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Complete List of Authors:	Rubio, Iratxe; BC3 Basque Centre for Climate Change, ; Universidade de Vigo, Future Oceans Lab, CIM-UVIGO ojea, elena; Universidade de Vigo, Future Oceans Lab, CIM-UVIGO Hobday, Alistair; CSIRO Oceans and Atmosphere; University of Tasmania, Centre for Marine Socioecology
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Skippers' preferred adaptation and transformation responses to catch declines in a large-scale tuna fishery

Iratxe Rubio[1, 2], Alistair J Hobday[3,4], Elena Ojea[1]
[1]Future Oceans Lab, CIM-Universidade de Vigo, Vigo, Spain
[2]Basque Centre for Climate Change (BC3), Leioa, Spain
[3]CSIRO Oceans and Atmosphere, Hobart, Tasmania, Australia
[4]Centre for Marine Socioecology, University of Tasmania, Hobart, Tasmania, Australia

Corresponding author: Iratxe Rubio iratxe.rubio@bc3research.org. Phone: 0034 944014690

Abstract

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 by skippers. 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.

1. 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. Barnes *et al.*, 2020; Frawley *et al.*, 2019), 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 incentivised 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 (Ogier et al., 2020; Pecl et al., 2019), 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 (van Putten *et al.*, 2017; Adger, 2016). 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 (Salomon *et al.*, 2019; Belhabib *et al.*, 2016), 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 (Pinsky *et al.*, 2020; Poloczanska *et al.*, 2016).

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 (Ojea *et al.*, 2020; Fedele *et al.*, 2019; Galappaththi *et al.*, 2019), 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, transforming (Ojea *et al.*, 2020; Barnes *et al.*, 2017). 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 (Ojea *et al.*, 2020; Marshall *et al.*, 2012; Park *et al.*, 2012). 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 adaption 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 (Barnes *et al.*, 2020; Cinner *et al.*, 2018). 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 incentivising adaptation.

2. Materials and methods

2.1. Case study

Tropical tuna fisheries are highly valuable worldwide economically and for food security (FAO, 2020; McCluney *et al.*, 2019). 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. Rubio *et al.*, 2020; Erauskin-Extramiana *et al.*, 2019; Monllor-Hurtado *et al.*, 2017; Senina *et al.*, 2018). 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 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 are 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 tuna *(Thunnus albacares)* stocks needed improvement in the Indian and the Eastern Pacific oceans and were healthy in the Atlantic and Western and Central Pacific (ISSF, 2020). Finally, Bigeye tuna *(Thunnus obesus)* stocks were in a healthy status in the Pacific and the Indian but needed improvement in the Atlantic ocean (ISSF, 2020).

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 four-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.

2.2. Surveys

Short surveys of about 10 minutes 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 email 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 SI *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: (1) past adaptation actions; (2) hypothetical responses to catch decreases and (3) adaptive capacity variables (SI *1.Survey questions*). Past adaptation actions (1) 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 (SI *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 (2) we used a multiple-response question with five scenarios of decreasing catches (SI *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 (Fujitani *et al.*, 2017; Webb and Sheeran, 2006). 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' (SI *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 (3) were recorded from SI *1.Questions 1 to 5 and 8 to 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 (SI *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).

2.3. 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 SI 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 less than 250 observations (Kaufman and Rousseeuw, 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 maximise the average silhouette width and are appropriate for interpretation (SI Figure3 and 4). Each cluster corresponded to a different skipper typology, depending on his stated behaviour when facing catch decrease scenarios. A heatmap was used to visualise 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 versus 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 (GLM) (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.

3. 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 (SD ±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. Very few skippers would transform once a 30% catch decrease is reached, until the worst scenario. Only one skipper indicated he would not change his behaviour (i.e. 'Remain' category) for the 50% decline scenario. Finally, at 30% scenario, 3 skippers stated they would not change their behaviour, compared to 9 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 (SI Table 3), we only found 3 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 intergenerational 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 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.

4. 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 (Piggott-McKellar *et al.*, 2019; Bennett *et al.*, 2016). 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 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 (Belhabib *et al.*, 2016; Daw *et al.*, 2009; Young *et al.*, 2012) 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 (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 adaption 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. Erauskin-Extramiana et al., 2019; Dueri et al., 2016; Senina et al., 2018). 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 adaptations to climate change (Galappaththi *et al.*, 2019).

When looking at adaptive capacity domains related to adaptation responses, flexibility, represented by the years a skipper has worked in his current position, is playing a role in stated behaviours. More experienced skippers would exit the fishery earlier, which could be linked to a conservative behaviour in order to avoid income losses (Marshall *et al.*, 2013) or to retirement expectations as stated by a few skippers (Option I in SI Table 1). Job and place attachment were not significant when explaining the willingness to follow adaptation strategies, but learning was measured as being significant. According to van Valkengoed and Steg (2019) factors such as experience, knowledge, place attachment and trust play only a marginal role in adaptation. Regarding technology, Gardezi and Arbuckle (2020) found that greater techno-optimism can increase the intention to delay adaptation-related actions. However, this techno-faith was not significant when explaining the willingness to follow adaptation strategies among skippers from the Spanish tuna fishery.

Barnes *et al.* (2020) found that perceptions of past experience with more severe impacts were significantly related to adaptive action, but the socio-cognitive domain was not linked to transformative action. In our case, past experience of environmental changes was not significantly associated with the willingness to follow adaptation strategies (*sensu* van Putten *et al.*, 2017), neither was the fact that skippers may have already adapted. From a socio-cognitive perspective, only perception of abundance changes was related to the stated behaviour towards adaptation. In addition, agency and aspects of social organization encourage adaptive actions (Barnes *et al.*, 2020), however, we did not find these associations. This might be because of differences in variables used to represent each adaptive capacity domain. Besides, assets have been usually associated with adaptation (Barnes *et al.*, 2020), but we could not include variables such as catch or income due to privacy and sensible data concerns.

Finally, are the results we obtained more general beyond the Spanish fishery used as a case study? Frawley et al. (2019) state that strategies to facilitate adaptation and overcome its associated barriers will likely be context dependent. Skippers from the Spanish fishery have performed many adaptation actions in the past, which are probably similar in other adaptable large-scale fisheries. However, this is different from identifying what human characteristics are prone to drive in adaptation behaviour. Studying adaptation behaviour through adaptive capacity domains could be complemented with approaches from other disciplines such as the theory of planned behaviour (Miller, 2017) or protection motivation theory (Feng et al., 2017). As Wilson et al. (2020) point out, behavioural adaptation research is at its infancy and we think that more robust theory must be developed to understand adaptation and stated behaviour in fisheries, including small and large-scale fisheries. From this study, three variables can be considered as important for distinguishing skippers and their potential adaptation and transformation behaviour when confronting catch declines (i.e. importance given to intergenerational knowledge, perceptions of change in target species abundance and years working in the current position). These should be further tested in other case studies to ascertain they are not context dependent.

5. 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 ~~change~~diverge, and some skippers are whiling 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.

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7. CAPTIONS

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). Responses options were grouped into four categories: ‘Remain’, ‘Adapt’, ‘Transform’ and ‘Exit’ (SI Table 1). The number of skippers choosing each response by scenario is indicated within ‘donut charts’. ‘Not assessed’ accounts for missing responses.

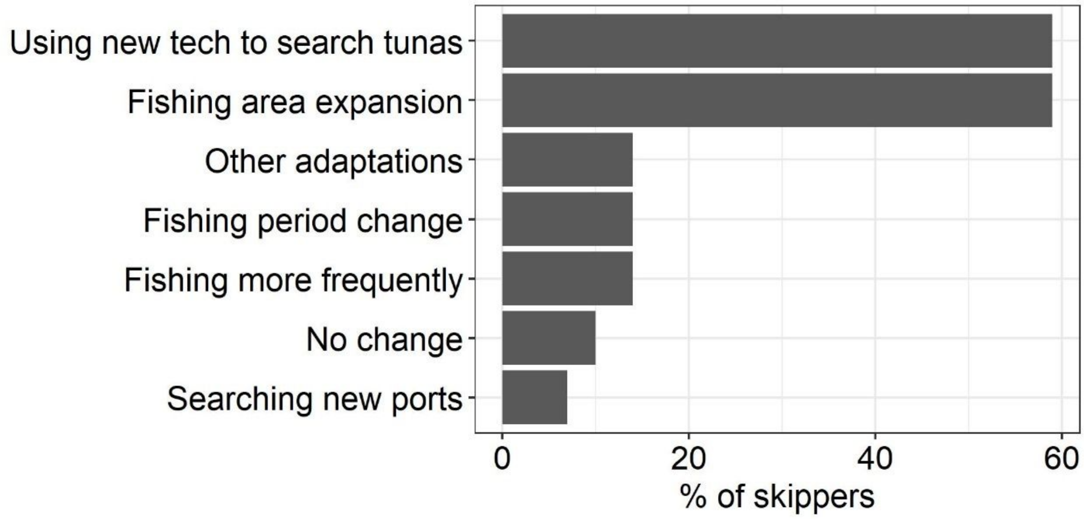
Figure 3. Skipper clusters based on their choices. The heatmap shows hierarchical clustering of 29 skippers, according to the response they assigned to different scenarios of catch decreases. The dendrogram in the y axis, where each individual is included as a row (coded as skipper#), shows the 2 selected clusters. Hypothetical scenarios of decreasing catches are depicted in columns. Response categories are shown in the legend: ‘Remain’, ‘Adapt’, ‘Transform’ and ‘Exit’ (SI Table 1). ‘Not assessed’ accounts for missing responses.

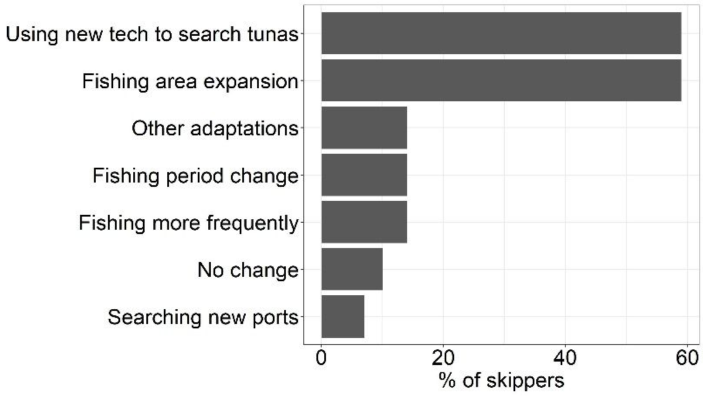
Table 1. Results from 3 binomial GLMs. The models test the association between the willingness to follow adaptation or transformation strategies (or belonging to cluster 1 or 2, dependent variable) versus each adaptive capacity variable (independent variables). The results of each model are shown on separate lines

containing the coefficient (estimate), the standard error (SE) and the p-value per model. Only significant associations ($p < 0.05$) are shown.

8. Figures and table

1





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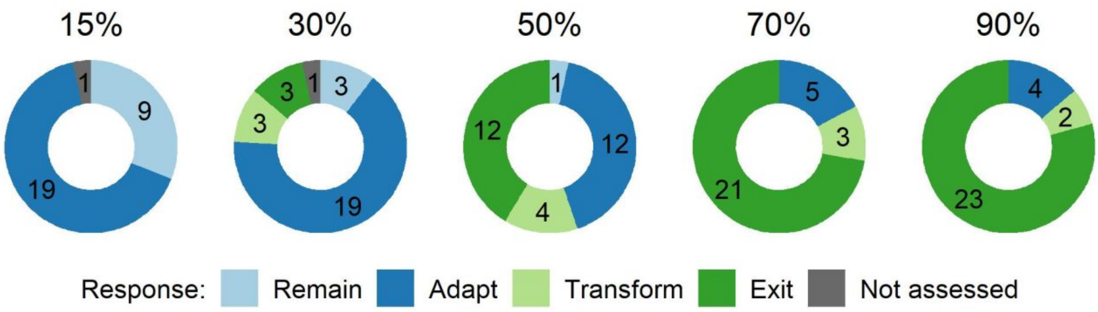
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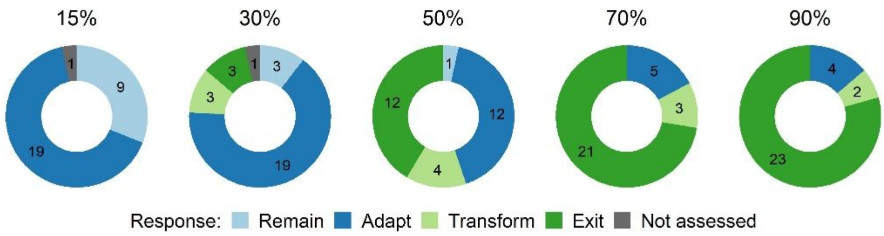
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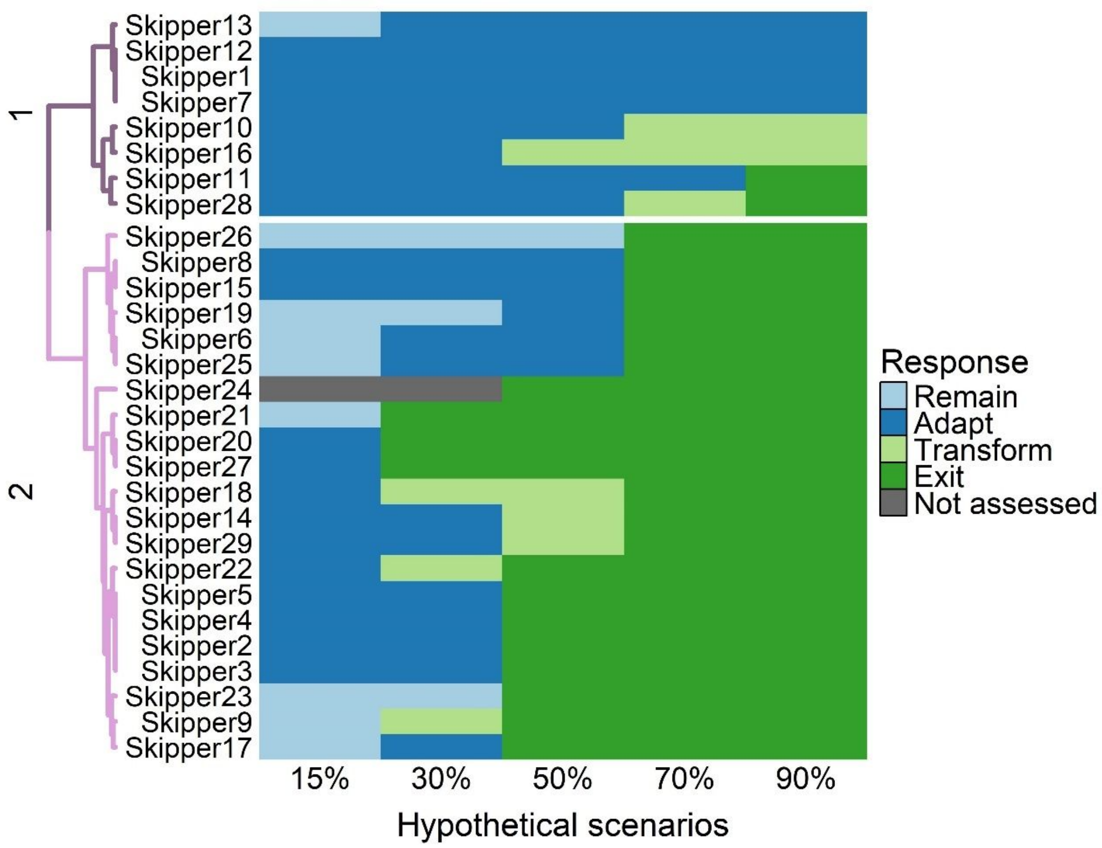


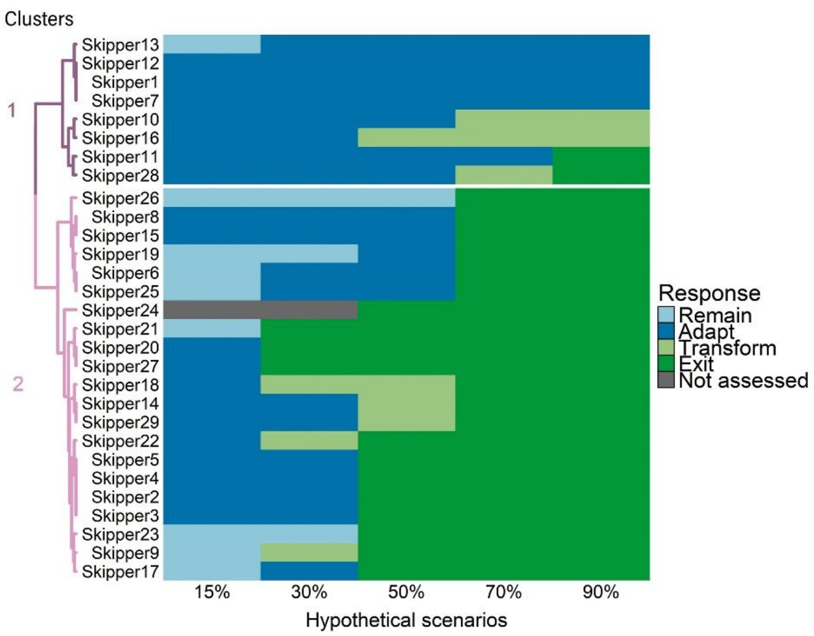


Table 1

Adaptive capacity category	**Independent variable definition**	**Code in SI Table 3**	**Estimate**	**SE**	**p-value**
Flexibility	Number of years spent in current job	job_years	-0.3146	0.1357	0.0204
Learning	Intergenerational knowledge importance	intergen_knowld	2.0658	0.9238	0.0253

Socio-cognitive	Perception of abundance change	change_abundance	2.8620	1.1730	0.0147

9. Supplementary material

The following supplementary material ("Supplementary_material.pdf") is available at ICESJMS online. It includes the survey questions and information about representativeness of data, the adaptation continuum, variables for association measures and cluster choice.

10.Acknowledgments

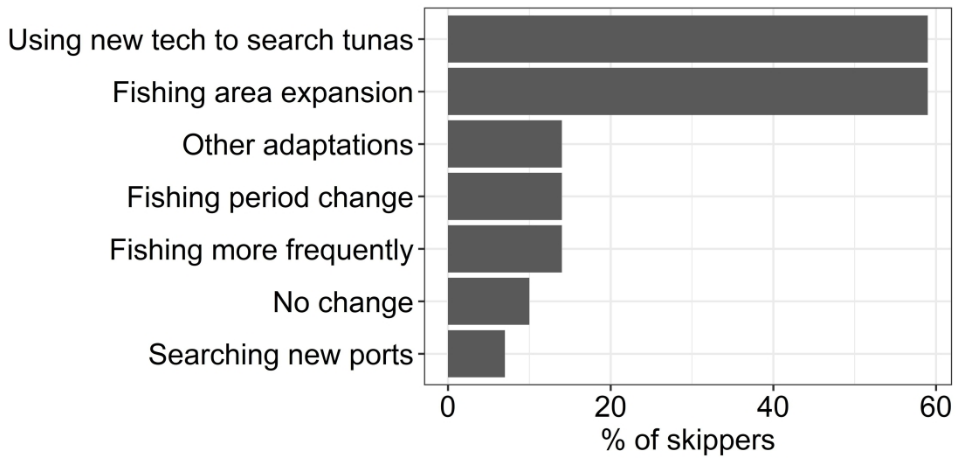
This research was supported by the project CLOCK, under the European Horizon 2020 Program, ERC Starting Grant Agreement nº679812 funded by the European Research Council. It is also supported by the Spanish Government through María de Maeztu excellence accreditation 2018-2022 (Ref. MDM-2017-0714). EO thanks Gain-Xunta the Galicia for the Oportunius program. We specially thank all the skippers and workers from the fishing companies and associations who facilitated this study and participated to share their knowledge. Two anonymous reviewers also improved the manuscript.

11.Data Availability Statement

The code that supports the findings of this study is openly available in ~~‘tropituna_skipper_adapt_transform’ at~~ https://github.com/irrubio/tropituna_skipper_adapt_transform and

https://doi.org/10.5281/zenodo.4612052

~~https://doi.org/ to come after major revisions~~. 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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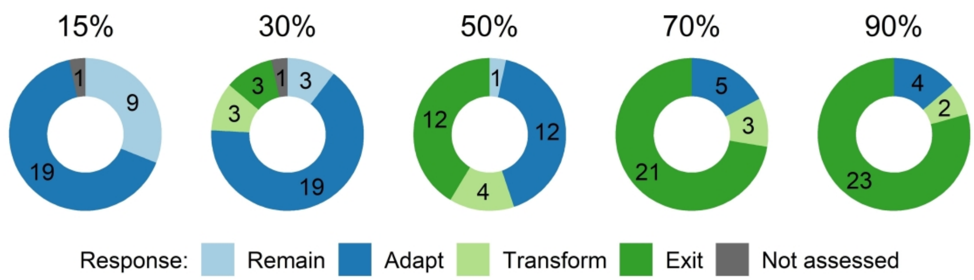

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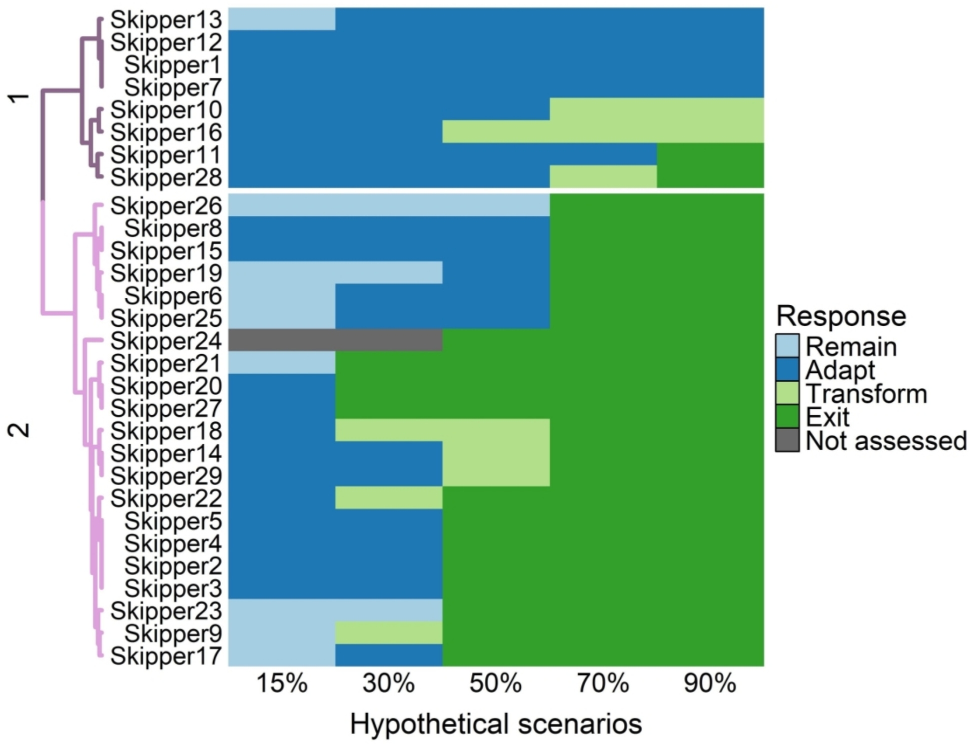

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Adaptive capacity category	Independent variable definition	Code in SI Table 3	Estimate	SE	p-value
Flexibility	Number of years spent in current job	job_years	-0.3146	0.1357	0.0204
Learning	Intergenerational knowledge importance	intergen_knowld	2.0658	0.9238	0.0253
Socio-cognitive	Perception of abundance change	change_abundance	2.8620	1.1730	0.0147

Dear Dr Jan Jaap Poos,

Thank you very much for this good news! Thank you very much to the reviewers too who gave constructive feedback for the manuscript improvement.

In this last version of the manuscript we have added a few edits including the references suggested by the reviewer (Lines 163 and 177-180), the code repository and DOI (Lines 223 and 569), the figures sized as requested by the journal (Lines 542, 546 and 549), and minor text edits (Lines 370 and 378).

Please feel free to contact me if I can provide any additional request about our work.

Sincerely,

Corresponding author