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Fishers' perceptions of global change to inform coastal planning in a data-poor socio-ecological system

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Abstract :

Global change has a significant impact on coastal populations and their reliance on coastal ecosystems and resources. This is particularly true for small-scale fisheries (SSF) in Brazil, where limited data exacerbates their vulnerability. Acquiring local user knowledge is crucial to enhancing the sustainability of SSF. In Rio Formoso, Northeast Brazil, a fisher's association plays a vital role in conserving coastal ecosystems and raising awareness about anthropogenic activities. This study examines various social, governance, economic, and ecological aspects of Rio Formoso fisheries, focusing on fishers' perceptions of global change. We carried out individual and collective interviews, participatory mapping, and discourse analysis. Rio Formoso fisheries stood out by the diversity of their activities (gears, species, habitats), women's leading role, and the intense involvement of the association in coastal management initiatives. Fishers reported decreased abundance and biodiversity, and increased demand for their products. They perceived the threats to their fishing activities posed by the consequences of global change, including temperature and rainfall modifications, pollution generated by anthropogenic activities, and conflicts with tourism. Social challenges, such as gender discrimination against fisherwomen and the ongoing struggle for fishers to be included in policy-making decisions, further hinder fisheries' sustainability. This study demonstrates the valuable insights gained from fishers' perceptions in a data-poor system, enabling a preliminary global assessment to identify conflicts, social challenges, ecological concerns, and suitable actors to lead feasible and acceptable policies. As conflicts and community concerns can provide opportunities for co-management, it is imperative to operationalise community-based management tools, particularly in Brazil, to alleviate fishers' struggles in meaningful decision-making involvement.

Keywords : Socio-ecological systems, Small-scale fisheries, Participatory management, Climate change, Coastal planning

1. Introduction

Human activities have had far-reaching effects on ecosystems, leading to global-scale environmental consequences, such as climate change and biodiversity loss, as well as transformative societal changes, such as urbanization and population growth (Sage, 2020). Such drastic modifications jeopardise the numerous benefits to humans provided by healthy ecosystems and reduce ecosystems resilience to future pressures (Boone et al., 2018; Weiskopf et al., 2020). Coastal biomes, already prone to natural phenomena like erosion, tsunamis, and floods, are particularly susceptible to the effects of global change (Day and Rybczyk, 2019; Marsooli et al., 2019; Wang and Toumi, 2021). As a result, populations that depend directly on coastal resources, such as artisanal fishers, are highly vulnerable to global change (Bell et al., 2018; Hanich et al., 2018).

An effective management policy to address global change requires integrating scientific and empirical knowledge to ensure that the particularities of each socio-ecological system are respected (Lindkvist et al., 2020; Roux et al., 2019). Fishing communities interact closely with their local environment and acquire empirical knowledge about physical and biological processes and anthropogenic impacts on coastal ecosystems (Abreu et al., 2017). Consequently, fishers' local ecological knowledge (LEK) is essential for managing and conserving coastal resources (Alati et al., 2020; Carrasquilla-Henao et al., 2019) and to improving society's ability to cope with global change and contribute to the sustainability of small-scale fisheries (SSFs) (Malakar et al., 2018; Mulyasari et al., 2018). Unfortunately, the cultural, economic, and environmental changes faced by rural and indigenous communities lead to the loss of this local knowledge (Aswani et al., 2018), which argues for urgent inclusion of the LEK.

In addition to their socio-economic and cultural importance, SSFs are closely linked to food security issues, as they account for about half of the fish caught in developing countries. SSFs employ more than 90% of fishers and are the primary source of income and protein for several local communities (Kelleher et al., 2012 ; Gasalla and Ykuta, 2015; FAO, 2017). In Brazil, there are approximately 600 000 fishers, most of whom are located in the Northeast region (Bertrand et al., 2019; Gomes De Alencar et al., 2019). SSFs provide almost all the catches in this region and play a crucial role in the economy, food security, and poverty eradication (Sonoda et al., 2012). However, there is a severe lack of data on the status of Brazilian stocks, as fishing statistics have not been available since 2007 (Gasalla et al., 2017). Signs of depletion were already noted in the Northeast in the late 1990s (MMA, 2006).

Furthermore, fisheries in northeast Brazil face a multitude of anthropogenic pressures such as pollution, mangrove removal, overfishing, urbanisation, and tourism (Justino et al., 2021; Pelage et al., 2019). The competition from tourism, aquaculture, and port infrastructure has led to a process of marine resources appropriation, known as "ocean grabbing," resulting in fishers losing access to valuable coastal fishing grounds (Queffelec et al., 2021). These conflicts between users with divergent interests dramatically affect resource management and the

sustainability of these socio-ecosystems. Northeast Brazil is also particularly vulnerable to climate change (Pörtner et al., 2022). Due to the high precipitation variability in this region, extreme weather events (floods and droughts) are increasing (de Holanda et al., 2022; Marengo et al., 2022). These extreme events, coupled with sea-level rise and global warming, are expected to have a negative impact on the yields of small-scale fisheries (Lira et al., 2010) further exacerbating the challenges faced by fishing communities in the region.

In the state of Pernambuco, located in the densely populated northeast region of Brazil, fishing fleets mainly consist of small boats powered by sail, rowing, and motor (Lessa et al., 2009). These boats typically lack advanced technological instruments for navigation and locating shoals (Lessa et al., 2004). The Pernambuco coast is characterised by mangroves, an ecosystem of high productivity, favouring estuarine fishing (ICMBio, 2018). Rio Formoso, known as the "City of mangroves," has a long-standing tradition of artisanal fishing, which serves as a livelihood for the local population (Pelage et al., 2022; Ribeiro and Callou, 2015). Furthermore, the presence of a "quilombola" community (descendants of Afro-Brazilian enslaved people who escaped from the slave plantations in Brazil until the abolition in 1888) adds a historical and cultural dimension to fishing in the area. Most fishers operating in Rio Formoso are part of the Z-7 colony, which is deeply involved in developing public policies for conserving the ecosystems comprising their fishing grounds (Ribeiro and Callou, 2015).

In addition to being surrounded by a sugarcane exploitation area and a very touristic place, Rio Formoso was affected by an oil spill in 2019 (Araújo et al., 2020). The region is also burdened by the dumping of domestic effluents, vegetation suppression, and local pollution, which compromises the quality of water bodies and subsequently impacts the population’s health (Dos Santos et al., 2020). However, little is known about the local community's perception of such impacts.

In this context, the aim of this study is to characterize the Rio Formoso SSFs as a socio-ecosystem, by describing fishers’ socio-professional profile, the governance role of the Z-7 colony, the value chain of the main products, and fishing activities. Additionally, the study seeks to explore fishers’ perceptions regarding global change and its potential impacts on the sustainability of the socio-ecological system. This information could be used to develop effective management strategies, thereby ensuring the long-term viability of the Rio Formoso fisheries.

2. Material and methods

2.1. Study area

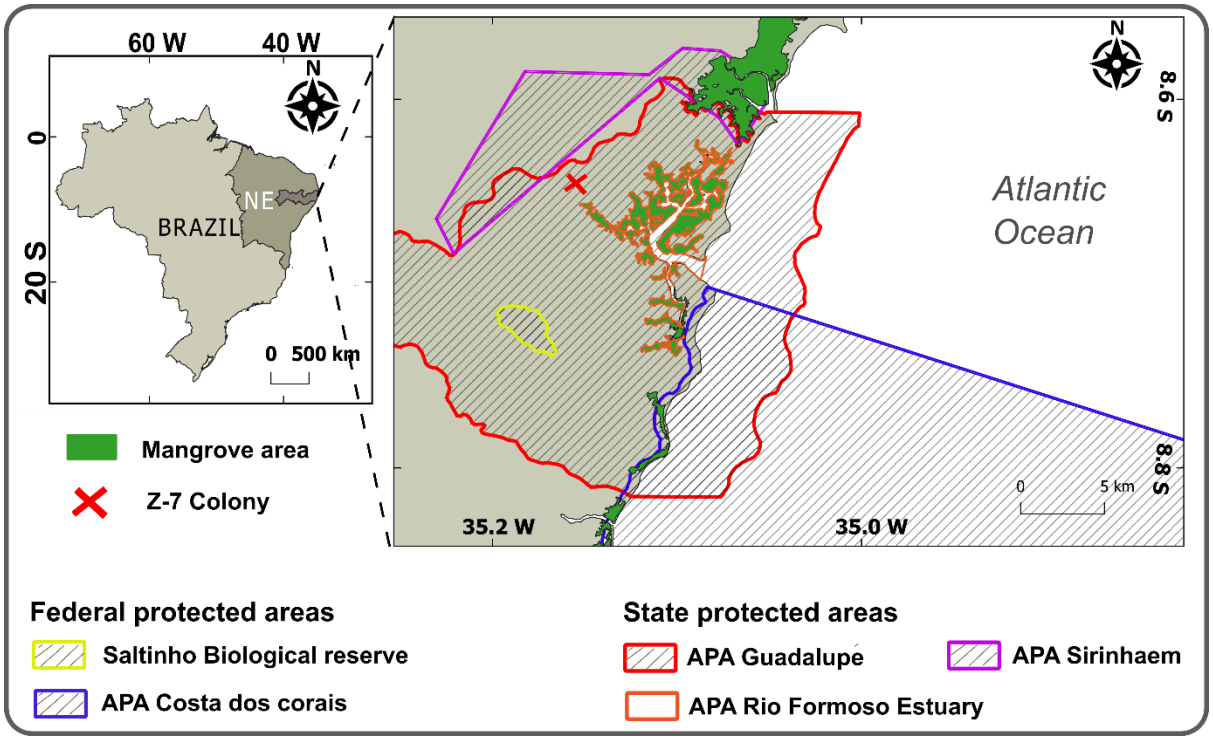

Figure 1: Study area and location of Z-7 fisher's colony, mangrove and protected areas at federal and state levels, including the Areas of environmental protection (APA) allowing for the sustainable exploitation of natural resources and a biological reserve where only indirect use of resources that do not involve the collection, damage or consumption is permitted.

The study area is Rio Formoso, Zona da Mata, southern coast of Pernambuco. The city has an estimated 22,151 inhabitants distributed over 227 km² (Instituto Brasileiro De Geografia e Estatística, 2012). Artisanal estuarine fishing constitutes an essential source of income (Lira et al., 2010; Pedrosa et al., 2013). An area of 27 km² of mangrove provides resources of great relevance to the local population, such as fish, molluscs, and crustaceans (Araújo et al., 2014). The region is currently inserted in five protected areas with different level of protection. Four of these areas are Areas of Environmental Protection (APA), which permit sustainable exploitation of natural resources. The remaining area is a biological reserve where only indirect use of resources that do not involve collection, damage, or consumption is allowed. Of these conservation units, two are administered at the federal level (APA Costa dos Corais and Biological reserve of Saltinho) and three at the state level (APA Rio Formoso estuary, APA Guadalupe and APA Sirinhaem). The federally protected areas are administered by the Chico Mendes Institute for Biodiversity Conservation (ICMBio), which has been responsible for national action plans in Brazil since it was founded in 2007 and whose primary mission is the conservation of biodiversity, especially within protected areas. Conversely, state APAs are ruled by the environmental agencies established in Pernambuco.

The Rio Formoso fishers' colony does essential work to preserve local ecosystems. Colony members organise awareness campaigns and clean-up actions in rivers and estuarine areas,

enforce environmental laws, provide financial support to fishers and riverside communities and promote local culture. In addition, the colony participates in projects to benefit the riverside community through donations, social and educational projects working with research units, education and socio-economic interests. Since its creation in 1996, Colony Z-7 has always been active in socio-environmental work and was even awarded the Ecologist Award Vasconcelos Sobrinho in 2002.

2.2. Sampling

Semi-structured interviews were conducted with fishers from the Z-7 colony (Rio Formoso, PE). Interviews were carried out in 2020, face-to-face by a researcher residing in Rio Formoso or through telephone conversations due to the context of the pandemic. The interviews were recorded with a camera or a mobile phone (in the case of telephone interviews).

Questionnaires addressing economic, ecological and socio-environmental aspects were used (see Appendix 1 for the detailed questionnaire). Some of the audio-visual material collected during the project in Rio Formoso and the document on image rights and use of scientific data is available at https://tapioca.ird.fr/video-report-about-the-project-the-perception-of-artisanal-fishers-of-rio-formoso-pe-on-global-changes/.

The applied questionnaires lasted about 30 minutes and were divided into the following five sections:

i) Characterisation of the respondent (age, education) and their fishing activity (time per week, fishing location, etc.).

ii) Perceptions of changes in fisheries resources

iii) Perceptions of anthropogenic activities

iv) Perceptions of climate change

v) Expectations about the future of the activity.

Participants were informed of their right not to answer questions if they felt uncomfortable and of the possibility of abandoning the interview if they thought it necessary.

The snowball method was used for the interviews, consisting of a non-random sampling technique that emphasises the qualitative nature of the information. In this approach, key informants (leaders of the fishing colony) were interviewed in the first instance. These, in turn, indicated new people to be interviewed and so on, until the names told began to repeat, indicating that the group could be considered sufficiently sampled/represented (Naderifar et al., 2017). Priority was given to fishers with more experience, considering that they have a better notion of how fishing used to be compared to today and are better able to describe global environmental changes. Interviews were conducted with 30 fishers from the Z-7 fishing colony

in Rio Formoso (PE) (representing more than 10% of the total colony membership). In addition, information was gathered through direct observations in situ, photographic documentation, and a literature review.

2.3. Data analysis

2.3.1. Colony, interviewees and fisheries characterisation

Firstly, we elaborated a conceptual model representing the organisation of the colony (hierarchy, partners, involvement in marine spatial planning processes).Then, the respondents' socio-economic background was established to profile the members of the Z-7 colony regarding education, age, family context and professional activity. We also described the fisheries of Rio Formoso by characterising the main fishing gears, fishing areas and target species. Another conceptual model was drawn to illustrate the organisation of the value chain for the main products harvested (fish and shellfish). It included the different actors and a semi-quantitative estimation of the importance of each actor.

2.3.2. Perceptions of global change and expectations for future generations

Fisher's views on global change (including climate change and the direct anthropic impact) were represented by plotting the percentage of respondents who provided a given answer. In addition, participatory mapping of anthropogenic activities in the region was carried out. To this end, we met with members of the Z-7 Colony board to identify areas where different sectors (industry, agriculture) could impact marine resources.

Additionally, a discursive textual analysis was carried out with the IRAMUTEQ software (Sousa et al., 2020) (interface coupled to the R software). We used the word cloud analysis consisting of a set of words grouped, organised, and structured in a cloud. The words are presented with different sizes, i.e. the largest words have greater importance in the text corpus based on the frequency indicator or another chosen statistical score. This method allows quick identification of the keywords in a corpus, i.e. a quick visualisation of its content. The most important words are closer to the centre and written in a larger font. This analysis enabled us to highlight the main ideas of the fishers' answers.

3. Results

3.1. Colony, interviewees and fisheries characterisation

3.1.1. Colony organisation and implication in marine spatial planning processes

Most members of the Rio Formoso fishers' colony are women (Figure 2). This female majority is also reflected in the board of directors, composed of nine members occupying four positions (president, secretary, treasurer, fiscal councillor). In addition, the colony maintains

close ties with environmental organisations such as IBAMA (Brazilian Institute of Environment and Natural Resources, CPRH (State environmental agency) and APA Guadalupe and communicates with non-governmental organisations such as fishers' associations or mangrove preservation associations.

The Z-7 colony of Rio Formoso is participating in an advisory board for the environmental and territorial zoning of nautical activities (ZATAN), which aims to promote the sustainable planning of waterways in the Rio Formoso estuary. The ZATAN is part of the APA Guadalupe managing plan, written in 2011. It originated in the 1990s when the boom in tourism led to a surge in nautical activities (Elvira et al., 2020). The ZATAN involves a diverse range of actors from the fishing sector (ministry of agriculture and livestock, fisher's colonies), tourism (hotel groups, water sports companies, small touristic companies operating with traditional boats), environmental and cultural preservation (including quilombola and APA dos corais). The monitoring and management of ZATAN are carried out by government-linked institutions including municipalities and the secretary of environment and sustainability.

Since the 2000s, the Z-7 colony has also taken the lead in creating a Marine Extractive Reserve (Marine RESEX). The colony is directly involved in the management of the Resex since the community forms part of a deliberative board responsible for decision-making. The process brings together local actors from the civil society, i.e., three fisher's colonies (Rio Formoso, Sirinhaem and Tamandare), the quilombola, the NGO « Associação mangue Verde », and a legal department specialised in advocating fisher's rights. The Resex proposal is currently under examination by the State Environment Council (Consema).

Figure 2: Fisher's colony organisation and their involvement in marine spatial planning processes

3.1.2. Profile of the interviewees

The average age of the interviewees was 55.5± 15.6. Half of the respondents were women over 35 (Table 1). Most respondents have a low level of formal education (i.e. only the first years of primary school), are married (formal or informal), have one to four children and have at least one family member working in fishing. The majority have more than 30 years of fishing

experience, with an average duration of 47.5 years± 14.0. Most respondents invest more than 6 hours per day in fishing activity more than three days per week. Other income sources complement the fishing activity for most respondents (57%).

Table 1: Socio-professional information of the interviewees expressed in the number of respondents belonging to the given category (N) and corresponding percentage (%).

Variable	Category	N	%
Age (years)	< 20	0	0.0
	20 - 34	5	16.7
	35 - 49	8	26.7
	50 - 65	12	40.0
	> 65	5	16.7
Number of people in the family	1 - 3	11	36.7
	4 - 6	12	40.0
	> 6	7	23.3
Level of formal education	Elementary School	16	61.5
	Middle School (incomplete)	3	11.5
	Middle School (complete)	7	26.9
Fishing experience (years)	< 30	6	20.0
	30 - 50	13	43.3
	> 50	11	36.7
Fishing hours per day	0 - 5	7	24.1
	6 - 8	13	44.8
	> 8	9	31.0
Fishing days per week	< 3	5	17.9
	3 - 5	13	46.4
	> 5	10	35.7
Income source	Only fishery	13	43.3
	Fishery and others	17	56.7

3.1.3. Rio Formoso fisheries

The Rio Formoso fisheries encompass a wide range of fishing modalities, including manual collection, handline fishing, and the use of various types of nets and crab traps (Figure 3). Active gear, such as trawls that are pulled by one or two people, beach seines, and cast nets (known locally as *tarrafas*) that are thrown at low tide, are commonly used. In addition, passive nets such as gillnets or block nets (known as *camboa*), which are attached to stakes to trap fish at low tide, are also employed. Most of the gear used in these fisheries is handmade by local fishers or residents. Of these methods, gillnets and cast nets are the most frequently used for catching fish.

The Rio Formoso fisheries operate in diverse habitats, including the mangrove forest, the muddy intertidal zone, estuarine waters within mangroves and shallow coastal waters. A wide variety of organisms is targeted, including seashells, crabs and fish. Except for crab traps, all fishing devices target several species. Furthermore, several species are caught from more than one gear and in more than one environment. Nets target numerous small migratory species, such as mullet (Mugil spp) and carapeba (Gerreids). However, some juveniles of long-lived species with higher commercial value, such as snappers and snooks, are also caught. Seashells are manually collected, sometimes with the help of a blunt object, mainly by women, known as *marisqueiras* in Brazil. Most of the colony members are *marisqueiras*.

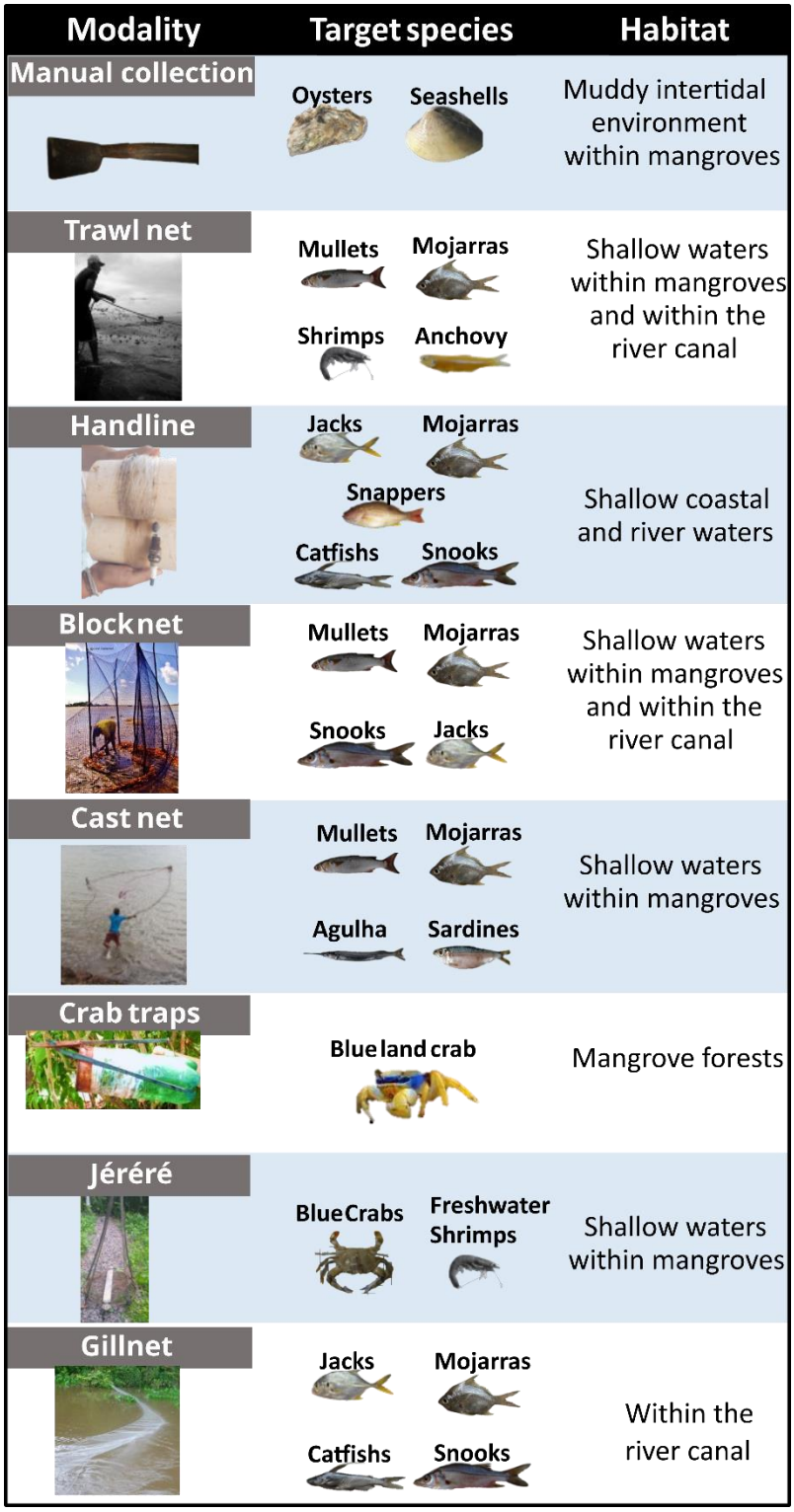

Figure 3: Fishing gears, target species and fishing grounds of Rio Formoso.

Rio Formoso fisheries resources follow two value chains (Figure 4). Fish is predominantly sold directly to final consumers, typically residents, or to residents selling to others. In rare instances, fish is sold to restaurants. In contrast, shellfish is primarily marketed to restaurants of Rio Formoso and nearby touristic cities, as well as to a lesser extent, to

intermediaries and consumers. The vast majority of fishers (81.5%) reported supplying their products to a fixed consumer or client, such as a restaurant or intermediary.

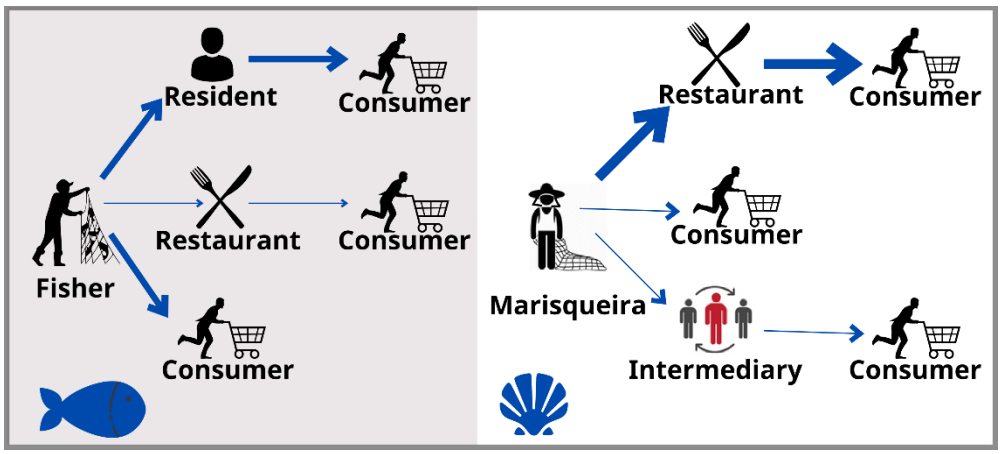

Figure 4: Value chain for fish (left) and seashell (right). The width of the arrows represents the relative importance of the exchanges between actors.

3.2. Perceptions of global change and expectations for future generations

The most striking change reported by fishers concerning global change pertains to species diversity in their catches (Figure 5). Indeed, 83.3% of the respondents noted a decrease and even cited local extinctions of species they used to catch, such as the acoupa weakfish « *Cynoscion acoupa* » and various catfish species. In addition, 76.7% of the fishers reported reduced fish or seashell abundance in their catches. Conversely, fishers did not clearly perceive changes in fish size since more than half of the interviewees did not answer or state that the sizes remained the same (43.3%). Only 26.7% of the respondents observed a decrease in fish size. With regard to the demand for fish or seashells, over half of the fishers reported an increase, while 30.0% indicated a decrease, and 16.7% noticed no change.

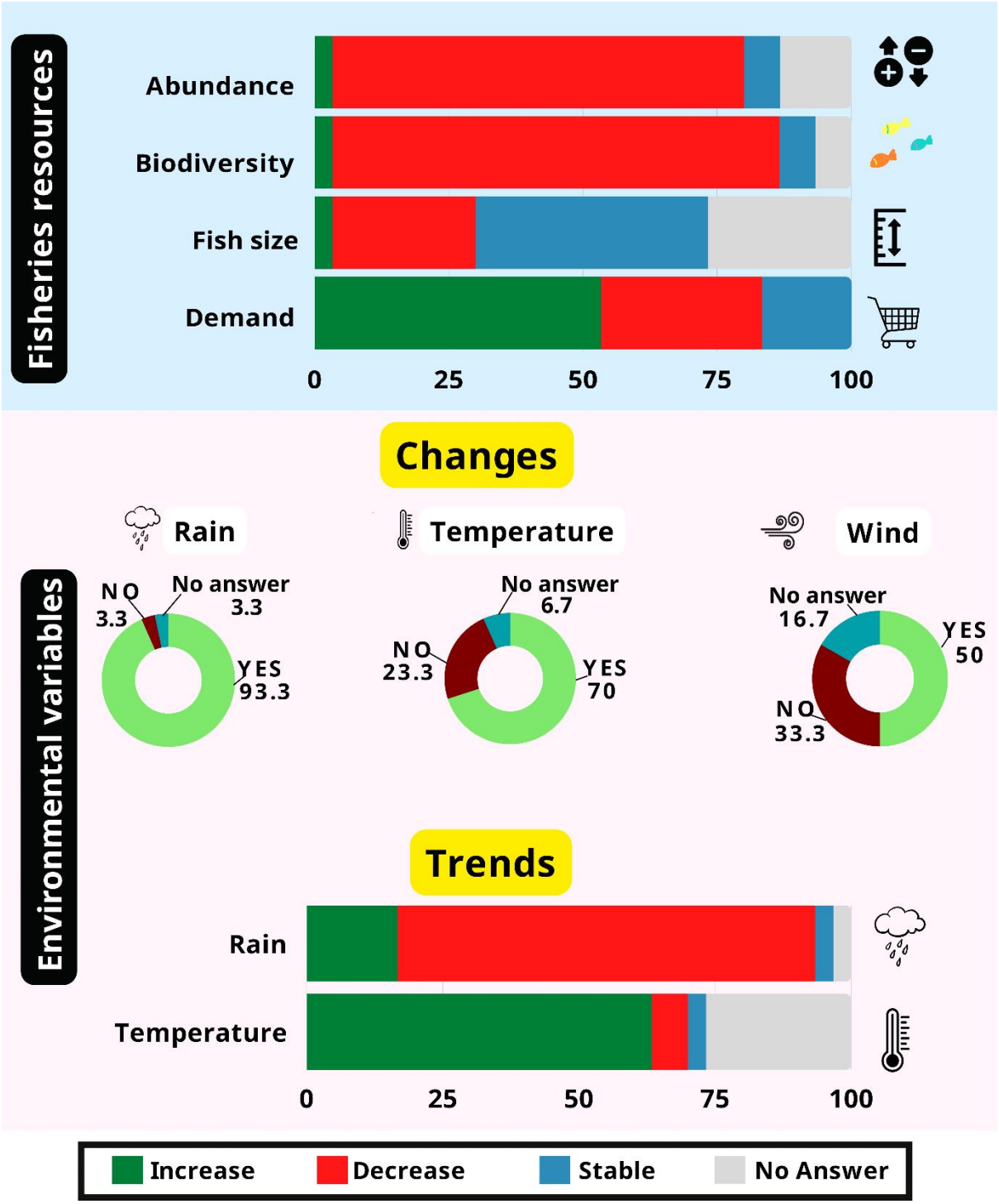

Figure 5: Fishers' perceptions of fisheries resources and environmental variables.

Fishers perceived a difference in the rainfall pattern, with a strong tendency towards decreased rainfall (Figure 5). Additionally, most respondents reported temperature changes, with the majority noting an increase. In contrast, only half of the interviewees observed changes in the wind. The percentage of no responses was insignificant for changes in rainfall, slightly higher for temperature changes, and high for changes in the wind.

Rainfall is perceived as a facilitator for seashells collection, as the mud from which they extract them is softer when it rains. Conversely, temperature increase was perceived as a threat for three reasons: habitat destruction (especially of reefs), changes in species ecology (reproduction and spatial distribution), and changes in catch composition (due to species' thermal preferences). Fishers who reported changes in wind mentioned that alterations in this variable directly impacted navigation and, as a result, indirectly affected their activity.

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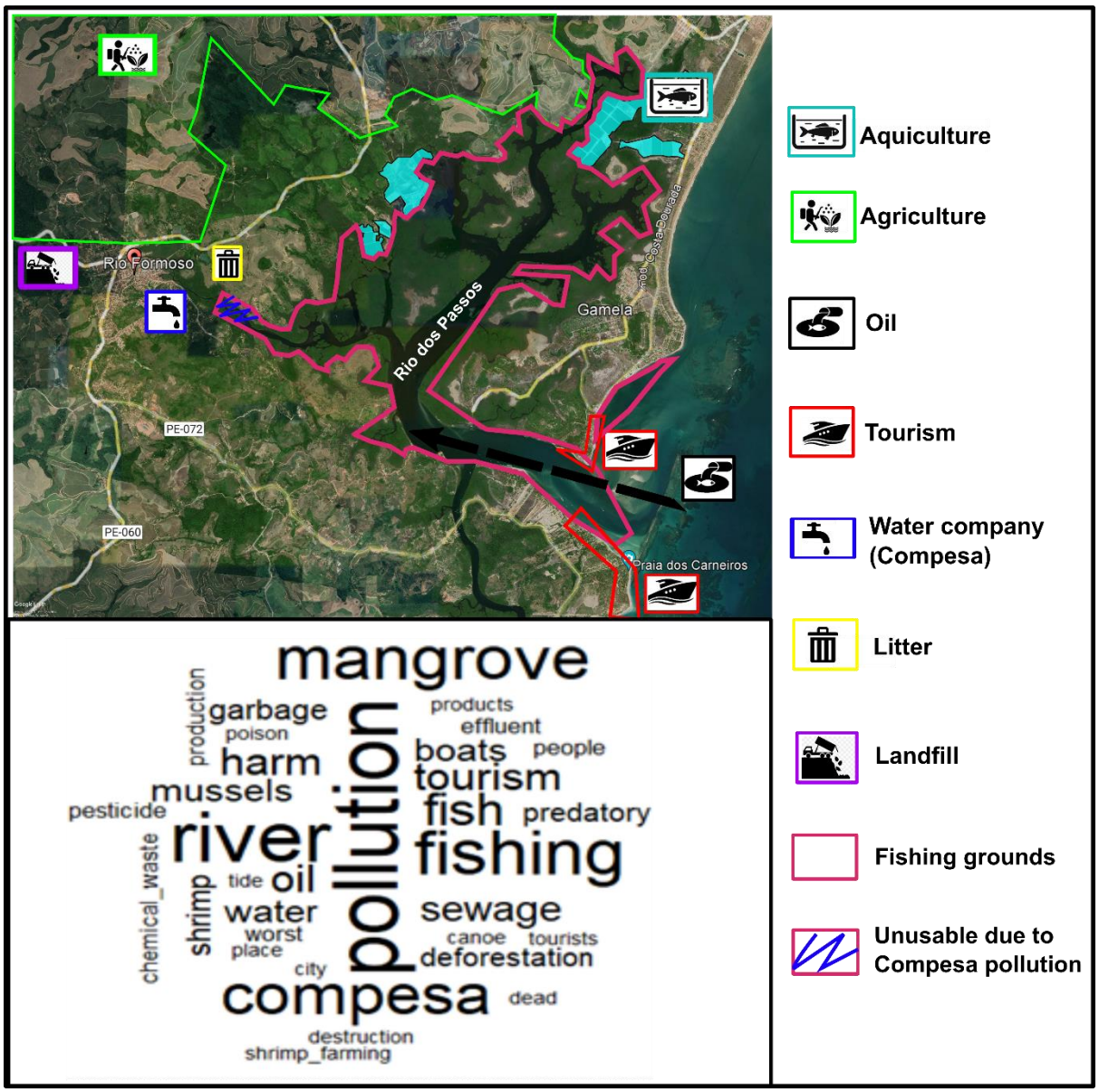

Figure 6: Participative mapping and word cloud representing the anthropic impacts perceived by the interviewees. The word "compesa" refers to the name of the water company operating in the region.

Several anthropic activities are located around the fishing areas of Rio Formoso (Figure 6). The fishers reported that aquaculture had altered the mangrove habitat, and its effluents would likely contaminate the rivers. They noted that waste is mainly concentrated in the northwestern part of the estuary (near Rio Formoso) and the coastal tourist areas. The water company and the landfill are possible sources of contamination in the western part of the estuary. In addition, the estuary is surrounded by agricultural areas (mostly sugarcane) where herbicides and fertilisers are used.

The interviewees frequently mentioned pollution, such as chemical waste, poison and effluents. The respondents often cited the water company ("Compesa"), and reported that several complaints have already been filed. Some pollution linked to shrimp farming and agriculture (pesticides) was also mentioned. The mangrove was highlighted as an impacted biome, and deforestation was cited as a contributing factor. Tourism was mentioned as a relevant impact associated mainly with boats and canoes. Fishing activity associated with "predatory" was also underlined as a potential impact. They define predatory fishing as an unsustainable fishing method (tiny mesh/electric fishing).
The fishers also mentioned the strong impact of the oil spill, with 100% stating that their activity was impacted. Several reasons were given:
-Residents would not buy fish, fearing that it would be contaminated.
-Fishers could not sell their product.
-The oil stuck to the net and could not be removed, permanently damaging it
-Fishing resources such as shrimps or crabs became scarce after the oil spill. For example, sensitive organisms like freshwater shrimps were absent for several months after the oil spill.
The oil spill trajectory was also mapped based on the fishers' perceptions.

When asked whether their children (if they had one or in a hypothetical situation) would be able to become fishers like their parents, 73.3% of the interviewees gave a negative answer.

"I don't want my son to become a fisherman. Why should he do that? So that he will starve to death? (...) seeing how humanity destroys everything..." (Fisher 1)

*"No, it's too difficult... It's getting worse every day." (*Fisher 2)

"I see much dishonesty. Much lack of commitment to fishing (...) I'll be honest, I don't expect much because humanity is making fishing unsustainable." (Fisher 3)

"Because as things stand, we can only expect the worst. Today, we spend all day fishing; we bring back 1 kg of fish and sometimes nothing. Probably in 30 or 40 years, it will be even worse... Seeing how things are going, human beings and their ambition will destroy everything." (Fisher 4)

However, several interviewees stated that they enjoy their profession:

"I like working with fish. I like working with seafood. I can work with other things, but I only want to work with the tide. If I could find another job, in my spare time, I would go fishing." (Fisher 1)

"I like to work. I like fishing for crab. I wouldn't trade crab fishing for anything. (...) I hope that people become aware that they do the right thing, that they always try to improve, that they give value to what they do... whether it's any service if you don't know how to give it value... the ideal is to give value to what you do. That's why I love fishing. I wouldn't trade it for any service. I want to fish until the end until the limit of what I can bear." (Fisher 2)

"I love it; I love being a 'marisqueira'. It's a pride." (Fisher 3)

4. Discussion

4.1. Consequences of global change on Rio Formoso fisheries

Fishers who participated in this study reported a decline in both abundance and biodiversity, accompanied by increased demand. These perceptions indicate that the « fisheries crisis » features, namely the progressive depletion of marine resources and the increasing need for seafood to meet society's protein requirements, are being felt locally. The fishers also reported some local extinctions, highlighting the value of local ecological knowledge (LEK) in a data-poor context where stocks are not assessed (Leduc et al., 2021). In addition, this LEK contributes to the characterisation of the fishery (gears, habitat, target species), which is essential for management (Previero and Gasalla, 2018).

The interviewees did not observe changes in fish sizes. More than a matter of shifting the baseline (Pauly, 1995) , the lack of perception of the well-described fisheries-induced reduction in fish size is probably because the respondents work in estuarine and adjacent coastal areas where they mainly target small organisms, including juveniles, sub-adults or small species (Pelage et al., 2022, 2021). Since these ecosystems serve as nurseries for the targeted migrant fishes, the available fish in estuaries and shallow coastal waters are mostly immature individuals (Benzeev et al., 2017; Gonzalez, 2021). The small organisms targeted by Rio Formoso fishers are marketed in short circuits (sometimes from fishers to consumers) and are essential for food security. This predominance of small organisms is an intrinsic feature of the socio-ecological systems (SES), and should be understood as such rather than as a proxy for overfishing (Kolding and van Zwieten, 2014). However, Colony Z-7 warns against "predatory" fishing, which includes electrofishing or tiny mesh sizes (less than 1 cm) that catch even larvae and organisms that will not be used for consumption. The banning of small mesh is already informally enforced by the colony board and, according to the colony directors, is well-understood by most colony members. Thus, co-management between the state and Colony Z-

7 could be beneficial in finding cost-effective measures that would be ecologically beneficial and well-accepted by the fishers.

The rain and the temperature were identified as the two physical variables that have undergone the most significant changes over the years. However, Human perception of climate change may be biased by the difficulty in perceiving long-term changes and the high meteorological variability, especially in regions with frequent extreme events (Limuwa et al., 2018). Nevertheless, fishers' observations of decreased rainfall and increased temperature in the region are corroborated by time series data (Silva et al., 2017). These trends are expected to worsen in the future, along with the increasing occurrence of extreme events such as droughts and floods (Carvalho et al., 2015), which could significantly impact catch composition. Fishers may adopt different coping mechanisms to cope with the climate change-induced decline in catches, such as using more efficient gear, which may be unsustainable, or switching to other activities, such as agriculture or small businesses (Limuwa et al., 2018). It is, therefore, crucial to consider socio-ecologically sustainable alternatives to adapt to future changes.

Fishers reported that temperature influences species ecology, habitat degradation and catch composition. Local ecological knowledge of species' thermal limits could help anticipate changes in catch composition, species distribution and the resulting socio-economic consequences (Lopes et al., 2019). Modifications in rainfall, affecting *marisqueiras* ability to extract shellfish from the mud, are expected to have socio-economic impacts. Hence, conducting a vulnerability assessment that incorporates fishing community insights is essential to develop adaptation and mitigation strategies (Sowman, 2020).

Collaborative mapping was used to document the spatial distribution of various anthropogenic impacts and to identify possible conflicts between users. This map showed that discharges from land-based activities pollute the upper catchment and affect water quality, highlighting the need for land-sea management (Noble et al., 2019). Fishers identified pollution generated by all activities (e.g., agriculture, industry), primarily the water company Compesa, as the primary threat to Rio Formoso fisheries. The federal justice has already condemned this water company for dumping effluents without adequate treatment into the Rio Formoso (and other rivers), violating the environmental standards required by the State Environmental Agency (CPRH) and the National Environmental Council (Conama)(PE, 2014). Tourism was also cited as a significant problem in the area, and the rise of nautical activities led to the creation of the APA and the ZATAN (Elvira et al., 2020). In addition, Rio Formoso fisheries had to deal with unforeseen impacts such as covid-19 and the oil spill (Araújo et al., 2020). Therefore, planning for potential adaptation should include mitigation of unforeseen events, whether of climatic (droughts, floods) or anthropogenic (oil, pandemic) origin.

Fishers express a sense of despair about artisanal fishing and the sustainability of future generations in the profession. The obstacles they face in being included in governance exacerbate this feeling and negatively affect their work, income and mental health (Sorensen

et al., 2022). Facilitating community engagement in decision-making is a way to stimulate ownership and provide hope for potential solutions.

4.2. Towards participatory management planning for Rio Formoso SES

In Rio Formoso, the Z-7 colony is critical in ensuring socio-ecological resilience for effective management (Noble et al., 2021). It advocates for the conservation of essential ecosystems that support fishers and assert their rights. Its connection with various actors, including NGOs, government, and environmental agencies, makes it a strategic entity that can gather stakeholders for participatory management. The Z-7 colony is already involved in participatory processes that bring together all users of the Rio Formoso estuary (Elvira et al., 2020). Moreover, it is an established and respected institution, which is crucial for gaining local endorsement for management (Howson, 2020; Silva et al., 2021).

However, in the ZATAN process, civil society is only part of an advisory board and does not actively participate in decision-making (Lígia Barros, 2022). In addition, many actors with different levels of power are involved in the process, such as big water sports companies and small boatmen in the tourism sector, with differing interests (mass tourism vs ecotourism) and degrees of influence (insertion in a structured interregional tourism network vs self-organisation), which creates unfair competition and conflicts (Elvira et al., 2020). While representing different stakeholders in marine spatial planning processes is essential, it does not guarantee that their voices are equitably heard enough to prevent ocean grabbing (Queffelec et al., 2021). Therefore, legal tools must reinforce polycentric governance to empower small actors like fishers and traditional communities.

The Marine Extractive Reserves (Marine RESEX) programme is a community management instrument in Brazil in which the Z-7 colony is already involved. A RESEX is a protected area that promotes the co-management of natural resources by adopting social and environmental objectives (Santos and Brannstrom, 2015). The programme aims at empowering marginalised traditional communities that depend on local natural resources to become actively involved in managing RESEX areas with support from the national government (Partelow et al., 2018). However, the Z-7 colony's ongoing struggle over ten years to implement a RESEX illustrates that this instrument was not designed to be a straightforward process (Ribeiro and Callou, 2015). For this legal tool to be truly effective, it must be more operational.

In addition, a growing challenge for the long-term sustainability of SSF is to mitigate women's vulnerability to global change (Axelrod et al., 2022). As the Z-7 colony is comprised mainly of women, it is a relevant example of how this challenge is being addressed locally. The predominance of women is reflected in the board of directors, which is rare enough to be noted. Despite their significant contribution to SSFs yield, women's wide range of roles (including direct involvement in catching, trading, processing, and marketing operations) are often overlooked or unaccounted for (Ameyaw et al., 2020, 2021; Gopal et al., 2020). The traditional stereotype of 'fishermen' as male workers remains strong, while shellfish hand-picking, mainly

carried out by women, is usually not even considered fishing (Harper et al., 2013). As a result, men often hold higher positions in the fishing sector, including in decision-making processes.

However, seashell fisherwomen are essential in many tropical countries (Frangoudes and Gerrard, 2019; Lokuge and Hilhorst, 2017). Indeed, the seafood collected by fisherwomen is necessary for nutritional safety at a household level and plays a crucial role in the regional economy (Harper et al., 2020; Santos, 2015). In Rio Formoso, the seashell value chain involves a higher diversity of actors since fish are primarily marketed to local consumers, while seashells are mainly sold to restaurants but may also be bought by intermediaries. The seashells sector offers the opportunity to expand the market scale, as most shellfish are destined for restaurants in nearby towns. In addition, the *marisqueiras* usually process the shellfish for sale to restaurants, adding value to the product (Harper et al., 2013).

Rio Formoso is just one of many examples where the profitability of SSF is closely linked to the roles of fisherwomen. However, the sustainability of this SES is threatened by the social constraints that women often face, including social exclusion, care burden, and social norms associated with marital relationships, which can undermine their commitments (Manyungwa et al., 2019). Therefore, implementing simple ways to mitigate these constraints, such as providing childcare, subsidies for women's health, and raising awareness to avoid gender-based discrimination, is essential for enhancing the socio-ecological resilience of the SES.

Moreover, the majority of respondents did not complete primary school, which could affect fishers' household revenue (Rahim and Hastuti, 2018). Educational incentives should be implemented to provide more opportunities for young people from fishing communities to attend university. If some of the students reside in the community, as in this study, building trust between the fishing community and universities would be much easier, which is essential for collaboration (Anbleyth-Evans and Lacy, 2019). Additionally, this would allow for the valorisation of LEK by someone from the community and the development of citizen science initiatives, where the fishing communities could relay concrete questions to universities (Kermish-Allen et al., 2019).

5. Conclusion

In poor-data contexts, it is important to carry-out a socio-ecosystem characterisation, as done in this study, to design a management plan that integrates various aspects of sustainability. Fishers in Rio Formoso perceived threats to their fishing activities from global change consequences, including climate change, pollution and conflicts with tourism. As global change accelerates, their activities are likely to face even greater challenges. The viability of multiple fishing practices in Rio Formoso is based on the sustainable harvesting of several species that use a variety of threatened biomes such as mangroves and reefs. In addition, the socio-economic context, including low level of education, informal market, and *marisqueiras* discrimination reinforces fishers' precariousness. Nonetheless, the Rio Formoso colony is an example of successful fishers' self-organisation through a locally respected institution strongly

empowered in marine spatial planning processes and advocates for fisheries' socio-economic and ecological sustainability. Furthermore, this colony enables women to exert their influence in crucial decision-making processes. Thus, facilitating the colony's involvement in governance and participatory adaptive management has great potential to address the future socio-ecological challenges of global change effectively. More broadly, the Brazilian legal instruments for implementing participatory management could benefit from greater operationality to avoid protracted bureaucratic struggles for fishers and provide faster solutions to the urgent fisheries crisis.

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Supplementary material

Appendix 1 :QUESTIONNAIRE FOR THE RIO FORMOSO FISHING COLONY (Z-7)

Observation: The first 3 minutes were reserved for explaining who we were, the purpose of the project, asking for the fishermen's availability (30-40 min), their permission to disclose the research and making them understand that they don't need to answer questions they don't know the answer to/are not comfortable answering.

1. Identification *(3 min)*

- Name and age? Did you ever attend school (level of education)?
- How many people in your family?
- Are you a local resident?
- In what year did you start fishing?
- Is fishing your only source of income? If not, what are your other activities to complement your income?
- What fishing gear do you use? How much time per day do you spend on the activity? How many times a week? What type of boat do you use? Where do you fish? In the river, estuary, sea? What is the most sought after "brand of fish" (target species)?
- Is your fishing activity for subsistence or commercial?

2. Fishing resources *(6 min)*

- Has there been any change in fisheries productivity compared to years ago? What were those changes? What do you think might have contributed to these changes?
- What species do you fish the most?
- Have some species or types of fish such as ***(representative species) decreased or increased?
- Has the size of the fish decreased or increased?
- Has the number of fish decreased or increased?
- Is there any fish that you used to catch and today you can't find it anymore? Or some species that had a significant decrease in the frequency it was fished? Which? What do you think might have contributed to this?
- Did any new species emerge? Or some species that already existed, but in low frequency in the past, and is now more frequent? Which?
- What is the most productive season for fishing?
- Is there any monitoring sheet or any database with information about the fish? When you return from fishing, do you measure/weigh, record the catch? Do you record how many fish were caught that day?

About consumption, who are your customers? People from the community? Tourists? Residents of adjacent communities? Any company? Is there a fixed consumer?

- Has demand by the population increased or decreased?
- Recently our coastline was affected by an oil spill. Did this affect you in any way?If Yes, how?

- Also recently, the world faced a new disease, Covid-19. Has this illness affected you in any way?

3. Anthropogenic activities *(5 min)*

- What human activities or environmental impacts (such as tourism, chemical waste from industry in the region, destruction of mangroves or engineering works) threatens fisheries resources? Do you think these activities have increased or decreased over time?
- About these activities, which do you think is the worst for fishing?
- Do you think that garbage in the region has increased or decreased? What is the most frequent item? Bags, bottles (plastic and glass), cups, straws or cigarettes?
- Is there a type of fishing or fishing equipment that you think is particularly harmful to the environment and even to the fishing activity itself? Which one? Why?

4. Climate change *(7 min)*

-Have you noticed any recent change in rainfall compared to years ago? Has it rained more or less? Does it harm fishing? Do you know why? Is the rainfall concentrated in any month/season or is it more distributed throughout the year?
- Have you noticed any changes in the air temperature? Are the days warmer compared to the past? Does it impact your fishing activities? If yes, do you know why?
- Have you noticed any change in the winds? Have they been stronger, weaker, or no change compared to before? Has this been affecting you? Has there been a change in the direction of the winds? Is there a time of year when the wind is better for fishing? Do you know why? What is the wind direction that makes fishing most productive for you?
- Have you noticed any changes in the strength or direction of the currents compared to before? Does it harm fishing? If yes, do you know why?
- Has the sea/river water been warmer, colder or the same as before? Does water temperature interfere with your fishing activities? Are there any species that you notice that become more frequent or larger when the waters are warmer or colder? Which are?
- Has the sea been more agitated? Are the waves bigger, smaller or the same as before? Does it impact your fishing activities? Do you know why?
- During the day, do you notice that the weather has changed more quickly (e.g. it is sunny in the morning, but soon afterwards, it rains)? Is it more difficult to predict the weather or precipitation now than before? How do you predict local weather/sea conditions?
- Did you notice any rise in sea level compared to years ago? Have you seen houses destroyed by the rise in sea level around the region? Has any work been built in recent times to contain the advance of the sea? Are they for or against these works? Why?
- Did the observed environmental changes (temperature, wind etc..) make you adapt in any way? Did they change the target species? What environmental change has most interfered with fishing and why?

5. Expectations *(6 min)*

- In general, do you enjoy working with artisanal fisheries or do you do it out of necessity? Would you like to be trained and work in some other activity that could become a source of income? Do you want your children, if you have or wish to have them, to work in fishing? Why? What do you expect from fishing in the future?- What do you expect from environmental changes in the future? Do you think that the climate, rainfall, water temperature, winds, currents can change and affect your fishing productivity?
- Do you have any idea how you could adapt to climate change (changes in temperature, winds etc..) in the future?