Contribution to the Themed Section: ‘Exploring Adaptation Capacity of the World’S Oceans and Marine Resources to Climate Change’

Skippers’ preferred adaptation and transformation responses to catch declines in a large-scale tuna fishery

Iratxe Rubio 1,2*, Alistair J. Hobday 3,4, and Elena Ojea 1

1Future Oceans Lab, CIM-Universidade de Vigo, Vigo, Spain
2Basque Centre for Climate Change (BC3), Leioa, Spain
3CSIRO Oceans and Atmosphere, Hobart, TAS, Australia
4Centre for Marine Socioecology, University of Tasmania, Hobart, TAS, Australia

*Corresponding author: tel: +34 944014690; e-mail: irrubio@uvigo.es; iratxe.rubio@bc3research.org

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At first glance, large-scale fisheries may seem adaptable to climate change. Adaptation takes place from the governance to the individual level of fishers. At the individual level, skippers make day-to-day decisions on where to fish and are at the forefront of the response to changes at sea. We seek to understand such individual adaptation in large-scale fisheries, using the case of the Spanish tropical tuna fishery. We surveyed 22% of Spanish freezer purse seine skippers operating in the Atlantic, Indian, and Pacific Oceans. In the last 10 years, more than half of skippers used new technology to search for tunas and expanded their fishing area as adaptation actions. Using cluster analysis, we identified two skipper groups—based on stated behaviours to confront different hypothetical scenarios of catch decline—that would follow adaptation or transformation strategies. The majority of skippers would follow adaptation strategies until a hypothetical 30% catch decrease and then choices diverge. Skipper characteristics, such as importance given to intergenerational knowledge, perceptions of change in tropical tuna abundance, and years working in the current job, can explain the adaptation and transformation choices. These findings help understand the potential for adaptation behaviour by skippers involved in fisheries confronting catch declines.

Keywords: global warming, industrial fisheries, perception analysis, purse seiners, scenario, skippers

Introduction

The marine environment is currently and will continue to face profound transformations triggered by climate change (IPCC, 2019a). Adaptation is thus a reality for people who depend on marine ecosystems for a living, a food source or other uses connected to the oceans (Miller et al., 2018). Adaptation in human systems is defined as “the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities” (IPCC, 2019b). Two recent reviews on how marine systems and fisheries adapt to climate impacts highlight the lack of examples of concrete adaptation actions and measures in the marine literature (Lindegren and Brander, 2018; Miller et al., 2018). With regard to specific factors triggering human adaptation responses in recreational or commercial fisheries, only a few recent studies show key aspects explaining adaptation (e.g. Frawley et al., 2019; Barnes et al., 2020), or stated adaptation behaviour (van Putten et al., 2017). Addressing these research gaps is timely since identifying factors triggering adaptation responses is essential from a policy-making perspective. Findings on stated behaviour also help understand the potential for adaptation that can be incentivized through policy (van Putten et al., 2017).

The common assumption is that governments aim to identify effective ways and approaches to promote adaptation strategies to
climate change (Pecl et al., 2019; Ogier et al., 2020), in a top-down approach. From this perspective, a research goal might be to help management and policy design and increase the likelihood of adaptation, ensuring sustainable marine resource use outcomes (Adger, 2016; van Putten et al., 2017). However, individuals are also responding to climate change, and so to avoid antagonistic adaptation efforts between governments and individuals, one strategy is to investigate individual adaptation options. The identification of approaches and capacity for individual adaptation efforts (bottom-up approach), will have effects for broader social structures (Wilson et al., 2020) and overall adaptation success.

In this study, we seek to improve the understanding about individual adaptation responses to climate change impacts in large-scale fisheries. Large-scale fisheries are seen as adaptable to changing conditions (Belhabib et al., 2016), which makes them of particular interest for elucidating specific characteristics that might make them adaptable. For example, vessels are highly mobile, they can follow shifting stocks in easier ways than small-scale fisheries (Belhabib et al., 2016; Salomon et al., 2019), some fleets use high levels of technology (Lopez et al., 2014), and others are supported by a strong fishing industry (Mullon et al., 2017). Unfortunately, under rapid climate change, even being adaptable might not be sufficient and adaptation planning is needed since changes in species distributions and abundances happen rapidly (Poloczanska et al., 2016; Pinsky et al., 2021).

We use the case of the Spanish tropical tuna freezer purse seine fishery, which has historically experienced environmental and management changes, among others (Rubio et al., 2020), and to this day remains with an intense fishing activity (Ugalde and Samano, 2019). In this fishery, organizations from the fishing industry and other institutions like governments, scientific bodies, and non-governmental organizations were found to promote several ongoing adaptation actions (Rubio et al., 2021). However, decision-making at the fleet operational level relies on the individual skippers, who decide where to fish, and can respond in different manners to ongoing changes at sea. In fact, the literature predicts that adaptation takes place at different levels, from the governance to the individual level of fishers (Fedele et al., 2019; Galappaththi et al., 2019; Ojea et al., 2020), and understanding adaptation at all levels is key to respond efficiently to climatic impacts. In the Spanish tropical tuna freezer purse seine fishery, skippers make day-to-day decisions on where to fish and are thus at the forefront of the fishery response to changes. For this reason, we investigate the individual adaptation actions that have been undertaken by skippers in the past within the Spanish large-scale fishery as the first objective of this article.

Furthermore, adaptation to climate change in fisheries can be studied within the broader perspective of resilience thinking, where responses to climatic impacts lie along an adaptation continuum, i.e. remaining, adapting, and transforming (Barnes et al., 2017; Ojea et al., 2020). Individual responses to climate impacts in fisheries systems range between remaining in the activity, without behavioural changes, to engaging in adaptation or transformation actions. The combination of individual responses to climate impacts can drive the system to remain, adapt or transform as a whole. For example, an adaptive response at the individual level (i.e. skipper) can rely on improvement of fishing gear. This response allows the skipper to continue his or her activity and avoids more systematic changes, like modifying livelihoods. When most individuals in a fishery make adaptation responses, the fishery system as a whole is likely to be able to absorb impacts and therefore have a collective adaptation response (Barnes et al., 2020; Wilson et al., 2020). If the individual responses are transformational, there will be more fundamental changes to the system, altering the fishery and even creating a new system (Barnes et al., 2020). At the individual level, changing livelihoods or exiting a fishery can be considered transformational actions (Marshall et al., 2012; Park et al., 2012; Ojea et al., 2020). Little is known regarding individual responses of fishers to changes in resource availability due to climate change (Barnes et al., 2020), and to our knowledge, this is the first study that applies the adaptation continuum to an industrial fishery.

To do this, we investigate how skippers would respond to different levels of hypothetical catch declines and explore whether they would follow adaptation or a transformation strategies. We also explore the reasons behind these responses. For that purpose, we collect skippers’ stated behaviours to different levels of hypothetical catch decrease along the adaptation continuum and associate them with factors related to adaptive capacity since links remain unclear (Cinner et al., 2018; Barnes et al., 2020). Therefore, our second goal is to investigate what drives the individual stated behaviours of skippers in marine large-scale fisheries, through exploring the association between factors from adaptive capacity and adaptation or transformation responses to hypothetical scenarios. Understanding the potential for adaptation behaviour by skippers involved in fisheries confronting catch declines is key for posteriorly incentivizing adaptation.

**Material and methods**

**Case study**

Tropical tuna fisheries are highly valuable worldwide economically and for food security (McClune et al., 2019; FAO, 2020). Among them, tropical tuna freezer purse seiners funded by Spanish investment, are responsible for around 10% of the global tropical tuna catch (Ugalde and Samano, 2019). As mentioned above, the fishery has been subjected to many changes over time, with the added pressure of climate change (Rubio et al., 2020). Climate change impacts have been recently recorded and projected for tropical tunas and some of their fisheries in the three oceans (e.g. Monllor-Hurtado et al., 2017; Senina et al., 2018; Erauskin-Extramiana et al., 2019; Rubio et al., 2020). At a global scale, tuna habitat distribution limits have shifted poleward in both hemispheres (Erauskin-Extramiana et al., 2019).

In addition, abundance decreases and increases are projected during the 21st century depending on the species and ocean (Erauskin-Extramiana et al., 2019), but patterns are mixed. For example, models project an increase of Skipjack global biomass between 2010 and 2050 and a decrease between 2050 and 2095 under a Representative Concentration Pathway (RCP) 8.5 high emission scenario in the Atlantic Ocean (Dueri et al., 2016). However, Erauskin-Extramiana et al. (2019) project an abundance increase through to 2100 for both Yellowfin and Skipjack. Bigeye tuna is projected to decrease in abundance under the same scenario, time period in the Atlantic and Indian oceans (Erauskin-Extramiana et al., 2019). In the Pacific, an eastern shift in the biomass of Skipjack and Yellowfin over time is projected, with a large and increasing uncertainty for the second half of the century (Senina et al., 2018).

The status of tropical tuna stocks also varies by species and ocean region. In 2020, Skipjack tuna (Katsuwonus pelamis) stocks were found to be in a healthy status in all the oceans; Yellowfin...
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Spanish tropical tuna freezer purse seiners operate in the Indian, Atlantic and Pacific oceans. In this article, when referring to “Spanish vessels”, we include both Spanish and associated flagged vessels owned by fishing companies that are associated within the two existing fisheries associations or producer organizations in Spain. Two skippers work on every vessel, rotating to each lead 4-month fishing campaigns. They are the ones who make the final day-to-day decisions on where to fish at sea, being at the forefront of the fishery response to changes. This characteristic makes them an ideal target to study their responses to changes in the sea. In total (year 2020), there are 134 skippers from freezer purse seine vessels under Spanish capital (calculated from data provided by the fisheries associations representing the fishing companies); 54 of them currently operating in the Atlantic, 52 in the Indian, and 28 in the Pacific Ocean.

Surveys

Short surveys of about 10 min were designed, pre-tested and implemented from October 2019 to March 2020. We targeted all skippers from the Spanish fishery operating in the three oceans, i.e. a sample size of 134 skippers. All are male between 35 and 64 years old. In order to reach the maximum number of skippers, a mixed approach was taken. We first contacted fishing companies to ask for skippers’ contact details, however, this was unsuccessful due to data protection protocols. Contact with skippers was only possible when companies were willing to act as intermediaries. Some face to face surveys were conducted when skippers attended company events such as training courses (n = 5). In addition, surveys were sent by e-mail or administered in person by company workers willing to collaborate with the research (n = 26, of which 9 were face to face and the rest online). We collected 31 survey responses (23% of the total sample size of skippers) (see Supplementary Section 2 “Representativeness of data”). Almost half of the companies (46%) rejected participation, and two survey responses were not included in data analysis due to quality concerns, resulting in survey reach of 22% of the total possible sample.

In the surveys, we covered three topics: (i) past adaptation actions; (ii) hypothetical responses to catch decreases; and (iii) adaptive capacity variables (Supplementary Section 1 “Survey questions”). Past adaptation actions (i) were recorded based on a semi-closed question (Schuman and Presser, 1979), where skippers specified from a list what adaptation actions they had performed in the last 10 years, as a response to changes they observed, which included climatic and non-climatic changes (Supplementary Section 1, Question 5). These actions were based on the knowledge gathered from previous interviews performed with the fishing industry (Rubio et al., 2021).

For the responses to hypothetical catch declines (ii) we used a multiple-response question with five scenarios of decreasing catches (Supplementary Section 1, Question 6). We used catch decrease scenarios of 15, 30, 50, 70, and 90% with respect to current annual catches to capture the full adaptation response continuum for the negative expectations derived from climate change impacts, combined with other potential issues such as overexploitation. This is independent from the most likely abundance changes from climate change, which, as previously shown, are different or uncertain depending on the ocean, time period and species. We acknowledge abundance increases are also expected, but for assessing the potential for adaptation behaviour when catch declines occur, we decided to focus on negative impacts. Skippers had to specify “actions” (i.e. state their behaviour) in response to each scenario. While recognizing stated behaviour can be biased if compared to actual behaviour, we also note that intentions are the most important precursors to perform (or not perform) a behaviour (Webb and Sheeran, 2006; Fujitani et al., 2017). Responses were grouped to match the adaptation continuum—which we slightly modified as we split “exit the fishery” behaviour from other transformations. However, we still interpreted “exit the fishery” as a transformation strategy; we split it with the purpose of having a more detailed view on the results. We therefore used four response categories: “remain”, “adapt”, “transform”, and “exit” (Supplementary Section 3 "Adaptation continuum"). “Remain” corresponds to skippers stating they would not change their usual fishing behaviour when facing a particular scenario of catch decrease; “adapt” corresponds to skippers who would change their fishing behaviour (e.g. technology use or fishing location) but keeping their activity in the current ocean; “transform” matches skippers who would change ocean, gear or job within the fishing sector; and “exit” matches skippers who would exit the fishing sector.

Finally, adaptive capacity variables (iii) were recorded from Supplementary Section 1, Questions 1–5 and 8–10, which account for 41 different variables (e.g. sociodemographic as age or perceptions of changes) that were classified based on Cinner and Barnes (2019) adaptive capacity domains (Supplementary Section 4 "Variables for association measures"). These domains include the resources individuals can access in times of need (assets); the flexibility of individuals to change strategies (flexibility); learning capacities to recognize and respond to change (learning); the ability to organize the system and act collectively (social organization); the socio-cognitive constructs that determine human behaviour; and the capacity to undergo change (agency) (Cinner and Barnes, 2019).

Data analysis

To first explore differences in skipper responses based on the ocean region currently fished, we used the non-parametric Kruskal–Wallis test (Hollander and Wolfe, 1973). This was performed for both questions on past adaptation actions and hypothetical responses—and based on the outcome we would pool responses or treat them by ocean basin. The Kruskal–Wallis test indicated no differences between ocean basins (p-value >0.05) for both; we therefore pooled the data. We also verified that the sampling strategy and company belonging did not affect responses (see details in Supplementary Section 4).

Then, we performed cluster analysis to group skippers based on their hypothetical responses to the decreasing catch scenarios. This method of analysis is suitable for small sample sizes, i.e. typically <250 observations (Kauffman and Rousseuw, 2005). Clusters were determined through Ward’s linkage method (Ward, 1963) with Gower distances (Gower, 1971), implying a minimum increase in the total within-cluster variance (Murtagh and Legendre, 2014). Two clusters were set since they maximize the
average silhouette width and are appropriate for interpretation (Supplementary Figures S3 and S4). Each cluster corresponded to a different skipper typology, depending on his stated behaviour when facing catch decrease scenarios. A heatmap was used to visualize clusters. The relationships between stated behavioural clusters (dependent variable) and the adaptive capacity variables (independent variables) were then investigated. All associations were tested separately, i.e. one adaptive capacity variable vs. the behavioural cluster (binomial) at a time. When the association was between a binomial variable (dependent) and a categorical one (independent) we used the Fisher’s exact test (Fisher, 1935) and when the association was between a binomial variable and a numeric or ordinal variable we used binomial general linear models (GLMs) (Hastie and Pregibon, 1992). All analyses were performed using the R Environment for Statistical Computing (R Core Team, 2020), and the scripts with their workflow are available on GitHub/irrubio/tropituna_skipper_adapt_transform.

Results

A range of adaptation actions were performed by skippers as a response to perceived changes during the last 10 years (Figure 1). Skippers could report more than one action, and the mean number of actions per skipper was 2 (standard deviation ±1). The two most commonly reported adaptation actions were using new technology to search for tunas and fishing area expansion, which were nominated by 59% of skippers. The next most commonly selected actions were a fishing period change (14%), fishing more frequently (14%), and other adaptation actions (i.e. adapting to new regulations, changing their effort, adjusting to costs and carrying out sustainable and selective fishing) (14%). About 10% of skippers did not state any change in their behaviour, while 7% of skippers had searched for new ports. None of them stated having fished “unusual species” (other than tunas).

Responses of skippers to hypothetical scenarios of decreasing catches from 15 to 90% showed a progressive decrease of “remain” and “adapt” responses along the scenarios of impact intensification, both options were selected less often when catch decreases are higher (Figure 2). Among all skippers, 21 and 23 would exit the fishery if their catches decreased by 70 and 90%, respectively. However, only 12 skippers would exit the fishery if their catches decreased by 50%. At 15 and 30% scenarios, 19 skippers would adapt. Few skippers would transform once a 30% catch decrease is reached, until the worst scenario. Only one skipper indicated that he would not change his behaviour (i.e. “Remain” category) for the 50% decline scenario. Finally, at 30% scenario, three skippers stated that they would not change their behaviour, compared to nine skippers at 15% scenario.

Responses to catch decrease scenarios fell into two clusters. Cluster (or group) 1 corresponds to skippers who could be early adaptors and either would not exit, or only exit the fishery for extreme catch decrease scenarios (Figure 3). These skippers would keep their adaptation behaviour at least until 30% of catch decrease, maintaining an adaptation or transformation response until 70% decrease, and would exit the fishery at a 90% decrease. We refer to them as skippers who would follow an adaptation strategy; and they represent 28% of surveyed skippers. In contrast, cluster 2 represents skippers who would exit the fishery earlier. They would start exiting the fishery if their catches decreased by 30%. They tend to expand the “remain” responses and would transform earlier than skippers from group 1. We refer to this group as skippers who would follow a transformation strategy; they represent 72% of surveyed skippers.

Table 1 shows the significant associations between belonging to cluster 1 or 2 and adaptive capacity variables. Among the 41 variables measured for adaptive capacity (Supplementary Table S3), we only found three that are significantly related to adaptation (cluster 1) or transformation (cluster 2) stated behaviour. These variables are the number of years a skipper has spent in his current job (flexibility), the importance a skipper gives to inter-generational knowledge (learning), and whether he perceives changes in abundance of tropical tunas (socio-cognitive). There is a negative relationship (estimate value −0.3146, Table 1) between the probability of willing to follow an adaptation strategy and the number of years spent in the skipper’s current job. This means that skippers that have been less years at their current job are more prone to be in cluster 1. The opposite happens with the rest of variables that have a positive relationship with the

Figure 1. Adaptation actions performed by skippers (n = 29) in the last 10 years. The percentage of skippers undertaking each adaptation action (y-axis) is shown on the x-axis. “Other adaptations” refers to an open option where skippers could add adaptation actions not listed in the provided options.

Figure 2. Responses of skippers to hypothetical scenarios of decreasing catches (n = 29 for all scenarios). Response options were grouped into four categories: “Remain”, “Adapt”, “Transform”, and “Exit” (Supplementary Table S1). The number of skippers choosing each response by scenario is indicated within “donut charts”. “Not assessed” accounts for missing responses.
dependent variable, i.e. intergenerational knowledge importance and perception of abundance change (estimate values 2.0658 and 2.8620 respectively, Table 1). Skippers giving more importance to intergenerational knowledge and perceiving changes in tropical tuna abundance are more prone to be in cluster 1 or are willing to follow an adaptation strategy. Skippers having worked for longer periods in their job, giving less importance to intergenerational knowledge and not perceiving changes in tropical tuna abundance are the ones who would adopt a transformation strategy and also exit the fishery in early stages of catch decrease.

Discussion
The analysis conducted in this article represents investigation of bottom-up approaches, where we seek to understand the individual responses of skippers to catch declines in a large-scale fishery. Knowledge derived from this kind of study can be used to take informed decisions when developing policies to facilitate or promote adaptation responses (van Putten et al., 2017). This is in line with efforts using participatory approaches (Ogier et al., 2020), with the aim of avoiding antagonistic top-down measures, that could be less effective when seeking collective adaptation for a community (Bennett et al., 2016; Piggott-Mckellar et al., 2019).

In the Spanish large-scale fishery, skippers are not the only actors adapting; the fishing companies can have their own adaptation strategies (Rubio et al., 2021), which can be synergistic or antagonistic with other actors’ such as governments (Pecl et al., 2019), or even with the skippers themselves. Thus, another future aspect to elucidate could be to what extent skippers’ adaptive responses could be influenced by the fishing companies’ strategies or vice versa. From this study, there were no differences among stated behaviours depending on the company, suggesting that skippers could freely choose what they would do to confront hypothetical catch declines.

Most skippers (90%) reported adaptation actions to perceived changes in the last 10 years, which is what we would expect in an adaptable fishery. This is in line with commonly reported adaptation actions, i.e. using technology and fishing area expansion (Daw et al., 2009; Young et al., 2012; Belhabib et al., 2016) that most skippers were able to accomplish. However, nowadays, the problem is probably more focused on adapting to the spatiotemporal shifts of the fish and complying with international rules—such as the decrease in the use of fishing aggregative devices
strategies (e.g. ICCAT, 2019)—rather than expanding the fishery. When confronting hypothetical catch decrease scenarios, around two-thirds of skippers were willing to follow transformation strategies when a certain impact is reached instead of following adaptation strategies (~30% catch decline). This threshold is the point after which transformational adaptation would emerge, which could affect the fishery at a collective level (Wilson et al., 2020). Below that threshold, incremental adaptation would be common among skippers. In addition, we venture to say that catch decline could be interpreted as a proxy for revenue decline since skippers earn their salary depending on the fished quantity. Thus, skippers who would follow transformation strategies earlier have a lower threshold, which is the majority of skippers.

One of the limitations of this study is that we did not confront positive impacts (i.e. abundance increase), which could turn out to be the most likely scenario for this fishery depending on the area and time period. We acknowledge this and recommend future analysis to test the adaptation continuum in such impact settings. Adaptation can be planned in response to the positive impacts and further investigation should also include potential catch increases. We focus on catch declines that are not specifically located and we do not address distribution impacts per se, in part because uncertainty and mixed patterns around these remain (e.g. Dueri et al., 2016; Senina et al., 2018; Erauskin-Extramiana et al., 2019). However, respondents were able to select adaptation and transformation actions that are applicable to confront distribution shifts (e.g. “search for different fishing areas in the ocean where I fish” or “change the ocean”). It is certain that, if the fish “disappear or move”, skippers change their fishing areas (Young et al., 2019).

Another limitation of the study is the difficulty in reaching the skippers (22% response rate). Our sample size could be driven by the most participative companies, particularly open towards science and seeking to improve current knowledge about the sector. Distrust towards science when contacting a few fishing companies, and the work overload in other companies, both difficulted reaching more skippers. Thus, additional efforts are needed to build trust and communication spaces in the Spanish fishery when fostering adaptation from a top-down approach, and to gain insight into bottom-up responses. Bidirectional knowledge transfer is also necessary; researchers need to better understand mentalities and conceptualizations of the marine environment and social-ecological relations, which can differ between researchers and skippers or other kind of actors (Rassweiler et al., 2020). An examination of the ways in which fishers experience and respond to change is essential to better understand adaptions to climate change (Galappaththi et al., 2019).

Concluding remarks

In this study, the individual adaptation and transformation responses of skippers in an industrial fishery were explored. The Spanish tuna freezer purse seine fishery is a highly technological industry operating in the Atlantic, Indian and Pacific Oceans. As opposed to other contexts, the adaptive capacity of such an industrial fishery has a high level of assets and flexibility. We explored to what extent these and other adaptive capacity domains play a role in the stated behaviour of vessel skippers when confronting hypothetical scenarios of catch declines. A survey was designed for skippers, since they are one of the main decision-makers in the Spanish tropical tuna fishery when choosing where to fish at sea. We found that skippers carried out adaptation actions in the past and are willing to engage in adaptation options until a 30% catch decline. However, when facing larger declines, strategies diverge and some skippers are willing to keep adapting while others transform or exit the fishery.
Importance given to intergenerational knowledge, perceptions of change in tropical tuna abundance and the years spent in the current job explained these adaptation and transformation choices. Finally, understanding adaptation and transformation responses at all levels (i.e. from skipper to company) and fishery contexts is crucial to manage the risk of climate change impacting the oceans.

Supplementary data
Supplementary material is available at the ICESJMS online version of the manuscript.

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Data availability statement
The code that supports the findings of this study is openly available in https://github.com/irrubio/tropituna_skipper_adapt_transform and https://doi.org/10.5281/zenodo.4612052. The data that support the findings of this study are available on request from the corresponding author, I. Rubio (iratxe.rubio@bc3research.org).

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