Climatic Change (2018) 147:441–456
https://doi.org/10.1007/s10584-018-2144-z

Perceptions of climate and ocean change impacting the resources and livelihood of small-scale fishers in the South Brazil Bight

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Received: 28 November 2016 / Accepted: 15 January 2018 / Published online: 12 February 2018

Abstract Coastal fishing communities are closely linked to the biological and ecological characteristics of exploited resources and the physical conditions associated with climate and ocean dynamics. Thus, the human populations that depend on fisheries are inherently exposed to climate variability and uncertainty. This study applied an ethno-oceanographic framework to investigate the perceptions of fishers on climate and ocean change to better understand the impacts of climate change on the coastal fishing communities of the South Brazil Bight. Seven coastal fishing communities that cover the regional diversity of the area were selected. Fishers were interviewed using a semi-structured questionnaire. The results suggest that fishers have detected climate-related changes in their environment such as reduced rainfall, increased drought events, calmer sea conditions, increases in air and ocean temperatures, changes in wind patterns and shoreline erosion. The perceptions of the fishers were compared to the available scientific data, and correlations were found with rainfall, wind speed and air and ocean temperatures. New hypotheses were raised based on the perceptions of fishers about sea level, coastal currents and sea conditions such as the hypothesis that the sea has become calmer. These perceived changes have positive and negative effects on the yields and livelihoods of fishers. The present work is the first evaluation of the perceptions of fishers on climate and ocean change and brings new understandings of climate-fishery-human interactions as well as provides inputs for future adaptation plans.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10584-018-2144-z) contains supplementary material, which is available to authorized users.

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1 Introduction

The perceptions of fishers on the physical and biological aspects of the ocean can convey the intricate relationship that sea workers have with the natural environment and can help identify and understand the changes in those habitats (Huntington 2000). With respect to climatic conditions and changes, fishers may provide details and local peculiarities that are often not detected by regional and global ocean models and may also supply information in areas where historical data are missing (Gasalla and Diegues 2011). This local view can provide novel perspectives for scientific purposes and support the local stakeholders in developing climate-change-adaptation strategies, management actions and policies (Allison and Bassett 2015).

Climate variability and changes in the environment are experienced daily by fishers (Jahan et al. 2015). The variability can be monitored by the simple act of going out to fish, which is strongly affected by climate and ocean conditions (Ford et al. 2006). In addition to detecting and perceiving climate regimes, fishers are also able to adapt and cope with new conditions (Zhang et al. 2012). Local knowledge is particularly useful for understanding the feedbacks among environmental change, livelihoods, and coastal management and for characterizing social-ecological transformations (Andrachuk and Armitage 2015). The perceptions of fishers on the impacts of climate change on fisheries can also be used to identify the changes and patterns that are sometimes not detected by scientific research, which enhances the features of local management (Berkes et al. 2007).

Changes in marine ecosystems due to climate change have been detected in many regions around the world (Bell et al. 2016). Those climate-related changes can have severe impacts on populations, coastal environments and livelihoods (Allison et al. 2009), particularly those in developing countries that are highly dependent on marine activities for food and economic security, as well as for the maintenance of traditional cultures (Gattuso et al. 2015). It is by adapting to environmental changes and variability that fishers can develop technologies, knowledge and forms of social organization that enable the maintenance of their livelihoods (Davidson-Hunt and Berkes 2003). The individual and social memory can be accessed by studying the perceptions of fishers of the natural system.

The present study is the first analysis of the perceptions of climate and ocean changes of Brazilian coastal fishers. Other studies have explored the local knowledge on climate and environmental change, but these studies have focused on the inland ecosystems of Brazil and have mainly focused on the Amazon (Pinho et al. 2015) and Pantanal wetlands (Silva et al. 2014). However, there is a clear lack of research addressing the impacts of climate change in coastal communities, and research on the impacts on the livelihood of those dependent on fishing is particularly lacking.

To fill that gap, the objectives of the present study were to understand how small-scale fishers perceive climate and ocean change and evaluate the impact of climate and ocean change on the fisheries and livelihoods across the South Brazil Bight (SBB) area. Our specific objectives were to understand the perception of fishers on changes in climate and ocean parameters, correlate those perceptions with the available ocean and climate literature, cross-validate the perceptions of the fishers or raise novel research hypotheses when no correlation is found, and analyze how the perceived changes impact the fisheries and livelihoods of the fishers. This study was conducted in this area mainly because the SBB is one of the global marine "hotspots" of ocean warming (Hobday and Pecl 2014). Those goals align with the recent calls for treating the hotspots as natural laboratories for observing, suggesting, and

developing adaptation options and management strategies related to coastal communities and the fisheries sector (Hobday et al. 2016).

2 Methods

Given the diversity of the communities and environments along the SBB, the selection of traditional fishing communities sought to represent the diversity in the region. The selection criteria were based on the vulnerability aspects of the communities, as the data used in this study were collected in a survey administered as part of the Belmont Forum's *Global Understanding and Learning for Local Solutions* (GULLS) project (Hobday et al. 2016). A preliminary assessment of the communities was performed using information available from the literature and local archives. Seven traditional communities with different characteristics, such as population size, dependence on fishing, target species, tourism, remoteness, and

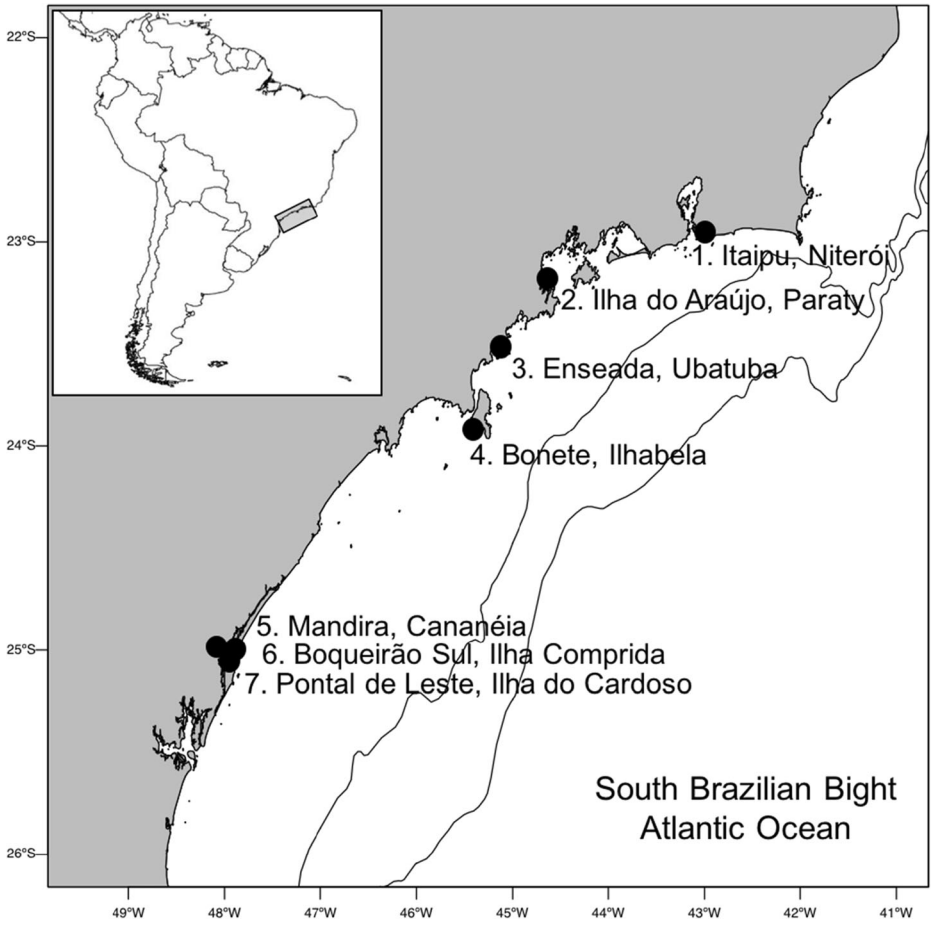

Fig. 1 Map of the study area and locations of the surveyed sites (in dark gray, from 1 to 7: Itaipu, Ilha do Araújo, Enseada, Bonete, Mandira, Boqueirão Sul and Pontal de Leste fishing communities)

infrastructure, were selected, which provided a comprehensive sample of the regional fishing communities (Fig. 1; Table 1).

The ethno-oceanographic framework (Gasalla and Diegues 2011, Online Resource 1) was applied, focusing on the perceptions of fishers about climate and ocean changes. The framework combines bottom-up (people) and top-down (science) systems of knowledge to investigate climate change issues. The first step is to identify the climate change drivers affecting the area, which is followed by a survey that seeks to understand the perceptions of fishers about each driver. The next step is to analyze the perception of fishers and on each perceived change using a full revision of the ocean science literature to cross-validate the perceptions and drivers. The perceived changes that are not yet evidenced by scientific literature are used to outline new research hypotheses that may eventually add new drivers, scenarios or system responses to the regional knowledge.

A total of 120 fishers from the seven selected communities were surveyed. The survey consisted of two groups of semi-structured questions. In the first group, the perceptions of changes in a set of parameters (sea level, rainfall, wind, air temperature, current strength, sea conditions, sea surface temperature (SST), and ocean column temperature) were explored. In response to any perceived change, a guided conversation was initiated to explore how that change was perceived and how it had or had not impacted the livelihood of the respondent. The second group focused on the occurrence of climate-related events (large storms, floods, droughts and shoreline changes) over the last 5 years. For each type of event, fishers were asked to state whether they had felt any direct impact at the community level. The survey protocol is further described in No. 2 in the electronic supplemental material (ESM).

The interview data were grouped by community and parameter. The available climatic and ocean literature was searched and compared with the perceptions of the fishers (No. 3 in the ESM). The comparisons were used to cross-validate the scenarios of change and eventually delineate new hypotheses, as proposed by the ethno-oceanographic framework (Gasalla and Diegues 2011). No data were found in the literature on the sea conditions parameter that would allow for a correlation with the local perception. In that case, data on cold fronts were extracted from national reports, as Siegle and Calliari (2008) suggested these data as a factor to explain the local sea conditions (Climanalise 1986–2016). Data from the Iguape, Ubatuba and Rio de Janeiro municipalities were selected because of the proximities to the surveyed communities. The number of days per month with the occurrence of a cold front was plotted for the 1986–2016 period. Then, the trend in the cold front events was analyzed and fit by a linear regression model.

3 Results

3.1 Perceptions about climate and ocean change

Sea level changes were perceived in Itaipu, Ilha do Araújo, Boqueirão do Sul and Pontal de Leste, where some noted that the sea level had risen, while others said it had dropped (Fig. 2a). Perceptions of reduced rainfall were unanimous in Boqueirão Sul and Bonete and shared by approximately three-quarters of fishers in Ilha do Araújo, Mandira and Pontal de Leste (Fig. 2b). Fishers perceived that the wind had changed in recent years, but there was no clear pattern to the answers (Fig. 2c). Most fishers from Itaipu, Ilha do Araújo, Bonete, Boqueirão Sul and Mandira perceived an increase in atmospheric temperature, while approximately half of the

Table 1 Summary information on the studied fishing communities (*hh* household, *MPA* marine protected area, +++ high, ++ medium; + low)

Community site	No. hh sampled	hh with fisher	Estimated total hh	Fishers hh coverage	Sampling period	Surveyed fishers' age range	Main fishing gear	Main target species	Fishing spots
1. Itaipu	20	40	>300	50%	November, 1–15, 2015	29–75	Gillnet, line and beach seine	*Micropogonias furnieri, Cynoscion* spp., *Trichiurus lepturus, Pomatomus saltatrix*	Coastal, but exposed to wave and wind action
2. Ilha do Araújo	27	60	118	45%	December 1–20, 2014	26–82	Trawl, line and gillnet	*Litopenaeus schmitti, Xiphopenaeus kroyeri*	Coastal islands in a protected bay
3. Enseada	12	14	>300	86%	December 1–20, 2014	38–84	Gillnet, mussel farming and floating fish trap	*Perna perna* farming and multspecies fishing	Protected bay and surroundings
4. Bonete	20	25	100	80%	September 6–20, 2015	24–75	Gillnet, line, jigging and floating fish trap	*Pomatomus saltatrix, Loligo* spp., *Epinephelus marginatus*	Coastal, but exposed to wave and wind action
5. Mandira	18	20	22	90%	November 1–25, 2014	25–64	Oyster extrativism	*Crassostrea* spp.	Protected, inside the estuary
6. Boqueirão Sul	12	17	100	71%	November 1–25, 2014	29–74	Gillnet	*Cynoscion* spp., *Micropogonias furnieri, Mugil liza*	Coastal, but exposed to wave and wind action
7. Pontal de Leste	11	15	15	73%	November 1–25, 2014	31–75	Gillnet	*Centropomus* spp., *Mugil liza, Macrodon ancylodon*	Coastal, but exposed to wave and wind action

Community site	Population size	Degree of dependence on fishing	Involvement on tourism	Urbanization	Isolation	Infrastructure	Type of MPA
1. Itaipu	+++	+++	+	+++	+	++	Extractive reserve
2. Ilha do Araújo	+	+++	+	+	++	+	Environmental protection area
3. Enseada	++	+	+++	++	+	++	Environmental protection area
4. Bonete	+	+++	++	+	+++	+	National Park and Environmental Protection Area
5. Mandira	+	+++	++	+	+++	+	Extractive eserve
6. Boqueirão Sul	+	++	+	+	++	+	Environmental protection area
7. Pontal de Leste	+	+++	+	+	+++	+	State park and environmental protection area

fishers in Enseada and Pontal de Leste had the same perception (Fig. 2d). A change in the coastal currents was perceived in only Boqueirão Sul, where one-quarter of the fishers said that the currents had decreased in strength (Fig. 2e). The majority of fishers perceived that the sea is currently calmer than it was in the past. However, this perception was not shared by the fishers in Mandira, which is located within the Cananeia-Iguape estuarine complex (CIEC). Itaipu, Bonete and Boqueirão Sul are the communities that are most exposed to wave action, and they had the highest number of fishers that perceived that the sea is calmer (Fig. 2f). The SST has increased according to the perceptions of the fishers. Most of the perceived increases were from the fishers from the southernmost communities, with more than half in Boqueirão Sul and Pontal de Leste (Fig. 2g). Fishers from Ilha do Araújo and Enseada perceived a decrease in ocean column temperature, suggesting a possible stratification in these areas, with warm water on the surface and cold water at the bottom (Fig. 2h).

The perceived changes have positively and negatively impacted the livelihoods of the fishers (Table 2). The positive impacts included a decrease in the number of days in which fishers could not go fishing due to rough seas and increased sea temperature, which is beneficial because it improves catches as well as the production of mussels, oysters and seaweed. On the other hand, if the water becomes too warm, the impact is negative, as it can hinder production and because greater care for fish conservation is required. Other negative impacts include the increase in erosive processes due to sea level rise and increased drought, which causes water shortages, catch reductions and crop losses. The changes in wind patterns and erosion debris carried by coastal currents, increased air temperature and decreased bottom temperature also have negative impacts on the livelihoods of fishers (Table 2).

3.2 Occurrence of extreme events

Fishers from all communities recalled a large storm over the last five years, but the numbers of fishers affected were higher in Ilha do Araújo and Pontal de Leste (Fig. 3a). Drought events were perceived by most fishers from all communities except Itaipu, and the direct impacts were higher in Boqueirão Sul and Pontal de Leste (Fig. 3b). Shoreline changes were perceived by nearly all fishers in Boqueirão Sul and Pontal de Leste and by approximately half in Ilha do Araújo and Mandira, but fishers were directly affected in only Ilha do Araújo and Pontal de Leste (Fig. 3c). Floods were reported in only the Bonete community, but they had not had a direct impact on any of the surveyed fishers despite the frequency (Fig. 3d).

3.3 Environmental data

The perceptions of fishers about climate and ocean change were compared with scientific data, and correspondences were not found for all perceptions (No. 3 in the ESM). The scientific data show that the sea level has increased, but this was not perceived by all fishers. The perceptions of fishers of calmer seas and decreases in wind intensities and coastal currents did not correspond to the published data. Other factors such as rainfall, air temperature and ocean temperature were found to correspond with the scientific data.

The historical cold front data indicate a declining trend in the number of days with cold fronts per month, despite the low explanation of the model due to the high monthly variability (Fig. 4). Nevertheless, the decreasing number of cold fronts in the last decade reinforces the decreasing trend of the event in the analyzed period.

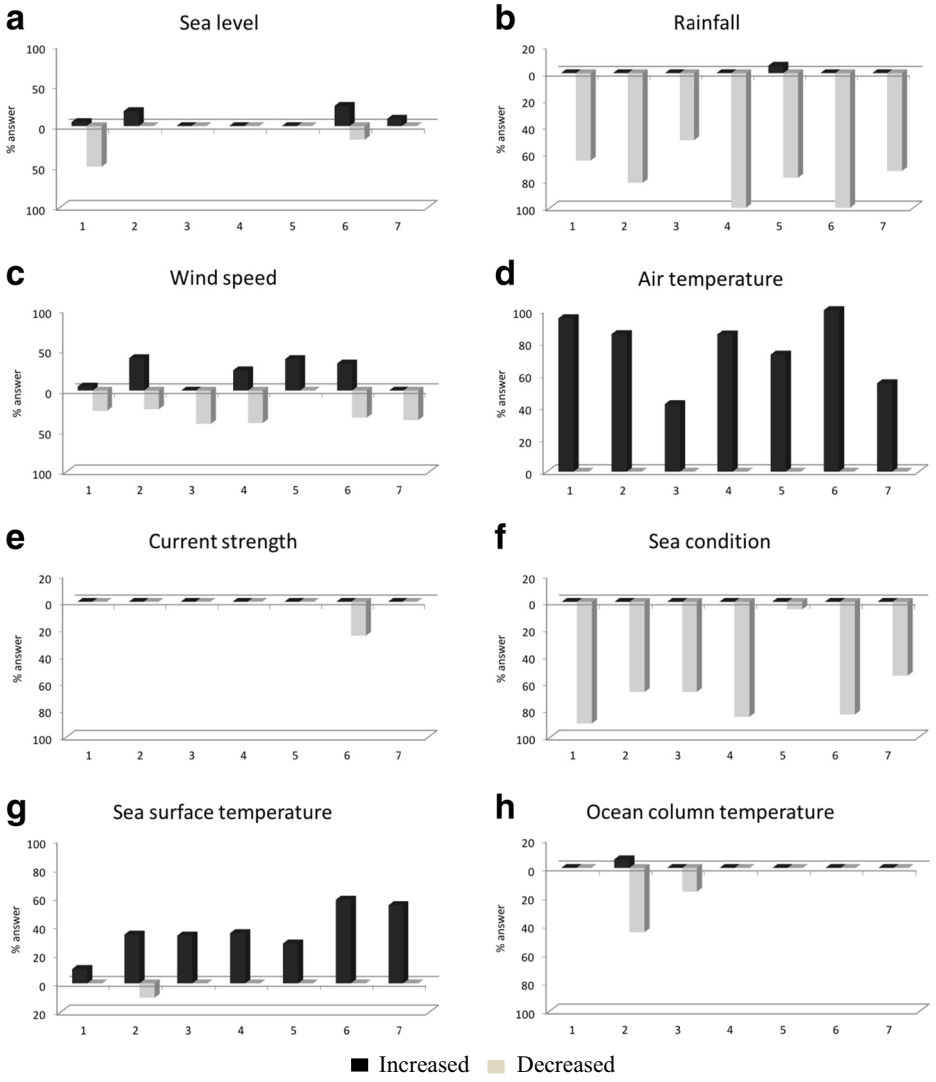

Fig. 2 Percentages of fisher perceptions of indications of increases or decreases in climate and ocean parameters by community site (X-axis: 1 Itaipu, 2 Ilha do Araújo, 3 Enseada, 4 Bonete, 5 Mandira, 6 Boqueirão Sul and 7 Pontal de Leste)

4 Discussion

4.1 Sea level rise and shoreline changes

The global sea level rose by an average of 19 cm between 1901 and 2010 (Church et al. 2013). Along the Brazilian coastline, the relative sea level is increasing at a rate of 40 cm/century (Harari et al. 2013). Even so, a rise in sea level was poorly perceived by the surveyed fishers. The low perception can be explained by the fact that the fishers experience the daily tidal fluctuations, and the annual rate of increase is a slow process that is not fast enough to draw their attention to the fact.

Table 2 Description by fishers on the impacts to their livelihoods due to changes in weather and ocean parameters

Parameter	Livelihood impact	Direction of impact
Sea level	Increased the erosion process and jeopardized the homes of the fishers and access to the sea	Negative
Rainfall	Increased the number of drought events, which caused water shortages (consumption and home supply), catch reductions and crop losses	Negative
Wind speed	Changes in the traditional known weather patterns	Negative
Air temperature	Increased the costs of fish conservation (ice and more frequent landings)	Negative
Current strength	Trash carried by coastal currents damages gillnets and therefore decreases the catch and increases the cost of fishing gear maintenance	Negative
Sea condition	Reduced the number of days that the fisher could not fish due to rough seas	Positive
Sea surface temperature	Increased sea temperatures improve fish, shrimp and squid catches and the production of mussels, oysters and seaweed	Positive
	If the water becomes too warm, it may reduce production and require greater concern over fish conservation	Negative
Ocean column temperature	The catches decrease when the water is cold and when the water column is stratified	Negative

The communities with fishers that perceive sea level rise are the same communities that are facing shoreline changes caused by erosion. The erosion process has been well studied on Comprida and Cardoso Islands, where the Boqueirão Sul and Pontal de Leste communities are located. Both islands are very sensitive to erosion due to their sedimentary compositions and low average altitudes (Angulo et al. 2009), but human activities have also influenced the erosion processes in the area (Mahiques et al. 2009). The data show that erosion does not have a direct relation to sea level rise, but our results show that fishers indirectly construct this relation, despite knowing the natural and anthropogenic influences in the process. Fishers are concerned because sea level rise can increase the exposure of their communities to erosion, which can affect their homes and livelihoods. The same concern was found in other places

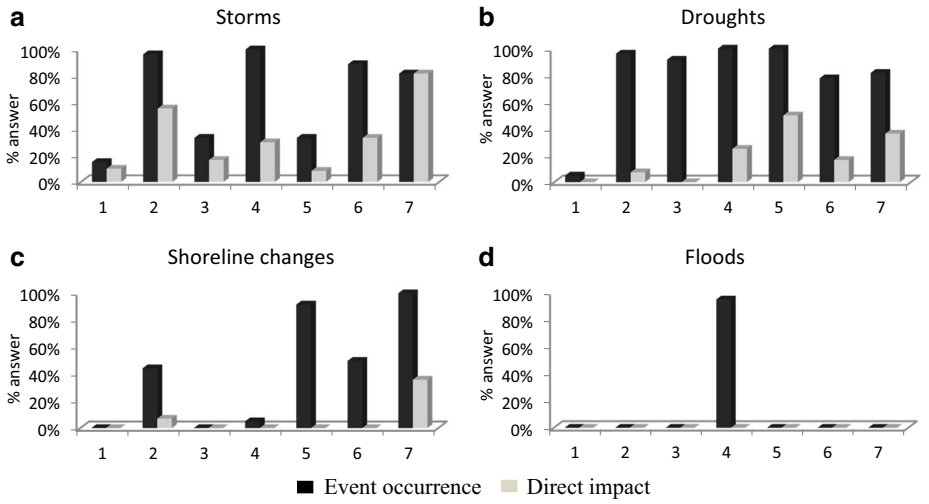

Fig. 3 Fisher perceptions of the occurrence of extreme events (black bars) and the perception of direct impact by the event (gray bars). X-axis: 1 Itaipu, 2 Ilha do Araújo, 3 Enseada, 4 Bonete, 5 Mandira, 6 Boqueirão Sul and 7 Pontal de Leste

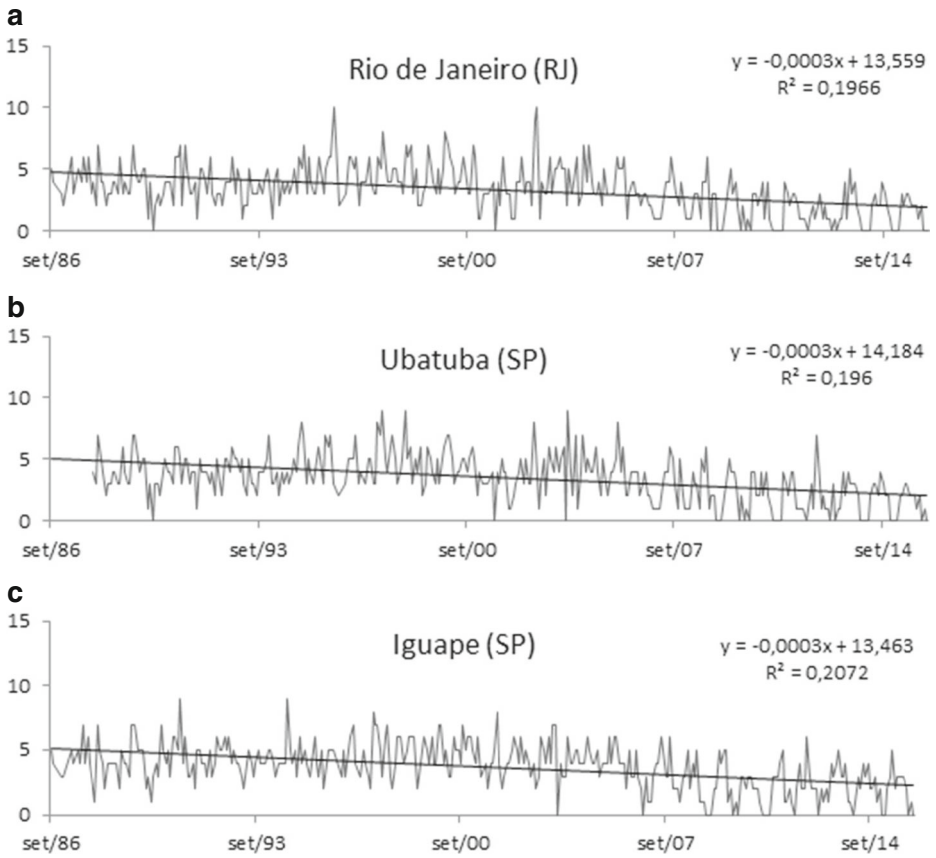

Fig. 4 Monthly history of the occurrence of days with cold fronts in the coastal cities of **a** Rio de Janeiro, **b** Ubatuba and **c** Iguape in the period of September 1986 to April 2016. Source: *Bulletin of Monitoring and Climate Analysis* (Climanalise) published by CPTEC/INPE

such as Bangladesh, where fishers had to relocate their houses several times due to rising sea levels and other climate-related factors (Rahman and Schmidlin 2014).

There is no evidence in the literature to support the perception of fishers that the sea level is decreasing. The perception in Itaipu is that there are currently greater stretches of sand than in the past. This perception seems to be related to the local sediment dynamics and not to sea level change. In the 1970s, a channel was built, and this permanently connected the Itaipu lagoon with the sea, which may have changed the coastal dynamics of the region and increased the stretches of sand on the beach, which is a hypothesis that needs to be investigated by future work. In Boqueirão Sul, fishers perceived a decrease in the maximum limit that the sea reaches during storms. This perception may be related to a decrease in the intensity of the storm surge, and this hypothesis is discussed in the next topic.

The sea level is projected to rise by up to 98 cm by the end of the century (Church et al. 2013), and the low number of fishers that perceive the phenomenon draws attention to the need for a discussion on the causes and projected consequences of sea level rise. Rising sea levels will have consequences other than erosion (e.g., saltwater intrusion, increased flooding and decline in mangroves) that will compromise the ecological functions of coastal areas and affect

fish production (Nicholls and Cazenave 2010). Fishers need to be aware of the risks and be included in the adaptation plan for coastal zones, as participation by fishers has the potential to minimize conflicts and reduce costs during the adaptation process (Shelton 2014).

4.2 Rainfall and drought-flood events

The perceptions of fishers about rainfall reduction can be explained by recent scientific observations that showed that São Paulo state has been suffering from a rainfall deficit since the late 1990s (Coelho et al. 2015). The most recent summers in southeastern Brazil have suffered from exceptional rainfall deficits when compared to other summers since 1961. The reduction in rainfall can also be evidenced by a decrease in the frequency of cold fronts in the area, as cold fronts influence the intensity and distribution of rainfall throughout South America (Cavalcanti et al. 2009).

The reduction in rainfall is one of the reasons for the perception of fishers of increased drought events. The shortage of water is of great concern to those communities that are not supplied by the public system (Ilha do Araújo, Bonete, Boqueirão Sul, Mandira and Pontal de Leste). In Bonete, the concerns about water shortages are even greater because the community power supply depends on a small generator linked to the local waterfall. During drought periods, energy production is impaired, requiring the use of a diesel generator and creating additional costs to the residents. The droughts generate an additional problem for those communities that rely on crops for income and food supply, as droughts generate additional costs associated with additional planting.

The fishers in the communities located in the CIEC (Boqueirão Sul, Mandira and Pontal de Leste) perceived that the droughts also affect the fishing industry. They perceived that during the long periods without rain, the catches decrease as the water becomes clearer. Fishers are not sure why the droughts affect fishing, but it may be related to changes in salinity and the nutrient supply, which affect the species distribution (Passos et al. 2013). A recent study conducted in the CIEC showed that the abundance of fish increased in the southern region of the estuary during the rainy season (Contente 2013), supporting the perception of the fishers that drought negatively affects catches.

Scientific observations have shown that during the rainy season, intense precipitation is becoming concentrated in only a few days (Dufek and Ambrizzi 2007). These situations make flood events more frequent and intensify their impacts in areas that are already often flooded. This is the case in Bonete, where floods are common but do not have a direct impact on the fishers because their houses were built with the knowledge of the natural flood areas. However, the expected concentration of rainfall and municipal interest in urbanizing the community may increase the scale of floods and have an impact on the residents. In addition, the urbanization of the area will encourage real estate development in a traditional community that is already lacking in infrastructure and depends upon nature to maintain its livelihood.

The existing literature on the perceptions of traditional communities on flood and drought events in the Amazon shows that local people have a strong set of observations and practices that allow them to withstand the challenges during years of 'normal' variability, providing the social resilience required to cope with such events (Maru et al. 2014). However, the recent extreme events have taken them outside the range of conditions that can be handled by these practices (Pinho et al. 2015); thus, the resilience of the social system is diminished, and vulnerabilities are exacerbated. Similar results may be occurring with the SBB fishers, were

climate change is reducing the resilience of the social system and limiting their ability to cope and adapt to the new scenarios.

4.3 Wind patterns

The small-scale fishers in Brazil are known to have good traditional knowledge of the natural cycles. It has been common for fishers to be guided by the behavior of winds, clouds and lunar cycles to perform their daily fishing (Diegues 2006), but currently, they find difficulty in using this traditional technique, mainly due to the changes in the known wind patterns. An example given by fishers is that there is currently no longer an east wind, which is regarded as a wind for good weather and good fishing (Bezerra et al. 2012).

The perception of wind decrease seems to be due to the decrease in the number of windstorms, which are becoming sporadic events. Moreover, the perception that the wind has increased seems to be related to the increase in the power of the windstorms. Most of the impacts associated with large storms are related to windstorms, including roof damage, falling trees, loss of fishing gear and shipwrecks. Shipwrecks often occur in the SBB region, and in most cases, the shipwrecks involve small vessels used in coastal fisheries. Fishers suggest that the causes of the shipwrecks are windstorms and strong waves. A recent study showed that strong wind was the main cause of the shipwrecks recorded along the Brazilian coast (Fuentes et al. 2013).

Hurricane Catarina over the western South Atlantic Ocean in 2004 marked the first hurricane recorded in the South Atlantic basin (McTaggart-Cowan et al. 2006). Catarina caused deaths and millions of dollars of damage to the South Brazilian coast. The observed and predicted trends in climate change scenarios suggest that similar conditions could occur and increase the probability of more tropical cyclones in the region (Pezza and Simmonds 2005). These results suggest that extreme windstorm events may become more frequent and can cause major damage to the coastal populations.

4.4 Coastal currents

The fishers from only one community perceived changes in the ocean current, noting that it is weaker than in the past. The perception is related to the erosion debris from the mouth of the CIEC that is ending up on the beach and hindering fishing activities. When the outflow is strong, the debris goes offshore and does not reach the beach. The perception of the fishers seems not to be related to ocean currents, but to changes in the estuary outflows. There was no evidence of changes in the estuary outflows, but the frequent drought events in the region (Coelho et al. 2015) may suggest a decrease in the number of streams flowing into the estuary. The link between rainfall reduction and the CIEC outflow is a new hypothesis that should be further investigated and related to the perceptions of the fishers.

4.5 Is the sea calmer?

Fishers perceived that the sea is currently calmer than it was in the past. The perception is that the storms are weaker, both in duration and intensity. Storm durations are related to the number of days without fish because of a storm, which was approximately 15–30 days in the past, whereas this period does not currently exceed 3 days. The perception of storm intensity is based on the area flooded by the storm surge, which is lower than in the past. This situation

seems to be seen positively, as it allows for more frequent fishing, as the daily lives of the fishers are tuned to the weather and ocean conditions (Grant and Berkes 2007).

One way to investigate if the sea is calmer is to evaluate whether the frequency of storms has decreased. The only ocean scientific observation found was one evidencing an increase in the frequency of storm surge events over the last few decades in the city of Santos (Alfredini et al. 2014), which is in some disagreement with the perceptions of the fishers. The decrease in the number of cold fronts could mean a reduction in the number of storm surges and thus be one of the factors that led to the perception by the fishers that the sea is calmer. This hypothesis needs to be tested, as the decrease in storm surges is contrary to what is expected by climate change scenarios (von Storch 2014). The understanding of the storm surge behavior is necessary for proper adaptation planning in the coastal areas and improvement of the projection of future events.

4.6 Air and ocean temperature

An increase in air temperature was perceived in all surveyed communities, and it was one of the factors drew the most attention from the fishers. Scientific observations of the global average temperature show a warming of 0.85 °C over the period from 1880 to 2012 (Hartmann et al. 2013). In Brazil, temperatures have increased by 0.75 °C over the past 50 years (Marengo et al. 2009). The models indicate rising temperatures as well as a reduction in the frequency of frost due to an increase in the minimum temperature in the SBB (Chou et al. 2014). The perception of the fishers of temperature increases is based on the lack of cold days and frost, corroborating the findings in Chou et al. (2014).

Global warming is expected to increase the vertical stratification of the ocean, creating barriers to nutrient mixing between layers (Roy et al. 2011). Generally, an increase in stratification tends to slow ocean carbon uptake, reduce oxygen levels and decrease the supply of nutrients to the surface, reducing fish sizes and potential yields of fisheries (Gattuso et al. 2015). Fishers perceived that catches decreased when the water column was stratified, and the projected increase of this process may be expected to reduce the fishing yields in the area.

In South Brazil, the SST increased by 0.53 °C from 1982 to 2006 (Belkin 2009), and the region is one of the ocean warming hotspots (Hobday and Pecl 2014). According to fishers, the warm water is beneficial as it improves most of the catches and seafood production. Postuma and Gasalla (2010) confirmed the perceptions of fishers and found that squid fishing in the SBB is better in calm and warm water, but evidence related to other species was not found; however, water that is too warm becomes detrimental to marine farming production. In the Enseada community, for example, the warmer waters killed off the *Perna perna* production in the summer of 2010–2011. The shellfish producers from Cocanha beach along the São Paulo coastline also perceived that warm water is a major threat to their activities (Seixas et al. 2014). In the case of oyster production, the traditional management of *Crassostrea brasiliana* has allowed for the sustainable management of the resource in the Mandira community (Machado et al. 2015), but according to fishers, the production will be threatened by increased water temperatures, especially when added to rising atmospheric temperatures and long periods without rain. The optimal temperature to farm *P. perna* ranges between 22 and 26 °C, and after that, the species begins to undergo physiological alterations (Resgalla et al. 2007). The best growth conditions for *C. brasiliana* occur at stable temperature and salinity conditions (Pereira et al. 2001), suggesting that extreme events such as drought and high temperatures can threaten the species. Only Itaipu fishers see the summer cold water as beneficial to fishing, probably

due to the proximity of the community to the Cabo Frio upwelling, which increases the local productivity (Coelho-Souza et al. 2012).

The shifts in the distribution of marine species have been related to ocean warming with greater changes in distribution being evidenced (Cheung et al. 2010). A shift in species distribution due to climate change was not perceived by the surveyed fishers. The present concern of the fishers over the ocean temperature is related to a loss of yield and the fact that fish spoils more easily; however, the changes in the species distribution and catch composition need further investigation as this was not the focus of the paper. Moreover, distribution shifts could be an additional concern of the small-scale fishers in Brazil that was not detected in this study.

4.7 Applicability of perceptions by fishers

Communities that depend on small-scale fishing activities are inherently exposed to climate variability and uncertainty (Allison and Ellis 2001). The understandings of the effect of climate change on the livelihoods of fishers and fisher-environment relationships are of major importance to solve fishing conflicts that occur because of the climate and to ensure the future livelihoods of the communities (Hobday et al. 2015).

Traditional populations have a considerable ability to monitor variability and cope with this through adaptive cultural responses (Gasalla and Diegues 2011). Local perceptions of climate change, as well as the associated adaptations made by the local populations, are fundamental for designing comprehensive and inclusive mitigation and adaptation plans both locally and nationally (Aswani et al. 2015). In this context, understanding how climate change is understood by fishers, as presented here, is vital to the planning of an inclusive adaptation process (Nursey-Bray et al. 2012).

Climate-related changes are already impacting the livelihoods of people, particularly those in developing countries that are highly dependent on marine-related activities (Gattuso et al. 2015). That is the case in the SBB fishing communities, where some of the impacts to their livelihoods can be positive such as calmer seas and the warmer ocean. As proposed by the ethno-oceanographic framework, these perceptions needed to be investigated in depth in future studies. However, our findings indicate that the perceptions of fishers present themselves as crucial and complementary information sources for the development of local/regional adaptation strategies, bringing a distinct and relevant point of view from the marine dependent communities to the decision makers. Therefore, the perceptions of fishers presented in this study have the potential to improve the description and interpretation of changes observed in recent decades, the associated impacts on livelihoods and coastal ecosystems and support the development of local adaptive strategies to climate change.

5 Conclusion

Our findings demonstrate that fishers have perceived climate and ocean changes such as rainfall reduction, sea agitation, increased drought events, increased air and ocean temperatures and changes in wind patterns and the shoreline. The perceived changes have positive and negative impacts on the yields and livelihoods of fishers. New hypotheses were raised with respect to sea level, coastal currents and sea condition. These results reinforce the importance of fisher knowledge to identify peculiarities and local features that have not yet been detected by regional and global models, such as changes in cold fronts related to ocean conditions.

Indeed, fishers proved to be an important social capital in climate and ocean monitoring, and the approach of this research illustrated how natural and social science research can be integrated and used by both policymakers and the broader society.

Acknowledgements We thank CNPq for the scholarship, and the GULLS project (Belmont Forum research initiative) for the opportunity to interact and collaborate with international experts. Sincere gratitude to all fishers who kindly collaborated with the study.

Funding Information Thanks are given to FAPESP for funding the research.

References

Alfredini P, Arasaki E, Pezzoli A et al (2014) Exposure of Santos Harbor metropolitan area (Brazil) to wave and storm surge climate changes. Water Qual Expo Health 6:73–88

Allison EH, Bassett HR (2015) Climate change in the oceans: human impacts and responses. Science 350:778–782

Allison EH, Ellis F (2001) The livelihoods approach and management of small-scale fisheries. Mar Policy 25(5): 377–388

Allison EH, Perry AL, Badjeck MC et al (2009) Vulnerability of national economies to the impacts of climate change on fisheries. Fish and Fisheries 10:173-196.

Andrachuk M, Armitage D (2015) Understanding social-ecological change and transformation through community perceptions of system identity. Ecol Soc 20(4):26

Angulo RJ, Souza MC, Muller ME (2009) Forecast and consequences of a new inlet opening at Mar do Ararapira, southern Brazil. Quater Environ Geosci 01(2):67–75

Aswani S, Vaccaro I, Abernethy K et al (2015) Can perceptions of environmental and climate change in island communities assist in adaptation planning locally? Environ Manag 56(6):1487–1501

Belkin IM (2009) Rapid warming of large marine ecosystems. Prog Oceanogr 81:207–213

Bell JD, Cheung W, De Silva S et al (2016) Impacts and effects of ocean warming on the contribution of fisheries and aquaculture to food security. In: Laffoley D, Baxter JM (ed) Explaining ocean warming: causes, scale, effects and consequences. IUCN, Gland, Switzerland, pp 409–435

Berkes F, Berkes MK, Fast H (2007) Collaborative integrated management in Canada's north: the role of local and traditional knowledge and community-based monitoring. Coast Manag 35:143–162

Bezerra DMM, Nascimento DM, Ferreira EN et al (2012) Influence of tides and winds on fishing techniques and strategies in the Mamanguape River estuary, Paraíba state, NE Brazil. Ann Acad Braz Sci 84(3):775–787

Cavalcanti IFA, Ferreira NJ, Silva MGA, Dias MAF (2009) Tempo e Clima no Brasil. Oficina de textos, São Paulo, Brazil

Cheung WWL, Lam VWY, Sarmiento JL et al (2010) Large-scale redistribution of maximum fisheries catch in the global ocean under climate change. Glob Change Biol 16(1):24–35

Chou SC, Lyra A, Mourão C et al (2014) Assessment of climate change over South America under RCP 4.5 and 8.5 downscaling scenarios. Am J Climate Change 3:512–525

Church JA, Clark PU, Cazenave A et al (2013) Sea level change. In: Stocker TF, Qin D, Plattner G-K et al (eds) Climate change 2013: the physical science basis. Cambridge University Press, Cambridge

Climanálise (1986–2016) Boletim de monitoramento e análise climática. CPTEC/INPE. http://climanalise.cptec.inpe.br/~rclimanl/boletim/. Accessed 14 Oct 2017

Coelho CAS, Cardoso DHF, Firpo MAF (2015) Precipitation diagnostics of an exceptionally dry event in São Paulo, Brazil. Theor Appl Climatol 1:16

Coelho-Souza SA, López MS, Guimaraes JRD et al (2012) Biophysical interactions in the Cabo Frio upwelling system, southeastern Brazil. Braz J Oceanogr 60:353–365

Contente RF (2013) Padrões ecológicos locais e multidecadais da ictiofauna do estuário Cananéia-Iguape. PhD Thesis, University of São Paulo, Brazil

Davidson-Hunt IJ, Berkes F (2003) Nature and society through the lens of resilience: toward a human-in-ecosystem perspective. In: Berkes F, Colding J, Folke C (eds) Navigating social-ecological systems: building resilience for complexity and change. Cambridge Press, Cambridge, pp 53–82

Diegues AC (2006) Artisanal fisheries in Brazil. Samudra Monograph, ICSF, Rome

Dufek AS, Ambrizzi T (2007) Precipitation variability in Sao Paulo state, Brazil. Theor Appl Climatol 1:1–12

Ford JD, Smit B, Wandel J, MacDonald J (2006) Vulnerability to climate change in Igloolik, Nunavut: what we can learn from the past and present. Polar Record 42(221):127-138.

Fuentes EV, Bitencourt DP, Fuentes MV (2013) Análise da velocidade do vento e altura de onda em incidentes de naufrágio na costa brasileira entre os estados do Sergipe e do Rio Grande do Sul. Rev Bras Meteorol 28(3): 257–266

Gasalla MA, Diegues ACS (2011) People's seas: "ethno-oceanography" as an interdisciplinary means to approach marine ecosystem change. In: Ommer R, Perry I, Cochrane KL, Cury P (eds) World fisheries: a social-ecological analysis. Wiley-Blackwell, Oxford, pp 120–136

Gattuso J-P, Magnan A, Billé R et al (2015) Contrasting futures for ocean and society from different anthropogenic CO_2 emissions scenarios. Science 349:aac4722

Grant S, Berkes F (2007) Fisher knowledge as expert system: a case from the longline fishery of Grenada, the eastern Caribbean. Fish Res 84:162–170

Harari J, França CAS, Camargo R (2013) Long-term variability of tidal and mean sea level components on the Brazilian coast. Braz J Geophys 31:49–52

Hartmann DL, Klein TAMG, Rusticucci M et al (2013) Observations: atmosphere and surface. In: Stocker TF, Qin D, Plattner G-K et al (eds) Climate change 2013: the physical science basis. Cambridge University Press, Cambridge

Hobday AJ, Pecl GT (2014) Identification of global marine hotspots: sentinels for change and vanguards for adaptation action. Rev Fish Biol Fisher 24:415–425

Hobday AJ, Bell JD, Cook TR et al (2015) Reconciling conflicts in pelagic fisheries under climate change. Deep-Sea Res II 113:291–300

Hobday AJ, Cochrane K, Downey-Breedt N et al (2016) Planning adaptation to climate change in fast-warming marine regions with seafood-dependent coastal communities. Rev Fish Biol Fisher 8:177–214

Huntington HP (2000) Using traditional ecological knowledge in science: methods and applications. Ecol Appl 10:1270–1274

Jahan I, Ahsan D, Farque MH (2015) Fishers' local knowledge on impact of climate change and anthropogenic interferences on Hilsa fishery in South Asia: evidence from Bangladesh. Environ Dev Sustain 19(2):461–478

Machado IC, Fagundes L, Henriques MB (2015) Multidimensional assessment of sustainability extractivism of mangrove oyster *Crassostrea* spp. in the estuary of Cananéia, São Paulo, Brazil. Braz J Biol 75:670–678

Mahiques MM, Burone L, Figueira RCL et al (2009) Anthropogenic influences in a lagoonal environment: a multiproxy approach at the Valo Grande mouth, Cananéia-Iguape system. Braz J Oceanogr 57:325–337

Marengo JA, Jones R, Alves LM, Valverde MC (2009) Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate modeling system. Int J Climatol 29:2241–2255

Maru YT, Smith MS, Sparrow A et al (2014) A linked vulnerability and resilience framework for adaptation pathways in remote disadvantaged communities. Glob Environ Chang 28:337–350

McTaggart-Cowan R, Bosart LF, Davis CA et al (2006) Analyses of Hurricane Catarina. Mon Weather Rev 134: 3029–3053

Nicholls RJ, Cazenave A (2010) Sea-level rise and its impact on coastal zones. Science 328:1517–1520

Nursey-Bray M, Pecl GT, Frusher S et al (2012) Communicating climate change: climate change risk perception and rock lobster fishers, Tasmania. Mar Policy 36:753–759

Passos AC, Contente RF, Abbatepaulo FV et al (2013) Analysis of fish assemblages in sectors along a salinity gradient based on species, families and functional groups. Braz J Oceanogr 61(4):251–264

Pereira OM, Machado IC, Henriques MB, Yamanaka N (2001) Crescimento da ostra *Crassostrea brasiliana* semeada sobre tabuleiro em diferentes densidades na região estuarino- lagunar de Cananéia-SP (25°S, 48°W). B Inst Pesca 27(2):163–174

Pezza AB, Simmonds I (2005) The first South Atlantic hurricane: unprecedented blocking, low shear and climate change. Geophys Res Lett 32L:15712

Pinho PF, Marengo JA, Smith MS (2015) Complex socio-ecological dynamics driven by extreme events in the Amazon. Reg Environ Chang 15:643–655

Postuma FA, Gasalla MA (2010) On the relationship between squid and the environment: artisanal jigging for *Loligo plei* at São Sebastião Island (248S), southeastern Brazil. ICES J Mar Sci 67:1353–1362

Rahman MK, Schmidlin TW (2014) The perception and impact of natural hazards on fishing communities of Kutubdia Island, Bangladesh. Geogr Rev 104(1):71–86

Resgalla CJ, Brasil ED, Salomao LC (2007) The effect of temperature and salinity on the physiological rates of the mussel *Perna perna* (Linnaeus 1758). Braz Arch Biol Techn 50:543–556

Roy T, Bopp L, Gehlen M et al (2011) Regional impacts of climate change and atmospheric CO2 on future ocean carbon uptake: a multimodel linear feedback analysis. J Clim 24:2300–2318

Seixas ARC, Hoeffel JLM, Renk M et al (2014) Perception of fishermen and shellfish producers on global environmental changes in the northern coast of São Paulo state, Brazil. JICZM 14(1):51–64

Shelton C (2014) Climate change adaptation in fisheries and aquaculture: compilation of initial examples. FAO Fisheries and Aquaculture Circ. 1088, FAO, Rome

Siegle E, Calliari LJ (2008) High-energy events and short-term changes in superficial beach sediments. Braz J Oceanogr 56(2):149–152

Silva C, Albernaz-Silveira R, Nogueira PS (2014) Perceptions on climate change of the traditional community Cuiaba Mirim, Pantanal wetland, Mato Grosso, Brazil. Clim Chang 127:83–92

von Storch H (2014) Storm surges: phenomena, forecasting and scenarios of change. Procedia IUTAM 10:356–362

Zhang J, Fleming J, Georicke R (2012) Fishermen's perspectives on climate variability. Mar Policy 36:466–472