13.68	0.04	39.03	13.93	39.87	14.68	0.06
Gender	0.46	0.50	0.50	0.50	0.10	0.46	0.50	0.46	0.50	0.01
Married	0.57	0.50	0.68	0.47	0.22	0.57	0.50	0.58	0.49	0.03
Education	2.12	0.82	2.01	0.86	0.14	2.12	0.82	2.08	0.85	0.05
Income	3.35	1.31	3.23	1.70	0.08	3.35	1.31	3.33	1.76	0.01
Math	5.66	2.22	5.69	2.50	0.01	5.66	2.22	5.52	2.59	0.06
N	246		356			246		246		

Note: *p<0.1; **p<0.05; ***p<0.01

Table A-1: Balance Table for the matching procedure. To test for imbalance we used the software R, specifically the package 'stddiff' . Imbalance is usually defined as a *Diff* greater than 0.1 or 0.2

5.F Average marriage rate

Year	Antalya	Mean Treatment
2012	8.28	10.09
2013	8.00	10.12
2014	7.91	9.98
2015	7.97	9.30
2016	7.61	8.74
2017	7.02	8.29
2018	6.76	8.31
2019	6.76	7.87
2020	6.17	7.16
2021	6.59	8.02
2022	6.80	7.39
t- test	t = -3.611, df = 17.36***	

Note: *p<0.1; **p<0.05; ***p<0.01

Table A-2: Average marriage rate per 1000 population among 2012 and 2022 for Antalya (control) and the treatment provinces including Adiyaman, Gaziantep, Hatay, Malatya, Kahramanmaraş, Şanlıurfa and Osmaniye. The t-test in the last row shows that there are significant differences among these two regions. Source: Turkish Statistical Institute (XXXXX)

5.G Regression with the whole sample - Before matching

	Dependent variable:	
	Risk Index	
	(1)	(2)
EarthQ	1.531***	-0.697
	(0.550)	(0.739)
Gender	-2.407***	-5.202***
	(0.544)	(0.828)
EarthQ*Gender		4.706***
		(1.063)
Income	0.703***	0.715***
	(0.203)	(0.200)
Married	0.344	0.364
	(0.663)	(0.653)
Age	-0.034	-0.043*
	(0.024)	(0.023)
Education	0.136	0.077
	(0.395)	(0.389)
Savings	0.800	0.752
	(0.736)	(0.724)
Math	0.352***	0.347***
	(0.122)	(0.120)
Network	-0.503	-0.445
	(0.565)	(0.556)
Constant	6.275***	7.980***
	(1.468)	(1.496)
Observations	594	594
R^2	0.115	0.144
Adjusted R^2	0.101	0.129
Residual Std. Error	6.424 (df = 584)	6.324 (df = 583)
F Statistic	8.443*** (df = 9; 584)	9.802*** (df = 10; 583)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table A-3: OLS regression with the whole sample before matching

5.H Difference among earthQ and non-earthQ area in 2012

	Control		**Control Plus**		**Treatment**			
	Mean	SD	Mean	SD	Mean	SD	F-Test-A	F-Test-B
Gender	0.42	0.50	0.57	0.50	0.61	0.49	4.38**	0.38
Age	45.20	14.69	39.55	13.72	35.88	13.58	14.04***	4.93**
Self Risk	4.75	2.71	5.34	2.69	5.14	2.96	0.56	0.32
Stair Risk	10.14	10.66	11.04	11.08	10.95	12.36	0.14	0.00
Math	4.15	2.73	4.78	2.81	5.41	2.69	6.55	3.58
Risk Index	7.30	5.35	8.03	5.66	7.89	6.43	0.28	0.04
N	40		136		136			
Note:		*p<0.1; **p<0.05; ***p<0.01						

Table A-4: Descriptive statistics for groups in the control and treatment regions in the year 2012 based on data from Falk et al., 2018. The control columns refer to Antalya, but as we have only 40 observations we added to the control group the places of Kastamonu, Trabzon and Samsun which also have the same HDI. The group with the added cities corresponds to the control plus columns. The treatment regions gather Adana, Malatya, Hatay and Gaziantep, which are the regions affected by the earthquake in 2023. The F-Test-A shows the significant differences among control and treatment regions. The F-Test-B shows the differences among the control plus and the treatment regions.

	Dependent variable:
	Risk Index
EarthQ	-0.597
	(0.727)
Gender	-1.153
	(0.744)
Age	-0.099***
	(0.028)
Math	0.217
	(0.138)
Constant	11.621***
	(1.650)
Observations	268
R^2	0.079
Adjusted R^2	0.065
Residual Std. Error	5.863 (df = 263)
F Statistic	5.652*** (df = 4; 263)
Note:	*p<0.1; **p<0.05; ***p<0.01

Table A-5: OLS regression with the extended sample: The control plus and the treatment regions.

5.I Histograms per level of house damage

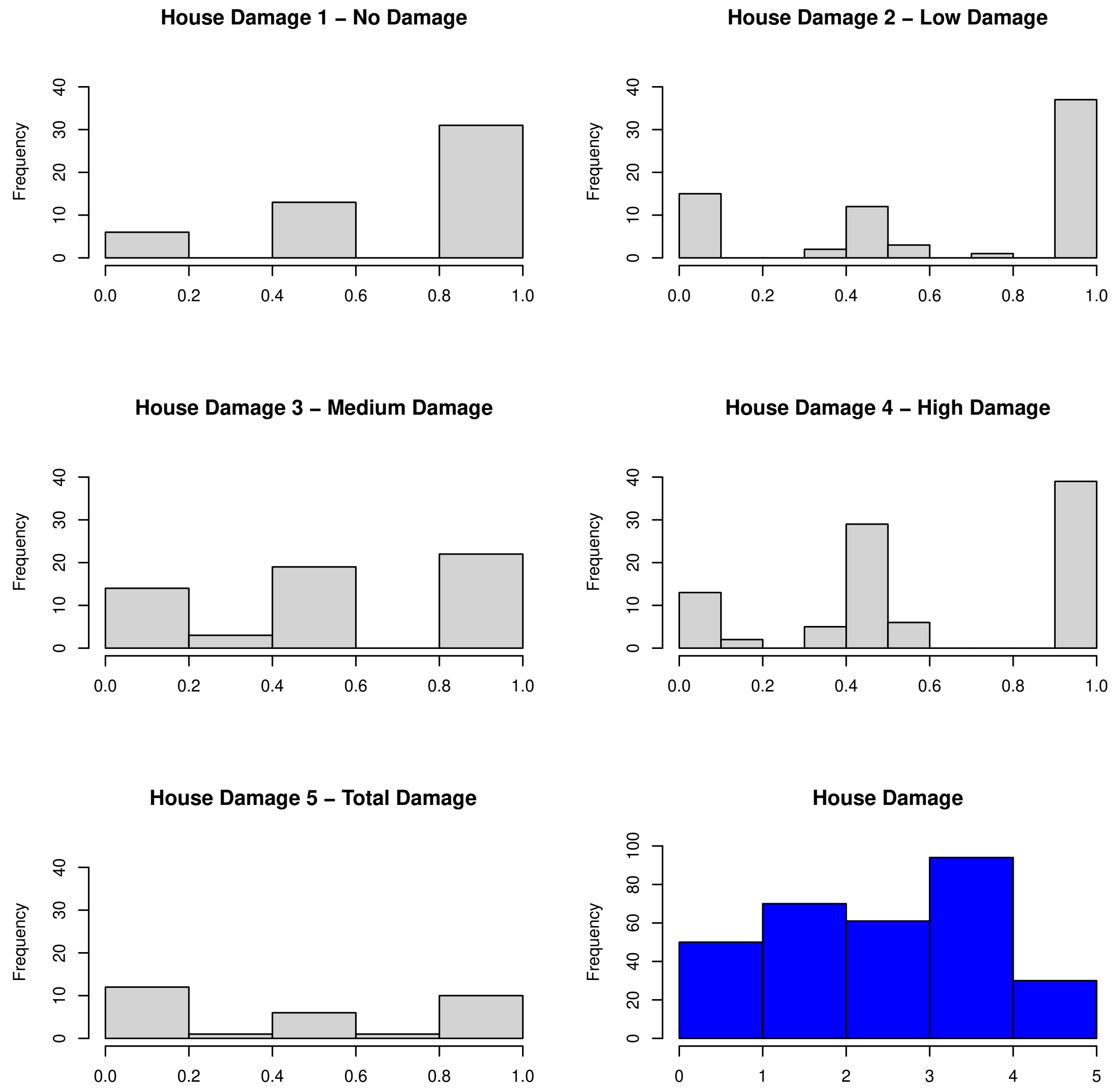

Figure A-6: Histograms of proportion of initial endowment invested in the bag per level of damage. X- axis: for proportion invested in the Bag. The blue histogram shows the distribution of house damage in the whole sample.

5.J Histogram displacement per level of damage

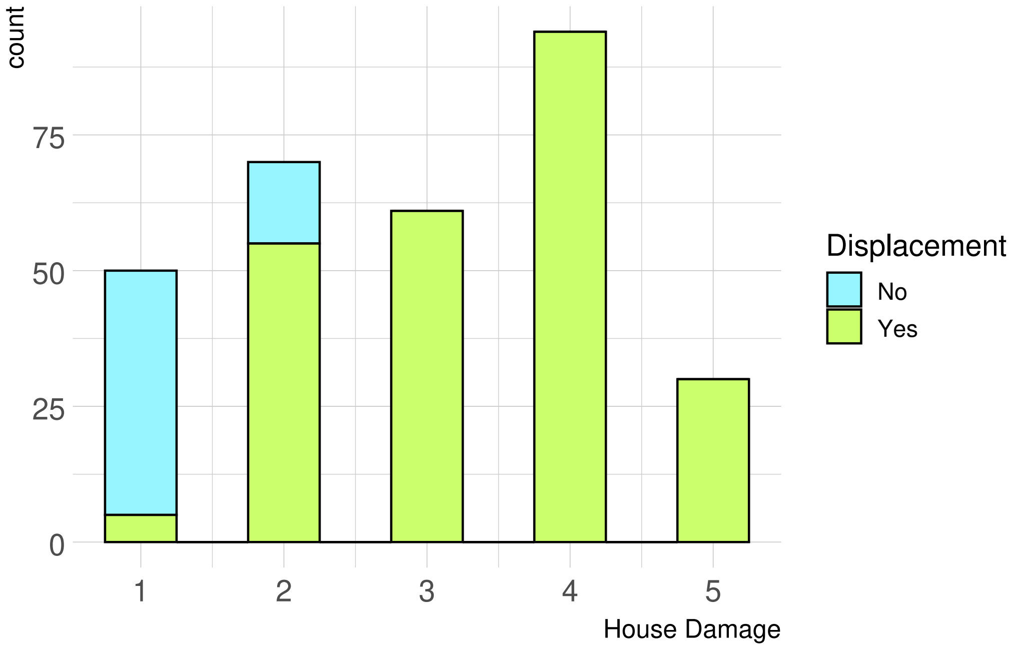

Figure A-7: Histogram displacement per level of damage: 5: total damage. 1: no damage.

5.K Realized losses on risk behavior

	Dependent variable:			
	Risk Taking			
	(1)	(2)	(3)	(4)
House Damage	-0.727**		-0.391	
	(0.310)		(0.405)	
Medium Damage		-1.795		
		(1.090)		
Total Destruction		-3.218**		
		(1.595)		
Displacement			-1.755	-2.604**
			(1.363)	(1.043)
Gender	-0.976	-0.892	-0.936	-0.903
	(0.772)	(0.775)	(0.772)	(0.771)
Age	-0.069*	-0.072*	-0.069*	-0.073*
	(0.037)	(0.038)	(0.037)	(0.037)
Married	-0.683	-0.615	-0.472	-0.336
	(0.931)	(0.944)	(0.944)	(0.933)
Education	-0.280	-0.271	-0.240	-0.194
	(0.523)	(0.526)	(0.523)	(0.521)
Income	0.876***	0.835***	0.742**	0.725**
	(0.286)	(0.296)	(0.304)	(0.303)
Employed	1.270	1.256	1.345	1.350
	(0.941)	(0.945)	(0.942)	(0.942)
Retiree	0.893	0.889	0.770	0.811
	(1.380)	(1.387)	(1.382)	(1.381)
Unemployed	-5.313*	-5.297*	-5.625**	-5.572**
	(2.710)	(2.739)	(2.718)	(2.717)
Constant	12.890***	12.526***	13.522***	13.040***
	(2.155)	(2.188)	(2.208)	(2.151)
Observations	299	299	299	299
R^2	0.110	0.106	0.115	0.112
Adjusted R^2	0.082	0.075	0.084	0.084
Residual Std. Error	6.449 (df = 289)	6.472 (df = 288)	6.442 (df = 288)	6.441 (df = 289)
F Statistic	3.963***	3.432***	3.740***	4.053***
	(df = 9; 289)	(df = 10; 288)	(df = 10; 288)	(df = 9; 289)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table A-6: Realized losses on risk behavior

Chapter 6

Conclusion

In this thesis I improved the understanding of adaptation using multiple methodologies and approaches. Two approaches are used in the majority of the work: The ecological resilience and the human/political ecology approach[1]. These approaches stem from the analysis of vulnerability and resilience, in which adaptation is key.

In chapter 2 I studied adaptation from the ecological resilience lens, analysing the interactions and feedback between the social and ecological systems. The framework presented builds upon the work on adaptation and vulnerability by Ionescu et al. (2009), and the discussions of Hinkel (2011) and (Gallopín, 2006). The framework provided an analytical approach to address the question "Adaptation of what to what?", allowing to quantify the "adaptation of" many system components "to" many threats. The motivation behind this is that many studies and frameworks are focused on a single threat, generally climate change, while neglecting other economic or social threats. Since the social, economic and ecological components are interrelated, threats affecting the socio-economic subsystem also affect the ecologic subsystem. Abrupt changes such as pandemics or economic crises are also of importance to the ecological aspects.

I used a bio-economic model in chapter 2 to exemplify the framework because it is the minimum viable product that involves human-ecological interactions. The use of a bio-economic model to analyse a complex system such as the North Sea flatfish fishery requires setting boundaries focused in answering the research questions. I showed an analysis of the socioeconomic situation of the North Sea flatfish fishery in chapter 3 highlighting the

[1]This is called 'human ecologist school' by Hufschmidt (2011) and 'Economy and political ecology' approach by Berrouet et al. (2018).

critical state of this fishery, with profits and fishing vessels continuously decreasing. As a result, the focal point of analysis in the framework centred on the adaptive capacities of fishers to mitigate impacts to their profits in response to multiple threats. While the framework allowed for the analysis of the adaptation "of" many system properties "to" multiple threats, fishers' profits were chosen due to their critical importance for this socio-ecological system. Although chapter 2 also provided insights of the changes in utility given by the fishers' adaptation to multiple threats, the focus remained on profits, leaving a deep analysis of utility for future work.

Applying the framework to the bio-economic model required assumptions regarding the functioning of the market. One of the most relevant assumptions is that of free entry and exit for fishing firms. However, as I described in chapter 3, firms in reality are constrained by the capital required to acquire a new vessel, leading to an ageing fleet. Another significant assumption is the use of effort as the sole input for production, which overlooks the need for investment to maintain ageing vessels and keep the fishery viable. These issues could be addressed by expanding the model to include capital stocks for the fishing firms, that would allow them to renew the fleet allowing for more flexibility in the entry and exit of the market.

The critical socioeconomic situation of the German flatfish fishery described in chapter 3 also replicates in the shrimp fishery. In the flatfish fishery, a crucial factor for adaptation is the fishing culture and the self-perception of fishers. The incentives for fishers extend beyond economic considerations; they see themselves as fishers engaged in the act of fishing, rather than as economic entrepreneurs. This self-perception partly explains how this fishery remains despite decreasing profits and highlights the significant role of culture in adaptation, particularly in enhancing adaptive capacity.

Inspired by the finding in chapter 3, that the persistence of the fishery is owed to the fishers' culture and self perception, in chapter 4 I assessed the value of the fishing culture in the German shrimp fishery, one of the oldest fishing techniques in the North Sea, for wider society. Fishing culture extends beyond the mere act of fishing; it encompasses the cultural landscape, the waterfronts, and fishing traditions, together termed maritime cultural heritage (Khakzad and Griffith, 2016). Knowing that culture is crucial for fishers' adaptation, identifying its value for consumers is key for policy makers to make more informed decisions. I found a positive willingness to pay among consumers to maintain this cultural heritage, suggesting that, despite its lower value compared to other shrimp dish attributes (origin, processing, harvesting, and certification), this heritage is important not only for fishers but also for consumers. These findings could influence the design of socio-ecological fishing models, advocating for the incorporation of cultural heritage as a factor that enhances consumers' utility and supports fishers' adaptation. This approach could help explain the existence of non-profitable fishing businesses and delve into the direct connection between fishing cultural heritage and the adaptation process.

Aside of culture, in this thesis I also explored the role of individuals' risk preferences on the adaptation process. In chapter 5 I analysed adaptation using the human/political ecology approach, focusing on individual characteristics that affect the adaptive capacity after a natural disaster. I examined changes in individuals' risk behaviour after an abrupt change, considered as part of the post-impact phase of the adaptation process (Hufschmidt, 2011). In chapter 5 I provided insights into the co-evolution of risk preferences with the environment and demonstrated how post-disaster behaviours align with the theoretical expectations exposed by Imas (2016). The results presented a view of changes in risk preferences from multiple perspectives, emphasizing differentiated adaptive behaviours by gender, migration/displacement status, and damage level after a natural disaster. Regarding gender, results showed that women adapt to natural catastrophes differently than men, taking more risks after the earthquake. Concerning migration, results showed the relationships between protective behaviours (migration) and high-order risk preferences. For damage-level, results revealed that individuals with higher damage show high risk aversion. This chapter brought understanding of the adaptation behaviours, through changes in risk preferences, in a post-impact adaptation phase. It showed that post-impact adaptive actions are affected by risk preferences and are differentiated by gender and the degree of damage individuals experienced.

In addition to the improvement of adaptation measurements, as in chapter 2, in this thesis I covered two important factors affecting the adaptation process: culture and risk behaviour. Culture plays a significant role in adaptation, as humans implement strategies beyond mere economic incentives, influencing how they cope with abrupt changes. For instance, the recent the pandemic had different impacts across countries due to cultural differences and risk perceptions (Ibanez and Sisodia, 2020). Although the ecological resilience approach recognizes the role of culture in adaptation and its importance in improving resilience (Nicoll and Zerboni, 2020), it remains under represented in socio-ecological systems models. An avenue for future research, emerging from this thesis, is the inclusion of cultural aspects and differentiated risk behaviours in the modelling design, to improve adaptation strategies.

In this thesis I employed a variety of methods to analyse adaptation. Chapter 2 relied on an analytical framework applied to a bio-economic model, chapter 4 used surveys and discrete choice experiments, and chapter 5 incorporated field experiments and surveys. The use of multiple methodologies broaden the perspective on adaptation: bio-economic models and analytical approaches enhanced understanding of human-ecological interlinks that are difficult to capture empirically; discrete choice experiments identified the value of non-market goods in adaptation; and field experiments assessed individuals' risk preferences. The utility of different methodologies lies in developing metrics that can evaluate the adaptation capacity in communities or adaptation processes in socio-ecological systems.

In the context of the North Sea fishery in this thesis I showed a way to improve the measurement of adaptation in coupled human-ecological systems using a framework applied to a bio-economic model. I also showed that adaptation is influenced by culture and that consumers value this aspect in society. Moreover, in the context of natural disasters, I showed how humans adapt through changes in risk preferences to an earthquake, and how these adaptations differentiate between gender and realized and unrealized losses. I consider that the results of this thesis improve the understanding of adaptation from the social and socio-ecological systems perspective. While numerous frameworks exists to measure vulnerability, including adaptation (Hay and Mimura, 2013), the contribution of this thesis lies in including aspects such as culture and individuals risk preferences, which are still under represented in current methodologies.

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Appendix A

List of publications resulting from the dissertation

Conferences

Quiroga, Emily and Blanz, Benjamin (2021), *Vulnerabilities of a Socio-Ecological System Through the Lens of a Bio-Economic Model.* In *Proceedings of the 26th Annual Conference of the European Association of Environmental and Resource Economists.*

Quiroga, Emily and Blanz, Benjamin (2022), *Vulnerabilities of a Socio-Ecological System Trough the Lens of a Bio-Economic Model.* In *World Conference on Natural Resources Modeling (WCNRM), June 2022.*

Quiroga, Emily and Tanner, Michael (2024), *Revealing risk preferences: Evidende from Turkey's 2023 Earthquake.* In *Proceedings of the 29th Annual Conference of the European Association of Environmental and Resource Economists.*

Appendix B

Declaration

I hereby declare that I, Emily Quiroga Gomez, have not received any commercial consultation on my doctoral thesis. This thesis has not been accepted as part of any previous doctoral procedure or graded as insufficient.

Place/Date Doctoral candidate's signature

Appendix C

Affidavit

I, Emily Quiroga Gomez, hereby declare under oath that I wrote the dissertation titled "*Essays on Adaptation and Behavioural Responses to Abrupt Changes*" myself and in case of cooperation with other researchers pursuant to the enclosed statements in accordance with Section 6 subsection 3 of the Doctoral Degree Regulations of the Faculty of Business, Economics and Social Sciences dated 18th January 2017. I have used no aids other than those indicated.

Place/Date Doctoral candidate's signature

Appendix D

Personal declaration for dissertation by publication

Concept/planning: Formulation of the fundamental academic problem, based on previously unanswered theoretical questions, including a summary of general inquiries that can be answered on the basis of analysis or experiments/investigation. Planning of the experiments/analyses and formulation of the methodological approach, including decision about methods and independent methodological development.

Implementation: Degree of integration in the concrete investigations or analyses.

Creation of the manuscript: Presentation, interpretation, and discussion of sought-for findings in the form of an academic article.

Calculation of personal contribution proceeds according to a point system of 1–100 percent. Candidate has made an independent contribution of 100 percent to at least one of the articles.

For the article “A Framework to Quantify Adaptation to Multiple Drivers” the candidate’s personal contribution breaks down thus:

Concept / planing	25%
Implementation	50%
Creation of Manuscript	75%

For the article “A Fisheries Social-Ecological System at Risk of Losing Its Capacity to Adapt to Global Change” the candidate’s personal contribution breaks down thus:

Concept / planing	5%
Implementation	10%
Creation of Manuscript	5%

For the article “Beyond Fishing: The Value of Maritime Cultural Heritage in Germany” the candidate’s personal contribution breaks down thus:

Concept / planing	100%
Implementation	100%
Creation of Manuscript	100%

For the article “Revealing risk preferences: Evidence from Turkey’s 2023 Earthquake” the candidate’s personal contribution breaks down thus:

Concept / planing	50%
Implementation	70%
Creation of Manuscript	30%

My respective co-authors have agreed to the above percentages for my own contributions.

Place/Date Doctoral candidate’s signature