



Adaptive Capacity Level Shapes Social Vulnerability to Climate Change of Fishing Communities in the South Brazil Bight

Ivan Machado Martins^{1,2*†} and Maria A. Gasalla^{1,2,3*‡}

¹ Fisheries Ecosystems Laboratory (LabPesq), Oceanographic Institute, University of São Paulo, São Paulo, Brazil,

² Graduate Program on Oceanography, University of São Paulo, São Paulo, Brazil, ³ Institute of Advanced Studies, University of São Paulo, São Paulo, Brazil

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*Correspondence:

Ivan Machado Martins
ivanmartins@gmail.com
Maria A. Gasalla
mgasalla@usp.br

† Present address:

Ivan Machado Martins,
Faculdade São Lucas, Caçapava,
Brazil

‡ ORCID:

Maria A. Gasalla
orcid.org/0000-0003-1506-7040

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Understanding the social vulnerabilities and community strategies to adapt to environmental changes are crucial for the development of actions to enhance both community conservation and survival. With the aim to identify the drivers of vulnerability to climate change among different coastal communities a comprehensive multi-scale vulnerability framework was here adopted. Eight selected fishing communities representative of the South Brazil Bight (SBB) area were surveyed at the household level. A total of 151 fishers were interviewed. Quantitative indicators were calculated at the community-level, and their drivers identified, allowing for comparisons of the overall vulnerability score. Findings revealed that remoteness and the lack of climate change-related institutional support increase vulnerability among fishing communities in the region. On the other hand, community organization, leadership, research partnerships, community-based co-management, and livelihood diversification reduce vulnerability. Our analysis focused on social vulnerability to climate change in regional fishing communities and provides a better understanding of these effects in coastal zones, the factors explaining vulnerability and some perspectives on resilient and adaptable systems. Learning from comparisons at the ecosystem level may be applied to coastal regions elsewhere.

Keywords: small-scale, fishing community, climate change, vulnerability, adaptation

INTRODUCTION

Climate change causes a progressive loss of productive capacity in some coastal and oceanic regions, with changes in the distribution, availability and production of marine food resources (Booth et al., 2018). The impacts of climate change in marine ecosystems and coastal zones are predominantly felt by small-scale fishers, especially in developing countries (Badjeck et al., 2010; Martins and Gasalla, 2018). The limited spatial context and the small scale of some fisheries, as well as the complex socioeconomic and policy trends associated with the activity, make them highly susceptible to environmental changes, reducing their adaptive capacity (Morton, 2007). Assessing fishing communities effects of anthropogenic stressors and their capacity to adapt is a necessary and important step to inform management initiatives, to assist decision makers in

weighing trade-offs and to promote and increase resiliency of coastal communities (Perry et al., 2010; Cinner et al., 2012; Mozaria-Luna et al., 2015). A set of different research frameworks has been developed to examine the vulnerability of small-scale fishers to environmental change (Badjeck et al., 2010; Cinner et al., 2012; Béné, 2009; Jacob et al., 2013; Aswani et al., 2018), proposing general definitions of vulnerability as the susceptibility of a system to cope with the adverse effects of a disturbance (Adger, 2006; Cinner et al., 2013) and resilience as the ability of the system to recover the functional state after a disturbance (Buckle, 2000). These concepts have been considered as complementary, considering the high vulnerable communities are expected to be less resilient and demand additional resources to retrieve from a disturbance (Jacob et al., 2013). In this study a recent framework proposed by Aswani et al. (2018) was applied to address the social vulnerability of coastal communities in Brazil seeking to raise innovative data on a local scale to support more effective management actions.

In the environmental change context, vulnerability is typically measured as a component of sensitivity, exposure, and adaptive capacity (Cinner et al., 2013). Sensitivity is the state of susceptibility to harm from perturbations or long-term trends (Adger, 2006; Allison et al., 2009). The sensitivity of socio-ecological system is usually defined as the intrinsic degree to which economic, political, cultural, and institutional factors are likely to be influenced by extrinsic stresses or hazards (Allison et al., 2009). Exposure is the degree to which a climatic event can stress a specific region (Adger, 2006; Allison et al., 2009). In other words, exposure can be defined as the scale to which a region, resource, or community experiences change (Cinner et al., 2012). In the fisheries context, exposure is the extend to which the resource will be affected by an climatic event (Cinner et al., 2013). Adaptive capacity is the ability of individuals to anticipate and respond to changes, or to cope, reduce and recover from the effects of the climatic stressor (Gallopín, 2006). Which means, those with low adaptive capacity are expected to have difficulty adapting to change or seeing opportunities that climate change may create in the availability of resources and services (Cinner et al., 2012, 2013).

There are no single measures of exposure, sensitivity, or adaptive capacity and because of that the interpretation and analysis is linked to the scale of the study and available data (Mozaria-Luna et al., 2015). However, understanding the vulnerabilities of fishing communities and their strategies to cope with and adapt to climate change is extremely important to the development of policies that seek to preserve the communities livelihoods (Kalikoski et al., 2010). Actions with the aim of reducing vulnerability to climate change should generally be focused on reducing sensitivity and exposure, and at the same time increase local adaptive capacity (Cinner et al., 2012). Another key step in addressing the effects of climate change will be to develop clear management objectives that reconcile competing goals and consider multiple objectives, such as conservation-based, biological, economic, social, cultural, and political objectives of marine social-ecological systems (Perry et al., 2010; Mozaria-Luna et al., 2015).

Moreover, understanding the vulnerabilities of fishing communities to climate change and their capacity to adapt is urgently needed (Allison et al., 2009). Nevertheless, fishing communities vulnerability to climate change has not been properly identified and evaluated in coastal Brazil. A few studies focusing on coastal fishing communities in southern Brazil found that vulnerability varies among communities and households, mainly due to the differences in their dependence on fishing, the distribution of assets and the level of participation in community organizations (Faraco, 2012), and vulnerability varies because the knowledge of small-scale fishers contributes to reducing that vulnerability and adapting to changes (Silva et al., 2014; Martins and Gasalla, 2018). Both of these previous studies helped to understand some effects of climate change on fishing communities, although, they do not provide an understanding of which are the positive and negative drivers behind regional social vulnerability. Addressing these drivers should be useful to collaboratively build on the adaptation pathways that increase coastal community resilience.

Within this context, the present study aims to explore social vulnerability and adaptation patterns among distinct traditional fishing communities in the South Brazil Bight (SBB) with a goal of understanding how climatic changes are impacting their vulnerability and informing adaptation pathways and policy responses.

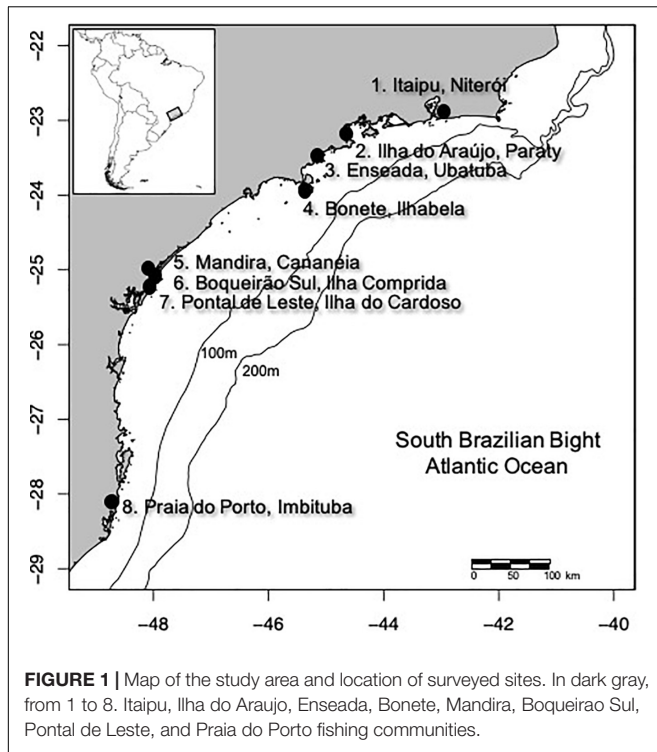
MATERIALS AND METHODS

Study Area

The SBB is the area of the continental shelf of southeastern Brazil extending from Cabo Frio (23°S; 42°W) to Cabo Santa Marta (28.5°S; 48.6°W). The SBB region has a coastline with multiple features and a diversity of ecosystems and social characteristics, sustaining a diversity of economic activities such as small- and large-scale fishing, tourism, shipping, and oil and gas exploration. Fishing communities are diverse and abundant, provide seafood and employment opportunities to the country and have been impacted by recent development as well as climate issues (Martins and Gasalla, 2018). Considering the diversity of the communities along the SBB, eight small-scale fishing communities with different socioeconomic context were selected to represent the different communities of the region in terms of population size, proportion of households with fishers, fishing gear, target species, isolation, and inclusion in protected areas. The communities were: Itaipu, Ilha do Araújo, Enseada, Bonete, Mandira, Boqueirão Sul, Pontal de Leste and Praia do Porto (Figure 1 and Supplementary Appendix 2).

Social Vulnerability Framework

The framework used to evaluate coastal fishing community vulnerability to climate change has been developed to address different marine-dependent coastal communities in an internationally comparative effort across Southern Hemisphere coastal zones (Aswani et al., 2018; Martins et al., 2019). The framework was proposed by a multilateral scientific team from different countries and disciplines aiming at improving fishing

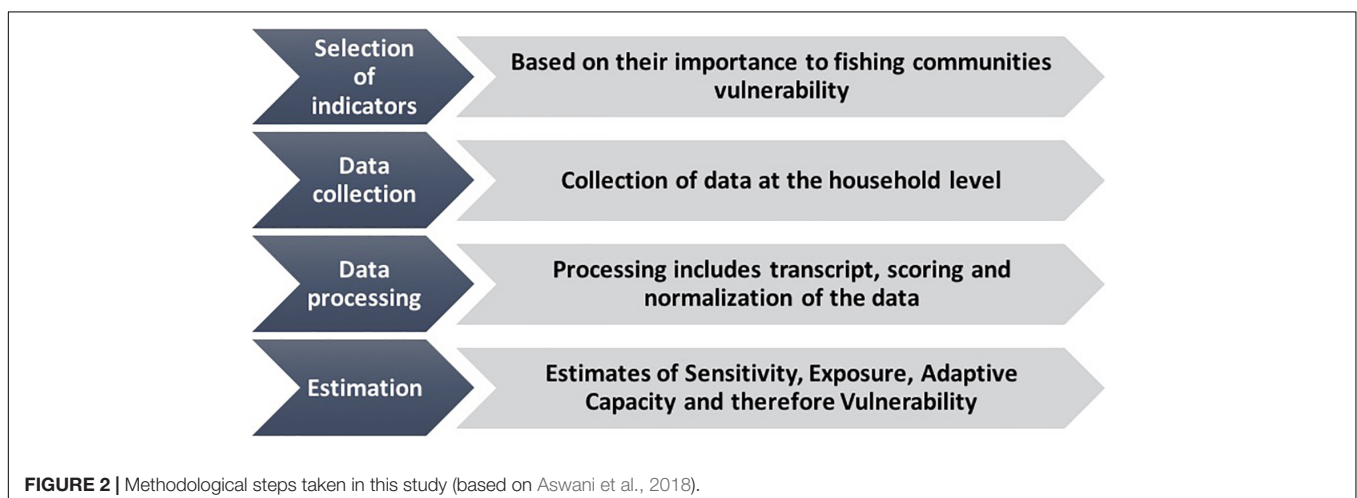


community adaptive capacity by characterizing, assessing and predicting the future of coastal-marine resources and by co-developing adaptation options through the provision and sharing of knowledge across fast-warming marine hotspot regions (Hobday et al., 2016; Popova et al., 2016). A key component of the vulnerability framework is to collect rich, local-level, social vulnerability data to provide a detailed understanding of the local-scale processes influencing community vulnerabilities while allowing for the data to be scaled up to regional, country, and global levels (Aswani et al., 2018). Here, the framework was used to understand the local process influencing the social vulnerability of coastal areas at a community level, but the

same framework is also being used to scale up to regional and global analyses (Aswani et al., 2018; Martins et al., 2019). The framework consists of a four-step process that is described in the sections below (Figure 2).

The indicators that make up the framework used here were built in the context of the GULLS project, which sought to have a flexible structure to allow comparison between different cultural, social, and economic contexts. This meant that the same framework could be used in this in-country assessment. As the survey used had a wide range of questions (Supplementary Appendix 3) with redundancy in the structuring of the indicators (Supplementary Appendix 1), it meant that the survey could be customized to the local context of the SBB region. The indicators were used to measure the separate categories of vulnerability. The individual components of sensitivity, exposure and adaptive capacity categories were then divided in subcomponents to provide more detailed descriptors. The original framework has a total of 255 indicators categorized into 90 subcomponents and 20 components (Aswani et al., 2018). For the present study, a total of 160 indicators, 67 subcomponents and 20 components were selected and are described in Supplementary Appendix 1. The selected indicators are those that best applied to the Brazilian coastal fishing communities and those that had quality data after sampling.

After defining the indicators, the survey instrument was carefully constructed to translate the indicators into the questionnaire. The survey had previously been field tested in two other communities in the region. As proposed by the framework (Aswani et al., 2018) the questions that did not produce reliable data were identified during the field testing and subsequently improved or omitted. The final survey instrument has a mix of Likert scale, open, closed, binary (yes/no), and multiple-choice questions. The full survey can be accessed at Supplementary Appendix 3. Sampling occurred during two field periods, with the first in November and December 2014 and the second in September and November 2015. Sampling was done at household level using a systematic approach, which means one house with fisher was sampled and the next not until it reached 50% of fishers. In some cases the planned number of sampling was not



reached due to refusal to participate in the research. Communities with up to 30 fishers were all invited to participate in the survey. Each survey was followed by the signed informed consent of the interviewed. A total of 151 households that had regular interaction with the ocean were sampled face-to-face in the eight selected communities. The average length of the interview was 1.08 h (0.35–2.35 h).

The answers were coded and scored for each of the indicators according to the rationale, as describe in **Supplementary Appendix 1**. As the survey included questions with different structures, the indicators resulted on measures of different scales, and to allow comparison the indicators were normalized to a value between 1 and 4 by dividing the number of alternatives by four (e.g., a question with 8 alternatives each would score 0.5, a question with 5 alternatives each would score 0.8).

The vulnerability score was derived from the indicators and the metrics of the following equation (IPCC, 2007): $Vulnerability = (Exposure + Sensitivity) - Adaptive\ capacity$. This approach assumes that each index is equally important for overall vulnerability (Mozaria-Luna et al., 2015). A balanced weighted average approach was used in a way that each sub-component contributes equally to the overall index (Hahn et al., 2009). No weight was used because of the complexity of weights assignment due to subjectivity and bias (Becker et al., 2017). The complexity lies in the fact that communities may assign different weights, which would make the comparison goal of the study infeasible in the first phase of the GULLS project, which aimed at comparing communities and countries. On the other hand, the non-weighting approach allowed evaluating equally the strength of each indicator in each component of vulnerability.

With the objective of both assessing the vulnerability of the selected communities representative of the region and comparing them, the individual household level data were considered within communities but the comparisons were undertaken at the community level. With this approach, the internal variability of each community was considered by using the household data when running the analysis comparing the communities. A bubble plot containing the scores for sensitivity, exposure, and adaptive capacity were used to visualize the differences among the three key components of vulnerability. The normality of the sensitivity, adaptive capacity, exposure and vulnerability index were tested using a Shapiro-Wilk test. As a consequence of the data eventually violating the criteria for normality, the non-parametric Kruskal-Wallis test was used to test if there was a difference among communities. To determine which community was significantly different from the average a *post hoc* pairwise comparison test was applied. All tests were considered at a 0.05 level of statistical significance. The analyses and plots were performed using *devtools*, *pgirmess*, *plotly*, and *ggbiplot* packages for the R program.

RESULTS

Sensitivity

The sensitivity category ended with a total of 36 indicators divided into four components that made up the final sensitivity

category score, showing the communities with the highest overall sensitivity as being Pontal de Leste and Ilha do Araújo, while the community with the lowest was Enseada. The Kruskal Wallis test ($p = 0.0033$) indicated that there was a difference in the sensitivity between communities (**Figure 3**). The pairwise comparison test showed that the Enseada sensitivity index was significantly lower ($p < 0.05$) compared to Ilha do Araújo, Mandira and Pontal de Leste (**Table 1**). It was observed that the sensitivity of Pontal de Leste and Bonete are mainly influenced by the economic dependence on other resources index, Itaipu by the economic dependence on fishing index and Mandira by the historical and cultural dependence on fishing index.

Considering the social dependence on fishing component containing nine indicators, the community with the highest score was Itaipu, and the one with the lowest score was Enseada. For the historical and cultural dependence on fishing component, fifteen indicators were used; the community with the highest score was Ilha do Araújo, and the community with the lowest score was Boqueirão Sul. The economic dependence on fishing component was based on eight indicators; the community with the highest score was Itaipu, and the community with the lowest score was Bonete. For the economic dependence on other resources component, four indicators were used; the community with the highest score was Pontal de Leste, and the community with the lowest score was Enseada.

Exposure

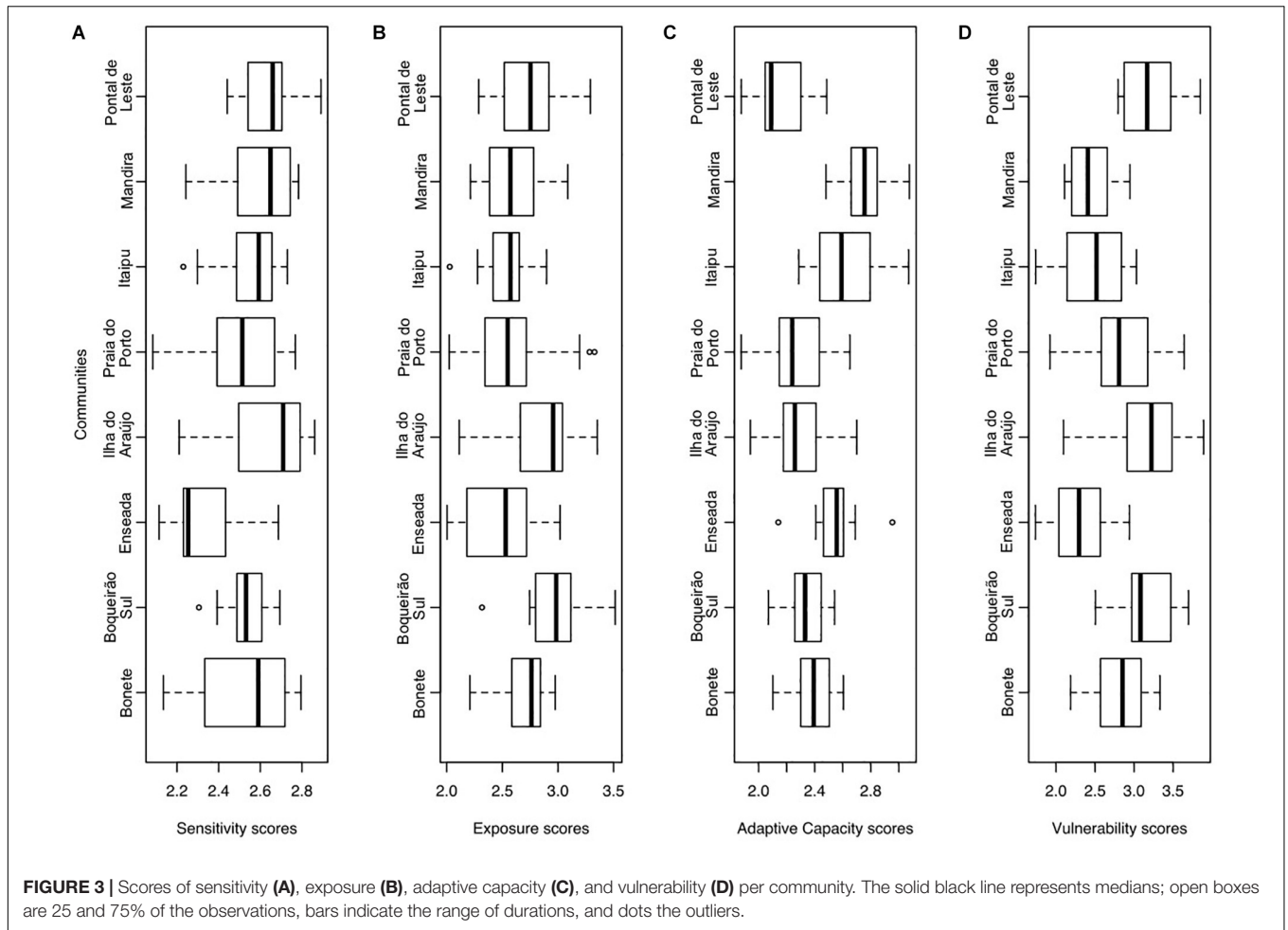
For the exposure category, a total of 35 indicators were divided into four components. The environmental change component was based on eight indicators; the community with the highest score was Boqueirão Sul, and the community with the lowest score was Mandira. Two indicators were used for the institutional support component, and all communities had high scores. For the personal exposure component, twenty-one indicators were used; the community with highest exposure score was Pontal de Leste, and the community with the lowest score was Itaipu. For the attitude and perception component, four indicators were used; the community with the highest score was Itaipu, and the community with the lowest score was Pontal de Leste.

Itaipu and Enseada had a distinct pattern from the other communities due to the low scores of the personal exposure index, while Pontal de Leste had the highest scores. Boqueirão Sul was also influenced by the personal exposure and the environmental change indexes.

The community with the highest exposure was Boqueirão Sul, and the community with the lowest score was Enseada. The Kruskal Wallis test ($p < 0.0001$) indicates that there is a difference in the exposure between communities (**Figure 3B**). The pairwise comparison test showed that the Boqueirão Sul exposure index was significantly higher ($p < 0.05$) than that of Enseada, Praia do Porto, Itaipu and Mandira (**Table 1**). The Ilha do Araújo exposure index was also significantly higher ($p < 0.05$) than that of Praia do Porto and Itaipu.

Adaptive Capacity

A total of 89 indicators categorized into 12 components made up the adaptive capacity category. From the analysis, it is evident that



Pontal de Leste differentiated from other communities mainly influenced by the lowest scores in the social dependence in fishing and occupational flexibility indexes. Whilst Ilha do Araújo, Bonete, Boqueirão Sul and Praia do Porto and was influenced by the low scores in the overall indexes. Mandira, Itaipu, and Enseada had the highest adaptive capacity in the overall indexes.

The final adaptive capacity score contained the twelve components; the community with the highest adaptive capacity

was Mandira, and the community with the lowest overall adaptive capacity was Pontal de Leste. The Kruskal Wallis test ($p < 0.0001$) indicated that there was a difference in the adaptive capacity between communities (Figure 3C). The pairwise comparison test shows that the Mandira adaptive capacity index was significantly higher ($p < 0.05$) than those of Bonete, Boqueirão Sul, Ilha do Araújo, Praia do Porto and Pontal de Leste (Table 1). The Pontal de Leste adaptive capacity was also significantly higher ($p < 0.05$)

TABLE 1 | Pairwise comparison test for the vulnerability categories between communities, where the differences were significant ($p < 0.05$).

	IT	IA	ES	BN	MD	BS	PL	PP
IT								
IA	AC, E, V							
ES		S, AC, V						
BN								
MD		AC, V	S	AC				
BS	E, V		E, V		AC, E, V			
PL	AC, V		S, AC, V		AC, V			
PP	AC	E	AC, V		AC	E		

IT, Itaipu; IA, Ilha do Araújo; ES, Enseada; BN, Bonete; MD, Mandira; BS, Boqueirão Sul; PL, Pontal de Leste; PP, Praia do Porto; S, sensitivity; AC, adaptive capacity; E, exposure; V, vulnerability.

than the adaptive capacity of Itaipu and Enseada, while Ilha do Araújo and Praia do Porto had adaptive capacities that were significantly lower ($p < 0.05$) than Enseada and Itaipu.

Vulnerability

The vulnerability score was based on 160 indicators split into sensitivity, exposure and adaptive capacity categories. The Kruskal Wallis test ($p < 0.0001$) indicated that there is a difference in the vulnerability between communities (Figure 3D). The pairwise comparison test showed that the vulnerability of Boqueirão Sul was significantly higher ($p < 0.05$) than Enseada, Itaipu and Mandira (Table 1). The vulnerability of Enseada was also significantly lower ($p < 0.05$) than that of Ilha do Araújo, Praia do Porto and Pontal de Leste. The vulnerability of Ilha do Araújo was also significantly higher ($p < 0.05$) than that of Itaipu and Mandira. The vulnerability of Pontal de Leste was also significantly higher ($p < 0.05$) than that of Itaipu and Mandira.

The most vulnerable community was Pontal de Leste, followed by Ilha do Araújo, Boqueirão Sul, Bonete, Itaipu, Mandira and Enseada, and the least vulnerable was Praia do Porto. Pontal de Leste, Ilha do Araújo and Boqueirão Sul were the most vulnerable due to their highest scores in all three categories: sensitivity, exposure, and adaptive capacity. Bonete obtained intermediate values in the three categories and thus a moderate vulnerability score. Itaipu and Mandira had high sensitivity scores, but the highest adaptive capacity and low exposure, were determined to have low vulnerability. Enseada had the lowest vulnerability score due its low sensitivity and exposure, and intermediate adaptive capacity score (Figure 4 and Table 2).

A scheme with the key drivers affecting the vulnerability of fishing communities to climate change was established, showing the effects of each driver on the final adaptive capacity of the group (Figure 5).

DISCUSSION

Sensitivity Drivers

Economic dependence on fishing is usually considered in isolation to express the sensitivity category in many vulnerability assessments, but in the framework used in this study the level of social, historical and cultural dependence were also considered, giving a broad understanding of the sensitivities associated with climate change issues. The results show almost equal sensitivity scores for seven of the eight fishing communities surveyed, with the Enseada community being the only different one. The low sensitivity score for Enseada is due to livelihoods diversification. In this community, households have diversified their livelihoods with mussel and seaweed farming and activities related to tourism supported by their own means and by the local community organization. Finding other profitable activities and creating other sources of employment for the fishing communities under scenarios of collapsed fisheries and climate change are becoming a global challenge (Pauly, 2006). In our analysis, we indeed observed that livelihood diversification was an important factor driving a reduction in vulnerability. Although there is diversification and a non-exclusive dependence on

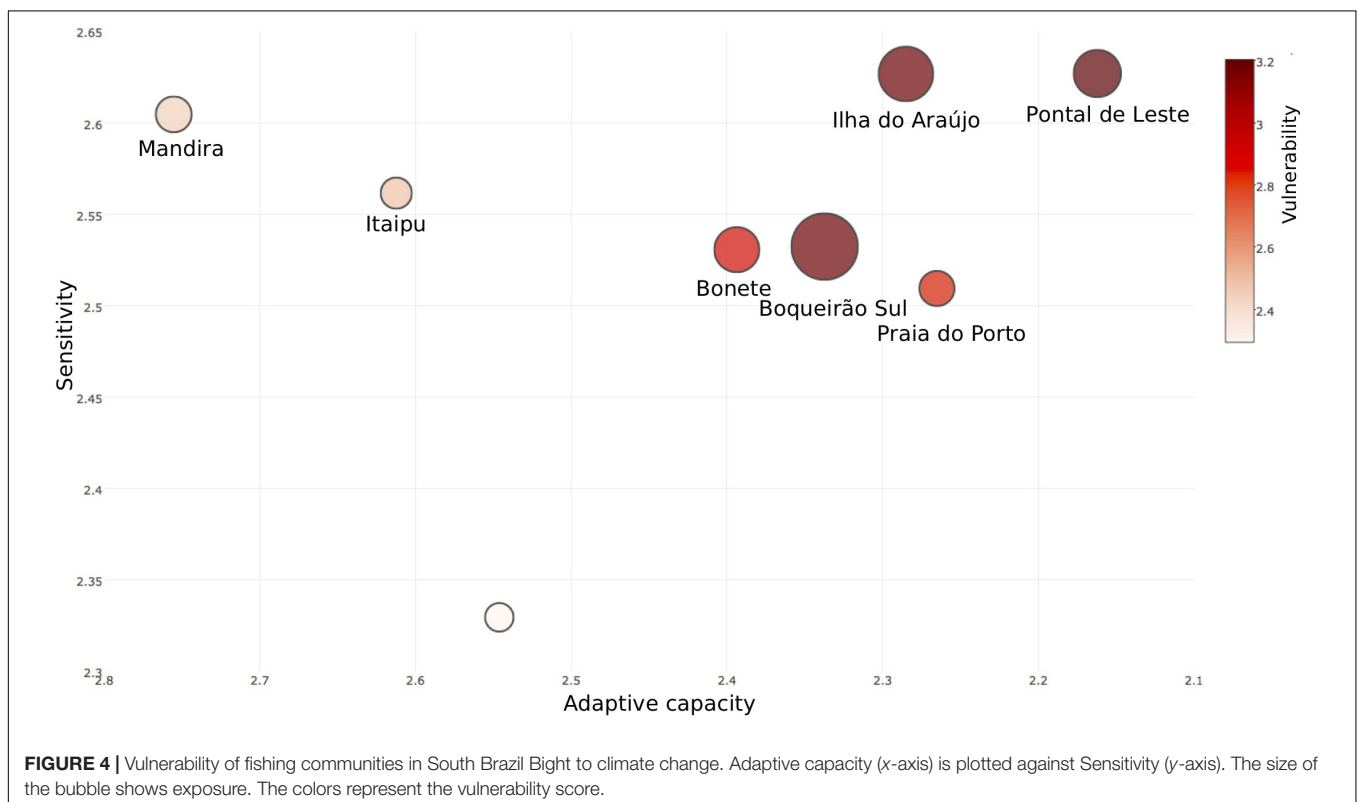


TABLE 2 | Scores of each index and the cumulative score of sensitivity, exposure, adaptive capacity, and vulnerability.

Categories	Component	PL	IA	BS	BN	PP	IT	MD	ES	
Sensitivity	Social dependence on fishing	2,88	2,84	2,79	2,81	2,86	3,02	2,78	2,64	
	Historical and cultural dependence on fishing	2,13	2,25	2,01	2,12	2,13	2,06	2,21	2,13	
	Economic dependence on fishing	2,33	2,69	2,71	2,17	2,56	2,87	2,69	2,29	
	Economic dependence on other resources	3,16	2,72	2,61	3,03	2,49	2,29	2,74	2,25	
		2,63	2,63	2,53	2,53	2,51	2,56	2,60	2,33	
Adaptive capacity	Natural capital	2,37	2,09	2,29	2,38	2,63	2,32	2,99	2,11	
	Human capital	2,09	2,53	2,48	2,82	2,09	2,97	2,90	2,70	
	Social capital	3,50	2,39	2,34	2,71	2,74	3,01	3,88	2,84	
	Bridging social capital	1	1,30	1,25	1,10	1,42	2,02	1,81	1,79	
	Physical capital	2,90	3,10	3,00	2,97	3,02	3,42	2,95	3,39	
	Financial capital	2,59	2,60	2,75	2,78	2,7	2,77	2,73	2,62	
	Personal flexibility	2,08	2,19	2,26	2,28	2,16	2,52	2,47	2,31	
	Attitude and perception	2,68	3,04	3,37	3,15	2,86	3,22	3,10	3,02	
	Occupational flexibility	1,76	1,92	1,79	2,37	1,9	2,05	2,02	2,38	
	Institutional support	1,91	1,97	2,27	1,81	1,85	2,42	3,21	2,08	
	Institutional flexibility	1,89	2,01	2,04	2,11	2,11	2,63	2,16	2,62	
	Social dependence on fishing	1,18	2,28	2,21	2,25	1,69	1,97	2,83	2,67	
			2,16	2,28	2,34	2,39	2,26	2,61	2,76	2,55
	Exposure	Environmental change	2,06	2,54	2,78	2,39	1,76	2,29	1,85	1,94
Institutional support		4,00	4,00	4,00	4,00	4,00	4,00	4,00	4,00	
Personal exposure		2,75	2,20	2,43	2,05	1,93	1,20	2,15	1,43	
Attitude and perception		2,17	2,56	2,67	2,40	2,66	2,67	2,39	2,67	
		2,74	2,82	2,97	2,71	2,59	2,54	2,60	2,51	
Vulnerability		3,20	3,17	3,17	2,85	2,83	2,49	2,45	2,29	
Vulnerability ranking		1	2	3	4	5	6	7	8	

Communities are ranked according to their cumulative vulnerability (1, most vulnerable; 7, least vulnerable). Scores are colored according to their value: green 1.00 – 1.74; yellow 1.75 – 2.49; orange 2.50 – 3.24; red 3.25 – 4.00). IT, Itaipu; IA, Ilha do Araújo; ES, Enseada; BN, Bonete; MD, Mandira; BS, Boqueirão Sul; PL, Pontal de Leste; PP, Praia do Porto. The bold values are the total scores of each category.

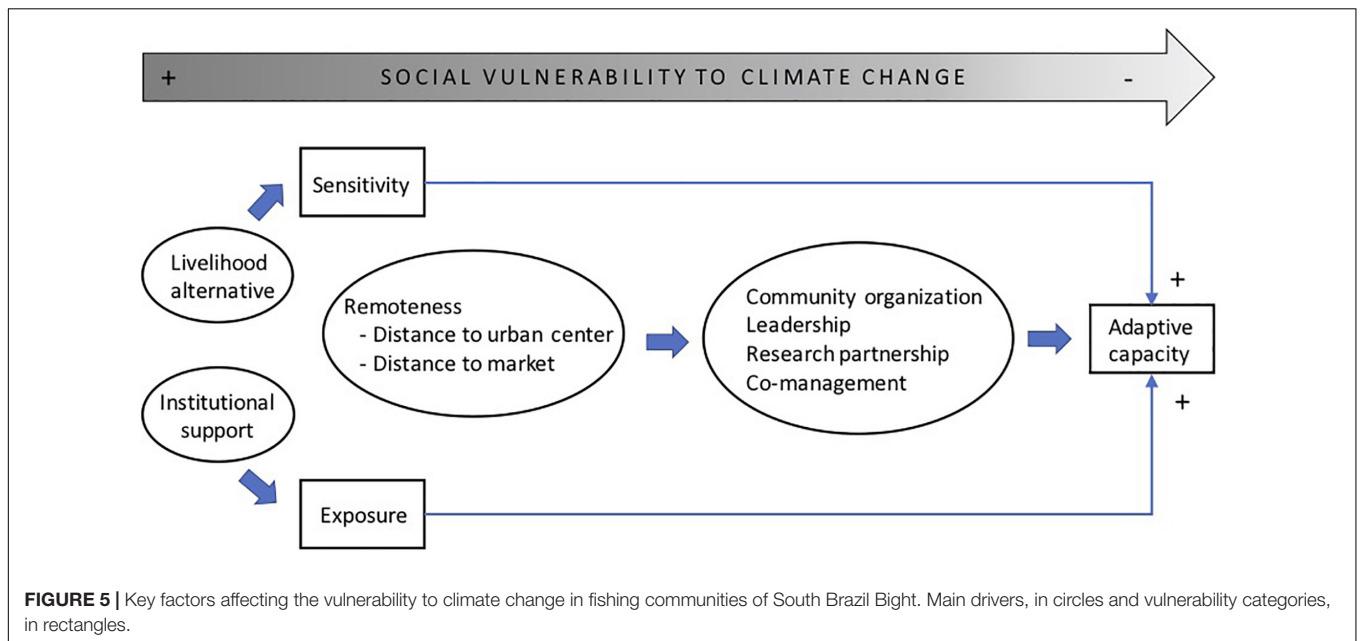


FIGURE 5 | Key factors affecting the vulnerability to climate change in fishing communities of South Brazil Bight. Main drivers, in circles and vulnerability categories, in rectangles.

fishing, the Enseada community still has a strong link with the fishing tradition, with it being practiced daily by all the interviewees.

The strong social, economic, and cultural dependencies on fishing were an important drive to increase sensitivity in Ilha do Araújo, Mandira and Pontal de Leste. The index of

economic dependence on other resources is the main factor affecting the sensitivity of Pontal de Leste and Bonete, the most isolated communities and accessed only by the sea. The index considered the distance to the market to buy and sell goods, methods to obtain food, importance of food source, and level of farming. The distance to market, which can express remoteness, is the factor that increases the sensitivity of the communities (Cinner and Aswani, 2007) as it limits their ability to negotiate prices and avoid the use of middlemen to sell their catches (Merlijn, 1989). In Pontal de Leste, the situation is worse, as it is a subsistence community and reliant on income from selling the fish. The strong dependence of these communities implies a concern in relation to food security, since their main source of income and food is threatened by climate change (Gasalla et al., 2018) and their access to markets, in addition to involving greater spending on transit, may also be impacted by the increase in storm surges predicted by climate change scenarios (von Storch, 2014). A similar situation is expected to be found in other isolated communities that also depend on the external market to buy and sell goods.

For the Itaipu community the high economic dependence on fishing leads to its high sensitivity score, as changes in fishery resource availability are expected to have proportionally negative effects on the turnover of the activity. To ensure the survival of fishing and the maintenance of income related to fishing, the community fought for over 20 years for the creation of the Itaipu MER, established in 2013. The MER ensured community participation in the (in progress) construction of the management plan and the exclusive right to explore the area, which is facing the speculation from the real estate and the oil and gas industries.

Exposure Drivers

Fisher personal exposure plays an important role in community exposure, with the shoreline change subcomponent playing the main influence on the most exposed communities. The erosion process has been well documented in the communities exposed (Angulo et al., 2009) and has a direct effect on the livelihoods of local fishers, by jeopardizing their homes and their access to the sea (Martins and Gasalla, 2018). Other associated impacts of personal exposure are related to large storms, such as damage on roof and on fishing gear, and occasionally shipwrecks. Shipwrecks occur with some frequency in the south and southeastern regions (Fuentes et al., 2013), and was reported by the Itaipu, Araujo Island and Bonete fishers over the past 5 years.

Another important driver of exposure that also affects the adaptive capacity of the communities is the distance to an urban center, with the closest communities being the less exposed, as they typically have better infrastructure and access to public services. The communities most exposed are those that have poor infrastructure and that use the ocean as the main mode of transport. Due to the lack of infrastructure in these communities, they must use the ocean to go the close town to sell their fish catches and to buy food and basics needs. Using the ocean as the main mode of transport also means that good ocean and weather conditions are not only important to fishing activities but also to community mobility and survival. An increase in the

frequency and intensity of the storms are predicted by climatic models (Pezza and Simmonds, 2005; von Storch, 2014), which may increase communities vulnerability.

The analysis has drawn attention to the lack of institutional support related to climate change. None of the localities have institutions or government departments working with the community on climate change issues. There are universities undertaking climate change research in the region, but communities are not aware of such research. In addition to the need for clear government action on climate change mitigation, focusing on the fishing communities, the institutions and universities that are already researching the climate change issues need to improve communication and knowledge exchange with local communities (Cvitanovic et al., 2015). The institutions also needs to better engage the social component of the ecosystem by using an interdisciplinary approach combining innovative frameworks and data (Osterblom et al., 2013; Bennett et al., 2017), and encourage the participation of local communities in climate research to increase the capacity of these populations to cope and adapt to changes (Nop, 2015). These actions are mandatory to improve the knowledge of the climate change issues and therefore to contribute toward effective implementation of adaptation policies (Makinde, 2005).

Adaptive Capacity Drivers

Adaptive capacity depends upon the availability of natural, human, social, physical, financial and institutional resources, as can be measured as the ability people have to convert these resources into useful adaptation strategies (Brooks and Adger, 2004; Folke et al., 2005; Smit and Wandel, 2006). The flexibility component (personal, occupational, and institutional) were also explored in the used framework to refine the measure of the potential of people and institutions to overcome their present situation and deal to future conditions (Marshall, 2010). Therefore, the community with the highest adaptive capacity was Mandira. The high adaptive capacity of the community was driven by well-established community organization, proper management of the oyster resulting from a partnership between government, university and local knowledge (Machado et al., 2015), control of commercialization through a community cooperative (Kefalás, 2016), and the search for local income alternatives such as handicrafts and community-based tourism. On the other hand, Pontal de Leste had the lowest adaptive capacity, mainly due to its high dependence on fishing, inability to negotiate fish price due to its distance to the market and lack of electricity to freeze and store the fish, and absence of livelihood alternatives not related to fishing. The community has tried to diversify its income by having a community restaurant and renting rooms for tourism, but these activities are not yet making significant economic contribution to the families as they are not yet part of the regional tourism route. The engagement of the community members into regional tourism councils is necessary to bring the community new employment opportunities even as local communities are faced with increasing responsibilities to provide for their own well-being and development (Flora and Flora, 1993). Reducing community vulnerability requires adopting similar

approaches to those used in Mandira, including collective sales of fish, community-based tourism, a representative community organization, and strong leadership (Haque et al., 2009; Gutierrez et al., 2011).

Communities within a MER, as is the case for Mandira and Itaipu, have the highest adaptive capacity. MER is a type of community-based marine protected area in Brazil, with management decisions being taken at a local level (Diegues, 2006; Santos and Schiavetti, 2018). The marine MER in Brazil has been successful in ensuring rights for fisheries to small-scale fisher organizations and to preserve marine resources, despite some implementation problems (Santos and Brannstrom, 2015). These characteristics increase the ability of a community to adapt to hazards, as well as reduce vulnerability. The combination of community organization, representative leadership, scientific support, and bottom-up decision-making was the key for a higher adaptive capacity. The infrastructure and income alternatives are aspects that still need to be worked on in all sampled communities, resulting in an overall low adaptive capacity. The diversification of livelihoods is expected to increase income and reduce the overall vulnerability of the community (Brugere et al., 2008). The diversification of livelihoods is usually dependent on external investments in community enterprises and microcredit interventions (Torell et al., 2017). However, Mandira proved that a strong leadership and community commitment can play an important role in the development of alternative livelihood options without dependence on external factors.

Overall Vulnerability

From a global aspect, developing countries, such as Brazil, are in the top half of the countries' most vulnerable to climate change in relation of marine resources (Blasiak et al., 2017). At the national level, Brazil is predicted to have high exposure and moderate sensitivity, adaptive capacity and vulnerability to the impacts of climate change on fisheries (Allison et al., 2009). At the local level, our findings were similar to those of a study conducted in Parana, southern Brazil, where infrastructure, household assets and level of participation in community organizations were also found to be key drivers of vulnerability (Angulo et al., 2009). A study carried out by Silva et al. (2014) in Praia da Almada, Ubatuba, southern Brazil, shows that fishers are looking for alternative source of income and diversifying their fishing grounds as means to reduce their vulnerability. This indicates that in the absence of policies addressing vulnerability, fishers in SBB are trying to reduce vulnerability by their own means drawing on local knowledge and collective action. A global analysis shows that strong leadership and community cohesion is beneficial for fisheries management (Gutierrez et al., 2011). Here, we showed that these factors are also contributing to reduce the vulnerability to climate change by increasing the community adaptive capacity.

The socioeconomic vulnerabilities of coastal communities to climate change are typically related to the ongoing challenges of managing urbanization, pollution, sanitation, and marginalization (Cinner et al., 2012). These factors are also influencing the communities of SBB, but we found that

the remoteness, in terms of the distance to urban center and to market, as the main drivers negatively affecting the vulnerability in the region. Remote communities tend to have limited or disadvantaged access to markets, and also poor access to basics services as health and education (FAO, 2015). In addition to these factors, communities located on islands have geophysical characteristics, as low average altitude of Pontal de Leste and Boqueirão Sul (Angulo et al., 2009) that create inherent physical vulnerabilities to those locations. These findings bring new elements to support policies to mitigate the effects of climate change in communities dependent on marine resources. The factors that guide the vulnerability of communities and the elements used by those that have managed to reduce them must be used to build local adaptation strategies. The use of these elements is important for implementing adaptation actions, but to become effective, it should involve the stakeholders, strengthen participatory processes and articulate them with local leaderships (Gasalla and Martins, 2019).

Lastly, the vulnerability framework used in this study (Aswani et al., 2018) was initially developed to ultimately allow cross-country comparisons, but as it was based on a wide and refined survey assessed on the very local scale, allowing a strong enough vulnerability comparison of local communities. The criteria for selecting the communities that were designed to represent the diversity of characteristics in the region were also useful, since the criteria allow the extrapolation of the data found here to communities with similar combination of factors founded in this study.

CONCLUSION

The study provided an important contribution to the understanding of the differences and similarities in the social vulnerability to climate change among coastal communities, bringing a rich interpretation of the local processes affecting the exposure, sensitivity, adaptive capacity and vulnerability of small-scale fishing communities of the SBB. Findings shows that those communities are highly affected by climatic events as fishers have a strong dependence on marine resources for maintaining their livelihoods. This dependence makes all the communities in SBB vulnerable to climate change.

The main factors affecting the vulnerability of the small-scale fishing communities of the SBB to climate change were: community remoteness, lack of institutional support related to climate change, livelihood diversification, well-established community organization, strong leadership, partnership with research institutions, and resources community-based co-management. Moreover, their particular ranking in the vulnerability framework should allow policy-makers to prioritize much needed actions.

The strengths of the method were highlighted, yet the use of indicators which appeared useful for cross-community (and future cross-country) comparisons deserves an in-depth outlook of the different drivers at the very local scale if lower-resolution policies are proposed. This is intended to be presented in the following series of contributions for each of the local

communities studied here. Also, the replicability potential of this approach seems to be high since similar studies were conducted in Northern Brazil and showed a clear and useful ranking within the different vulnerability components and impacts. Future research should build on and improve this approach especially in the qualitative analysis of the narratives from local fishers that were also accessed through this study.

Overall, our results allow a comprehensive understanding of social vulnerability to climate change in the SBB seeking to find the main drivers affecting the small-scale fishing communities elsewhere. This approach should be particularly important in a post-Covid19 setback scenario.

DATA AVAILABILITY STATEMENT

The datasets generated for this study will not be made publicly available because of the Ethics Commission requirement in Brazil.

ETHICS STATEMENT

The project was reviewed and approved by the Committee for Human Research Ethics of the University of São Paulo. All participants were informed about the research purposes and consented to participate.

AUTHOR CONTRIBUTIONS

IM conducted all the field trips for data collection, calculated the scores for each indicator, and wrote the first draft. MG was

the research's supervisor, brought ideas for methodology and analysis made, revised all the data and scoring analysis with suggestions, took care of the submission process, and was the PI of the research grant. Both authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2020.00481/full#supplementary-material>

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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