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Traditional Ecological Knowledge Supports Ecosystem-Based Management in Disturbed Coastal Marine Social-Ecological Systems

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A growing number of studies suggest a participatory ecosystem approach to support decision-making toward resilience and sustainability in social-ecological systems. Social-ecological resilience (SER) principles and practices are recommended to manage natural crises. However, it is necessary to broaden our understanding of SER on human-induced disturbances driven by economic development projects. In this paper we present the social-ecological system of Araçá Bay (Brazil), a small-scale fishery community that has experienced successive disturbances due to development projects since the 1930s. There was a lack of studies about the impacts of development projects in this bay. As part of a major project that aimed to build an ecosystem-based management plan for Araçá Bay through a participatory planning process, we focused on investigating fishers' traditional ecological knowledge (TEK) to understand Araçá Bay's small-scale fisheries social-ecological system. The objectives were to: (1) investigate fishers' TEK regarding management practices and linked social mechanisms, human-induced disturbances and their consequences for the social-ecological system, ecosystem goods and services, and future threats; and (2) provide information based on TEK to the participatory planning process and analyze its contribution to Araçá Bay's ecosystem-based management plan. Combined methods were used during 3 years of intense research-action (2014–2017): in-depth ethno-oceanographic interviews with expert fishers; monitoring Araçá Bay participatory meetings; and participant observation. Genuine local practices and social mechanisms from traditional culture were recorded, as well as TEK about 57 target fish species and methods to protect habitats and natural resources. Fishers also reported ecosystem disturbances and recovery processes. TEK was codified through SWOT analysis to assist the participatory planning process. Ecosystem services and threats based on TEK were brought to the participatory process, acknowledged by the participants, and incorporated into the management plan. TEK analysis proved to be an important methodology to

provide historical environmental data regarding the impacts of development projects and support planning in disturbed ecosystems. In order to support coastal marine ecosystem-based management strategies toward SER and sustainability, researchers and practitioners should consider traditional territories in planning, recognize local practices and social mechanisms, and consider TEK on ecosystem goods and services and on historical human-induced disturbances.

Keywords: social-ecological system, social-ecological resilience, traditional ecological knowledge, coastal marine planning, ecosystem based management, Araçá Bay

INTRODUCTION

Innovative approaches suggest that adaptive and participatory management practices of common pool resources, supported by ecosystem-based management, are crucial to favor resilience and promote sustainability in social-ecological systems (Feeny et al., 1990; Berkes et al., 2003; Douvere, 2008; Gibbs, 2009; Biggs et al., 2012; Jones et al., 2013; Simonsen et al., 2015). Social-ecological systems integrate people and nature with reciprocal and interdependent feedback. To better understand the links between ecosystems and social systems, it is necessary to understand the relationship between different forms of management, considering ecosystem goods and services, the values they generate and their resilience (Foley et al., 2005; De Groot et al., 2010; Sartori and Monteiro, 2010; Moberg and Simonsen, 2014).

Social-ecological systems are likely to be exposed to disturbances such as storms, droughts, pests, and resource collapse. However, some systems seem to be more resilient than others (i.e., have the capacity to undergo disturbance and maintain their functions and controls) (Gunderson and Holling, 2002). Social-ecological resilience (SER) is, therefore, the magnitude of disturbance that can be tolerated by a social-ecological system before it moves to a different region of state space controlled by a different set of processes (Carpenter et al., 2001).

To measure the tolerated disturbance in a social-ecological system can be an uncertain task, especially when suitable data are not available. In this context, many studies recommend practices and principles based on an ecosystem approach to manage natural disturbances and build SER (Folke et al., 2003; Biggs et al., 2012; Simonsen et al., 2015). Notwithstanding, it is still necessary to broaden the understanding of SER practices and principles to overcome human-induced disturbances, such as those introduced by economic development projects such as ports, industries, mining, and energy plants.

Traditional ecological knowledge (TEK) can play a key role in providing information about natural and human-induced disturbances, and in supporting coastal marine ecosystem-based management strategies (Berkes et al., 1995; Moura and Diegues, 2009; Stori et al., 2012). TEK refers to a cumulative body of knowledge, practices, institutions, and beliefs, evolving by adaptive processes and handed down through generations by cultural transmission (tradition). TEK encompass worldviews developed and sustained by traditional communities in interaction with their biophysical environments (Gadgil et al., 1993; Berkes et al., 1995; Berkes and Folke, 1998; Berkes, 1999, 2004; Toledo, 2002; Colding et al., 2003; Gómez-Baggethun et al., 2013). TEK lies behind the adaptive capacity of many rural and indigenous communities that have historically been able to conserve biodiversity while enhancing livelihoods and adapting to disturbances (Ruiz-Mallén and Corbera, 2013).

A diversity of local management practices and linked social mechanisms based on TEK are recommended to promote the management of common-pool resources and foster SER and sustainability in a defined social-ecological system (Berkes and Folke, 1998; Folke et al., 1998, 2003; Berkes et al., 2000; Gunderson and Holling, 2002). Specifically, Folke et al. (1998) codified thirteen management practices based on TEK and four types of social mechanisms associated with those practices, which can foster SER. Such practices include, for instance, monitoring temporal or total protection of species or habitats, multiple species management, resource rotation, and social mechanisms including cross-scale institutions, taboos and regulations, rituals or ceremonies, and social and religious sanctions (Folke et al., 1998; Berkes et al., 2000).

This study examines fishers' TEK and analyzes its role in supporting ecosystem-based management strategies in an area historically disturbed by economic development projects: Araçá Bay (São Paulo State, Brazil). The data obtained were used to inform a participatory planning process developed to elaborate a management plan for the area. Specifically, the objectives were to: (1) investigate fishers' TEK regarding management practices and linked social mechanisms, human-induced disturbances and their consequences for the social-ecological system, ecosystem goods and services, and future threats; and (2) provide information based on TEK to the participatory planning process and analyze its contribution to Araçá Bay's ecosystem-based management plan.

In the following section we present the local context followed by a brief explanation about the participatory planning process carried out in Araçá Bay, and the methods conducted to assess the TEK and its application in the Araçá Bay management plan. We then report the TEK assessment and its contributions to the participatory process. The results are discussed considering the importance of TEK for participatory ecosystem-based management strategies that favor SER and

sustainability in coastal marine areas threatened by economic development projects.

MATERIALS AND METHODS

Study Area

São Paulo State has 248,220 km^2 of land area, an estimated population of 45.1 million (Instituto Brasileiro de Geografia e Estatística [IBGE], 2017). The São Paulo State gross domestic product of USD 581 billion, represents 33% of the Brazilian total (SEADE, 2017). São Paulo is a strategic state to Brazilian growth, and the development of port activities has fundamental importance to achieve this. The State has two ports, the Santos Port (the largest port of South America) and the São Sebastião Port, located in the vicinities of Araçá Bay, São Sebastião municipality in the Northern Coast of the state (**Figure 1**).

The northern coast is characterized by a high diversity of natural resources and great potential for tourism development, but is threatened by uneven land division, intense real estate speculation, overfishing, and the development of nautical and port activities (Secretaria do Meio Ambiente do Estado de São Paulo/Coordenadoria de Planejamento Ambiental [SMA/CPLA], 2012). Furthermore, in 2007, the Brazilian government announced the discovery of a large field of oil and natural gas in the Santos Basin, which could raise the oil reserves to 87 billion barrels (Magalhães and Domingues, 2014; Aloise de Seabra et al., 2015; Petrobrás, 2018). This growing activity has increased the demand for port infrastructures in the coastal zone and is threatening fragile ecosystems.

Araçá Bay is a well-defined geographic area, which contains essential ecosystem goods and services. This bay has experienced severe disturbances to its ecological state due to the many phases of port expansion and the impact of oil production, affecting traditional culture (namely *caiçara*) and tourism activities (Amaral et al., 2010, 2015; Peres et al., 2016). Despite the impacts that the port construction brought to Araçá Bay, it remains a unique environment in the São Paulo State coastal zone. It is a tide-dominated shallow mudflat area near a channel with depths up to 40 m, and presents a mix of ecosystems such

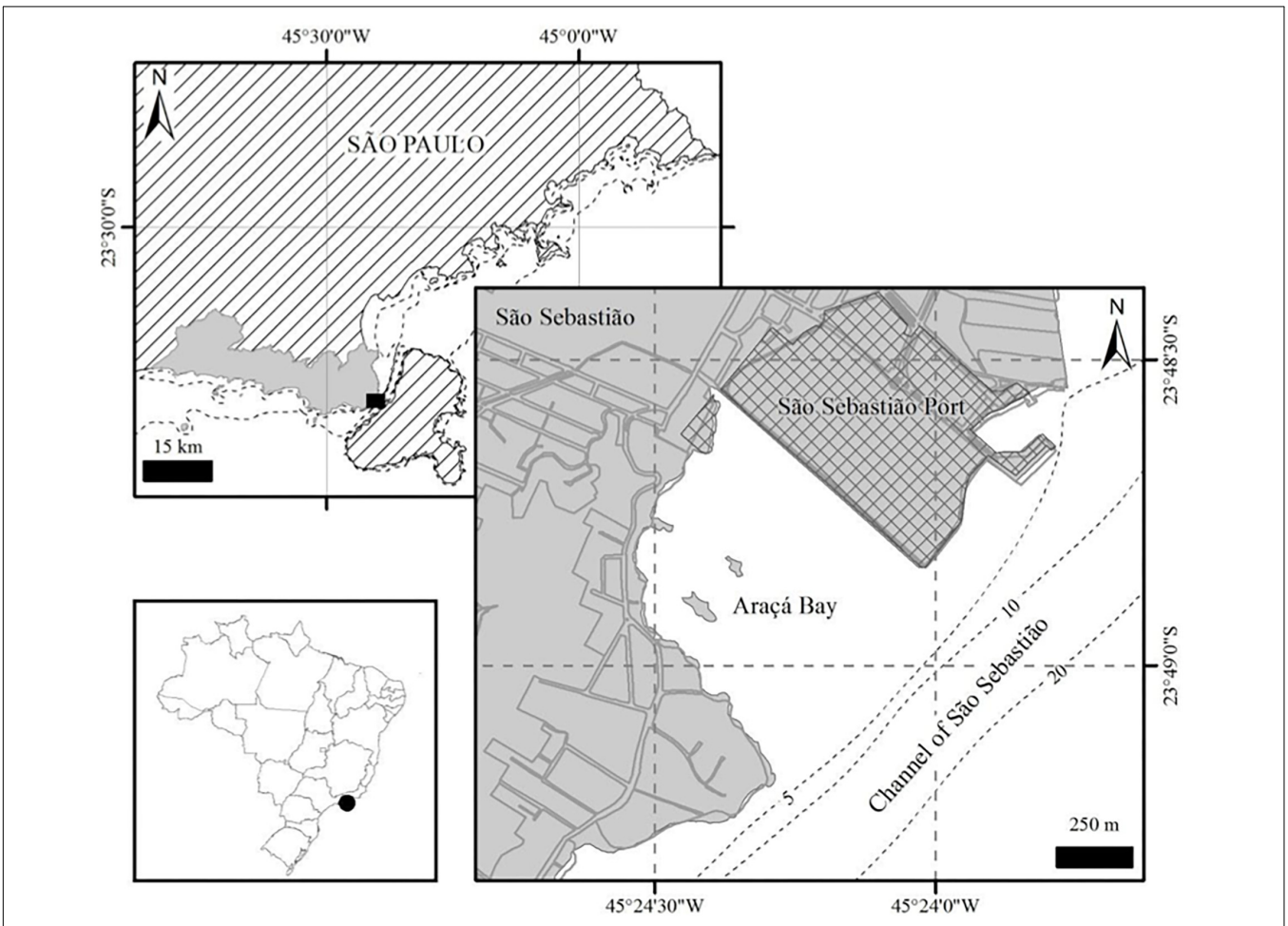

FIGURE 1 | Location of Araçá Bay on the northern coast of São Paulo State, Brazil. In the bottom left, the location of Araçá Bay in Brazil, represented by a black spot. In the **top left**, the location of São Sebastião municipality in the São Paulo State is represented in light gray, and Araçá Bay represented by a black square. Araçá Bay is represented in the **right**, and the area of the constructed port is represented by a grid (scheme kindly organized by Luciana Y. Xavier).

as mangroves, beaches, rocky shores, and islets. To date, more than 1,400 species have been described at Araçá Bay, which environments serves as an important breeding area for marine life and providing connectivity with other mangroves in the region (Amaral et al., 2015).

The São Paulo State Government created in 2008 three large marine protected areas (MPAs) along the entire coastal zone (Stori et al., 2019). At this point, Araçá Bay became encompassed by the Marine Protected Area of the Northern Coast of São Paulo (MPA-NC, State Decree N° 53.525, Governo, do Estado de São Paulo, 2008). However, the MPA-NC decree was not clear about the comprehensiveness of the Araçá Bay area within the MPA boundaries, leading to debates about whether economic developments projects could be placed there (**Figure 2**).

Araçá Bay is also governed by the Ecological-Economic Zoning of the Northern Coast (State Decree N° 62.913/2017, Governo do Estado de São Paulo, 2017), a binding instrument of the State Plan for Coastal Zone Management (State Law N° 10.019/1998, Governo do Estado de São Paulo, 1998). The zoning should consider abiotic and biotic structures, functions, as well as current and future uses and activities. Water standards, topography, protected areas, breeding areas, fishing activities, aquaculture, nautical activities and ports were the main attributes considered to classify the zones (Stori et al., 2019). This law adopted a multiple-use zone system that ranges from Z1M (the most preserved areas) to Z5M (areas impacted by urban-industrial activities).The maritime range inside Araçá Bay is classified as Z2M, while the classification varies in the intertidal range as follows: Z2M in the rocky shore; Z3M in the sandy shore and islets (in front of the urban area); and Z5M in the port area (**Figure 3**). The terrestrial range of the Ecological-Economic Zoning was classified as Z4 in the law in force from 2004 to 2017. However, in the process of zoning revision, the urban-industrial area was turned into a Z5 zone.

Araçá Bay comprises a marine area of 550,000 m^2 that was formed during the construction of São Sebastião Port (**Figures 1**, **3**). The port was built in four phases of land reclamation. The first phase, initiated in 1936 and finalized in 1955, was linked to the construction of an oil refinery by Petrobras, the major Brazilian oil company. The refinery construction was preceded by earthmoving works to gain more area, with voluminous excavations at the base of the mountain range, with the removed sediment used for port construction (Peres et al., 2016). The second phase was finished in 1973, the third phase in 1987, and the fourth phase was concluded in 1988 (Peres et al., 2016; Turra et al., 2017).

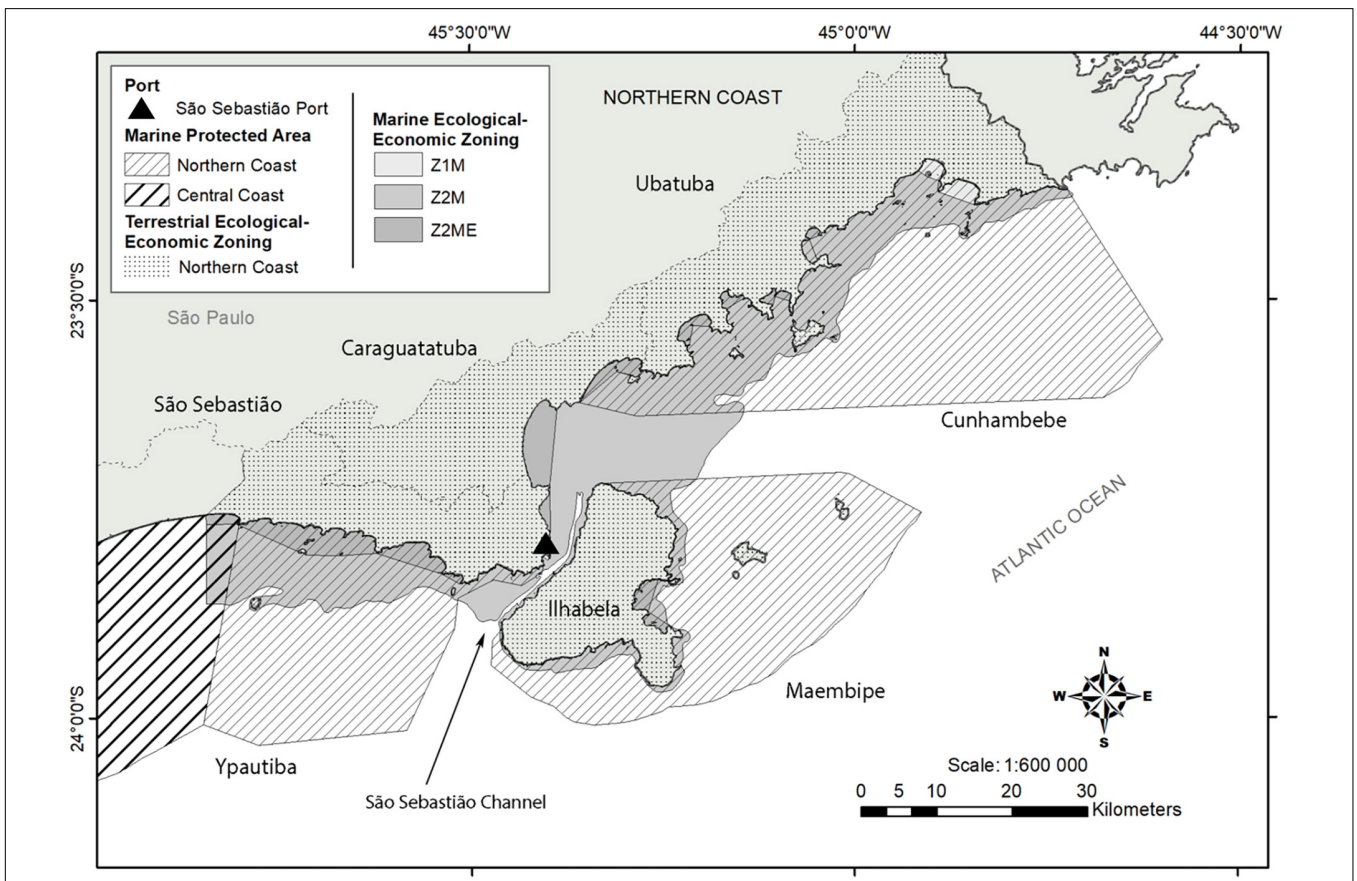

FIGURE 2 | The northern coast of the São Paulo State showing the Marine Protected Area of the Northern Coast (MPA-NC) (figure obtained from Stori et al., 2019). Araçá Bay is located along the São Sebastião channel, adjacent to the port (represented by the triangle symbol).

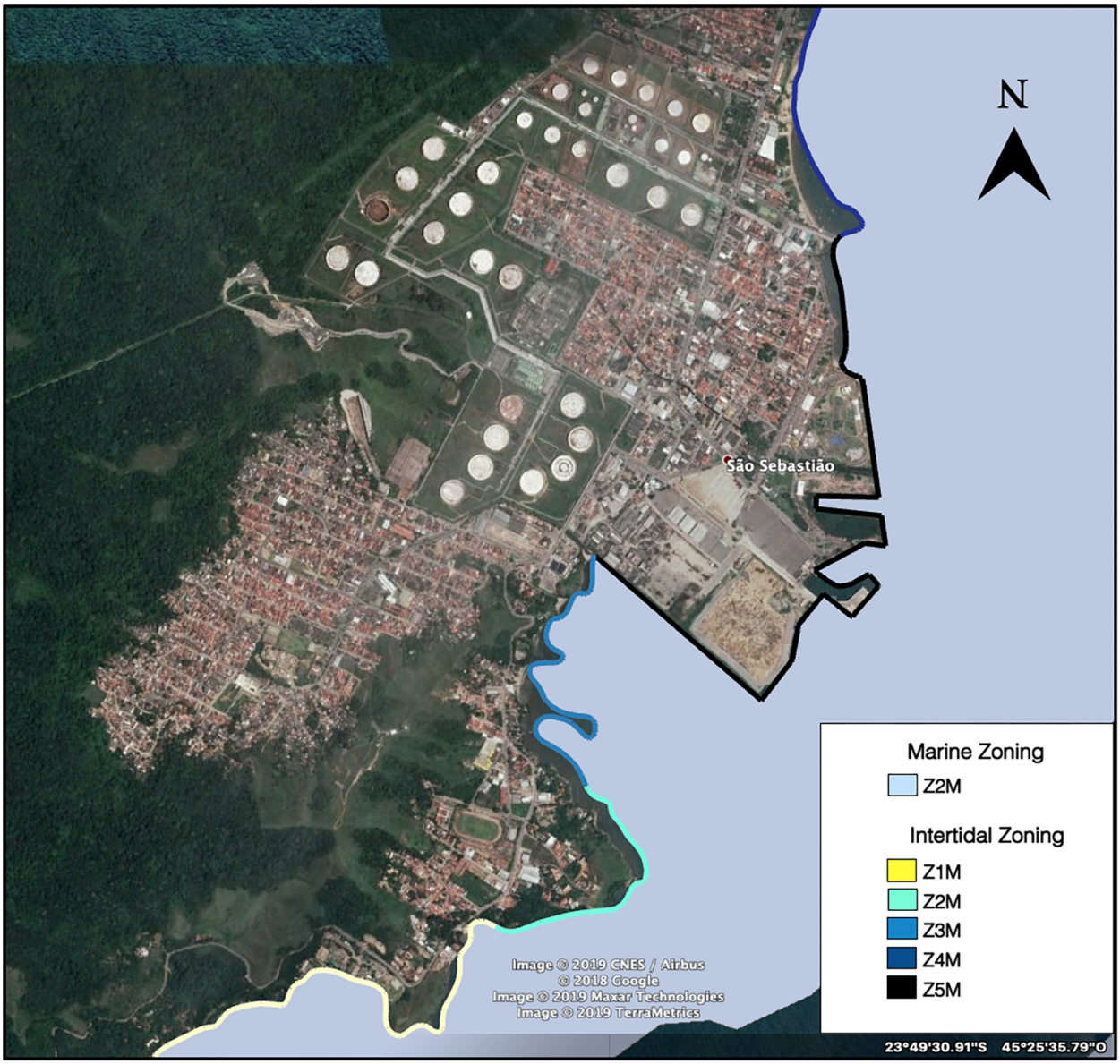

FIGURE 3 | The marine zoning of the State Plan for Coastal Zone Management in the central area of the Municipality of São Sebastião. In the marine range, Araçá Bay is classified as Z2M and, in the intertidal range, the coastline is classified in Z2M in the rocky shore, Z3M in the sandy shore and islets, and Z5M in the zone of the port. All the urban-industrial area, which includes residential occupation, the port and the Petrobrás (the round shapes are the oil storage tanks) are currently classified as Z5M (Image from Google Earth).

São Sebastião Port is a minor port in São Paulo State when compared to Santos Port, the largest port in Latin America, ranking at the 42nd global position (Lloyd's List, 2017). While Santos Port trades more than 3 million tons of products per year, São Sebastião Port trades nearly 700,000 tons (Porto de São Sebastião, 2019).

In order to increase the port's competitiveness, the São Sebastião Port Authority, a division of the Secretary of Logistics and Transports of the São Paulo State, applied in 2004 for an environmental license from the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), with the objective to expand the port land reclamation over 82% of Araçá Bay to serve as a container depot (Turra et al., 2017). This project would practically cover all the marine area left in the bay. Due to IBAMA recommendations and to public complains, the initial project (land reclamation) was replaced by the idea to build the port over a concrete slab supported by 17,000 piles, reducing the expansion area down to 34% (Turra et al., 2017). In December 2013, IBAMA approved the new project and granted the port authority a license to proceed with the port expansion. In 2016, the license was canceled due to a legal process jointly moved by Federal and State prosecutors, supported by the local community

and by the researchers involved in the participatory planning process of Araçá Bay. The judge stated that the authorities should wait for the results of the Biota-Fapesp/Araçá Project in order to further decide on the permanent elimination of part of the bay. According to the judicial decision, the port authority should start a new environmental impact assessment if the objective to expand the port persisted. More recently, the port authority announced the intention to fragment the expansion project into different stages and restart the licensing process (Porto de São Sebastião, 2019). However, the licensing process has not yet been initiated.

The Participatory Planning Process of Araçá Bay

The present research was part of the Integrated Management Group of the Biota-Fapesp/Araçá Project. Active from 2012 to 2018, the project aimed to understand in depth the functioning of Araçá Bay, with the collaboration of more than 170 researchers from 35 universities, distributed in 12 different research groups focused on subjects that comprised biology, chemistry, physics, and social sciences (Amaral et al., 2015).

In this context, the Integrated Management Group aimed to foster social learning by producing an ecosystem-based management plan for Araçá Bay, the so-called "Local Plan for Sustainable Development of Araçá Bay." The group adopted the scientific paradigm of Post-Normal Science to guide the planning (Stori et al., 2017a; Santos et al., 2018). This paradigm addresses complex situations, including uncertainties of facts, pluralities of opinions and values, and a pressing need for decision-making (Funtowicz and Ravetz, 1991, 1993, 1997). The Integrated Management Group's conceptual goal was to produce "*a science committed to the co-management of coastal marine common resources, that integrates formal and non-formal knowledge and institutions, stimulating the learning and strengthening of social networks to the social-ecological resilience for the sustainability of ecosystems goods and services*" (Stori et al., 2017a).

The core of the Integrated Management Group was composed of 13 researchers. However, the group also had the support of volunteers to organize the meetings. The researchers had common duties to plan, organize, lead the participatory activities, and evaluate the results of the participatory meetings (detailed information can be found in Turra et al., 2016). Additionally, each researcher had specific research to undertake about Araçá Bay, and to relate the results to the participatory process. The researchers produced studies on public policy analysis, the challenges of social participation, social learning, and the social-ecological system analysis presented in this manuscript.

In order to achieve the common objectives of the Integrated Management Group, the researchers developed diverse strategies to stimulate social participation. Participatory meetings to develop the Local Plan for Sustainable Development of Araçá Bay, and the establishment of a formal forum within the Marine Protected Area of the Northern Coast of São Paulo (MPA-NC) were the main strategies adopted. These approaches helped to create a relationship based on mutual respect and trust between community members and scientists.

Seven participatory meetings were organized from 2014 to 2016, aimed at developing the ecosystem-based management plan. A total of 141 people from different social sectors participated in the meetings, including representatives from the Araçá Bay community (fishers and non-fishers), citizens of other parts of the municipality or of the northern coast, researchers, students, representatives from non-governmental organizations, entrepreneurs, and representatives from the municipal government, MPA-NC, and port authority (Turra et al., 2016).

A detailed examination about the challenges of social participation in Araçá Bay is being produced by Santos et al. (unpublished results) and details about the mobilization strategy is available at Santos et al. (2018). In the first meeting, participants suggested the best venues and days of the week for the next events. Additionally, at the end of the meeting, participants were asked to give opinions about the positive and negative aspects of the participatory process. The high participation of scientists and the low participation of the Araçá Bay community, and of other São Sebastião residents and public authorities, was mentioned as a negative aspect of the first meeting. In order to promote wider social participation, the participants suggested intensifying the invitations to attract more participants. However, they were not able to carry out this action alone, so the research group was responsible for developing and performing the invitation strategies, while the participants were committed to inviting family members, friends, and neighbors (Santos et al., unpublished results).

The group of researchers tried different strategies to mobilize participants to the meetings, both at the scale of northern coast, and at the scale of the Araçá Bay neighborhood. The group compiled a mailing list with more than 1,000 e-mails targeting people and institutions interested in social and environmental issues on the northern coast, as well as official invitations to public authorities (Santos et al., 2018). Regarding the mobilization of people from the neighborhood, the researchers delivered the invitations "door to door," rented a sound car to announce the meetings, and installed a canopy tent in strategic locations to give information about the project (Santos et al., 2018).

The research group also took advantage of social media communication tools (e.g., Facebook and WhatsApp) to engage the community in the process. These tools assisted in organizing the meetings and helped to share information in the network, such as environmental news and complaints about environmental offenses (e.g., mangrove deforestation, irregular marine litter disposal, sewage contamination into the bay, shipping oil spills). Press releases were produced after each meeting and sent to the mailing list to inform people about the preliminary results and invite the participants to the next meetings (Santos et al., 2018). Despite all the efforts made to mobilize the Araçá community, not all those who were invited joined the participatory meetings (Santos et al., unpublished results). Also, the presence of people from other municipalities was low due to the long distances and difficulties in reaching the meetings on time. According to Santos et al. (unpublished results), participation is an act of will and the researchers were able to mobilize only the individuals who were motivated, i.e.,

those who exhibited interest, enthusiasm, and the determination to act toward a better quality of life.

Participants could suggest improvements to the participatory process at any time. For instance, they proposed a "kids' space" to facilitate adults' attendance, and suggested activities promoting *caiçara* culture, including canoe riding, organizing the meetings on the beach, and serving *caiçara* meals for the coffee break (Santos et al., 2018). The research group engaged a group of biology and oceanography students to create environmental games, so the children could play and learn while the adults were in the meetings (Santos et al., 2018). The researchers did not refuse any of the requests. However, they were not able to arrange all the meetings on the beach (only two meetings were organized on the beach) and to provide fresh fish in the coffee break as requested by some participants. Instead, the group found a wide and sheltered place for the meetings (a municipal public space) and provided fruits, juices, and traditional cakes for the coffee break.

Regarding the methods adopted, different participatory techniques were applied to obtain participants' opinions about the importance of Araçá Bay (the ecosystem goods and services), about the current problems and future threats, and to develop future scenarios and management actions (Turra et al., 2016; Santos et al., 2018). The researchers made a great effort to consider all the opinions during the participatory process and participants acknowledged learning, hope, union, strengthen, consensus, and integration between members as positive aspects of the meetings (Santos et al., unpublished results). At the seventh meeting, people were invited to form a group of stakeholders interested in the plan's implementation. The group was named by the participants as "The Guardians of Araçá Bay," currently with 25 members.

The scientists also helped the community to promote the traditional "*caiçara* canoe regatta." The regatta is a celebration promoted by the community with typical indigenous canoes, aiming to raise awareness about the importance of *caiçara* culture and its maintenance. The local community has promoted nine regattas so far, and the researchers helped them to organize three canoe regatta events (2014, 2015, and 2016).

Researchers also organized meetings to introduce the local community to the Federal and State prosecutors (the Public Ministry). During these meetings, participants discussed solutions to the main problems identified in the management plan (such as irregular litter and sewage disposal) and were informed about the pace of the legal appeal process for the cancelation of the port expansion. Leaders of the community organized a protest against the port expansion named "The embrace to Araçá Bay by land and by sea," which was supported by the researchers, environmental NGOs, and by neighboring communities that would also be affected by this economic development project.

The scientists promoted an approach with the MPA-NC advisory committee, creating in 2014 a special commission named "Araçá-Working-Group," aiming to engage representatives from the fishing sector, port authority, IBAMA, scientists and the local community. The main objective of this commission was to discuss the comprehensiveness of Araçá Bay as part of the MPA-NC delineation (Xavier et al., 2018), and later, the implementation of the ecosystem-based management plan.

Another action performed by the "Guardians of Araçá Bay" was to write a petition to the Secretary of Environment of the São Paulo State requesting modifications to the new Ecological-Economic Zoning discussed in public hearings in November 2016. Aiming to harmonize with the criteria established in other bays along the northern coast, the group requested to transform the marine area of Araçá Bay (classified as Z2M) into a Z2ME zone, a classification appropriate to fragile ecological areas. The group requested to change to a Z2M the intertidal zoning around the islets and sandy beaches (classified as Z3M), in order to allow a connection with the zoning defined in the rocky shore. Also, they requested to change the zoning in the port area (classified as Z5M) into a Z3M, with the aim of adjusting the targets to a better effluent standard. Finally, the group requested that the terrestrial range would keep the Z4 classification and not be modified to a Z5 as proposed by the government. Unfortunately, the Secretary of Environment of the São Paulo State refused all the requests of the group (Stori et al., 2019), a decision which will favor the port expansion in the future.

It is important to highlight that the Integrated Management Group elaborated many publications targeting science communication to support social learning during the whole process. These publications included the management plan itself, which contained proposals to solve 12 main problems identified in the area (Turra et al., 2016), and the publication of an illustrated book of infographics to enlighten students about the ecosystem goods and services of Araçá Bay (Xavier et al., 2017).

Another important action that helped to raise awareness about the importance of Araçá Bay was the production of a social-environmental documentary named "Pulsating: a film about Araçá Bay" (Stori et al., 2017b). The 25-min film was produced to attend another community request that emerged during the participatory meetings. The film highlights the importance of cultural maintenance, reveals the conflict with the port expansion project, and presents the social movement formed to impede the port expansion. The film-documentary spotlighted the conflict in the media and assisted strengthening of the social network.

Assessing and Applying Traditional Ecological Knowledge

Ethnoecology is the science responsible for the study of TEK, and aims to provide information about species, habitats, processes, livelihoods, and local management strategies (Marques, 2001; Toledo, 2002). Ethno-oceanography, a derivation of ethnoecology, aims to investigate the adaptive mechanisms of traditional communities regarding coastal marine environments (Moura and Diegues, 2009; Stori et al., 2012). The present work carried out ethno-oceanographic research throughout an in-depth approach, based on recurrent visits to the community to gain trust during 3 years of fieldwork (2014 – 2017).

Local practices and social mechanisms were investigated among Araçá Bay fishers and brought to discussion in the participatory planning process. All interviewees were local fishermen who used Araçá Bay as their traditional fishing territory and had a close connection with the place. Therefore,

those fishermen were considered as local experts due to their broad knowledge regarding the environment and their affinity with the area.

Recent research identified 56 people fishing in Araçá Bay, but only 26 fishers lived in the Araçá Bay area and had a close relationship with this environment (Amaral et al., 2015). A snowball sampling method (Wright and Stein, 2005) was conducted to identify the fishers that were considered experts by their peers ("*Who else do you know that has good experience about fisheries in Araçá Bay?")*. The snowball sampling method identified a total of 33 fishers. Three women were mentioned among the fishers, but they were excluded from the analysis because they were experts only in collecting clams, while the purpose was to interview fishers who had knowledge over multiple species. From the 30 fishermen mentioned, 11 were not found. Another seven fishers were found but were not interviewed because they refused or rescheduled meetings more than three times. Seventeen fishers had more than two mentions. From those, fourteen were interviewed. Another four fishers were identified *in situ*, totaling 18 interviewees. The fishers were aged between 27 and 72 years at the time of the interviews (from January to July 2015). According to these numbers, we assume that the sampling was satisfactory for reaching local experts.

In-depth semi-structured interviews (Viertler, 2002) were conducted, lasting from 2 to 3 h. All interviews were audio recorded and key information was also manually written to ensure its registration. All the interviewees gave written informed consent regarding the information provided. The questionnaire (**Supplementary Material)** focused on identifying local management practices and social mechanisms, ecosystem goods and services, changes in fisheries, disturbances promoted by economic development projects and recoveries over the decades, and future threats. The interviewees' quotes are identified in the text by their initials and age. The management practices and coupled social mechanisms identified were analyzed according to Folke et al. (1998).

A technique of ethno-mapping based on participatory mapping methods (Faria and Neto, 2006; Buarque, 2008) was also developed and applied. Ethno-mapping consists of individual drawings made by each expert during their interview, with a focus on TEK on natural resource dynamics and management practices. The information was manually drawn on an A3 size sheet previously filled with the shape of Araçá Bay coastline. Fishers were asked to point out ethno-oceanographic features such as fishery spots, habitats, preferred locations used by migratory species, type of bottom, and physical and oceanographic aspects such as tides, winds, and currents (**Figure 4**). The ethno-maps were digitized for further analysis through geoprocessing software (ArcGIS). All the interviewees gave written informed consent regarding the ethno-maps produced.

Part of the information obtained from the interviews, mainly regarding ecosystem goods and services, local problems and future threats, was organized using the SWOT framework: strengths, weaknesses, opportunities, and threats (Pickton and Wright, 1998; Srivastava et al., 2005). The SWOT is an analytical conceptual model used to group positive and negative elements that affect a certain environment or location (Buarque, 2008; Cowx et al., 2010). While strengths and weaknesses represent internal elements affecting a particular environment, opportunities and threats represent the external ones (**Figure 5**). By providing a clear organization of the elements influencing the social-ecological system, the SWOT framework can be a useful tool for integrated management and decision-making (Viegas et al., 2014).

The SWOT framework was later organized in a schematic poster and brought to participatory meetings to be completed by the participants. In order to inspire this task, the participants were encouraged to think about the ecosystem goods and services Araçá Bay provides, and to reflect upon current problems and future threats. Later, polls were conducted to classify the main results about (1) ecosystem goods and services in Araçá Bay, and (2) current problems and future threats. In Section "TEK As Support for Ecosystem-Based Management" we describe this process and discuss similarities and differences between the results obtained from TEK and the results obtained from the participatory meetings.

As previously explained, the participatory meetings engaged 141 participants from various social sectors. However, only six fishers interviewed attended the meetings. Furthermore, fishers' participation was not regular: one fisher participated in six of the seven meetings, one participated in three meetings, one participated in two meetings, and three fishers participated in only one meeting. Due to the small number of fishers in the meetings and their irregular attendance, it is not possible to affirm that the fishers strongly influenced the results of the participatory process, although their opinions were undoubtedly considered and respected by the other participants.

The area of traditional uses and activities mapped by the ethno-oceanographic research was brought to the debate about the comprehensiveness of Araçá Bay in the meetings of the Araçá Working Group (associated with the governance system of the MPA-NC).

The participatory meetings of the Local Plan for Sustainable Development and the meetings of the Araçá Working Group were monitored during the entire process to analyze how the information obtained from TEK contributed to decision-making in both forums. Participant observation was also conducted in every visit to Araçá Bay, in order to verify the social mechanisms of *caiçara* culture, to observe fisheries practices and to understand the environmental dynamics. The whole process was photo and video documented and stored in an external hard drive. The most representative images can be found in the social media of the Local Plan for Sustainable Development of Araçá Bay[1].

RESULTS

Management Practices and Social Mechanisms Based on TEK

The social-ecological system of Araçá Bay is characterized by a small-scale fishing community, which has been transformed by

[1]www.facebook.com/PLDSARACA

FIGURE 4 | An example of an ethno-map drawn by one interviewee. The ethno-map was turned 180° to facilitate reading.

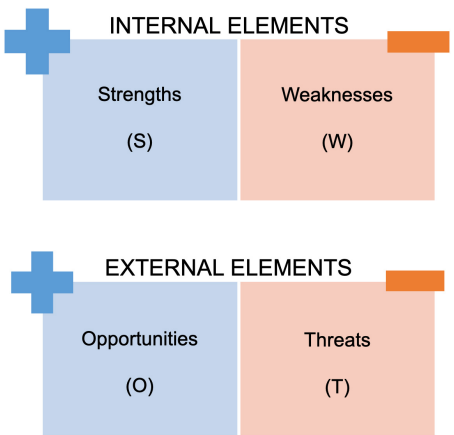

FIGURE 5 | Representation of the SWOT framework.

economic development projects associated with oil production and port expansion for almost 90 years (Peres et al., 2016). Economic growth stimulated the urban development of the region and, as a result, many fishers moved far from the shore due to the expropriation of their lands. Furthermore, the younger workforce was taken up by the oil industry and port activities. In addition to the environmental changes, economic development projects can disturb the *caiçara* culture by disconnecting the fishers from nature.

Caiçara people are a composed mix of Portuguese, Africans (ex-slaves) and indigenous people that inhabited the Southeast Brazilian coastal zone since colonial times (1500 d.c.), relying on nature for their social and material reproduction (Diegues, 1983; Begossi, 1998; Adams, 2000). It is important to highlight that the *caiçara* culture is safeguarded by the National Policy for Traditional People (PNPCT, Federal Decree N° 6.040/2007), which defines such communities as "*culturally differentiated groups and self-recognized as such, with own forms of social organization, that occupy and use the territories and the natural resources as a condition for their cultural, social, religious, ancestral and economic reproduction using knowledge, innovations, and practices generated and transmitted by tradition.*"

To verify interviewees' connections with the *caiçara* culture and its relationship with the environment, fishers were asked "What is it to be a *caiçara*?". This question revealed the social mechanisms and related aspects of *caiçara* culture, which endorsed the traditional feature of this community. All the 18 interviewees recognized themselves as *caiçara*, consistent with

the legislation statement. The fishers also linked *caiçara* culture to fisheries livelihoods, family relationships, reciprocity, and a lifestyle that "flows with the sea cycles." Folke et al. (1998) classifies these features as social mechanisms of generation, accumulation, and transmission of TEK, structure and dynamics of institutions, cultural internalization, and worldview and cultural values, as exemplified by the following statements:

> "*It is to be born and raised in a beach environment and nourish the caiçara culture. It is to fish and eat what you fished. It is to prepare the garden and picking the seasonings that you have planted.*" (S.S.O., 27).
> "*Yes, I am a native caiçara. . . Caiçara is to live in constant contact with nature, with fishing. . . I used to say that if the port constructs here, we would stay down there trapped together.*" (N.N.B., 43).

Most of the interviewees stated that they began to fish when they were between five and 10 years old (10 mentions). Three of them reported that they began before 5 years old and five interviewees reported they started fishing at 12 years of age. Fathers were mentioned as fishery mentors by 15 interviewees, but other relatives were also important to intergenerational knowledge transmission, including grandfathers (4), uncles (4), and mothers (1 mention). All the interviewees reported that they taught fisheries knowledge and skills to their children (9), friends (9), outsiders (5), and other relatives (4), but they also stated that urban development and the decrease of environmental quality were driving younger people away from fishing. An example of what Folke et al. (1998) identifies as a social mechanism for intergenerational transmission of TEK is exemplified below:

> *"Fishing is like this, my grandfather taught my father, who taught me. We learned from our ancestors that fishing in Araçá Bay should have three aspects: science, frequency, and patience. In fisheries, it happens that you go out to fish and don't catch anything. According to my knowledge, science shelters all the qualities; this is because the absence of fish may be related to the cold water or bad wind. . . Then I return on the other day and it works. Why? That's the frequency! You should go out every day. One day you catch, another day you don't catch. . . you need to 'punch the card'. . . you need patience."* (M.N.J., 72).

Regarding fishing practices, the interviewees demonstrated comprehensive TEK about 57 fishing species comprising knowledge regarding biodiversity distribution, breeding areas, and feeding areas based on habitat morphology and depth. All the 18 interviewees considered the entire bay important for fish production and, according to fishers' classifications on species habitats, the bay has seven main fishing spots: rocky shore and Araçá headland (10 mentions), islets (10 mentions), sandy bottom (9 mentions), São Sebastião channel and deep rocky reefs (6 mentions), port pier (5 mentions), small channel parallel to the beach (3 mentions) and mangrove (3 mentions).

> "*I fish on the rocky reefs near here. I mark the right places for fishing. . . I guide myself by the hills. . . I row the canoe in a direction and I crisscross the landmarks, then I find where the fishing ground is. Usually, in the rocky reefs we catch the bottom fish that eat clams. In the south direction, there are the rocky reefs and also a gravel bottom. . . that's where we catch the groupers*". (D.M.O., 62).

The ethno-maps provided information about the intensity of use and the comprehensiveness of Araçá Bay fisheries. Shallow areas of Araçá Bay (**Figure 6**), where the bay is daily exposed during the low tide, were mentioned as the locations of more intense use. This pattern was associated with habits of searching for clams, crabs and other invertebrates in shallow areas, where access is easier. The deepest areas of the bay, only accessible by boat, where most of the fish captures occur, were used with less intensity due to access difficulties. Nevertheless, during high tides, it is possible to fish by boat or canoe inside the whole area of Araçá Bay.

Fifteen interviewees affirmed that they had their own fishing boats and fourteen of them declared to share their vessels with relatives and friends when fishing. Fifteen declared that they also shared their fishing gears. Sharing is an acknowledged feature of small-scale fisheries and a recognized social mechanism of cultural value (Folke et al., 1998). All the interviewees considered the bay as an open and free access area and affirmed that the fishing spots were also shared.

All interviewees stated that there were no customary rules in Araçá Bay's fisheries. However, it was possible to identify social mechanisms of respect (seven mentions), cooperation (3), and secret (2). Yet, conflicts of use with other fishers were mentioned by four interviewees and social mechanisms of control and cultural sanctions, such as to exclude outsiders, were reported. Those social mechanisms are defined by Folke et al. (1998) as structure and dynamics of institutions and they are even more important due to the absence of a formal fishery union and/or of a communitarian association in Araçá Bay. The statements below illustrate respectively such social mechanisms:

Respect	*"If I put a fishing net and if you are not the owner, the only rule is not to touch. . . It is the respect. . . People respect, but nowadays it is not as it used to be, there are people who don't have the caiçara culture."* (D.M.O, 62).
Cooperation	*"Here there is no rivalry, on the contrary, it is camaraderie, one helps the other."* (M.N.J., 72).
Secret	*"In diving, for instance, if we catch a good fish we keep the secret about the fishing spot."* (M.A.O, 44).
Use conflicts	*"Araçá Bay is free for everyone to fish. You just should watch out for theft. . . this may happen, but they are not people from here, they are outsiders."* (I.S.F., 49).
Cultural sanctions	*"They should register the traditional fishers and exclude outsiders, allow fisheries only for the maintenance of the caiçara culture."* (E.P., 41).

The interviewees also reported practicing integrated management of multiple species and resources rotation, according to the season (summer and winter), tide, and fishing

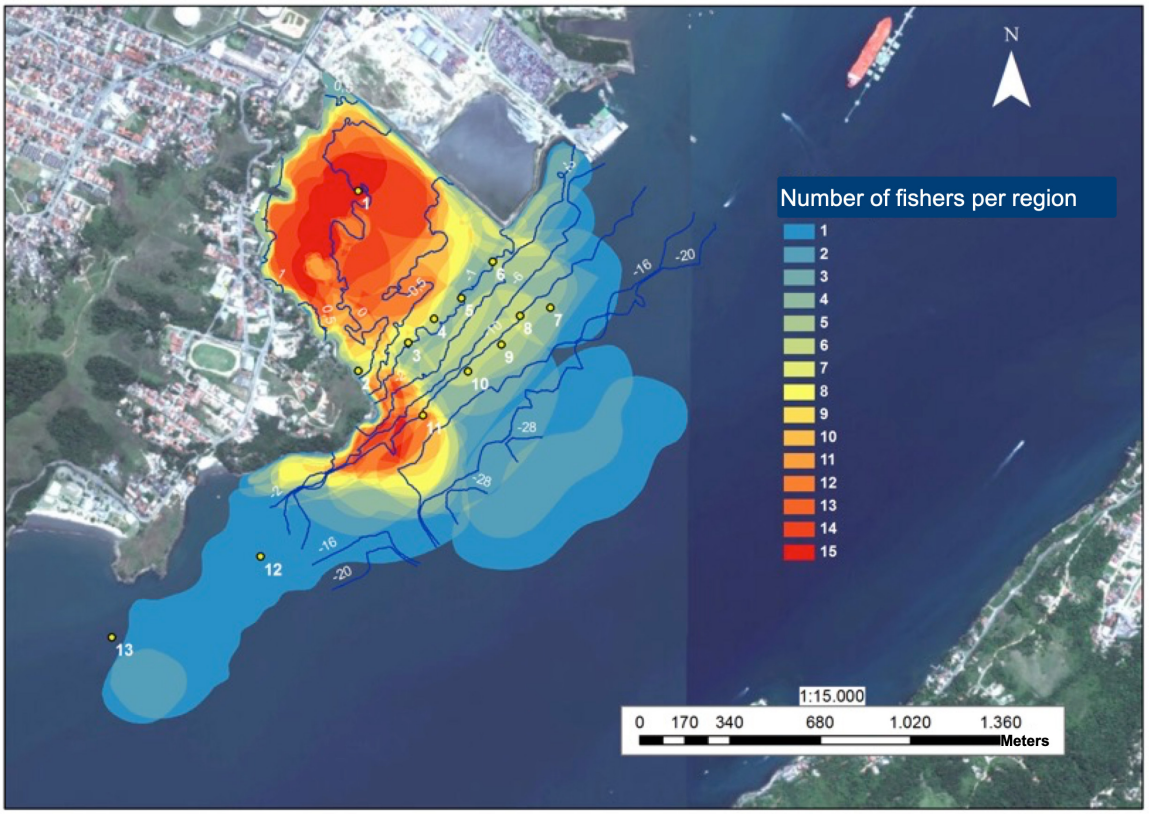

FIGURE 6 | Number of fishers per region. The blue lines correspond to depths (in meters).

spot. Such practices are recommended by Folke et al. (1998) as important strategies to build resilience in order to overcome natural disturbances. The interviewees' fishing targeted between 7 and 21 different ethno-species, with an average of 12 target species per fisher.

> *"In the summer season (mid-October to February) I fish most of the fish except the mullet that occurs in the cold season (June to July). From the edge of the channel and inside Araçá Bay, I catch the croaker and the hake with hook and line. From the Araçá Headland to the deepest part I use the fishing net to catch the 'guaiú,' sardine, 'parati'* (a little mullet), *mullet, and 'carapicu'."* (M.N.J., 72).

All 18 interviewees considered that Araçá Bay conservation is crucial, and suggested management practices to achieve it. Overall, 13 interviewees suggested restrictions on fishing. Seven fishers suggested implementing closed seasons for three ethno-species (shrimp, soft-shell crab and anchovy). Five interviewees proposed to ban fisheries in the entire Araçá Bay for recovery (3 to close the bay permanently and 2 to close it just for a period). However, eight fishers disagreed with idea of implementing no-take areas inside the bay. One fisher suggested closing only the Araçá headland (the rocky shore). Two fishers proposed excluding specific fishing techniques (trawlers and spear guns) and another two mentioned the necessity of improving fisheries enforcement. Only one fisher recommended the maintenance of total protection to an endangered group of animals, the turtle (which is already protected by law). The following statements are examples that represent the management practices identified in fishers' responses which correspond to local practices recommended to build resilience in social-ecological systems (Folke et al., 1998):

Temporal restrictions	*"In the summer there is a lot of shrimp trawling, but there is no enforcement, the closed season could last until April."* (N.N.B., 43)
Protection of vulnerable stages in the life-history of species	*"Each fisher has the awareness of not catching fish with roe and the smaller ones. When we collect the cockles, we don't catch the little ones, we let them grow. This is an awareness that came from our ancestors."* (N.N.B., 43)
Protection of specific habitats	*"If it were to create a kind of sanctuary here, I would close the marine area around 150 m from Araçá Headland until the lighthouse. Because all kinds of species live there."* (A.C., 60)
Total protection of certain species	*"I think the only rule is to release the turtle. . . we told a man to release the turtle."* (M.A.O, 44)

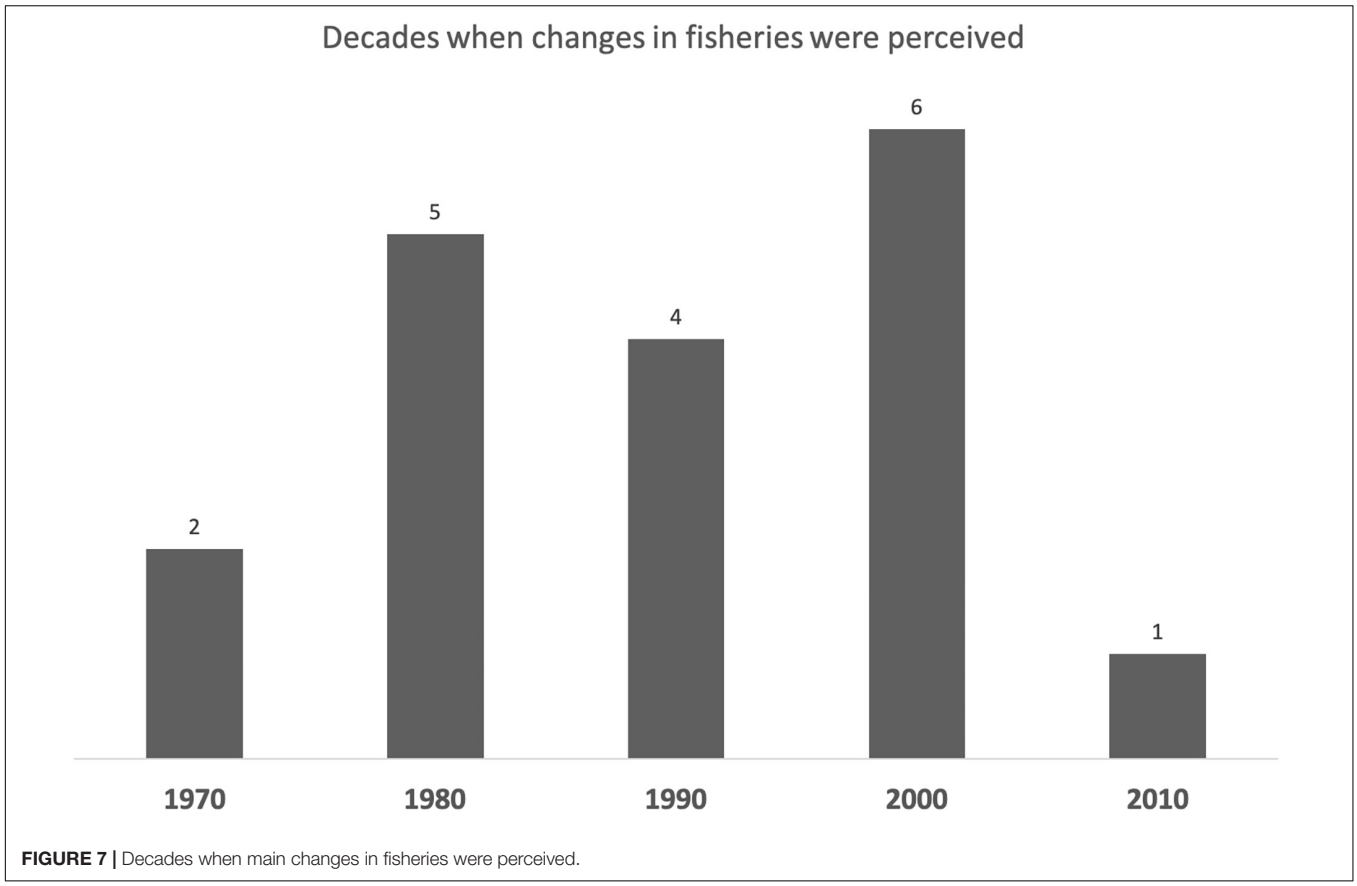

FIGURE 7 | Decades when main changes in fisheries were perceived.

Human-Induced Disturbances and Social-Ecological Consequences

All interviewees reported historical disturbances that led to the decline in fish stocks and biodiversity richness. Two fishers mentioned that they perceived major changes in fisheries since the 1970s, five fishers since the 1980s, four fishers since the 1990s, six fishers since the 2000s, and, just one interviewee observed changes since 2010 (**Figure 7**). The main reasons for fisheries decline were assigned to the port construction by land reclamation and dredging (11 mentions), port activities such as lights, noise and boat traffic (8), impacts of oil production (5), pollution by sewage and solid waste (5), irregular urban development (4), and excessive fishing outside Araçá Bay (2).

1970 *"The change here was cruel. . . there was a beach that amended with the city waterfront, it was a continuous shore, a magnificent beach! They constructed the land reclamation in such a way that they have destroyed everything. The Petrobrás destroyed a big part of the hill to build the land reclamation. They placed all the stones to make the first spit, which starts in the 'Mãe Isabel' river and ends at that place where they want to do the port expansion. The port and the Petrobrás were guilty".* (M.N.J., 72).

1980 *"About 42 years ago there was a small inlet inside the bay, where a lot of fish raised. We could fish grouper there. The Araçá was beautiful. . . We used to cross it swimming, we couldn't walk there. . . The bottom was firm sand and the water very clean. Nowadays if you walk from one island to another, you sink into the mud. Thousands of fish have died. . . What brought a lot of dirt, a lot of mud, was the dredging they did here".* (A.C., 60).

1990–2000 *"This beach had no mud, it was a sandy bottom. They dredged so the ships could dock and the mud came to halt here. Because the tide carried the mud into the bay and formed that mud bar, which should have had about 20 cm thick. So, all this area turned in to a mud about 10 years ago. Today the bay has recovered but it may happen again. Still, many residents don't take care of their sewer, people who came from other places and that occupied part of the waterfront and of the mangrove".* (I.S.F., 49).

The interviewees also reported a partial recovery in the system, which led to a new state in the ecosystem balance. They also described adaptive management practices, which corresponds to the literature recommendations toward SER (Folke et al., 1998): the monitoring of changes in the ecosystem and in resource abundance, responding to and managing pulses and surprises, and nurturing sources

of ecosystem renewal. The statements below demonstrate fishers' management practices based on TEK, and the adaptive management strategies adopted to face a new ecosystem state:

> *"The fisheries have declined a lot, several species have disappeared because of these attacks that have happened... the bass, the hake, the shrimp has diminished, the mangrove has disappeared, crabs have disappeared, some birds too, because it is the food chain... The first attack was due to the port land reclamation, a lot of mud came from the port. The second attack was the sewage pipeline and the third attack was another sewage pipeline of SABESP* (water company) *that affected everything there... Because of these changes a mud has formed, so today we fish more these mud species: 'piragica,' 'parati,' 'betara,' because they feed more in the mud. But in the past the focus was on the big fish: hake, sea bass, whiting, but they are practically extinct with these changes."* (W.S.B., 45).
>
> *"We lost in quantity, but the bay is very resistant! This mangrove is very strong... the mangrove says: I won't die! It survives even with oil spills because it has a natural washing, it has a very strong flow of water."* (E.P., 41).
>
> *"The sand changed a lot, it was firmer. It turned into mud and we couldn't walk there anymore. Now it's getting better. The fisheries changed a lot, but now it is returning."* (S.R.J., 37).
>
> *"In addition to the regattas and beach cleanings that we organize, I talk to the residents to raise environmental awareness. I also teach kayaking and soccer; my students are my great hope. I try to show them the importance of Araçá Bay. I want to register our NGO to have the means and the strength to speak on behalf of the community, to actually represent the residents and to be able to search for support."* (N.N.B., 43).

Fifteen interviewees considered that no other areas of Araçá Bay should be taken for port expansion. Three interviewees considered that the port could be expanded only toward the boundary between the current port and Araçá Bay, because this area is already impacted and "dirty" due to the port activities. However, any port expansion over this location would lead to a new dirty and impacted area.

> *"I think that if the port expansion really happens the way they're saying, will be the end! Because it will really mess up the ecosystem. They said they won't construct a land reclamation anymore, now will be on a slab. But most of the fish species don't like shade... It will affect the algae, turtles, everything, and Araçá Bay is a breeding area for many species."* (M.A.O., 44).

Gathering all the information above, nine local practices based on TEK recommended by Folke et al. (1998) were identified in Araçá Bay's small-scale fishery system: (1) monitoring change in ecosystems and in resource abundance; (2) total protection of certain species; (3) protection of vulnerable stages in the life-history of species; (4) protection of specific habitats; (5) temporal restrictions on harvest; (6) multiple species and integrated management; (7) resource rotation; (8) responding to and managing pulses and surprises; and (9) nurturing sources of ecosystem renewal. In addition, four types of social mechanisms classified by Folke et al. (1998) as important in fostering SER were identified: (1) generation, accumulation, and intergenerational transmission of TEK; (2) structure and dynamics of institutions (role of stewards or wise people, and social and cultural sanctions); (3) mechanisms for cultural internalization; and (4) worldview and cultural values such as sharing, reciprocity, and respect.

Ecosystem Goods and Services, Problems and Threats Identified in TEK

Detailed information obtained from the entire fishers' interview analysis was identified and organized through the SWOT framework (**Figure 8**). The elements identified, either positive or negative and internal or external, were grouped into four different clusters (strengths, weaknesses, opportunities, and threats). While ecosystem goods and services (e.g., fisheries, biodiversity and touristic potential) were classified as strengths and opportunities, current problems and uncertainties (e.g., oil spills, sewage pollution, and port expansion) were classified as weaknesses and threats.

When asked specifically "*What is good in Araçá Bay?*", and "*Why is Araçá Bay important?*" fishers mentioned various ecosystem goods and services, which were arranged in seven main groups: fisheries, food provision and income source (15 mentions); affinity with the place and *caiçara* culture heritage (12 mentions); breeding area and biodiversity maintenance (8 mentions); tranquility and life quality (7 mentions); nature, sea breeze and mangroves as protection from coastal erosion (7 mentions); leisure activities and tourism (7 mentions); sheltered area, good for navigation and to moor fishing boats (3 mentions).

Further, when specifically asked "*What is not good in Araçá Bay?*", fishers reported several problems that were arranged in eight main groups: solid waste pollution (9 mentions); sewage pollution (8 mentions); port operation and expansion activities (7 mentions); presence of drug users in Araçá Bay surroundings (6 mentions); oil pollution (4 mentions); dredging activities (4 mentions); urban and industrial growth (2 mentions); and absence of local government (2 mentions). The same questions were asked in the participatory meetings, and the results are presented in the next section.

TEK as Support for Ecosystem-Based Management

The information based on TEK contributed to support decision-making in two ways: in the participatory meetings of the Local Plan for Sustainable Development of Araçá Bay, and in the

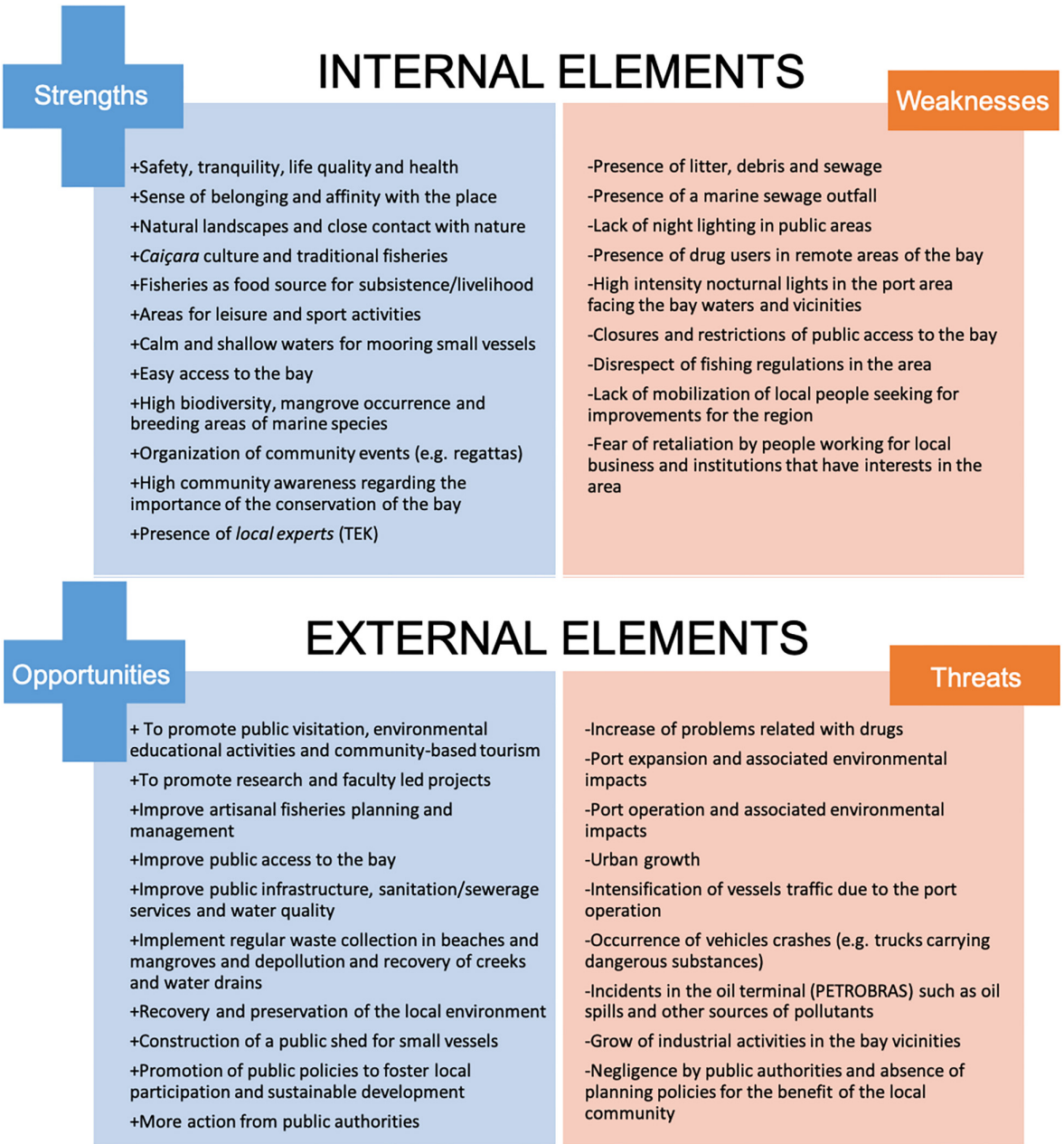

FIGURE 8 | SWOT framework detailing ecosystem goods and services, problems and future threats found in fishers' interviews.

Araçá Working Group of the Marine Protected Area of the Northern Coast (MPA-NC).

TEK as Support to the Local Plan for Sustainable Development of Araçá Bay

During the participatory meetings the participants were encouraged to identify potentialities and fragilities, considering current and future projections, by answering the following questions: "*What is good in Araçá today and for tomorrow?*"; and, "*What is not good in Araçá today and for tomorrow?*". The ecosystem goods and services identified were combined with the research results of the Biota-Araçá Project (Turra et al., 2016; Carrilho and Sinisgalli, 2018), and with the results obtained from TEK through the SWOT framework. The combination of all this information was organized in a schematic poster presented to the participants to be completed during the meetings (**Figure 9**).

In order to prioritize the ecosystem goods and services organized in the schematic poster the participants were asked to think about "*What Araçá Bay does for us?*". A total of 20 ecosystem goods and services were grouped and participants were asked to vote on the most important ones. The results were: food provision, small-scale fisheries, and source of

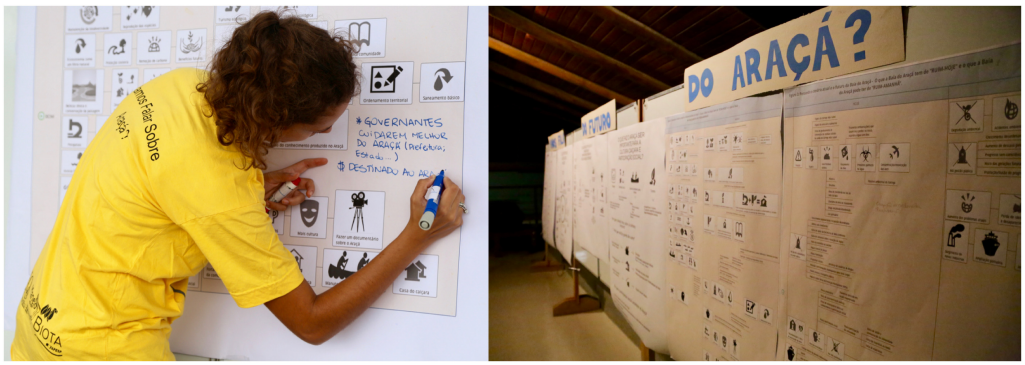

FIGURE 9 | The information obtained from SWOT was turned into icons and presented in posters to be completed during participatory meetings.

income (15 votes); education and research (14 votes); *Caiçara* culture maintenance (12 votes); social participation (11 votes); biodiversity maintenance (9 votes); supply of raw material for handcrafts (6 votes); leisure, recreation, sport and tourism (5 votes); species breeding (5 votes); future benefits (4 votes); easy access to the sea (3 votes); mangrove occurrence (3 votes); satisfaction with environmental conservation (3 votes); coastal protection (3 votes); affinity to the place (2 votes); diversity of landscapes (1 vote); scenic beauty and landscape conservation (1 vote); man-nature contact area (1 vote); effluent treatment (1 vote); and carbon storage (1 vote). The item "sheltered area for mooring boats" (previously identified in the debates) did not receive any vote, and the item "health and quality of life" was included in the list after the participatory discussion and the conclusion of poll results. It is important to highlight that food provision through small-scale fisheries, including its importance as a source of income, and linked social mechanisms of *caiçara* traditional culture were acknowledge by the participants as fundamental ecosystem goods and services in Araçá Bay.

The correspondence between the information obtained from TEK and the information obtained during the participatory meetings is demonstrated in **Figure 10**. All the information TEK provided was considered and classified by the participants in a similar order of importance to that given by the fishers. Nevertheless, distinct ecosystem goods and services were considered by the participants of the meetings: education and research; social participation; supply of raw material for handcrafts; future benefits; satisfaction with environmental conservation; coastal protection; diversity of landscapes; scenic beauty and landscape conservation; effluent treatment; and carbon storage. These results do not mean that the fishers do not recognize those ecosystem benefits, but perhaps that the questions applied in the ethno-oceanographic interviews were not sufficiently precise, or that more elucidation about the questions might have been necessary. Additionally, when analyzing the SWOT framework, it is possible to verify that other strengths and opportunities based on TEK were considered in the participatory process (such as the potential for developing tourism, health and quality of life, and sheltered area for mooring boats), because the SWOT framework was indeed totally incorporated into the schematic poster. The SWOT framework, in turn, was not able to provide an ordering of those features because it was based on the entire interviewees' responses. Only a classification based on well-defined questions could provide a rigorous method for ordering fishers' opinions. Due to this limitation, the classification was performed based on only two questions of the questionnaire ("*What is good in Araçá Bay?*", and "*Why is Araçá Bay important?*"). Nevertheless, ecosystem services linked to regulation processes and future benefits appeared to be too subtle to be identified by the fishers (such as effluent treatment, carbon storage and coastal protection). The process of social learning stimulated by the participatory meetings proved to be effective for the acknowledgment of such subtle ecosystem goods and services.

A poll regarding the current problems and future threats was also undertaken. Participants were asked to vote on the most concerning problems, considering a list of 12 main problems, which were identified and grouped in previous meetings. The 12 main problems were: sewage pollution (19 votes); the current port and Petrobrás activities (19 votes); solid waste pollution (17 votes); urban and industrial growth (16 votes); chemical pollution (15 votes); social problems associated with drug users (12 votes); inefficiency in management (5 votes); illegal fishing or overfishing (2 votes); impacts on mangroves (1 vote); current port structure (1 vote); low social control (1 vote); and infrastructure for leisure and tourism (1 vote).

Similar to the results regarding ecosystem goods and services, all the information provided by TEK was assimilated and acknowledged by the participants of the meetings (**Figure 11**). However, the order of importance was slightly different in this case. Additionally, other problems and threats were classified by the stakeholders, such as illegal fishing and overfishing, impacts on mangroves, low social control, and lack of infrastructure for leisure and tourism. The results demonstrate that fishers perceive the problems that directly affect fisheries. On the other hand, the stakeholders were stimulated to think about the causes that led to these problems, and in doing so they identified problems that affect the social-ecological system as a whole, including other economies (such as tourism) and the deep causes of environmental

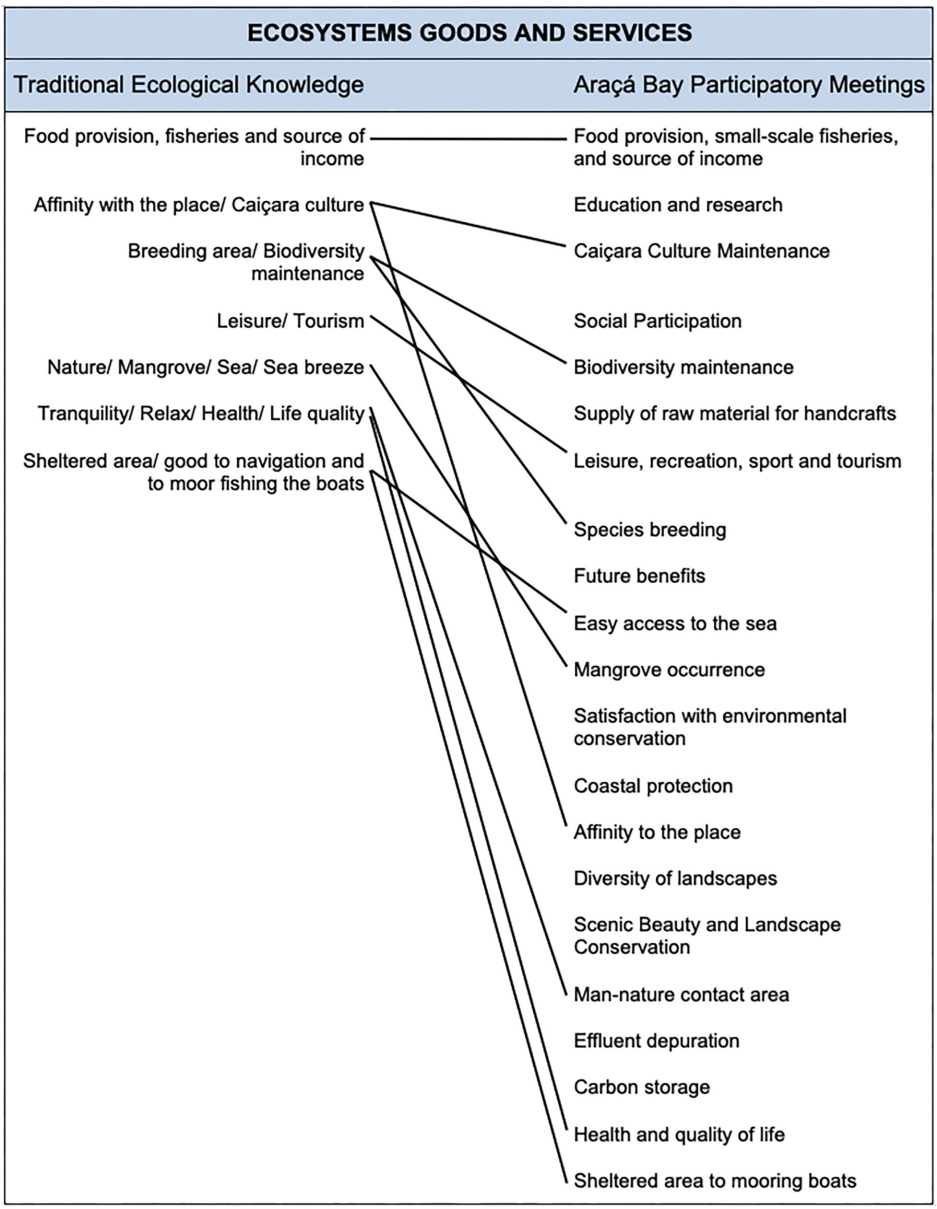

FIGURE 10 | Correspondence between the ecosystem goods and services classified by fishers and those classified by the participants.

problems (such as the low social control). Illegal fishing and overfishing were also identified as threats by the participants. However, the fishers did not consider them as main problems, although excessive fishing outside Araçá Bay was mentioned by them when questioned about historical changes in fisheries. Similar to the results regarding ecosystem goods and services, the ordering of current problems and future threats was possible only using one specific question of the questionnaire ("*What is not good in Araçá Bay?*"). Other weaknesses and threats classified by the participants can, however, also be identified in the SWOT framework, such as lack of mobilization of local people toward improvements for the region and the negligence of public authorities (which can be related to the low social control), and non-compliance with fisheries regulations.

TEK as Support to the Araçá Working Group of the Marine Protected Area of the Northern Coast (MPA-NC)

TEK was used to inform the Araçá Working Group of MPA-NC in order to discuss the comprehensiveness of Araçá Bay in MPA design. Traditional uses and activities identified from TEK were grouped with other scientific information produced by the Biota-Araçá Project (e.g., bathymetry, type of bottom, sand dispersion, marine currents, larvae dispersal, benthic species distribution, legislation), to provide information

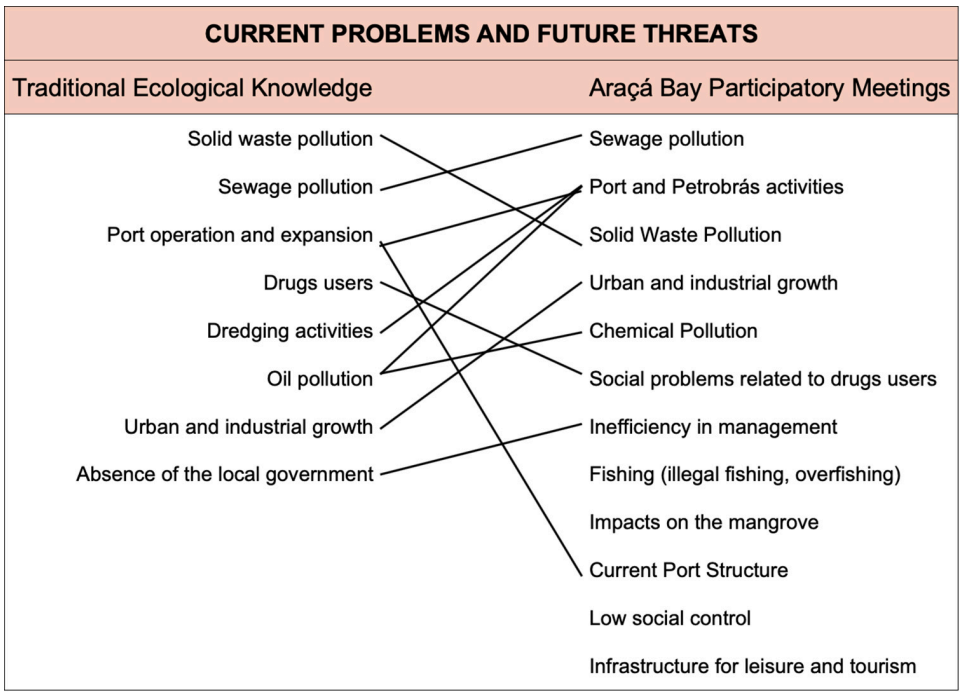

FIGURE 11 | Correspondence between the main problems and future threats classified by fishers and those classified by the participants.

about Araçá Bay and assist the decision-making process (Xavier et al., 2017).

The area of traditional uses and activities indicated by the fishers was chosen as the main criterion to define the comprehensiveness of Araçá Bay within the MPA-NC (**Figure 6**). Some fine adjustments were made to the map and the final proposal was submitted to the MPA-NC advisory committee to be discussed during the elaboration of the MPA-NC management plan (which is expected to be concluded in 2019). The comprehensiveness of Araçá Bay's small-scale fisheries territory was verified and the participatory planning process endorsed its significance as a management unit.

DISCUSSION

The Role of TEK to Inform Participatory Ecosystem-Based Management

Araçá Bay is an example of how human-induced disturbances can lead to continuous shifts in ecosystem state, affecting the whole social-ecological system. Complex adaptive ecosystems tend to have multiple stable states, or stability domains, toward which they progress and organize (Colding et al., 2003). Such shifts can occur in nature but tend to be exacerbated by human activities that simplify ecosystems and often cause loss of biological diversity and ecosystem services (Nyström et al., 2000). Hence, human-induced disturbances can shift an ecosystem to a less desirable functional state or to an irreversible one (Colding et al., 2003).

Fishers interviewed demonstrated their knowledge of past human-induced disturbance and recognized the consequences of an imminent threat to the coastal marine environment, such as the port expansion project that would shift this ecosystem to an irreversible state. Combined with the development of infrastructure projects planned for the region, such as roads and oil industry, the port expansion could intensify the disturbances in Araçá Bay by eliminating ecosystem structure and functions, impacting management practices and linked social mechanisms, and reducing social capital and the ability to adapt to environmental transformations.

The Araçá Bay social-ecological system evidenced important local practices and social mechanisms advocated by Folke et al. (1998) as essential features to provide flexibility in natural resources management, and to adapt to changes. The capacity to diversify and adapt fisheries according to resource availability, as verified in the system analyzed, is an important strategy to overcome natural disturbances and can be an advantage to face human-induced disturbances up to a tolerable level. It is likely that the high variety of environments combined with the high tidal amplitude have enabled the settlement of a high diversity of organisms adapted to these environments. Consequently, fishers have developed a vast array of fishing techniques and adjusted them to diverse environmental and oceanographic conditions. Therefore, the environmental diversity might have favored the diversity of local practices and social mechanisms found in this particular social-ecological system, and consequently, its adaptive capacity.

Management practices and social mechanisms are demonstrated to manage natural disturbances. However, these features alone were not able to constrain successive human-induced disturbances due by economic development projects in Araçá Bay, including oil production, port construction, and urban growth. In this case, the fishers were able to use their accumulated knowledge only to adapt fisheries according to these changes, not to influence these changes. The knowledge acquired regarding human-induced impacts and disturbances should be considered in further environmental licensing assessments, such as port expansion assessments, and in management plans at local and broader scales.

Some researchers have suggested that the flexibility of customary management systems has made them resilient to population growth and economic modernization. Others suggested that these systems might be effective common-pool resource-management institutions in situations of relatively low population density and subsistence economies, but could die out in response to factors such as increased population pressure, commercialization of resources and the breakdown of customary authority (Cinner and Aswani, 2007). Management practices and social mechanisms of the *caiçara* culture preserved in Araçá Bay might be powerful features to inform decision-making and help to design a sustainable future in this social-ecological system, despite the cultural erosion provoked by the urban and industrial growth.

Casimirri (2003) argued that fundamental issues about how TEK is defined are at the root of the barriers to incorporation of traditional values and knowledge into contemporary management practice. That author emphasized that there is a need to move beyond the current discourse in which TEK is merely a form of data to 're-define' TEK in resource management. The main question, according to that author, is how management systems and the TEK that informs them can form the basis of community-based, adaptive institutions of resource management. The question should not be so much "How to integrate TEK?" but 'How to integrate TEK holders into resource management?'. Where TEK holders have direct involvement in management processes through community-based, adaptive resource decision-making institutions, there is a much greater potential to meaningfully incorporate TEK into sustainable resource management (Casimirri, 2003).

When fostering a participatory planning process and striving to integrate TEK holders in this process, the researchers of the Biota-Fapesp/Araçá Project struggled to break the inertia of the community regarding the "lack of mobilization of local people toward improvements for the region," identified by TEK holders and participants. The researchers acted as facilitators to engage fishers and other stakeholders and endeavored to codify all the information obtained and set a common language, in a process known as "translation."

Processes of translation are recognized strategies to promote concertation in social networks, encouraging collective decision-making processes (Callon, 1986; Beuret, 2006; Beuret et al., 2006). The translation of the importance of ecosystem goods and services, and of the causes of current problems and future threats, was fostered by the researchers in the participatory planning process, providing bases for the Local Plan for Sustainable Development of Araçá Bay (the ecosystem-based management plan), and for the Araçá Working Group of the MPA-NC. TEK proved to be an important source of information to support decision-making in both processes, and was recognized and incorporated by the participants of these forums, helping them to achieve the desired outcomes (**Figure 12**).

Berkes et al. (2007) analyzed integrated management in the Canadian North, assessing its contribution to the advancement of knowledge and practice regarding the role of indigenous knowledge and community-based monitoring. The authors confirmed the relevance of TEK and stakeholders' participation to widen the range of knowledge in order to understand and help monitor environmental change.

Mutually beneficial outcomes in participatory research, to both indigenous/local communities and resource management agencies, have been widely documented in the marine resource management literature. However, participation might not always be of interest to target communities, and some forms of participation can actually be coercive (Shackeroff and Campbell, 2007). In advocating that researchers consider participatory engagements in conservation research, these authors encourage a critical treatment of the concept toward a true collaboration rather than superficial forms of participation. Partnerships in which all sectors gain from the participatory meetings are possible, given a situation in which potential power dynamics, ethical issues, and cultural context are explored, articulated and respected conscientiously throughout the research process. Only through an informed and conscientious approach can TEK be incorporated into conservation research in a manner beneficial to both conservation and TEK holders, achieving biological and socio-economic goals in a culturally appropriate manner, and recognizing and respecting TEK (Shackeroff and Campbell, 2007).

Further, Wiber et al. (2004) suggested that participatory research should target the needs of local communities by identifying interests among resources users, and designing and carrying out research projects to meet these needs. Their research demonstrated the effectiveness of extending participatory methods to challenge traditional scientific notions of the research process (Wiber et al., 2004).

Bélisle et al. (2018) analyzed 23 published studies regarding the integration of scientific ecological knowledge and TEK into ecological modeling and found that participatory research is a helpful tool to reach the full potential of combining both forms of knowledge. However, methodological guidelines are not completely settled yet, especially regarding participatory methods, and the most pressing challenge relies in the integration of methods and concepts from the social and natural sciences (Bélisle et al., 2018).

Ruiz-Mallén and Corbera (2013) performed a broad literature review with the aim of investigating how TEK, community-based conservation, and SER interrelate. The authors found that, in co-management initiatives, local people also benefited from cross-institutional arrangements and scientific knowledge that contributed to capacity building, knowledge generation through mutual learning, and trust building. Only by fully

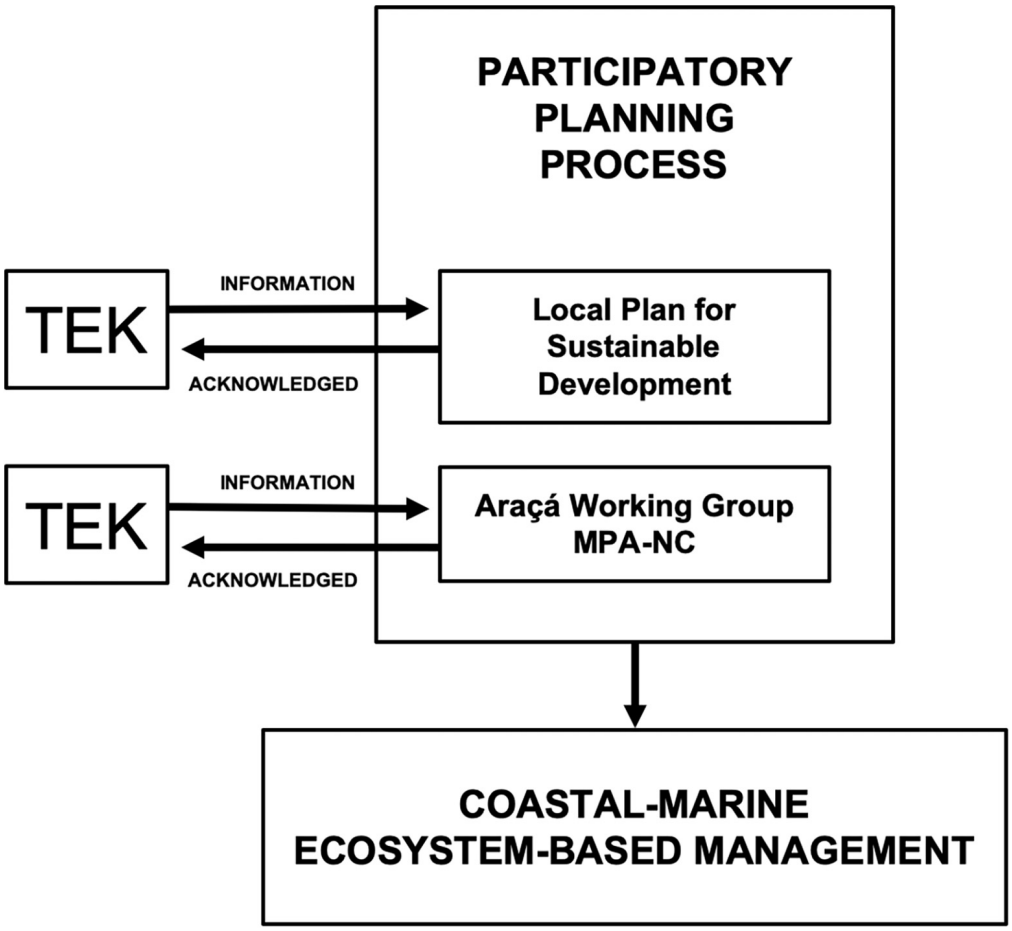

FIGURE 12 | Scheme of the application of TEK to support ecosystem-based management.

comprehending existing synergies, conflicts, and trade-offs between TEK, community-based conservation, and adaptive capacity in changing environments will it be possible to understand the complexities of social-ecological systems and guide decision making for conservation across governance scales in meaningful ways (Ruiz-Mallén and Corbera, 2013).

Combining scientific and TEK stands as a promising approach to design strategies that are both scientifically sound and attuned to local value systems and priorities (Gómez-Baggethun et al., 2013). TEK systems are increasingly acknowledged for their contribution to sustaining biodiversity and ecosystem services, as well as being important reservoirs of experiential knowledge that can provide significant insights for the design of adaptation and mitigation strategies to build SER in the face of global environmental change (Gómez-Baggethun et al., 2013).

Cinner and Aswani (2007) suggested that scientists and policy makers should encourage and strengthen institutional hybrids between customary and modern management systems. Hybrid institutions offer considerable potential for sustainable resource management by harnessing TEK, respect for traditions, scientific knowledge, and local acceptance. Hybrid management should understand and harness both scientific and local knowledge systems and mechanisms for detecting and reacting to changes in social-ecological systems. The participatory process during the establishment of hybrid strategies is critical for capturing TEK and for explaining scientific knowledge (Cinner and Aswani, 2007).

The emergent hybrid management initiated by the Biota-Fapesp/Araçá Project was successful in breaking the *status quo* of continuous human-induced disturbances in Araçá Bay, by creating a powerful resistance against the port expansion project. The port expansion and coupled economic development projects will be constant threats to this social-ecological system. Therefore, the established stakeholders' network supporting Araçá Bay conservation must keep connected and vigilant. Furthermore, governmental institutions, including the municipality, the port authority, and the Marine Protected Area, should engage with the community in discussions about the planning and management of the bay, acknowledging TEK as an important source of knowledge which, associated with scientific knowledge, can help to design a better future for this coastal marine area.

Science should provide key guidance in taking steps toward coastal marine ecosystem-based management and, by building

management from a foundation of the best available knowledge, the ecosystems and the services they provide can be managed or restored in relatively predictable ways (UNEP, 2011). Considering that, in some cases, TEK is the only source of knowledge available, investigating TEK and integrating TEK holders is highly recommended in order to develop ecosystem-based management plans in coastal marine areas. As the present research demonstrated, TEK can provide information about biological communities, ecological functions, oceanographic processes, natural resources management practices, and detailed information concerning the impacts of economic development projects on ecosystems. In this context, TEK played a key role in providing unique information to a participatory planning process aimed at coastal marine ecosystem-based management, in the absence of long-term scientific data.

CONCLUSION

This study has demonstrated the relevance of TEK in supporting a participatory planning process toward ecosystem-based management in coastal marine ecosystems. The effort of interviewing fishers contributed greatly to building the foundations of the participatory meetings. The process of translation in participatory meetings, combining TEK, scientific, and stakeholders' knowledge, was revealed as a powerful arrangement to foster social learning and favor SER in social-ecological systems.

At the beginning, Biota-Fapesp/Araçá Project researchers encountered some resistance from fishers and other stakeholders in participating in the research. Scientists found a disunited and powerless community due to the impact of successive human-induced disturbances caused by economic development projects. TEK research evidenced the lack of social organization in this place (a fact corroborated by fishers and participants of the meetings), a characteristic that undermines SER in social-ecological systems. However, throughout the project's implementation, the researchers gained the community's trust and people gradually joined the participatory meetings, culminating in the creation of a group of citizens concerned about implementing the plan and being aware of the conservation of Araçá Bay. As a result of this enthusiastic participatory planning process, the court canceled the environmental license for the port expansion, a rare event for environmental licensing in Brazil. We conclude that, in situations of weakened communities, external aid can be crucial in rebuilding the confidence to claim collective rights.

TEK analysis proved to be an important approach to provide environmental data in a human-induced disturbed ecosystem and to support planning in this coastal marine social-ecological system. There is a global need for a better understanding of SER in human-induced disturbed systems. Social-ecological research should advance the understanding of how humans interact with nature, how resilient these systems are in dealing with external and internal crises, and how to better inform decision-making toward sustainability. In order to support participatory ecosystem-based management strategies toward SER and sustainability of coastal marine social-ecological systems, researchers and practitioners should consider traditional territories in planning, recognize local management practices and linked social mechanisms, and elicit TEK on ecosystem goods and services and on the impact of human-induced disturbances.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Ethics Committee on Animal Experimentation of Oceanographic Institute of the University of São Paulo. The Ethics Committee on Animal Experimentation of Oceanographic Institute of the University of São Paulo exempts from formal ethical approval, studies employing non-invasive research methods with humans and which do not benefit from the utilization of the biodiversity genetic resources, in line with national legislation. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

FS, CP, and AT designed the research. FS and CP collected the data and performed the data analysis. CP transcribed the interviews and produced the maps. FS, CP, AT, and RP wrote the manuscript.

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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.2019.00571/full#supplementary-material

REFERENCES

Adams, C. (2000). *Caiçaras na Mata Atlântica: Pesquisa Científica Versus Planejamento e Gestão Ambiental*, 1st Edn, São Paulo: Annablume.

Aloise de Seabra, A., Khosrovyan, A., Del Valls, T. A., and Polette, M. (2015). Management of pre-salt oil royalties: wealth or poverty for brazilian coastal zones as a result? *Res. Policy* 45, 1–8. doi: 10.1016/j.resourpol.2015.03.006

Amaral, A. C. Z., Migotto, A. E., Turra, A., and Schaeffer-Novelly, Y. (2010). Araçá: biodiversidade, impactos e ameaças. *Biota Neotropica* 10, 1–47.

Amaral, A. C. Z., Turra, A., Ciotti, A. M., Wongtschowski, C. L., Del, B. R., and Schaeffer-Novelli, Y. (2015). *Life in Araçá Bay: Diversity and Importance*. São Paulo: Lume.

Begossi, A. (1998). "Resilience and neo-traditional populations: the caiçaras (atlantic forest) and caboclos (amazon, brazil)," in *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*, eds F. Berkes, C. Folke and, J. Colding, (Cambridge University Press: Cambridge), 129–157.

Bélisle, A. C., Asselin, H., LeBlanc, P., and Gauthier, S. (2018). Local knowledge in ecological modeling. *Ecol. Soc.* 23:14. doi: 10.5751/ES-09949-230214

Berkes, F. (1999). *Sacred Ecology: Traditional Ecological Knowledge and Resource Management*. Milton Park: Taylor & Francis.

Berkes, F. (2004). "Traditional ecological knowledge in perspective," in *Traditional Ecological Knowledge: Concepts and Cases*, ed J. T. Inglis, (International Program on Traditional Ecological Knowledge: Ottawa, QC), 1–6.

Berkes, F., Colding, J., and Folke, C. (2003). *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge: Cambridge University Press.

Berkes, F., Colding, J., and Folke, C. (2000). Rediscovery of traditional ecological knowledge as adaptive management. *Ecol. Appl.* 10, 1251–1262. doi: 10.2307/2641280

Berkes, F., and Folke, C. (1998). *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. Cambridge: University Press.

Berkes, F., Folke, C., and Gadgil, M. (1995). "Traditional ecological knowledge, biodiversity, resilience and sustainability," in *Biodiversity Conservation: Problems and Policies*, eds C. A. Perrings, K. G. Mäler, C. Folke, C. S. Holling, and B. O. Jansson, (Berlin: Springer), 281–299. doi: 10.1007/978-94-011-0277-3_15

Berkes, F., Berkes, M. K., and 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. doi: 10.1080/08920750600970487

Beuret, J. E. (2006). *La Conduite de la Concertation, Pour la Gestion de L'environnement et le Partage Des Ressources*. Paris: L'Harmattan.

Beuret, J. E., Dufourmantelle, N., and Beltrando, V. (2006). *L'evaluation des Processus de Concertation: RELIEF, Une Demarche, des Outils*. Paris: La Documentation Française.

Biggs, R., Schlüter, M., Biggs, D., Bohensky, E. L., Burnsilver, S., Cundill, G., et al. (2012). Toward principles for enhancing the resilience of ecosystem services. *Annu. Rev. Environ. Res.* 37, 421–448. doi: 10.1146/annurev-environ-051211-123836

Buarque, S. C. (2008). *Construindo o Desenvolvimento Local Sustentável: Metodologia de planejamento*. Rio de Janeiro: Editora Garamond.

Callon, M. (1986). *Eléments Pour Une Sociologie de la Traduction: la Domestication des Coquilles Saint- Jacques et des Marins-Pêcheurs Dans la Baie de Saint-Brieuc*. Paris: L'Année Sociologique.

Carpenter, S., Walker, B., Anderies, J. M., and Abel, N. (2001). From metaphor to measurement: resilience of what to what? *Ecosystems* 4, 765–781. doi: 10.1007/s10021-001-0045-9

Carrilho, C. D., and Sinisgalli, P. A. A. (2018). Contribution to araçá bay management: the identification and valuation of ecosystem services. *Ocean Coast. Manag.* 164, 128–135. doi: 10.1016/j.ocecoaman.2018.03.023

Casimirri, G. (2003). *Problems with Integrating Traditional Ecological Knowledge into Contemporary Resource Management*. Québec, QC: Annals of the XII World Forestry Congress/FAO.

Cinner, J. E., and Aswani, S. (2007). Integrating customary management into marine conservation. *Biol. Conserv.* 40, 201–216. doi: 10.1016/j.biocon.2007.08.008

Colding, J., Folke, C., and Elmqvist, T. (2003). Social institutions in ecosystem management and biodiversity conservation. *Trop. Ecol.* 44, 25–41.

Cowx, I. G., Arlinghaus, R., and Cooke, S. J. (2010). Harmonizing recreational fisheries and conservation objectives for aquatic biodiversity in inland waters. *J. Fish Biol.* 76, 2194–2215. doi: 10.1111/j.1095-8649.2010.02686.x

De Groot, R. S., Alkemade, R., Braat, L., Hein, L., and Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecol. Complex.* 7, 260–272. doi: 10.1016/j.ecocom.2009.10.006

Diegues, A. C. S. (1983). *Pescadores, Camponeses a Trabalhadores do Mar*. São Paulo: Annablume.

Douvere, F. (2008). The importance of marine spatial planning in advancing ecosystem-based sea use management. *Mar. Policy* 32, 762–771. doi: 10.1016/j.marpol.2008.03.021

Faria, A. A. D. A. C., and Neto, P. S. F. (2006). *Ferramentas de Diálogo - Qualificando o Uso das Técnicas de DRP: Diagnóstico Rural Participativo*, 2nd Edn, Brasília: IEB.

Feeny, D., Berkes, F., Mc Cay, B. J., and Acherson, J. M. (1990). The tragedy of the commons: twenty-two years later. *Hum. Ecol.* 18, 1–19. doi: 10.1007/BF00889070

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., et al. (2005). Global consequences of land use. *Science* 309, 570–574. doi: 10.1126/science.1111772

Folke, C., Berkes, F., and Colding, J. (1998). "Ecological practices and social mechanisms for building resilience and sustainability," in *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. eds F. Berkes, C. Folke and, J. Colding, (Cambridge: Cambridge University Press).

Folke, C., Colding, J., and Berkes, F. (2003). "Synthesis: building resilience and adaptive capacity in socialecological systems," in *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*, eds F. Berkes, J. Colding, and C. Folke, (Cambridge: Cambridge University Press).

Funtowicz, S., and Ravetz, J. R. (1991). "A new scientific methodology for global environmental issues," in *Ecological Economics: The Science and Management of Sustainability*, ed. R. Constanza (New York, NY: Columbia University Press).

Funtowicz, S., and Ravetz, J. R. (1993). Science for the post-normal age. *Futures* 25, 739–755. doi: 10.1016/0016-3287(93)90022-l

Funtowicz, S., and Ravetz, J. R. (1997). Ciência pós-normal e comunidades ampliadas de pares face aos desafios ambientais. *História Ciências Saúde Manguinhos* 4, 219–230. doi: 10.1590/s0104-59701997000200002

Gadgil, M., Berkes, F., and Folke, C. (1993). Indigenous knowledge for biodiversity conservation. *Ambio* 22:151–156.

Gibbs, M. T. (2009). Resilience: what is it and what does it mean for marine policymakers? *Mar. Policy* 33, 322–331. doi: 10.1016/j.marpol.2008.08.001

Gómez-Baggethun, E., Corbera, E., and Reyes-García, V. (2013). Traditional ecological knowledge and global environmental change: research findings and policy implications. *Ecol. Soc.* 18:72. doi: 10.5751/ES-06288-180472

Governo do Estado de São Paulo (1998). Lei Estadual N° 10.019, de 3 de Julho de 1998. Dispõe Sobre o Plano Estadual de Gerenciamento Costeiro e dá Outras Providências. São Paulo: Governo do Estado de São Paulo.

Governo, do Estado de São Paulo (2008). *Decreto N° 53.525 de 08 de Outubro de 2008. Cria a Área de Proteção Ambiental Marinha do Litoral Norte e dá Providências Correlatas*. São Paulo: Governo do Estado de São Paulo.

Governo do Estado de São Paulo (2017). *Decreto N° 62.913, de 8 de Novembro de 2017. Dispõe Sobre o Zoneamento Ecológico-Econômico do Setor do Litoral Norte, e dá Providências Correlatas*. São Paulo: Governo do Estado de São Paulo.

Gunderson, L. H., and Holling, C. S. (2002). *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, DC: Island Press.

Instituto Brasileiro de Geografia e Estatística [IBGE] (2017). *Instituto Brasileiro de Geografia e Estatística*. Available at: https://cidades.ibge.gov.br/brasil/sp/panorama (accessed November 30, 2017).

Jones, P. J. S., Qiu, W., and de Santo, E. M. (2013). Governing marine protected areas: social–ecological resilience through institutional diversity. *Mar. Policy* 41, 5–13. doi: 10.1016/j.marpol.2012.12.026

Lloyd's List (2017). *Maritime Intelligence Inform*. Available at: https://lloydslist.maritimeintelligence.informa.com/one-hundred-container-ports-2017#filter (accessed June 16, 2019).

Magalhães, A. S., and Domingues, E. P. (2014). Blessing or curse: impacts of the brazilian pre-salt oil exploration. *Economia* 15, 343–362. doi: 10.1016/j.econ.2014.11.002

Marques, J. G. W. (2001). *Pescando Pescadores: Ciência e Etnociência em uma Perspectiva Ecológica*, 2nd Edn, São Paulo: Núcleo de Apoio à Pesquisa sobre Populações Humanas e Áreas Úmidas Brasileiras.

Moberg, F., and Simonsen, S. H. (2014). *What is Resilience? An Introduction to Social-Ecological Research*. Stockholm: Stockholm Resilience Centre.

Moura, G. G. M., and Diegues, A. C. S. A. (2009). Os conhecimentos tradicional e científico do Saco do arraial, estuário da lagoa dos patos (RS). *Boletim do Instituto de Pesca* 35, 359–372.

Nyström, M., Folke, C., and Moberg, F. (2000). Coral reef disturbance and resilience in a human-dominated environment. *Trends Ecol. Evol.* 15, 413–417. doi: 10.1016/S0169-5347(00)01948-0

Peres, C. M., Xavier, L. Y., Santos, C. R., and Turra, A. (2016). Stakeholders perceptions of local environmental changes as a tool for impact assessment in coastal zones. *Ocean Coast. Manag.* 119, 135–145. doi: 10.1016/j.ocecoaman.2015.10.005

Petrobrás (2018). *Pre-Salt*. Available at: http://www.petrobras.com.br/en/our-activities/performance-areas/oil-and-gas-exploration-and-production/pre-salt/ (accessed May 14, 2018).

Pickton, D. W., and Wright, S. (1998). What's SWOT strategic analysis? *Strateg. Change* 7, 101–109. doi: 10.1002/(sici)1099-1697(199803/04)7:2<101::aid-jsc332>3.0.co;2-6

Porto de São Sebastião (2019). *Projeto de Ampliação*. Available at: http://portoss.sp.gov.br/home/porto/projet/ (accessed January 29 2019).

Ruiz-Mallén, I., and Corbera, E. (2013). Community-based conservation and traditional ecological knowledge: implications for social-ecological resilience. *Ecol. Soc.* 18:12. doi: 10.5751/ES-05867-180412

Santos, C. R., Xavier, L. Y., Peres, C. M., Stori, F.T., Grilli, N. M., Shinoda, D. C., et al. (2018). "Prática da gestão costeira integrada: da mobilização à elaboração participativa de um plano local de desenvolvimento sustentável," in *Métodos de Estudo em Ecossistemas Costeiros: Biodiversidade e Funcionamento*, 1st Edn, eds A. C. Z. Amaral, A. Turra, A. M. Ciotti, C. Wongtschowski, and Y. Schaeffer-Novelli, (São Paulo: Lume), 273–305.

Sartori, R. C., and Monteiro, A. A. (2010). Da crise ambiental para uma abordagem ecossistêmica do conhecimento: os desafios do conhecimento científico contemporâneo discutir a crise ambiental e seus complexos problemas é reconhecer que a solução deles também implica a reflexão sobre mudanças. *Ambient. Educ.* 15, 121–132.

SEADE (2017). *Informações dos Municípios Paulistas*. Available at: http://www.imp.seade.gov.br/frontend/#/perfil (accessed November 30, 2017).

Shackeroff, J. M., and Campbell, L. M. (2007). *Traditional Ecological Knowledge in Conservation Research: Problems and Prospects for their Constructive Engagement*. Beaufort, NC: Duke University.

Simonsen, S. T., Biggs, R., SchlüTer, M., Schoon, M., Bohensky, E., Cundill, G., et al. (2015). *Applying Resilience Thinking: Seven Principles for Building Resilience in Social-Ecological Systems*. Stockholm: Stockholm Resilience Centre.

Secretaria do Meio Ambiente do Estado de São Paulo/Coordenadoria de Planejamento Ambiental [SMA/CPLA] (2012). *Zona Costeira Paulista: Relatório de Qualidade Ambiental 2012*. São Paulo: SMA/CPLA.

Srivastava, P. K., Kulshreshtha, K., Mohanty, C. S., Pushpangadan, P., and Singh, A. (2005). Stakeholder-based SWOT 123 analysis for successful municipal solid waste management in Lucknow, India. *Waste Manag.* 25, 531–537. doi: 10.1016/j.wasman.2004.08.010

Stori, F. T., Santos, C. R., Vivaqua, M., Serafini, T. Z., Xavier, L. Y., Grilli, N. M., et al. (2017a). "Gestão costeira integrada com vistas à resiliência de sistemas socioecológicos para sustentabilidade dos bens e serviços ecossistêmicos: reflexões de um coletivo," in *Avanços em Oceanografia Humana: o Socioambientalismo Nas Ciências do Mar*, 1st Edn, ed. G. Moura, (Jundiaí: Paco Editorial).

Stori, F. T, Turra, A., and Castro, I. (2017b). *Pulsating: a Film About Araçá Bay*. Available at: https://youtu.be/_fnlPHSwq_c (accessed July 02, 2019).

Stori, F. T., Nordi, N., and Abessa, D. M. S. (2012). Mecanismos socioecológicos e práticas tradicionais de pesca na comunidade caiçara da ilha diana (Santos, Brasil) e suas transformações. *J. Integr. Coast. Zone Manag.* 12, 521–533. doi: 10.5894/rgci355

Stori, F. T., Shinoda, D. C., and Turra, A. (2019). Sewing a blue patchwork: an analysis of marine policies implementation in the southeast of brazil. *Ocean Coast. Manag.* 168, 322–339. doi: 10.1016/j.ocecoaman.2018.11.013

Toledo, V. (2002). "Ethnoecology: a conceptual framework for the study of indigenous knowledge of nature," in *Ethnobiology and Biocultural Diversity*, eds J. R. Stepp, F. S. Wyndham, R. K. Zarger,. (Athens, GE: University of Georgia Press), 511–522.

Turra, A., Amaral, A. C. Z., Ciotti, A. M., Rossi-Wongtschowski, C. L. D. B., Schaeffer-Novelli, Y., Marques, A. C., et al. (2017). Environmental impact assessment under an ecosystem approach: the São Sebastião harbor expansion project. *Ambient. Soc.* 20, 155–176. doi: 10.1590/1809-4422ASOC166V2022017

Turra, A., Santos, C. R., Peres, C. M., Seixas, C. S., Shinoda, D. C., Stori, F. T., et al. (2016). *PLDS/Araçá. Plano Local de Desenvolvimento Sustentável da Baía do Araçá*. São Paulo: Instituto Oceanográfico da Universidade de São Paulo.

UNEP (2011). *Taking Steps Toward Marine and Coastal Ecosystem-Based Management - An Introductory Guide*. Nairobi: United Nations Environment Programm.

Viegas, M. D. C., Moniz, A. B., and Santos, P. T. (2014). Artisanal fishermen contribution for the integrated and sustainable coastal management - 125 application of strategic SWOT analysis. *Procedia* 120, 257–267. doi: 10.1016/j.sbspro.2014.02.103

Viertler, R. V. (2002). "Métodos antropológicos como ferramenta para estudos em etnobiologia e etnoecologia," in *Métodos de Coleta e Análise de Dados em Etnobiologia, Etnoecologia e Disciplinas Correlatas*, eds M. C. M. Amorozo, L. C. Ming, and S. P. Silva, (Rio Claro: CNPQ-UNESP).

Wiber, M., Berkes, F., Charles, A., and Kearney, J. (2004). Participatory research supporting community-based fishery management. *Mar. Policy* 286, 459–468 doi: 10.1016/j.marpol.2003.10.020

Wright, R., and Stein, M. (2005). "Snowball sampling," in *Encyclopedia of Social Measurement*, ed. K. K. Leonard, (Cambridge, MA: Academic Press).

Xavier, L. Y., Jacobi, P. R., and Turra, A. (2018). On the advantages of working together: social Learning and knowledge integration in the management of marine areas. *Mar. Policy* 88, 139–150. doi: 10.1016/j.marpol.2017.11.026

Xavier, L. Y., Stori, F. T., and Turra, A. (2017). *Desvendando os Oceanos: Um Olhar sobre a Baía do Araçá*. São Paulo: Instituto Oceanográfico da Universidade de São Paulo.

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