Copyright © 2020 by the author(s). Published here under license by the Resilience Alliance.
Silva, M. R. O., M. G. Pennino, and P. F. M. Lopes. 2020. A social-ecological approach to estimate fisher resilience: a case study from Brazil. *Ecology and Society* 25(1):23. https://doi.org/10.5751/ES-11361-250123

Research

A social-ecological approach to estimate fisher resilience: a case study from Brazil

Monalisa R. O. Silva [1], *Maria Grazia Pennino* [1,2,3] *and Priscila F. M. Lopes* [1]

ABSTRACT. Social-ecological systems (SESs), such as fishing communities, are human and biophysical subsystems that are intrinsically connected to one another and strongly depend on natural resources. That is why these human groups are usually the first to feel the effects of policies concerning fisheries and ocean governance and the most affected by them. These policies can potentially build or erode social-ecological resilience (SER), especially if they are coupled with environmental changes. SER assessments offer a valuable tool to identify human-nature linkages, and the implications and feedbacks in SESs when facing human-induced or natural changes. We created a SER index by combining interviews with fishers with environmental datasets on a fine scale that has never been presented for the Brazilian coast. This scale was then tested in marine protected areas that allow sustainable use. Our approach estimated SER from information on fisheries ecosystem services and adaptive capacity at the local scale, considering the individual and community levels. We synthesized blocks of critical indicators of an individual or community's ability to build and maintain resilience in SESs, such as flexibility, ability to learn, ability to organize, assets, social capital, and ecological characteristics. We identified that fishers' ability to learn and to organize, as well as the biological sensitivity of an ecosystem are determinant to enhancing SER in the studied coastal communities. A Bayesian model also showed that the fishers' SER was related to socioeconomic factors, thereby indicating that older fishers, fishers who consistently catch more fish, and fishers with a higher reliance on fishing for their income presented lower index values. By knowing the variables that influence the ability of fishers to cope with changes to their SESs, we can devise smarter management approaches that may include compensatory mechanisms for more fragile fishers. Our findings can also inform decision making about where fisheries management strategies are likely to be more participative and effective in order to minimize the social impacts of policy decisions and increase SER in coastal communities.

Key Words: *adaptive capacity; coastal management; decision making; social capital; vulnerability.*

INTRODUCTION

Global environmental changes have led to an era characterized by rapid human-induced biodiversity loss (Corlett 2015) associated directly or indirectly to habitat destruction, climate change, and biodiversity overexploitation. This environmental crisis has been hitting the human groups that depend on natural resources the hardest because of its effects on social-ecological systems (SES) (He and Silliman 2019). Thus, human and environmental systems must be considered in unison, as an integrated system, when proposing approaches to cope with and mitigate global and local changes (Colding and Barthel 2019). It is especially important to consider that both environmental changes and the social mechanisms used to deal with changes may impact the resilience of a system, which is, in turn, also formed by environmental and social components. Resilience is defined as the ability of a system to cope with disturbances while maintaining its functions (Folke et al. 2004). For instance, the ecological resilience of coral reefs has declined because of chronic overfishing, acidification, rising temperatures, and water quality, which has led to radical regime shifts that make them more vulnerable to natural disasters (Hughes et al. 2003).

In the social context, resilience is the capacity of human communities to absorb changes and adversities while maintaining their livelihoods (Adger 2000). For example, fishing communities may maintain their social resilience despite transformative changes, e.g., technological or cultural, that involve regime shifts, such as a shift from a fishing economy to a tourism-based economy, if such transformations maintain or improve their livelihoods (Folke et al. 2010). When social systems are nested in ecological systems through mutual feedbacks, i.e., SES, the term social-ecological resilience (hereafter SER) is adopted (Berkes and Folke 1998, Adger et al. 2005). An example of this is top-down biodiversity conservation initiatives (Diegues 2008), such as the establishment of marine protected areas (MPAs), that are imposed upon a community and compromise the use of natural resources (Bueno and Schiavetti 2019). Although these measures can have a positive effect on ecological resilience, they can negatively impact social resilience if those affected cannot find alternative ways to cope with the limitations imposed on the use of natural resources. In turn, decreased social resilience can have a negative feedback on ecological resilience, e.g., by sabotaging conservation, thereby affecting the SER in the end (Carpenter et al. 2001). By better understanding SER within a system, better management policies can be devised and implemented accordingly, thus reducing the risk of SER backfire and negative impacts on local livelihoods. Furthermore, this would allow the simultaneous increase in the sustainability of an ecosystem's functions and services (Marshall and Marshall 2007).

Fish are an important marine ecosystem service and support human food security, well-being, and economic and cultural livelihoods, especially where fisheries are primarily small-scale (Béné and Friend 2011). However, global marine fisheries are currently underperforming because of the combined impacts of overfishing, degradation of ecosystems, and climate change

[1]Fishing Ecology Management and Economics (FEME), Dept. of Ecology, Universidade Federal do Rio Grande do Norte, Natal, Brazil, [2]Statistical Modeling Ecology Group (SMEG), Departament d'Estadística i Investigació Operativa, Universitat de València, Spain, [3]Instituto Español de Oceanografía, Vigo, Spain

(Cheung et al. 2009). This has demanded increasing efforts to restore marine ecosystems and rebuild fish stocks (Worm et al. 2009), which usually require a reduction of fishing exploitation rates. Despite the overall long-term ecological and social benefits (Sumaila et al. 2012), rebuilding small-scale fisheries in developing countries involves an overlooked challenge: fishers do not always have the means to ensure their income, food, and employment during the rebuilding process.

Coastal communities that depend on fisheries can respond to social and ecological changes differently, with coping and adaptation strategies dependent on the interactions between these changes and the SES they are in (Faraco et al. 2016). Local fishers can be affected by both the local ecological conditions, such as fluctuations of marine stocks, and their social surroundings, such as how resource governance is enacted at different scales (Broderstad and Eythórsson 2014). The severity of the consequences will depend on a combination of ecological shifts and institutional reforms, such as changes to fisheries management regimes with the establishment of MPAs (Broderstad and Eythórsson 2014). Although MPAs are a strategy to protect biodiversity and the flow of marine services (McCook et al. 2010), their effectiveness can be stunted when the social factors of SER, such as the local socioeconomic context and governance and livelihood aspects, are ignored in their design (Fox et al. 2012).

Coastal fisheries-dependent communities in Brazil represent an important case study for SER because they exploit a great diversity of fish, use multiple types of gear, and are under different management regimes (WWF 2016), in addition to being affected by complex socioeconomic mechanisms (Ruffino 2016). Here, we had two main goals: (1) to develop a broadly applicable index to measure SER and (2) to use case studies to identify the factors that raise or lower SER at an individual level. We first created an index of different factors at the individual, community, and ecosystem levels that were identified in the literature to contribute to SER, e.g., flexibility, ability to learn and to organize, assets, social capital, and ecological characteristics of the local marine ecosystem. We tested this index by estimating the individual SER of Brazilian fishers who live in MPAs that permit the sustainable use of natural resources. Finally, we analyzed the socioeconomic aspects that influence fisher SERs. The developed index can be applied worldwide, but it is especially proposed as a tool to provide information to support management initiatives that do not compromise, but rather enhance, SER in coastal systems in the tropical developing world in order to support both fish conservation and human well-being.

METHODS

The social-ecological resilience assessment lens

Studies addressing SER have increased over the last decade because of an interest in understanding, anticipating, and mitigating the increased risks of social-ecological disasters in coastal areas (Colding and Barthel 2019, Ferro-Azcona et al. 2019). A recent systematic review of the literature on adaptive capacity and SER highlighted that most studies are geographically biased toward developed countries and tend to address biophysical stressors related to climate change (Ferro-Azcona et al. 2019). Moreover, most studies use a single impact pathway, e.g., climate change (Cai et al. 2016), or, when focused on climate change, include only the socioeconomic aspects affecting SER (Ahmed et al. 2016). Additionally, and despite the advertised relevance of MPAs for conservation and the maintenance of ecosystem services (Eriksson et al. 2017), MPA SER assessments are scarce and inconclusive (Ferro-Azcona et al. 2019 identified only two studies on this topic). Thus, by recognizing that MPAs are crucial institutions to enhancing SER (IPCC 2014) and that they are poorly studied in developing countries, we created an approach to estimate fisher SER that combined the biophysical and socioeconomic aspects of coastal communities affected by MPAs.

In Brazil, specifically, the few existing SER studies have either focused on fisheries or adopted an exclusively qualitative social lens. For example, Prado et al. (2015) and Leite et al. (2019) used the SER concept to investigate coastal communities through a more qualitative approach, whereas Lopes et al. (2011) and Jones et al. (2013) analyzed different governance systems in protected areas by assessing flexibility, ability to organize, and diversity of those people living in these areas.

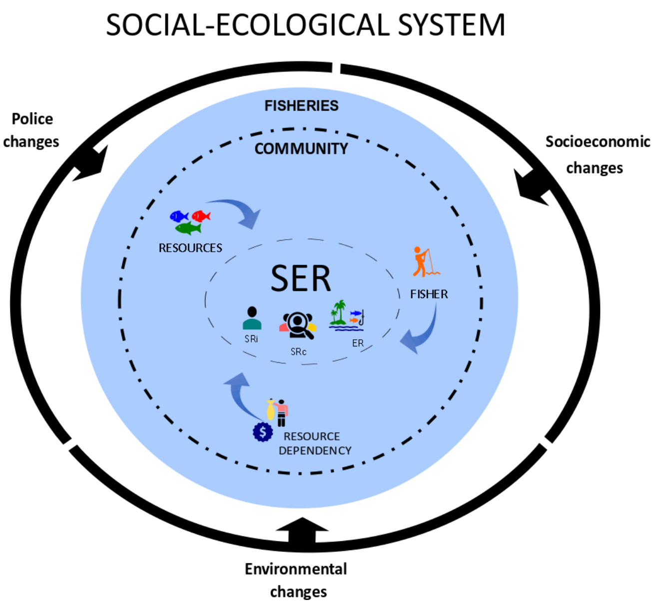
Considering that one of the objectives of measuring resilience is to inform policy and decision makers, we adopted a local-level approach (Hinkel 2011), especially because resilience is context specific (Tolentino-Arévalo et al. 2019). At the local level, there are better chances of understanding the interactions between humans and nature and, therefore, there is less room for misrepresentation of the vulnerabilities of a system (Tschakert et al. 2013). Our integrative and operational approach helps untangle the roots of anthropic stressors in MPAs. The previous attempts to operationalize SER have been bumpy, mostly because of the use of an extensive and not necessarily practical framework that makes implementation difficult (e.g., DasGupta and Shaw 2015). Our index, on the other hand, narrows the resilience indicators to a more localized level to capture the niceties that affect SER within fishing communities, with an easily replicable framework. This index provides rapid systematic measurement of SER across similar systems, facilitates comparative analyses, and enables the identification of interactions where supplementary analyses should be conducted to better plan priorities for the MPA to be effective.

Measuring resilience is context-specific and highly dependent on the type of threats posed (Quinlan et al. 2016). For the developing world, resilience should be understood according to its particular conditions, value sets, and livelihoods, instead of blindly adopting the findings from developed countries with different social-ecological needs and limitations.

A framework to build the social-ecological resilience index (SERI)

Despite important advances in studies addressing SER worldwide (Ferro-Azcona et al. 2019), the operationalization of SER still lacks quantitative approaches and there is much to learn about what makes SES resilient or not. An SES model should include the entities of common-pool resources, the links between these entities, and aspects related to resource dependencies, such as resource users, public infrastructure, infrastructure providers, institutional rules, and the external environment (Özerol 2013). Here, we consider the SES of fishing communities located within MPAs by integrating biophysical and social processes, community self-organization, and fisher behavioral aspects. Our framework is strongly focused on the needs of those affected by stresses because they tend to be ignored. We consider that altering the relationship between fishers and fisheries resources could influence fisher resilience, which is likely to depend on how management strategies are delivered and perceived, how environmental changes are felt, and on the intensity of resource dependency (Fig. 1).

Fig. 1. A conceptual framework for assessing the social-ecological resilience (SER) of small-scale fishers as a function of policy, environmental, and socioeconomic changes in the social-ecological system. SRi = Social Resilience at the individual level; SRc = Social Resilience at the community level; ER = Ecological Resilience. Adapted from Marshall et al. 2009.



One way to assess SER is by evaluating the capacity of resource dependent communities to cope with changes and uncertainty, and to evaluate whether they know how to nurture learning and adaptation, and create opportunities for self-organization (Berkes and Seixas 2005). Resource dependency is the relationship that people have with the environment that they depend upon (for example, fishers rely on fish) and is influenced by social, economic, and environmental factors at different scales (Marshall et al. 2009). These factors can interact and vary among resource-dependent communities and individuals, thereby resulting in different levels of dependency and resilience (Marshall et al. 2007). For instance, a resource user that is socially resilient could improve his/her resilience if he/she is inserted in a community that is also socially resilient.

Our variables are assigned to the individual, community, and ecosystem levels of the fisheries system, because fisher resilience is influenced by fishers themselves, fisheries resources, and aspects related to resource dependency at the community level. In the fisher element, we included personal characteristics known to promote or erode social resilience at the individual level. The resource element aggregates ecological aspects of the resilience of marine ecosystems. Finally, we considered preexisting conditions within communities, such as socioeconomic and political trends, that can affect impacts and a community's adaptive capacity (Cutter et al. 2008).

The framework is broken down into three components: social resilience at the individual level (SRi), social resilience at the community level (SRc), and ecological resilience (ER) of marine ecosystems (Fig. 1). Each component is formed by indicators commonly used in the literature (Adger 2000, Marshall and Marshall 2007, Cinner et al. 2009, Ruiz-Ballesteros 2011), such as flexibility, ability to learn and to organize, social capital, assets, and ecological variables (Fig. 2).

The SERI ranges from 0 to 1, after standardization of indicators and subindicators, which were equally weighted. A simple average approach was used to aggregate the indicators (IND) to form a component (C; OECD 2008). The value for each component was calculated as the average of these indicators:

$$C_i = (IND_1 + IND_2 + \ldots IND_n / \text{number of indicators}) \quad (1)$$

An equal weighting approach was used because it is assumed that each component is equally important to building SER in coastal communities:

$$SERI = (1/3 * C_1 + 1/3 * C_2 + 1/3 * C_3)/3 \quad (2)$$

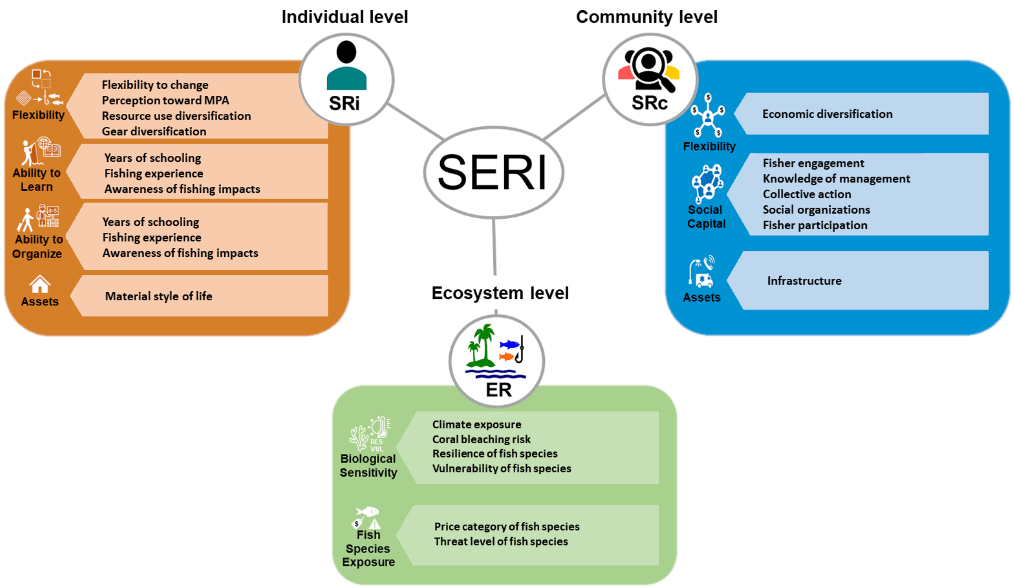
Although the number of indicators in each component is different, we normalized the data to vary from 0 to 1 and we used the mean values of each indicator to reduce possible bias from the number of variables. Because each fisher has his/her own score, we suggested a scale where a high SERI comprises values between 0.66 and 1, a moderate SERI exhibits values between 0.34 and 0.65, and a low SERI comprises values between 0 and 0.33.

Assessing the components of SERI

Social-ecological resilience at the individual level (SRi) was measured from four indicators related to the personal characteristics of fishers: flexibility (FLEi), ability to learn (AL), ability to organize (AO), and personal assets (ASi). These indicators show how flexible a fisher is to changes in the community and/or to new rules defining use and access to resources (Suman et al. 1999, Adger 2000). They also involve aspects that show how fishers can learn from environmental disturbances and local social-environmental actions (Adger et al. 2005), and the self-organizing ability of fishers both within the community and related to the fishing activities (Carpenter et al. 2001). Furthermore, communities with better infrastructure and better equipped households are considered more socially resilient because they can promote better conditions to learn and organize (Cinner et al. 2009).

Social-ecological resilience at the community level (SRc) focuses on indicators that represent proxies of a community's social resilience, such as institutional change, economic structure, and collective participation of the community (Adger 2000). Communities that are more flexible tend to be more resilient because they can more easily circumvent problems that arise with changes (Marschke and Berkes 2006). We selected three indicators to measure SRc: community flexibility (FLEc), social capital (SC), and community assets (ASc).

Fig. 2. Proposed components (three circles forming SERI), indicators (represented by icons), and subindicators (variables described in each of the three rectangles) to measure the social-ecological resilience index (SERI) of small-scale fishers, where SERI = (SRi + SRc + ER)/3. SRi = Social Resilience at the individual level; SRc = Social Resilience at the community level; ER = Ecological Resilience.



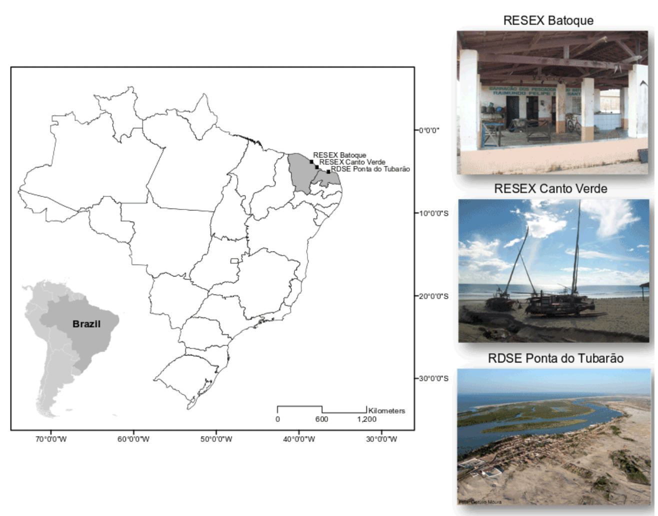
Communities that directly depend on natural resources are highly vulnerable to the effects of environmental management, climate change, overfishing, and environmental degradation, which can potentially undermine SER (Adger 2000). Therefore, the measure of resilience should consider the factors that contribute to ecosystem health and ecological adaptive capacity. Here, estimates of biological sensitivity (BS) and fish species exposure (FSE) were used as input indicators to determine the ER of the coastal ecosystem.

Table 1 presents a more thorough description of the SERI components and their indicators. More detailed information about the calculation process is presented in Appendices 1 and 2.

Case study context

The SERI was applied to fishers living in MPAs in Brazil's northeast: one in the state of Rio Grande do Norte (State Sustainable Development Reserve Ponta do Tubarão, hereafter RDSE Ponta do Tubarão) and two in the state of Ceará (Extractive Reserve Batoque, hereafter RESEX Batoque; Extractive Reserve Prainha do Canto Verde, hereafter RESEX Canto Verde; Fig. 3). The reserves share similar climates (humid tropical, Köppen Climate Classification System) and encompass beaches, dunes, dry Atlantic forest, mangroves, lagoons, and some shrubland (part of the semiarid biome known as Caatinga). There are multiple villages located inside the reserves, but we used the reserve as our sample unit. These reserves were established after intense local demand and are theoretically comanaged with the participation of the local people, but do not yet have formal management plans that define access rules. Given the latter, the rules in place are based on general federal laws, such as temporal bans on lobster fishing.

Fig. 3. Study area located on the Brazilian northeastern coast, highlighting the reserves located in the states of Rio Grande do Norte (RDSE Ponta do Tubarão) and Ceará (RESEX Batoque and RESEX Canto Verde). Pictures on the left, from top to bottom: the fisher association in RESEX Batoque, rafts (the main fishing craft in RESEX Canto Verde), and the estuary in RDSE Ponta do Tubarão.



The RDSE Ponta do Tubarão was created in 2003 and covers 12.946 ha. It incorporates three coastal villages and approximately 1000 fishing families (Dias et al. 2007). This reserve includes a marine area (847 ha) and coastal mangroves, dunes, and semiarid

Table 1. Description of the indicators and subindicators of the three components of the social-ecological resilience index (SERI).

Description of the indicators and subindicators
Social resilience at individual level (SRi)
• Flexibility indicator (FLEi)
The FLEi indicator shows how flexible a fisher is to changes in the community and/or to new rules defining use and access to the resources. The FLEi subindicators seek to determine whether fishers would be open to changing their economic activity. Improving flexibility by including additional income sources can be a key component to building resilience (Cinner et al. 2009). Perception of the marine protected area (MPA) reflects a fisher's flexibility when faced with change and uncertainty of resource policies or conservation initiatives that affect resilience in response to these changes (Suman et al. 1999). Dependence on a narrow range of resources can lead to social and economic stress because a smaller variety of economic resources to pool from makes people more susceptible to market variations (Adger 2000) and to natural fluctuations in resources. Greater diversification in fishing gear implies a more resilient fisher (Cinner et al. 2009).
Subindicators: flexibility to change, resource use diversification, gear diversification, and perception toward MPA
• Ability to learn indicator (AL)
The AL indicator relates to how fishers learn from environmental disturbances and social-environmental actions that occur in their areas. Social or environmental changes can teach fishers how to behave when faced with future disturbances, thus making them more resilient (Adger et al. 2005). Further, fisher memories and the local ecological knowledge they hold are crucial to innovation in resource monitoring and management, and to building SER (Berkes and Seixas 2005).
Subindicators: years of schooling, fishing experience, and awareness of fishing impacts
• Ability to organize indicator (AO)
Societies that have a higher level of social organization are considered to be more resilient because organization, cooperation, and collective action in a community decrease transaction costs and, therefore, make it easier to cope with and adapt to imposed changes (Carpenter et al. 2001). Here, elements of self-organizing ability include financial security, fishing investment, association involvement, and migration. Migration can either be understood as a risk to societies, given that it disrupts social and economic systems, or as an effective adaption strategy to environmental changes given that it represents an alternative during harsh periods in their place of origin (Adger et al. 2015). Here, migration shows a fisher's ability to deal with emerging risks in their communities, such as the loss of ecosystem services.
Subindicators: financial security, fishing investment, association involvement, and migration
• Assets indicator (ASi)
Quantitative data on quality of life was used to estimate fisher assets (ASi) through the proxy "number of home appliances" (Cinner and Pollnac 2004). We considered that fishers with a greater number of appliances were more resilient. Better household infrastructure is also an indicator of wealth, and wealthier people, within a given community context, are more likely to holistically understand the conservation practices of resource management (Cinner et al. 2012).
Subindicator: material style of life
Social resilience at community level (SRc)
• Flexibility indicator (FLEc)
The FLEc, which followed the same reasoning applied to individual flexibility, was measured from economic diversification, which was established by the maximum number of economic activities carried out in a specific reserve. The most resilient reserve was defined by the reserve with the greatest number of activities.
Subindicator: economic diversification
• Social capital indicator (SC)
At the community level, we used the SC indicator instead of ability to learn and to organize. Although both social capital and ability to learn and to organize focus on similar characteristics related to enhancing social resilience, social capital is measured from the collective aspects of resource users and their communities. Social capital, e.g., social cohesion, effective local governance, and capacity for collective actions, contributes to building resilience because it can create an appropriate social environment to sustain changes and unlock the capacities of communities to adapt to changes (Béné et al. 2016). We understand that social capital is a more appropriate nomenclature than ability to learn and to organize at the community level because it covers collective aspects related to fisher behavior and attitudes that influence fisher involvement in local management, assuming that high involvement can influence the promotion of SER.
Subindicators: fisher engagement, Knowledge of management rules, collective action, social organizations, and fisher participation
• Assets indicator (ASc)
Infrastructure provision can be a first step toward involving communities in the conservation process, given that when basic needs are cared for people are free to focus on exterior problems. A good level of infrastructure, with quality schools, for example, can contribute to other indicators of social resilience, such as the ability to learn and flexibility (Cinner and Pollnac 2004). Better infrastructure leads to higher flexibility and learning capacity because it generates economic alternatives, new sources of information, and opportunities (Adger 2000). ASc was measured by the presence or absence of 12 community-level types of infrastructure: schools, pharmacies, electrical services, banking access, sewage collection and treatment, access roads, food markets, phone services, post office service, police service, health centers, and hotels.
Subindicator: community infrastructure
Ecological resilience (ER)
• Biological sensitivity indicator (BS)
Predictable and unpredictable impacts of climate change are expected to affect marine systems and have direct effects on fish species because of the impacts on marine habitats, e.g., coral reefs and mangroves (Scheffers et al. 2016). For instance, temperature has a fundamental effect on biological processes, and the sea surface temperature (SST) has already increased by about 0.7 ºC over the last century (NOAA 2016). Increases in SST cause, for example, coral reef bleaching (Ojea et al. 2017), results in diversity and structural changes that, in turn, lead to reduced catches for fishers who target reef species (Pratchett et al. 2008), and undermine reef resilience (Hughes et al. 2010). The measures of climate exposure, e.g., changes to SST over time, and coral bleaching risk, e.g., occurrence of coral bleaching events, aim to capture such changes at the community level. Biological information on fish species, such as resilience and vulnerability, can be a proxy for marine ecosystem health because it contains aspects related to species vulnerabilities in fishing (Cheung et al. 2005). Biological traits were extracted from the FishBase dataset (http://www.fishbase.org/).
Subindicators: climate exposure, coral bleaching risk, resilience of fish species, and vulnerability of fish species
• Fish species exposure indicator (FSE)
The FSE indicator describes the exposure to fishing pressure and captures economic demand and threat level in a single measure, because economic demand can increase the threat level of a species over time. The FSE variables were also extracted from the FishBase dataset.
Subindicators: price category of fish species and threat level of fish species

areas. The fishers mostly target sardines (*Opisthonema oglinum*), flying fish (*Hirundichthys affinis*), and clams (*Anomalocardia brasiliana*; Dias et al. 2007). The reserve was established after an intensive process led by the local people against destructive environmental developments (shrimp farms and land encroachment) that threatened their land tenure and the use of space (Dias et al. 2007). The RDSE Ponta do Tubarão has its own office where meetings with the villages and partner institutions, such as NGOs and universities, are held. Financial restrictions were identified by the community and reserve staff to be the main hindrance to effective management actions.

RESEX Batoque was created in 2003 and is exclusively marine (601 ha). About 320 families live in this reserve and depend mostly on community-based tourism, local commerce, and fishing (Vidal and Silva 2007), especially lobster fishing (*Panulirus argus* and *P. laevicauda*). This reserve also faces problems related to land use and occupation, such as irregular construction near water bodies and dunes, which interferes with local environmental dynamics (Vidal and Silva 2007).

The RESEX Canto Verde is mostly a marine reserve (29.216 ha). There are approximately 300 families who live in its small land area (578 ha), who depend on finfish fishing (*Scomberomorus cavalla*, *S. brasiliensis*, *Katsuwonus pelamis*), lobster harvesting (*P. argus* and *P. laevicauda*; Schärer 2003), agriculture, crafts, and community tourism for their livelihoods. Canto Verde was created in 2009 after an intense struggle, dating back to the 1970s, among the local residents against land encroachment for tourism (Almeida and Pinheiro 2004). This reserve has a comparatively good level of organization. For example, they count on a local management council, a deliberative council (composed of leaders with the power to plan and execute environmental and social actions in the community), a neighborhood association that has been operating for over 20 years, regulation of land use, and a fisheries agreement that defines local fishing rules (Carvalho et al. 2010).

These coastal reserves were selected because of their high dependence on small-scale fisheries. Notwithstanding the importance of small-scale fisheries in coastal developing countries, increasing evidence indicates that coastal ecosystems have been deeply altered by overfishing, climate change, and changes to fishery governance, thus reducing their productivity and resilience (Ojea et al. 2017). Such effects have intensified conflicts over resources (Prestrelo and Vianna 2016) and, consequently, affected SER and the overall vulnerability of fishing villages. Therefore, understanding the factors that enhance the SER of fishers living within MPAs could help promote sustainability and effective conservation of these areas.

Data survey

In 2010 and 2011, 100 artisanal fishers were interviewed with the use of a semistructured questionnaire (Appendix 3): RDSE Ponta do Tubarão (N = 40), RESEX Batoque (N = 30), and RESEX Canto Verde (N = 30). From a list of names provided by the fisher associations in the region, we selected active full-time and part-time fishers who had been fishing in the area for at least five years. The minimum fishing experience in the area, although arbitrary, aimed to include people who could have felt changes brought about by the MPA. We also used the snowball method to reach the most experienced fishers in each village, by asking interviewees to indicate other experienced fishers who fulfilled the established criteria (Biernarcki and Waldorf 1981). Fishers were free to join the study or leave it at any point after being verbally informed of the research goals. The survey included questions related to the indicators used to estimate the index and fisher socioeconomic backgrounds, such as personal characteristics and fishery aspects. Secondary information about the historical climate data and coral bleaching events, target fish species traits, and socioeconomic aspects of the communities were collected using available online datasets. The necessary information and source data used to calculate the fisher SERI are in the supplementary materials (Appendices 1, 2, and 4).

Data analysis

Kruskal-Wallis tests were used to identify differences among indicators and among the average SERI values of the three MPAs. Pairwise comparisons were computed using Bonferroni post hoc tests to determine which indicators and SERI values were statistically significant (Neter et al. 1996).

The Pearson correlation ratio was used to check the relative importance of each indicator to the construction of the SERI (response variable). This analysis is a variance-based measure to examine dependence between input variables and the composite index (Becker et al. 2017). A Pearson correlation matrix was obtained using the “corrplot” package (Wei and Simko 2017) of the R software (R Development Core Team 2017).

A hierarchical Bayesian generalized linear mixed model (BGLMM) was used to analyze the influence of independent individual socioeconomic factors (fisher’s age, household economic dependence on fishing, and mean catch per unit effort (CPUE) on the fisher SERI. Data for these explanatory variables were also collected from the surveys with fishers and the calculations used to define these variables are explained in Appendix 5. A remaining potential source of variation on the SERI could be caused by idiosyncrasies between villages, which we dealt with by including a random village effect. We used the SERI for each fisher (Y_{i},) as a response variable of the BGLMM, which can take any continuous value between 0 and 1. We opted for a beta distribution given the interval that bounds the SERI and its asymmetric shape [0, 1] (Gupta and Nadarajah 2004). We assigned a noninformative zero-mean Gaussian prior distribution to the fixed effects with a variance of 100 (Held et al. 2010). In order to compare the goodness-of-fit between each model, three different measures were computed: (1) the Watanabe-Akaike information criterion (WAIC), (2) the root mean square error (RMSE), and (3) the adjusted coefficient of determination (R^2). Finally, for each estimated parameter of the final selected model we computed the probability (Pr) that they differed from 0 (Pr > or < 0) using the Bayes theorem property (Faraway et al. 2018). The BGLMs were performed using the R-INLA package (Rue et al. 2009). We also ran a sensitivity analysis to improve transparency in the construction of the SERI and to check the robustness of our findings (Appendix 6).

RESULTS

Fishing communities

The three reserves showed similar characteristics (Table 2). Fishers have been living in the reserves for more than 30 years, long before the areas became MPAs, but not all fishers were born on site (60% born on site). Most fishers were older than 40 (61%) and studied for at least five years (63%). Around 50% of the fishers

Table 2. Socioeconomic and fishery aspects of fishing communities in three marine protected areas located on the northeastern Brazilian coast: RDSE Ponta do Tubarão, RESEX Batoque, and RESEX Canto Verde. N = number of fishers; μ = Mean; ± = Standard deviation.

	Reserves		
	RDSE Ponta do Tubarão (N = 40)	RESEX Batoque (N = 30)	RESEX Canto Verde (N = 30)
Socioeconomic Aspects			
Age (μ years)	48 (±12.8)	61 (±10.9)	43 (±12.5)
Schooling (μ years)	5.5 (±4.1)	5 (±4.3)	7 (±4.3)
Born on site (%)	50	64	70
Fishers who own boats (%)	65	50	40
Time living in reserve (μ years)	37 (±14.6)	34 (±14.3)	38 (±12.6)
Fishery Aspects			
Fishing experience (μ years)	30 (±11.8)	23 (±11.4)	27 (±12.6)
Main boats (%)	motor boats (30%) canoes (25%) motorized canoes (10%)	rafts (43%) dinghy sail boats (7%)	rafts (27%) dinghy sail boats (13%)
Target species	*Lutjanus analis* *Ocyurus chrysurus* *Coryphaena hippurus* *Lutjanus jocu* *Scomberomorus brasiliensis*	*Scomberomorus cavalla* *Lutjanus analis* *Haemulon plumierii* *Scomberomorus brasiliensis* *Lutjanus jocu*	*Scomberomorus brasiliensis* *Carangoides bartholomaei* *Haemulon plumierii* *Scomberomorus cavalla* *Lutjanus synagris*
Main fishing gear (%)	hook and line (88%) seine nets (35%) cast nets (20%) jereré[†] (13%) flashlight (10%)	manzuá[‡] (57%) hook and line (100%) seine nets (60%)	manzuá[‡] (57%) hook and line (67%) seine nets (56%)

[†]hand net shaped like a funnel
[‡]semifixed small trap net

in each reserve owned boats and had been fishing for more than 20 years. Years of schooling, birthplace, and age of the interviewees were slightly different in RESEX Canto Verde, where fishers studied for more years, were mostly born in the community, and were younger than the other fishers (Table 2). The economic activities practiced by the fishers, in addition to fishing, were similar among the three reserves, with construction, commerce, and tourism being the most common. The fishers from RDSE Ponta do Tubarão had more motorboats and motorized canoes than the others, who were more artisanal. Additionally, fishers from the three reserves targeted similar species, especially snapper and mackerel (Lutjanidae and Scombridae families).

Social-ecological resilience index (SERI)

The average SERI of fishers, considering all MPAs together, was 0.59 on a scale 0–1 (with a range of 0.35 to 0.78). Most fishers (80%) showed moderate SERI values, followed by 20% high SERI values (highest SERI was 0.78 from RDSE Ponta do Tubarão). The ER component had the lowest average value (0.47, with a range of 0.22 to 0.69), followed by SRi (0.55, with a range of 0.01 to 0.90) and SRc (0.69, ranging from 0.59 to 0.86).

RESEX Batoque had the lowest median SERI value ($p < 0.05$, Bonferroni post hoc). The MPAs also differed in some of their components (Table 3). Specifically, RESEX Batoque performed worst in the SRc component, followed by RESEX Canto Verde and RDSE Ponta do Tubarão, respectively ($p < 0.05$, post hoc). RESEX Batoque again performed worse than RDSE Ponta do Tubarão and RESEX Canto Verde in the ER component ($p < 0.05$, post hoc).

RESEX Batoque was revealed to have lower economic diversification at the community level, lower fisher engagement in environmental monitoring, and precarious public infrastructure. However, fishers from this reserve had more knowledge of management rules and were more actively involved in the fishing association. Collective action and social organization variables were similar among the reserves. All three reserves presented worrisome ER results regarding fish resilience, fish vulnerability, and fish price category. Fishers from RESEX Batoque performed the worst because they targeted fish with lower resilience and higher vulnerability compared to the other reserves. The climate exposure and coral bleaching risks were similar among the reserves, as well as the fish price category. The SRi component was similar among the reserves, with all of them showing low gear diversification and low levels of individual financial security (Table 4).

Indicators from the three components showed around 50% correlations among themselves ($p < 0.05$). The biological sensitivity indicator was the most important to build the SERI. A correlation of 61% was found for this indicator ($p < 0.05$) in the ER component (Fig. 4).

Socioeconomic aspects defining fisher resilience

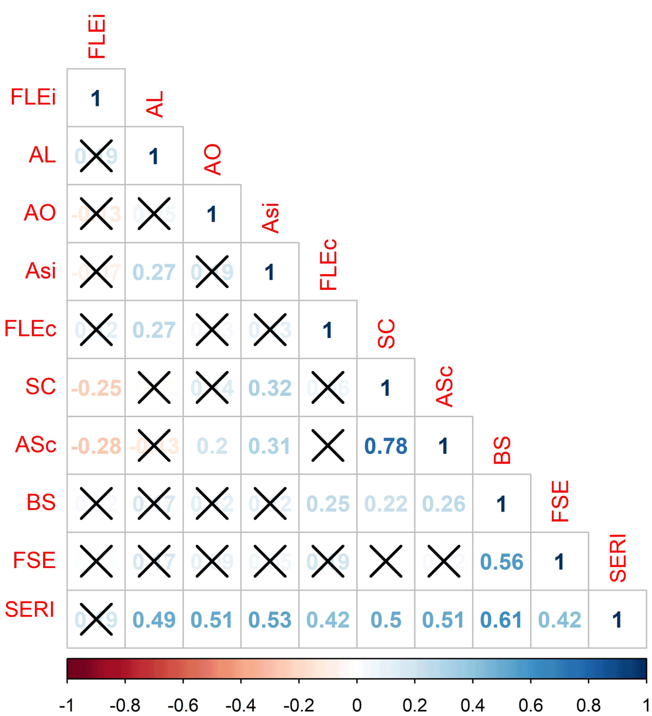
The final Bayesian GLMM included fishing dependency, fisher's age, mean CPUE, and the reserve random effect as relevant variables to explain the individual SERI (Table 5). The best model (based on the lowest WAIC, RMSE, and highest R^2) showed that the random effect of the reserve is an important factor in explaining data variability, meaning that the peculiarities of each reserve are important. Specifically, there was an 89% probability that older fishers have lower SERI values and an 83% probability that the higher the mean CPUE of the fisher, the lower their SERI (Fig. 5). Likewise, there was an almost 100% probability (97%) that fishers who live in households with a higher dependence on

Table 3. Average values for the social-ecological resilience index (SERI) and its components in the three marine protected areas (MPAs) analyzed: RDSE Ponta do Tubarão, RESEX Batoque, and RESEX Canto Verde. The sample column shows the average values among all fishers sampled, followed by MPAs average values, and the last two columns show the results of the Kruskal-Wallis statistical test.

Components and SERI composite index	Sample (N = 100)	RDSE Ponta do Tubarão (N = 40)	RESEX Batoque (N = 30)	RESEX Canto Verde (N = 30)	Kruskal-Wallis chi-squared	p-value
Social resilience (Individual)	0.55	0.54	0.49	0.57	4.09	0.129
Social resilience (Community)	0.69	0.86	0.59	0.69	94.50	0.000
Ecological resilience	0.47	0.47	0.42	0.48	11.27	0.003
SERI	0.59	0.63	0.50	0.59	40.17	0.000

fishing tended to be less resilient (Fig. 5). Percentages represent the posterior probability that the parameter is different from 0 (Pr > or < 0).

Fig. 4. Correlation matrix between the index of social-ecological resilience of fishers and the variables inputted in the composite index. The values marked with X mean that these are the nonsignificant values. FLEi = flexibility at the individual level, AL = ability to learn, AO = ability to organize, ASi = assets at the individual level, FLEc = flexibility at the community level, SC = social capital, ASc = assets at the community level, BS = biological sensitivity, FSE = fish species exposure, SERI = social-ecological resilience index.



DISCUSSION

Analyzing the SERI

There is a lack of consensus when it comes to understanding adaptation and resilience processes on a regional scale (Ferro-Azcona et al. 2019), but the findings of this study may provide a key to understanding the most important aspects of SER. By analyzing the resilience of fishing SES, we found low adaptive capacity and high environmental degradation among coastal villages to be critical factors affecting SER, thereby corroborating previous empirical studies (Thiault et al. 2018). For the case studies considered here, we found that the social resilience at both individual and community levels and the ecological resilience were important to fisher SER, with almost all indicators showing around 50% of correlation with the SERI. Thus, for further applications, we strongly recommend keeping the main structure of the SERI because it reflects the main aspects of SER worldwide. Still, for the MPAs considered here, biological sensitivity of the marine ecosystem, which includes climate exposure and traits of fish species, was the most important factor, despite the fact that the MPAs presented different levels of resilience among them.

Fig. 5. Posterior marginal distributions of the relevant variables of the final Bayesian model: fisher's age (top), their individual average capture per unit effort (middle), and the household economic dependence on fishing (bottom).

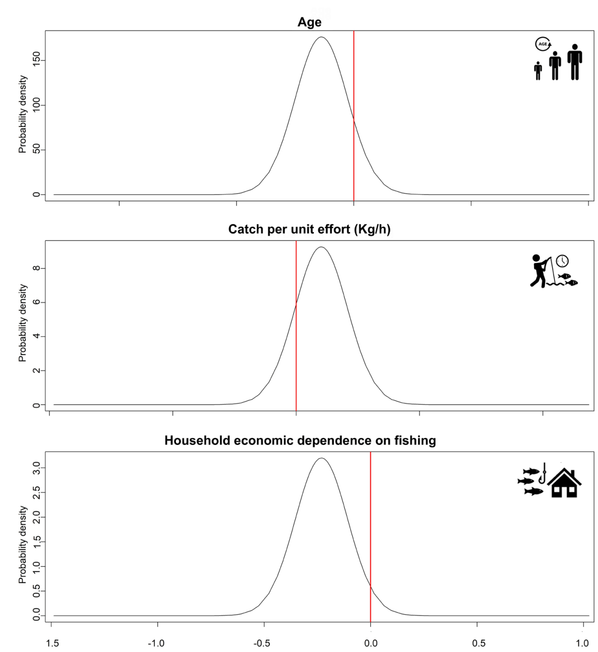


Table 4. Social-ecological resilience index (SERI) indicator interpretation and scores for the three studied reserves: RDSE Ponta do Tubarão, RESEX Batoque, and RESEX Canto Verde. SRi = Social resilience at individual level; SRc = Social resilience at community level; ER = Ecological resilience; Mxm score = Maximum score; MPA = marine protected area.

Component / Indicator / Subindicator		Interpretation	Scores		
			RDSE Ponta do Tubarão	RESEX Batoque	RESEX Canto Verde
Social Resilience ($SR_{Individual\ level}$)					
FLEi	Flexibility to change	Percentage of fishers that would be open to change their economic activity	68%	57%	80%
	Resource use diversification	Percentage of fishers that use other natural resources beyond fish	38%	67%	80%
	Gear diversification	Division of fishing gear used by fishers by the total fishing gear in the sample (n = 14; Scores are the median of fishers' gear diversification by reserve, higher score = greater resilience)	0.21	0.14	0.21
	Perception toward MPA	Percentage of fishers that agree with the MPA	40%	80%	73%
AL	Years of schooling	Percentage of fishers with higher schooling level higher than the Brazilian average	53%	57%	67%
	Fishing experience	Division of fishing time by fishers' age (Scores are the median of fishers' fishing experience by reserve, higher score = greater resilience)	0.71	0.68	0.67
	Awareness of fishing impacts	Percentage of fishers that quoted more than one cause explaining fish biomass decrease	40%	53%	83%
AO	Financial security	Percentage of fishers that have financial security	40%	20%	40%
	Fishing investment	Percentage of fishers that own a boat(s)	55%	50%	40%
	Migration	Percentage of fishers that migrated after their adulthood	35%	17%	13%
	Association involvement	Percentage of fishers that participated with high frequency in the social organization	53%	67%	77%
Asi	Material lifestyle	Number of fishers' home appliances out of 21 appliances (Scores are the average of fishers' home appliances, higher score = greater resilience)	9	7	8
Social Resilience ($SR_{Community\ level}$)					
FLEc	Economic diversification	Number of income alternatives in the reserve (Higher score = greater resilience)	5	4	6
SC	Fisher engagement	Percentage of fishers engaged in environmental monitoring	75%	47%	50%
	Knowledge of management rules	Percentage of fishers knowing more than one management rule	35%	90%	10%
	Collective action	Type of demand for MPA creation (Local demand = 1)	1	1	1
	Social organization	Presence of social or fishery organization (Presence = 1)	1	1	1
	Fisher participation	Percentage of active fishers in the association involvement	42%	53%	47%
ASc	Infrastructure	Community's infrastructure out of 12 aspects (Higher score = greater resilience)	12	7	7
Ecological Resilience (ER)					
BS	Climate exposure	Moderate increase in the sea surface temperature	0.5	0.5	0.5
	Coral bleaching risk	Absence of coral bleaching events	0	0	0
	Resilience of fish species	Median showing fish species resilience (Mxm score = 1, higher score = higher resilience)	0.41	0.28	0.38
	Vulnerability of fish species	Median showing fish species vulnerability (Mxm score = 1, lower score = higher vulnerability and lower resilience)	0.28	0.17	0.23
FSE	Price category of fish species	Median showing fish species price category (Mxm score = 1, lower score = higher price category and lower resilience)	0.32	0.36	0.39
	Threat level of fish species	Median showing fish species threat level (Mxm score = 1, higher score = lower threat level and greater resilience)	0.93	0.89	0.93

Notwithstanding the geographic and climate similarities of the region, ecological resilience was different among the reserves, which could be related to the different target species, which have different biological traits. In general, the fish species caught in the reserves were revealed to have low resilience and high vulnerability. Additionally, the studied region presented a moderate increase in sea surface temperature, which can alter the productivity of marine ecosystems (Cheung et al. 2009) and affect fisher livelihoods due to a decline of fishing resources. On the other hand, mangroves have been strongly affected in the study area, as a result of coastal development, pollution, deforestation, and climate change (MMA 2012). Mangrove protection and restoration are urgently needed, considering that they play a crucial role in coastal areas by reducing exposure to hazards and providing resources (Elfes et al. 2014) and, in turn, they reduce social vulnerability and improve resilience (Beck 2014).

At the individual level, fisher social resilience differed little among the reserves. Despite the similarity and high resilience at the

Table 5. Comparison of the models used. Statistics acronyms are: WAIC = Watanabe-Akaike information criterion; RMSE = root mean square error; R^2 = adjusted coefficient of determination (%). Predictors acronyms are: Age = fisher's age, CPUE = mean catch per unit effort (kg/h), HD = household fishing economic dependence, and RR = reserve random effect. The best model is highlighted in bold.

Model	WAIC	RMSE	R^2(%)
1 + A + CPUE + HD + RR	**-266.29**	**0.06**	**47**
1 + A + HD + CPUE	-218.78	0.07	10
1 + HD + CPUE	-220.71	0.07	10
1 + A + CPUE	-215.93	0.07	5
1 + CPUE	-217.79	0.07	5
1 + A + HD	-213.89	0.08	3
1 + HD	-215.58	0.08	3
1 + A	-211.59	0.08	0

community level, infrastructure could be improved overall, especially because our measure was based on the simple presence-absence of a given infrastructure and not on its quality. In agreement with a previous study (Faraco et al. 2016), the infrastructure of fishing communities were deficient in several aspects: the public health system, security, cultural options, and job opportunities. Improving these conditions could minimize the social impacts of extreme events (McDaniels et al. 2008). Studies of coastal fishing communities highlight that the socioeconomic dimension, such as community public infrastructure, constitutes the most binding dimension of building adaptive capacity (del Pilar Moreno-Sánchez and Maldonado 2013, Cinner et al. 2015).

In general, our findings suggest that some indicators are more important than others and should be considered accordingly. Given the high contribution of the biological sensitivity indicator to form SERI, together with the lower ER values found in the three reserves, working toward the protection, restoration, and maintenance of biodiversity may enhance SER. Individual and community resilience, especially through capacity building and leadership, should also be promoted.

Socioeconomic aspects affecting SERI

Human actions dominate SES and, in turn, humans influence their own resilience (Berkes et al. 2003). Here, we found that some fisher socioeconomic aspects, namely age, fishing dependency, and mean CPUE, are crucial to defining individual resilience among small-scale fishers in the considered MPAs. Older fishers, fishers who depend solely on fishing, and fishers who had higher mean CPUEs were found to be less resilient. Age is a crucial factor of a fisher's resilience in general (Marshall and Marshall 2007), and influences flexibility and adaptability (Teh et al. 2012), and fisher attitudes and perceptions toward fisheries management (Leleu et al. 2012). Older fishers, for example, are more resistant to the idea of learning something new, such as a new profession. The relationship observed between dependency and resilience was expected because the more dependent a fisher is on one specific activity, the less economically flexible s/he will be (Silva and Lopes 2015). Furthermore, user dependence on natural resources and access to markets strongly influence overexploitation and act as a barrier to conservation (Marshall et al. 2010). These findings support the idea that some fisher groups, such as older individuals and those highly dependent on fishing, may require additional incentives to accept any restrictions imposed by conservation policies. Moreover, unmeasured idiosyncrasies among the reserves are another important source of variation in the SERI and could be investigated further, to determine whether they represent measurable aspects of resilience yet to be identified.

SERI caveats and blind spots

Composite indexes are sensible to variable selection. Despite the careful choice of variables and carrying out a sensitivity analysis of the SERI to double check (see Appendix 6, which shows that the SERI is robust to changes in variables), there can still be some bias in their choice and use. For instance, migration can either be understood as a risk to the receiving society, given the disruption to existing socioeconomic systems, or as an effective adaptive individual response to changes, given that it allows emigrants to seek better opportunities somewhere else during harsh periods in their original place (Adger et al. 2015). In this study migration was estimated by analyzing the number of years immigrant fishers have been living in the community and the number of years they have been fishing there. Although some fishers could have been living in a community that never faced issues that forced them to emigrate and, therefore, never needed to show more resilience, we assumed that all fishers live under relatively similar conditions and face the same problems. However, considering that this index can be used in different socioeconomic scenarios around the world, we think that this variable must be adapted to the fisher context, by either increasing or decreasing fisher resilience.

Additionally, some of the indicators were estimated based on a comparative analysis among reserves, which can bring some bias to their operationalization. For instance, the community assets variable, which varied from 0 to 1, assigns a value of 1 to the reserve with the most infrastructure. It does not necessarily mean that this reserve has infrastructure that is good enough to enhance resilience, but simply that infrastructure is relatively better in one reserve than the others. Overall, both households and villages lacked assets and quality of the infrastructure was never assessed. Some of the biological variables are also subject to some uncertainty. For example, improvements to the global coral bleaching events dataset, such as percentage affected, bleaching duration, and mortality and recovery rates, could help refine the ecological resilience component. Although the Brazilian coastline is geographically located where there is not a high occurrence of climatic events, considering the current climate change scenario, the ability to measure SER should be seen as a key step toward disaster risk reduction in the future.

Thus, we suggest that anyone wanting to apply this index to another context make changes to the variables used to estimate indicators, provided that the three components used to build fisher SERs are maintained: individual, community, and ecosystem. Nevertheless, whenever possible, indicator selection should consider the aspects of SER used to build the SERI, given that they are widely accepted in the literature. We understand that fisher resilience is context-dependent, therefore some of the subindicators of our index may be adapted to consider local idiosyncrasies to better reflect the important aspects of local communities. Future analyses should also include variables to account for access to assets (e.g., cultural memory and natural capital), quality of existing infrastructure, and current governance and institutions (e.g., gender relations and levels of trust and cooperation; see Whitney et al. 2017). Despite these caveats, the index seems robust enough and could be used to support fisheries management in MPAs and their surroundings.

SER in Brazilian coastal areas: management implications

Building resilience in coastal regions is imperative, given current trends of urban settlement, resource use, global environmental change (Adger et al. 2005), and the political marginalization of fishing communities (Kalikoski et al. 2009). In Brazil, environmental and socioeconomic changes in coastal areas have affected both fish stocks and local livelihoods (MMA 2012), and although many such changes are common throughout the country, communities vary in their degrees of resilience (Hanazaki et al. 2013). Therefore, it is worth analyzing the case studies to provide specific directions for Brazilian fisheries management.

For example, fishers from RESEX Canto Verde were more flexible overall when it came to substituting fish and fishing with alternative resources and activities, such as collecting crustaceans and shellfish, gathering native fruits, and practicing small-scale agriculture. Yet, in the three reserves, crustaceans were the second most commonly exploited resource, indicating the same dependence on the coastal environment, although not necessarily on the same habitats. This dependence on a few livelihood strategies can lead to social and economic stress because a lower variety of economic resources makes people more susceptible to both market (Adger 2000) and resource fluctuations. Furthermore, fishers do not use a lot of gear which, therefore, limits their ability to exploit other resources, makes them more vulnerable to resource fluctuations (Aguilera et al. 2015), and simultaneously increases pressure on specific resources (Roos et al. 2016). Even under fluctuating environmental and economic conditions, catch diversification can reduce economic risks and be a potential management option for achieving SER (Matsuzaki et al. 2019). Management strategies should support sustainable diversification, whether it be of gear, fisheries, or alternative sources of income to improve fisher flexibility under vulnerable conditions.

Fisher ability to learn and to organize suggests a worrisome low level of fisher engagement in the decision-making process, despite the fact that these reserves were created by local demand. Less than half of the fishers in the three reserves said they were engaged in meetings. Low involvement in community organizations can increase the transaction costs associated with collective decision making (Castello et al. 2009). Moreover, it can affect participatory management because of the lack of trust between communities and other organizations that are also part of the decision-making process (de Vos and van Tatenhove 2011). Furthermore, the low schooling among fishers is an issue likely reflected in fisher plasticity and their low knowledge of the issues that affect fish stocks. MPAs would likely do better if they adopted strategies that integrate different institutions and create horizontal networks of civil society for social learning to facilitate the adaptive capacity of communities (Berkes 2009). Social organization could fill some of the gaps in education and enable fishers to better understand cause and effect connections, as observed in communities in the Brazilian Amazon (Kalikoski et al. 2009) and in Madagascar (Cinner et al. 2009).

The social resilience component at the community level (SRc) performed better than the other index components. However, the overall community resilience in RESEX Batoque should be given more attention, especially regarding social capital, economic diversification, and community infrastructure. A strong social context can enhance learning and adaptive capacity (Maldonado and del Pilar Moreno-Sánchez 2014), which together can also foster adaptive management, which is a useful tool for building resilience in SES (Folke et al. 2002). Resilience can also be improved if there are more flexible and income generating options beyond those offered by fishing (Hanazaki et al. 2013). Improving economic flexibility is not only important for building resilience (Cinner et al. 2009), but also for decreasing noncompliance (Karper and Lopes 2014) because fishers who have greater flexibility can turn to other economic activities when interventions limit fish extraction.

Even though the RDSE reserve presented a better SERI, it also faces challenges that can compromise its effectiveness, such as the lack of environmental awareness, ignorance about management rules, and disagreement with the MPA. Lack of environmental awareness and conservation support are among the global causes of environmental impacts, e.g., pollution, deforestation, and overfishing, and threaten conservation efforts (Easman et al. 2018). As such, urgent environmental education is needed, both in Brazil and elsewhere, to boost support among resource users (Ramírez and Santana 2019). This does not mean that all communities need to be told what to do or learn. In fact, in response to the inefficient management of coastal resources some coastal communities have self-organized and requested changes in the management regimes of Brazilian MPAs (Faraco et al. 2016). Investing in building and strengthening social capital in general can be a much more powerful tool with which to equip people to develop other necessary capacities.

The low ER average is worrisome because it could be suggesting alterations in the ecosystem health, e.g., changes in the trophic chain structure or equilibrium of the community, and this could undermine both fisher and ecosystem resilience. For example, the collapse of a fish stock, depending on the species, could hit select fishers harder. Here, the RESEXs presented the highest number of specialist fishers, whereas fishers from RESEX Batoque showed lower SRi and SRc, thus compromising their adaptive capacity if they were to face a disturbance to this system.

Investment in coastal management in Brazil is insufficient, but part of it could be spent on building social capital and increasing user involvement in management, especially in places where comanagement is mandatory, such as the studied MPAs. The presence of community leaders, strong social cohesion, and community-based management are important attributes that lead to successful fisheries comanagement (Gutiérrez et al. 2011) and should be promoted. Overall, for the MPAs studied here, none can be said to be social-ecologically resilient. The fact that two of them (RDSE Ponta do Tubarão and RESEX Canto Verde) perform slightly better than the third by no means suggests a satisfactory resilience level.

CONCLUSION

Our main goal with this study was to develop an index to measure fisher SER based on an integrative ecosystem approach. The analyses performed in this study reiterate important aspects that should be considered when designing management strategies for artisanal fisheries. The results suggest that individual, community, and ecological resilience are all strong indicators of SER. Furthermore, the results highlight areas in need of improvement to enhance fisher SER. The index has some limitations and some improvements could be applied to future global calculations. The proposed index could also easily be adapted to communities outside MPAs if some changes are made to the conservation perception variable, given that in its present form it only related to MPAs.

Overall, we believe that the SERI index proposed here can be of great value to marine conservation planning and to broaden the resilience discussion. It represents a useful framework that can assist governments and environmental organizations to better understand SER among fishing communities. It is a practical and feasible approach that comprises easily collected variables from structured surveys and datasets available online. In a changing and uncertain world, building resilience can sustain SES in the face of unexpected changes. Specifically, in poor fishing communities, where financial security and public services are limited, and the most basic infrastructure is inadequate, unexpected events that disrupt access to resources are often felt the hardest by fishers. Moreover, small-scale fisheries need to be managed by addressing the problems related not only to fish stocks but also to the welfare and satisfaction of the people who depend on them. By knowing the aspects that affect fisher coping strategies in response to changes to their SES, we can devise smarter management approaches that inform where conservation strategies and policy decisions are likely to be most effective.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/11361

Acknowledgments:

We thank the fishers from all the study sites for their permission to work in their communities, for their time, patience, and kind assistance. Thanks also to ICMBio for allowing the research in federal parks and IDEMA for assisting with logistical coordination and cooperation at the state park. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. Special thanks to CNPq for granting MROS a two-year Master's grant. PFML thanks CNPq for a productivity grant.

LITERATURE CITED

Adger, W. N. 2000. Social and ecological resilience: are they related? *Progress in Human Geography* 24(3):347-364. https://doi.org/10.1191/030913200701540465

Adger, W. N., N. W. Arnell, R. Black, S. Dercon, A. Geddes, and D. S. G. Thomas. 2015. Focus on environmental risks and migration: causes and consequences. *Environmental Research Letters* 10(6):60201. https://doi.org/10.1088/1748-9326/10/6/060201

Adger, W. N., T. P. Hughes, C. Folke, S. R. Carpenter, and J. Rockström. 2005. Social-ecological resilience to coastal disasters. *Science* 309:1036-1039. https://doi.org/10.1126/science.1112122

Aguilera, S. E., J. Cole, E. M. Finkbeiner, Le E. Cornu, N. C. Ban, M. H. Carr, J. E. Cinner, L. B. Crowder, S. Gelcich, C. C. Hicks, J. N. Kittinger, R. Martone, D. Malone, C. Pomeroy, R. M. Starr, S. Seram, R. Zuercher, and K. Broad. 2015. Managing small-scale commercial fisheries for adaptive capacity: insights from dynamic social-ecological drivers of change in Monterey Bay. *PLoS ONE* 10(3):e0118992. https://doi.org/10.1371/journal.pone.0118992

Ahmed, B., I. Kelman, H. Fehr, and M. Saha. 2016. Community resilience to cyclone disasters in coastal Bangladesh. *Sustainability* 8(8):805. https://doi.org/10.3390/su8080805

Almeida, H. L. P. S., and J. C. V. Pinheiro. 2004. A arte da sustentabilidade da pesca na comunidade da Prainha do Canto Verde, Beberibe-CE, in: *XLII Congresso Da Sociedade Brasileira de Economia E Sociologia Rural*. SOBER, Cuiabá, Brazil.

Beck, M. W. 2014. *Coasts at risk: an assessment of coastal risks and the role of environmental solutions.* A joint publication of United Nations University-Institute for Environment and Human Security (UNU-EHS), The Nature Conservancy (TNC), and the Coastal Resources Center (CRC) at the University of Rhode Island Graduate School of Oceanography, Narragansett, Rhode Island, USA.

Becker, W., M. Saisana, P. Paruolo, and I. Vandecasteele. 2017. Weights and importance in composite indicators: closing the gap. *Ecological indicators* 80:12-22 https://doi.org/10.1016/j.ecolind.2017.03.056

Béné, C., R. M. Al-Hassan, O. Amarasinghe, P. Fong, J. Ocran, E. Onumah, R. Ratuniata, T. Van Tuyen, J. A. McGregor, and D. J. Mills. 2016. Is resilience socially constructed? Empirical evidence from Fiji, Ghana, Sri Lanka, and Vietnam. *Global Environmental Changes* 38:153-170. https://doi.org/10.1016/j.gloenvcha.2016.03.005

Béné, C., and R. M. Friend. 2011. Poverty in small-scale inland fisheries: old issues, new analysis. *Progress in Development Studies* 11(2):119-144. https://doi.org/10.1177/146499341001100203

Berkes, F. 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. *Journal of* *environmental management* 90(5):1692-702. https://doi.org/10.1016/j.jenvman.2008.12.001

Berkes, F., J. Colding, and C. Folke. 2003. *Navigating social-ecological systems: building resilience for complexity and change.* Cambridge University Press, New York, New York, USA. https://doi.org/10.1017/CBO9780511541957

Berkes, F., and C. Folke. 1998. *Linking social and ecological systems. management practices and social mechanisms for building resilience.* Cambridge University Press, Cambridge, UK.

Berkes, F., and C. S. Seixas. 2005. Building resilience in lagoon social - ecological systems: a local-level perspective. *Ecosystems* 8:967-974. https://doi.org/10.1007/s10021-005-0140-4

Biernarcki, P., and D. Waldorf. 1981. Snowball sampling-problems and techniques of chain referral sampling. *Sociological Methods and Research* 10:141-163. https://doi.org/10.1177/004912418101000205

Broderstad, E. G., and E. Eythórsson. 2014. Resilient communities? Collapse and recovery of a social-ecological system in Arctic Norway. *Ecology and Society* 19(3):1. https://doi.org/10.5751/ES-06533-190301

Bueno, P. F., and A. Schiavetti. 2019. The influence of fisherman scale in the resilience of socio-ecological systems: an analysis using Q methodology. *Ocean & Coastal Management* 169: 214-224. https://doi.org/10.1016/j.ocecoaman.2018.12.008

Cai, H., N. Lam, L. Zou, Y. Qiang, and K. Li. 2016. Assessing community resilience to coastal hazards in the Lower Mississippi River Basin. *Water* 8(2):46. https://doi.org/10.3390/w8020046

Carpenter, S., B. Walker, J. M. Anderies, and N. Abel. 2001. From metaphor to measurement: resilience of what to what? *Ecosystems* 4(8):765-781. https://doi.org/10.1007/s10021-001-0045-9

Carvalho, R. M., L. N. Bezerra, and J. C. V. Pinheiro. 2010. Aspectos socioeconômicos da pesca na comunidade da Prainha do Canto Verde - Beberibe - CE. *Sociedade e Desenvolvimento Rural* 4:1-24.

Castello, L., J. P. Viana, G. Watkins, M. Pinedo-Vasquez, and V. A. Luzadis. 2009. Lessons from integrating fishers of arapaima in small-scale fisheries management at the Mamirauá Reserve, Amazon. *Environmental Management* 43(2):197-209. https://doi.org/10.1007/s00267-008-9220-5

Cheung, W. W. L., V. W. Y. Lam, J. L. Sarmiento, K. Kearney, R. Watson, and D. Pauly. 2009. Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries* 10:235-251. https://doi.org/10.1111/j.1467-2979.2008.00315.x

Cheung. W. W. L., T. J. Pitcher, and D. Pauly. 2005. A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing. *Biological Conservation* 124: 97-111. https://doi.org/10.1016/j.biocon.2005.01.017

Cinner, J. E., M. M. P. B. Fuentes, and H. Randriamahazo. 2009. Exploring Social resilience in Madagascar's marine protected areas. *Ecology and Society* 14(1):41. https://doi.org/10.5751/ES-02881-140141

Cinner, J. E., C. Huchery, C. C. Hicks, T. M. Daw, N. Marshall, A. Wamukota, and E. H. Allison. 2015. Changes in adaptive capacity of Kenyan fishing communities. *Nature Climate Change* 5(9):872-876. https://doi.org/10.1038/nclimate2690

Cinner, J. E., T. R. Mcclanahan, M. A. Macneil, N. A. J. Graham, T. M. Daw, A. Mukminin, D. A. Feary, A. L. Rabearisoa, A. Wamukota, N. Jiddawi, and S. J. Campbell. 2012. Comanagement of coral reef social-ecological systems. *Proceedings of the National Academy of Sciences of the United States of America* 109(14):5219-5222. https://doi.org/10.1073/pnas.1121215109

Cinner, J. E., and R. B. Pollnac. 2004. Poverty, perceptions and planning: why socioeconomics matter in the management of Mexican reefs. *Ocean & Coastal Management* 47(9-10):479-493. https://doi.org/10.1016/j.ocecoaman.2004.09.002

Colding, J., and S. Barthel. 2019. Exploring the social-ecological systems discourse 20 years later. *Ecology and Society* 24(1). https://doi.org/10.5751/es-10598-240102

Corlett, R. T. 2015. The Anthropocene concept in ecology and conservation. *Trends in Ecology & Evolution* 30(1):36-41. https://doi.org/10.1016/j.tree.2014.10.007

Cutter, S. L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb, 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change* 18(4):598-606. https://doi.org/10.1016/j.gloenvcha.2008.07.013

DasGupta, R., and R. Shaw. 2015. An indicator based approach to assess coastal communities' resilience against climate related disasters in Indian Sundarbans. *Journal of Coastal Conservation* 19:85-101. https://doi.org/10.1007/s11852-014-0369-1

de Vos, B. I., and J. P. M. van Tatenhove. 2011. Trust relationships between fishers and government: new challenges for the co-management arrangements in the Dutch flatfish industry. *Marine Policy* 35:218-225. https://doi.org/10.1016/j.marpol.2010.10.002

del Pilar Moreno-Sánchez, R. and J. H. Maldonado. 2013. Adaptive capacity of fishing communities at marine protected areas: a case study from the Colombian Pacific. *Ambio* 42 (8):985-996. https://doi.org/10.1007/s13280-013-0454-y

Dias, T. L. P., R. D. S. Rosa, and L. C. P. Damasceno. 2007. Aspectos socioeconômicos, percepção ambiental e perspectivas das mulheres marisqueiras da Reserva de Desenvolvimento Sustentável Ponta do Tubarão (Rio Grande do Norte, Brasil). *Gaia Scientia* 1(1):25-35. https://doi.org/10.31692/2526-7701.iicointerpdvagro.2017.00020

Diegues, A. C. 2008. *Marine protected areas and artisanal fisheries in Brazil.* Samudra monographs. International Collective in Support of Fishworkers, Chennai, India. [online] URL: http://aquaticcommons.org/id/eprint/1565

Easman, E. S., K. E., Abernethy, and B. J. Godley. 2018. Assessing public awareness of marine environmental threats and conservation efforts. *Marine Policy* 87:234-240. https://doi.org/10.1016/j.marpol.2017.10.030

Elfes, C. T., C. Longo, B. S. Halpern, D. Hardy, C. Scarborough, B. D. Best, T. Pinheiro, and G. F. Dutra. 2014. A regional-scale ocean health index for Brazil. *PLoS ONE* 9(4):e92589. https://doi.org/10.1371/journal.pone.0092589

Eriksson, H., J. Albert, S. Albert, R. Warren, K. Pakoa, and N. Andrew. 2017. The role of fish and fisheries in recovering from natural hazards: lessons learned from Vanuatu. *Environmental Science & Policy* 76:50-58. https://doi.org/10.1016/j.envsci.2017.06.012

Faraco, L. F. D., J. M. Andriguetto-Filho, T. Daw, P. D. C. Lana, and C. F. Teixeira. 2016. Vulnerabilidade de pescadores no litoral sul do Brasil e sua relação com áreas marinhas protegidas em um cenário de declínio da pesca. *Desenvolvimento e Meio Ambiente* 38:51-76. https://doi.org/10.5380/dma.v38i0.45850

Faraway, J. J., X. Wang, and Y. Y. Ryan. 2018. *Bayesian regression modeling with INLA*. CRC, Boca Raton, Florida, USA.

Ferro-Azcona, H., A. Espinoza-Tenorio, R. Calderón-Contreras, V. C. Ramenzoni, M. D. L. M. G. País, and M. A. Mesa-Jurado. 2019. Adaptive capacity and social-ecological resilience of coastal areas: a systematic review. *Ocean & Coastal Management* 173:36-51. https://doi.org/10.1016/j.ocecoaman.2019.01.005

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C. S. Holling, and B. Walker. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio* 31(5):437-440. https://doi.org/10.1579/0044-7447-31.5.437

Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson, and C. S. Holling. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution, and Systematics* 35:557-581. https://doi.org/10.1146/annurev.ecolsys.35.021103.105711

Folke, C., S. R. Carpenter, B. Walker, M. Scheffer, T. Chapin, and J. Rockström. 2010. Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and Society* 15(4):20. https://doi.org/10.5751/ES-03610-150420

Fox, H. E., M. B. Mascia, X. Basurto, A. Costa, L. Glew, D. Heinemann, L. B. Karrer, S. E. Lester, A. V. Lombana, R. S. Pomeroy, C. A. Recchia, C. M. Roberts, J. N. Sanchirico, L. Pet-Soede, and A. T. White. 2012. Reexamining the science of marine protected areas: linking knowledge to action. *Conservation Letters* 5(1):1-10. https://doi.org/10.1111/j.1755-263X.2011.00207.x

Gupta, A. K., and S. Nadarajah. 2004. *Handbook of beta distribution and its applications.* CRC, Boca Raton, Florida, USA. https://doi.org/10.1201/9781482276596

Gutiérrez, N. L., R. Hilborn, and O. Defeo. 2011. Leadership, social capital and incentives promote successful fisheries. *Nature* 470:386-389. https://doi.org/10.1038/nature09689

Hanazaki, N., F. Berkes, C. S. Seixas, and N. Peroni. 2013. Livelihood diversity, food security and resilience building among the Caiçara of coastal Brazil. *Human Ecology* 41(1):153-164. https://doi.org/10.1007/s10745-012-9553-9

He, Q., and B. R. Silliman. 2019. Climate change, human impacts, and coastal ecosystems in the Anthropocene. *Current Biology* 29 (19):R1021-R1035. https://doi.org/10.1016/j.cub.2019.08.042

Held, L., B. Schrödle, and H. Rue. 2010. Posterior and cross-validatory predictive checks: a comparison on MCMC and INLA. Pages 91-110 *in* T. Kneib and G. Tutz, editors. *Statistical modelling and regression structures.* Physica-Verlag, Berlin, Germany. https://doi.org/10.1007/978-3-7908-2413-1_6

Hinkel, J. 2011. "Indicators of vulnerability and adaptive capacity": towards a clarification of the science-policy interface. *Global Environmental Change* 21(1):198-208. https://doi.org/10.1016/j.gloenvcha.2010.08.002

Hughes, T. P., A. H. Baird, D. R. Bellwood, M. Card, S. R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J. B. C. Jackon, J. Kleypas, J. M. Lough, P. Marshall, M. Nyström, S. R. Palumbi, J. M. Pandolfi, B. Rosen, and J. Roughgarden. 2003. Climate change, human impacts, and the resilience of coral reefs. *Science* 301(5635):929-933. https://doi.org/10.1126/science.1085046

Hughes, T. P., N. A. J. Graham, J. B. C. Jackson, P. J. Mumby, and R. S. Steneck. 2010. Rising to the challenge of sustaining coral reef resilience. *Trends in Ecology & Evolution* 25(11):633-642. https://doi.org/10.1016/j.tree.2010.07.011

Intergovernmental Panel on Climate Change (IPCC). 2014. *Climate change 2014: impacts, adaptation, and vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK.

Jones, P. J. S., W. Qiu, and E. M. De Santo. 2013. Governing marine protected areas: social-ecological resilience through institutional diversity. *Marine Policy* 41:5-13. https://doi.org/10.1016/j.marpol.2012.12.026

Kalikoski, D. C., C. S. Seixas, and T. Almudi. 2009. Gestão compartilhada e comunitária da pesca no Brasil : avanços e desafios. *Ambiente e Sociedade* 7:151-172. https://doi.org/10.1590/S1414-753X2009000100011

Karper, M. A. M., and P. F. M. Lopes. 2014. Punishment and compliance: exploring scenarios to improve the legitimacy of small-scale fisheries management rules on the Brazilian coast. *Marine Policy* 44:457-464. https://doi.org/10.1016/j.marpol.2013.10.012

Leite, M., H. Ross, and F. Berkes. 2019. Interactions between individual, household, and fishing community resilience in southeast Brazil. *Ecology and Society* 24(3):2. https://doi.org/10.5751/ES-10910-240302

Leleu, K., F. Alban, D. Pelletier, E. Charbonnel, Y. Letourneur, and C. F. Boudouresque. 2012. Fishers' perceptions as indicators of the performance of marine protected areas (MPAs). *Marine Policy* 36(2):414-422. https://doi.org/10.1016/j.marpol.2011.06.002

Lopes, P. F. M., R. A. M. Silvano, and A. Begossi. 2011. Extractive and sustainable development reserves in Brazil: resilient alternatives to fisheries? *Journal of Environmental Planning and Management* 54(4):421-443. https://doi.org/10.1080/09640568.2-010.508687

Maldonado, J. H., and R. del Pilar Moreno-Sánchez. 2014. Estimating the adaptive capacity of local communities at marine protected areas in Latin America: a practical approach. *Ecology and Society* 19(1):16. https://doi.org/10.5751/ES-05962-190116

Marschke, M. J., and F. Berkes. 2006. Exploring strategies that build livelihood resilience: a case from Cambodia. *Ecology And Society* 11(1):42. https://doi.org/10.5751/ES-01730-110142

Marshall, N. A., D. M. Fenton, P. A. Marshall, and S. G. Sutton. 2007. How resource dependency can influence social resilience within a primary resource industry. *Rural Sociology* 72 (3):359-390. https://doi.org/10.1526/003601107781799254

Marshall, N. A., and P. A. Marshall. 2007. Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. *Ecology and Society* 12(1):1. https://doi.org/10.5751/ES-01940-120101

Marshall, N. A., P. Marshall, and A. Abdulla. 2009. Using social resilience and resource dependency to increase the effectiveness of marine conservation initiatives in Salum, Egypt. *Journal of Environmental Planning and Management* 52(7):901-918. https://doi.org/10.1080/09640560903180982

Marshall, N. A., P. A. Marshall, A. Abdulla, and T. Rouphael. 2010. The links between resource dependency and attitude of commercial fishers to coral reef conservation in the Red Sea. *Ambio* 39(4):305-313. https://doi.org/10.1007/s13280-010-0065-9

Matsuzaki, S. I. S., R. Shinohara, K. Uchida, and T. Sasaki. 2019. Catch diversification provides multiple benefits in inland fisheries. *Journal of Applied Ecology* 56(4):843-854. https://doi.org/10.1111/1365-2664.13316

McCook, L. J., T. Ayling, M. Cappo, J. H. Choat, R. D. Evans, D. M. De Freitas, M. Heupel, T. P. Hughes, G. P. Jones, B. Mapstone, H. Marsh, M. Mills, F. J. Molloy, C. R. Pitcher, R. L. Pressey, G. R. Russ, S. Sutton, H. Sweatman, R. Tobin, D. R. Wachenfeld, and D. H. Williamson. 2010. Adaptive management of the Great Barrier Reef: a globally significant demonstration of the benefits of networks of marine reserves. *Proceedings of the National Academy of Sciences of the United States of America* 107(43):18278-18285. https://doi.org/10.1073/pnas.0909335107

McDaniels, T., S. Chang, D. Cole, J. Mikawoz, and H. Longstaff. 2008. Fostering resilience to extreme events within infrastructure systems: characterizing decision contexts for mitigation and adaptation. *Global Environmental Change* 18(2):310-318. https://doi.org/10.1016/j.gloenvcha.2008.03.001

Ministério do Meio Ambiente (MMA). 2012. *Panorama da Conservação dos Ecossistemas Costeiros e Marinhos no Brasil*. Pages *in* Gerência de Biodiversidade Aquática e Recursos Pesqueiros, editor. *Gerência de Biodiversidade Aquática e Recursos Pesqueiros*. MMA, Brasília.

National Oceanic and Atmospheric Administration (NOAA). 2016. *Extended reconstructed sea surface temperature (ERSST. v4)*. National Centers for Environmental Information. NOAA, Washington, D.C., USA. [online] URL: https://www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. *Applied linear statistical models*. Vol.4. Irwin, Chicago, Illinois, USA.

Ojea, E., I. Pearlman, S. D. Gaines, and S. E. Lester. 2017. Fisheries regulatory regimes and resilience to climate change. *Ambio* 46(4):399-412. https://doi.org/10.1007/s13280-016-0850-1

Organisation for Economic Co-operation and Development (OECD). 2008. *Handbook on constructing composite indicators: methodology and user guide.* OECD, Paris, France. [online] URL: https://www.oecd.org/std/42495745.pdf

Özerol, G. 2013. Institutions of farmer participation and environmental sustainability: a multi-level analysis from irrigation management in Harran Plain, Turkey. *International Journal of the Commons* 7(1):73-91. http://dx.doi.org/10.18352/ijc.368

Prado, D. S., C. S. Seixas, and F. Berkes, 2015. Looking back and looking forward: exploring livelihood change and resilience building in a Brazilian coastal community. *Ocean & Coastal Management* 113:29-37. https://doi.org/10.1016/j.ocecoaman.2015.05.018

Pratchett, M. S., P. L. Munday, S. K. Wilson, N. A. J. Graham, J. E. Cinner, D. R. Bellwood, G. P. Jones, N. V. C. Polunin, and T. R. McClanahan. 2008. Effects of climate-induced coral bleaching on coral-reef fishes: ecological and economic consequences. *Oceanography and Marine Biology: An Annual Review* 46:251-296. https://doi.org/10.1201/9781420065756.ch6

Prestrelo, L., and M. Vianna. 2016. Identifying multiple-use conflicts prior to marine spatial planning: a case study of a multi-legislative estuary in Brazil. *Marine Policy* 67:83-93. https://doi.org/10.1016/j.marpol.2016.02.001

Quinlan, A. E., M. Berbés-Blázquez, L. J. Haider, and G. D. Peterson. 2016. Measuring and assessing resilience: broadening understanding through multiple disciplinary perspectives. *Journal of Applied Ecology* 53(3):677-687. https://doi.org/10.1111/1365--2664.12550

R Development Core Team. 2017. *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. [online] URL: https://www.R-project.org/

Ramírez, F., and J. Santana. 2019. Environmental education and biodiversity conservation. Pages 7-11 *in* F. Ramírez and J. Santana, editors. *Environmental education and ecotourism.* Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-030--01968-6_2

Roos, N. C., M. G. Pennino, P. F. M. Lopes, and A. R. Carvalho. 2016. Multiple management strategies to control selectivity on parrotfishes harvesting. *Ocean & Coastal Management* 134:20-29. https://doi.org/10.1016/j.ocecoaman.2016.09.029

Rue, H., S. Martino, and N. Chopin. 2009. Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. *Journal of the Royal Statistical Society Series B* 71:319-392. https://doi.org/10.1111/j.1467-9868.2008.00700.x

Ruffino, M. L. 2016. A gestão dos recursos pesqueiros no Brasil. Pages 7-22 *in* M. A. R. Araújo, editor. *Repensando a gestão ambiental no Brasil: uma contribuição ao debate de reconstrução nacional.* Ed. kindle. Conselho Regional de Biologia 4a Regiao, Belo Horizonte, Brasil. [online] URL: https://www.researchgate.net/profile/Mauro_Ruffino/publication/315074954_A_gestao_dos_recursos_pesqueiros_no_Brasil/links/58c982a8a6fdcc08b16492f5/A-gestao-dos-recursos-pesqueiros-no-Brasil.pdf

Ruiz-Ballesteros, E. 2011. Social-ecological resilience and community-based tourism: an approach from Agua Blanca, Ecuador. *Tourism Management* 32(3):655-666. https://doi.org/10.1016/j.tourman.2010.05.021

Schärer, R. 2003. Turismo sustentável: um estudo de caso sobre a experiência da comunidade de prainha do Canto Verde no litoral do Ceará. *Pasos* 1(2):231-242. https://doi.org/10.25145/j.pasos.2003.01.022

Scheffers, B. R., L. De Meester, T. C. Bridge, A. A. Hoffmann, J. M. Pandolfi, R. T. Corlett, S. H. M. Butchart, P. Pearce-Kelly, K. M. Kovacs, D. Dudgeon, M. Pacifici, C. Rondinini, W. B. Foden, T. G. Martin, C. Mora, D. Bickford, and J. E. M. Watson. 2016. The broad footprint of climate change from genes to biomes to people. *Science* 354(6313):7671. https://doi.org/10.1126/science.aaf7671

Silva, M. R. O., and P. F. M. Lopes. 2015. Each fisherman is different: taking the environmental perception of small-scale fishers into account to manage marine protected areas. *Marine Policy* 51:347-355. https://doi.org/10.1016/j.marpol.2014.09.019

Sumaila, U. R., W. Cheung, A. Dyck, K. Gueye, L. Huang, V. Lam, D. Pauly, T. Srinivasan, W. Swartz, R. Watson, and D. Zeller. 2012. Benefits of rebuilding global marine fisheries outweigh costs. *PLoS ONE* 7:e40542. https://doi.org/10.1371/journal.pone.0040542

Suman, D., M. P. Shivlani, and J. W. Milon. 1999. Perceptions and attitudes regarding marine reserves: a comparison of stakeholder groups in the Florida Keys National Marine Sanctuary. *Ocean & Coastal Management* 42:1019-1040. https://doi.org/10.1016/S0964-5691(99)00062-9

Teh, L. C. L., L. S. L. Teh, and M. J. Meitner. 2012. Preferred resource spaces and fisher flexibility: implications for spatial management of small-scale fisheries. *Human Ecology* 40:213-226. https://doi.org/10.1007/s10745-012-9464-9

Thiault, L., P. Marshall, S. Gelcich, A. Collin, F. Chlous, and J. Claudet. 2018. Mapping social-ecological vulnerability to inform local decision making. *Conservation biology* 32(2):447-456. https://doi.org/10.1111/cobi.12989

Tolentino-Arévalo, O., M. Markantoni, A. Espinoza-Tenorio, and M. A. Mesa-Jurado. 2019. Drivers of adaptive capacity to climate change in coastal fishing communities of Tabasco, Mexico. Pages 125-147 *in* S. Salas, M. J. Barragán-Paladines, and R. Chuenpagdee, editors. *Viability and sustainability of small-scale fisheries in Latin America and the Caribbean*. Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-319-76078-0_6

Tschakert, P., B. van Oort, A. L. St. Clair, and A. LaMadrid. 2013. Inequality and transformation analyses: a complementary lens for addressing vulnerability to climate change. *Climate and Development* 5(4):340-350. https://doi.org/10.1080/17565529.2013.828583

Vidal, M. R., and E. V. Silva. 2007. Caracterização e delimitação das unidades geoambientais da reserva extrativista do Batoque-Aquiraz/CE como subsídio para a elaboração do plano de manejo. *Culture and Science Periodicals* 2(2):1-10.

Wei, T., and V. Simko. 2017. R package “corrplot”: visualization of a correlation matrix. Version 0.84. [online] URL: https://github.com/taiyun/corrplot

Whitney, C. K., N. J. Bennett, N. C. Ban, E. H. Allison, D. Armitage, J. L. Blythe, J. M. Burt, W. Cheung, E. M. Finkbeiner, M. Kaplan-Hallam, I. Perry, N. J. Turner, and L. Yumagulova. 2017. Adaptive capacity: from assessment to action in coastal socialecological systems. *Ecology and Society* 22(2):22. https://doi.org/10.5751/ES-09325-220222

World Wildlife Fund (WWF). 2016. *Situação e tendências da pesca marítima no Brasil e o papel dos subsídios.* WWF-Brasil, São Paulo, Brasil.

Worm, B., R. Hilborn, J. K. Baum, T. A. Branch, J. S. Collie, C. Costello, M. J. Fogarty, E. A. Fulton, J. A. Hutchings, S. Jennings, O. P. Jensen, H. K. Lotze, P. M. Mace, T. R. McClanahan, C. Minto, S. R. Palumbi, A. M. Parma, D. Ricard, A. A. Rosenberg, R. Watson, and D. Zeller. 2009. Rebuilding global fisheries. *Science* 325(5940):578-585. https://doi.org/10.1126/science.1173146

Appendix 1. Building the Social-Ecological Resilience Index

Please click here to download file 'appendix1.pdf'.

Appendix 2 - Measuring the components of social-ecological resilience index

Here, we explain how to estimate the variables in each component of the SERI: social resilience at the individual level (SRi), social resilience at the community level (SRc), and ecological resilience (ER). Component values are the average of their indicators, whereas the SERI is the average of the three components: SERI = (SRi + SRc + ER)/3. Components, indicators, and sub-indicators, and the score calculation are detailed below (See table A2.1).

Social resilience at the individual level (SRi)

This component includes aspects regarding social resilience at the individual level, considering the personal characteristics of individual fishers. SRi was measured through four indicators: flexibility (FLEi), ability to learn (AL), ability to organize (AO) and personal assets (ASi).

The FLEi indicator was based on four sub-indicators: flexibility to change, perception of MPA, resource use diversification, and gear diversification. Flexibility to change seeks to determine whether fishers would be open to changing their economic activity. Fishers who did not want to change their economic activity scored zero, whereas those that said they would be willing to change scored 1 point. The perception of the MPA reflects fishers' flexibility in a context of change and uncertainty of resource policies or conservation initiatives which affect the resilience of people in response to these changes (Suman et al. 1999, Marshall 2007). We used the fishers' acceptance of the planning or implementation of the MPA as a sub-indicator of the flexibility at the individual level. Fishers who agreed that a protected area was needed scored 1 point and those who disagreed were attributed 0. The resource use diversification sub-indicator was estimated from the number and types of natural resources exploited by an individual fisher. Fishers who exploited marine and terrestrial resources received 1 point; those who only exploited marine resources received 0.5 points, and those who only exploit fish received zero points (0 points). The gear diversification sub-indicator was measured by the ratio of the number of fishing gears used by a fisher and the variety of fishing gears represented in the sample, i.e., the number of fishing gears used by all the fishers interviewed.

The AL indicator refers to the years of schooling, fishing experience, and awareness of fishing impacts. The level of schooling, specifically, was calculated by the years of formal education achieved by a fisher and the relationship between the Brazilian average formal education and the average of all fishers in the sample. Fishers with a score below the average Brazilian schooling level did not receive points, those whose level was between the Brazilian and the sample average received 0.5 points and those who had a higher level than the sample average received 1 point. Fishing experience was measured by the ratio between fishing experience in years of an individual fisher and his age. Awareness of fishing impacts was estimated by a fisher's perception of the causes of stock reduction (e.g., overfishing, sea pollution, lack of governance, religion, predatory fishing and illegal fishing). Fishers who were unaware of the causes of stock reductions or quoted religion as a reason did not receive any points, those who quoted only one documented cause (e.g., overfishing, sea pollution, lack of governance, and illegal fishing) received 0.5 points, and those who quoted more than one documented cause received 1 point.

The ability to organize (AO) indicator covers aspects related to a fisher's ability to self-organize to prepare for changes to the socio-ecological system, either within the community or in their fishing activities. We understand that such an ability could include financial security, fishing investment, involvement in an association, and migration (but see below regarding how migration can be interpreted either way, depending on the situation). Financial security was assessed by the existence of alternative sources of income (e.g., savings or property), whereas fishing investment was measured by ownership of at least one boat. Fishers that had some sort of financial security or owned a boat scored 1 point in each of these sub-indicators, respectively. The association involvement sub-indicator is estimated by the involvement and frequency that a fisher participates in any community organization (e.g., fisher association, neighborhood organization). Fishers who were not involved with any organization did not score, those who were involved but rarely participated in meetings (maximum once a year) scored 0.5 points and those who showed a higher level of involvement (two or more meetings a year, which were generally held once a month) scored 1 point. Migration can be either understood to be a risk to societies, given its disruption to social and economic systems, or as an effective adaption strategy to environmental changes, given that it provides and alternative to people during harsh periods in their original place (Adger et al. 2015). Here, we used the second concept of migration to show a fisher's ability to deal with emerging risks in the communities, such as the loss of ecosystem services. Emigration may be the most effective way to allow people to diversify their income and build resilience when environmental changes threaten livelihoods (Adger 2000), and thus can function as an adaptive response to these changes. Considering that the communities examined here have similar socioeconomic and environmental characteristics, and there are overfishing concerns with some fish species, we expected equally emerging risks among fishers. Considering that the communities examined here have similar socioeconomic and environmental characteristics, and some of the target species may be overfished or overexploited, we expected equally emerging risks among fishers. Migration was estimated based on a fisher's relationship to the community they live in, by analyzing the number of years the outside fishers have been living in the community and the number of years they have been fishing there. Native fishers or fishers who migrated to the community in their childhood are not considered migrants and they did not receive points. However, if a fisher had migrated after they had turned 18 (adulthood in Brazil), and only then began to fish there, then they were considered to be a migrant and received 1 point.

Quantitative data on quality of life was used to estimate a fisher's' assets through the proxy "number of home appliances" (Cinner and Pollnac 2004). Our sub-indicator, assets at the individual level (ASi), measured an individual's material style of life based on the presence of household possessions from a list of 21 appliances, such as television, radio, gas stove, car, and refrigerator. After a normalization process was carried out to create a range between 0 and 1, we considered that those who had a greater number of appliances were more resilient.

Social resilience at the community level (SRc)

We selected three indicators to measure SRc: community flexibility (FLEc), social capital (SC) and community assets (ASc).

FLEc was measured based on economic diversification, which was established by the maximum number of economic activities for a specific reserve mentioned by interviewees and the manager of the reserve. The most resilient reserve was determined to be the one that had a greatest number of activities, whereas in the least resilient reserve the only economic activity carried out was fishing. We also carried out a normalization process to place the variable in a range between 0 (least resilient) and 1 (most resilient).

SC was estimated by fisher engagement, knowledge of management rules, collective action, social organizations and participation. Fisher engagement takes on different values depending on a fisher's level of engagement in environmental monitoring actions in the community. For example, a fisher who was engaged in any type of environmental monitoring (e.g., helping with government, university or non-governmental organization environmental projects) received 1 point and those who were not engaged did not score. Knowledge of management rules was based on a fisher's knowledge about local management rules in their communities: fishers who did not know the rules (0 points), fishers who knew one rule (0.5 points) and those who knew more than one rule (1 point). In turn, collective action was measured by demand for the reserve creation. Local demand (1 point) was considered more resilient in opposition to a top-down initiative (0 point), as local demand is assumed to promote community involvement in the management and promotion of SER (Gunderson, 2000). The social organizations sub-indicator was measured by the presence of social and fishery organizations in the MPA's region. Only reserves with social organizations were attributed 1 point and they were considered more resilient than the others. The fisher participation sub-indicator assessed the level of engagement that fishers have in social organization meetings and events (s/he acts only as a spectator, issues opinions, proposes ideas, etc.); essentially, it assessed whether a fisher participation is active or passive. The active fishers were attributed 1 point and the passive ones did not score. Fisher engagement, knowledge of management rules, and fisher participation sub-indicators were measured as the percentage of fishers who scored 0 or 1 in each reserve.

ASc was measured from fieldwork observations of the presence of 12 community-level aspects of infrastructure: schools, pharmacies, electrical services, banking access, sewage collection and treatment, access roads, food markets, phone services, post office service, police service, health centers, and hotels. The total number of infrastructure aspects by reserve was normalized to attribute a proportional score to each community which ranged from 0 to 1, whereby 1 was assigned to the reserve with most infrastructure.

Ecological resilience (ER)

Here, estimates of biological sensitivity (BS) and fish species exposure (FSE) were used as input indicators to determine the ER of the coastal ecosystem.

Four sub-indicators were used to estimate BS: climate exposure, coral bleaching risk, resilience of fish species and vulnerability of fish species. To measure climate exposure, we considered the differences in the average temperatures in the study area between 2011 (year of the sample) and the period 1985-2000, based on a dataset provided by the National Oceanic and Atmospheric Administration - NOAA (http://www.noaa.gov). According to the RCPs

(Representative Concentration Pathways) scenarios from the Intergovernmental Panel on Climate Change (IPCC), the RCP8.5 scenario is the worst for the climate. It ranges from 0.71 to 2.73 ° C in the 2090s compared to the 1990s (Bopp et al. 2013). Here, we considered an increase of up to 0.5ºC to be low (1 point), between 0.6 ºC and 2ºC to be medium (0.5 points) and over 2ºC to be high (0 points).

Coral bleaching risk was estimated by the presence of coral bleaching events in the study area, available from the Global Information System for Coral Reefs (http://www.reefbase.org). Based on the ReefBase categories of bleaching events (no bleaching, low bleaching, medium bleaching, and high bleaching), we attributed a score for coral bleaching risk: presence of one high bleaching event did not score, presence of low or medium bleaching events scored 0.5 points and absence of bleaching events scored 1 point.

Biological information on target fish can be extracted from scientific datasets available online. We used the indexes of fish species vulnerability (VUL) and resilience available in FishBase (httt://fishbase.org, Froese and Pauly 2017). The vulnerability index integrates the fish species characteristics related to their ecology and life history using fuzzy logic (Cheung et al. 2005). Similarly, the resilience index combines biological parameters of a species' life history with the intrinsic rate of population growth as the main determinant of resilience because it is the most complete parameter. Resilience is expressed on a scale that varies from very low, low, medium, and high and vulnerability is expressed by low, moderate, high, and very high. Following the FishBase classification, we created three categories for each indicator: low resilience – 0 points (including the very low and low categories), moderate resilience – 0.5 points (including the medium category), and high resilience - (including the high and very high categories); and low vulnerability – 1 point (including the low category), moderate vulnerability – 0.5 points (including the moderate category), and high vulnerability – 0 points (including the high and very high categories). Once we had those, we searched this information for all fish species caught by each fisher, as cited in the interviews, and used the mean as our sub-indicator value.

The economic demand sub-indicator follows the same estimates of scores and averages used in the VUL sub-indicator. For the threat level sub-indicator, we estimated the score by critically endangered or endangered (0 points), vulnerable (0.5 points) and near threatened, least concern or data deficient (1 point). We double-checked the status presented on FishBase with the status on the Brazilian Red List (Decree nº 445; Brazil's Red List 2014) (MMA 2014) and, whenever there was some divergence, we assumed the latter to be more accurate as it was more recent.

Table A2.1: Information used to calculate the Social-Ecological Resilience Index (SERI) of fishers, including components, indicators and sub-indicators. The specified data source is provided for each sub-indicator. RDSE Ponta do Tubarão = State Sustainable Development Reserve Ponta do Tubarão; RESEX Batoque = Extractive Reserve Batoque; RESEX Canto Verde = Extractive Reserve Prainha do Canto Verde.

Component / Indicator / Sub-indicador		**Information**	**Calculation/Scores**	**Data source**
Social Resilience at individual (SRi)				
Flexibility (FLEi)	Flexibility to change	Whether fishers were open to change or did not want to change their economic activity	Open to change = 1 Not open to change = 0	Survey question
	Resource Use Diversification	Number and types of natural resources used by fishers	Only fish = 0 Fish + other marine resource = 0.5 Fish + other resources = 1	Survey question
	Gear Diversification	Total number of fishing gear used by a fisher (FGF) Total number of fishing gear in the sample (FGS)	GD = FGF / FGS	Survey question
	Perception toward MPA	Fisher acceptance of the planning or implementation of MPAs	Agree = 1 Disagree = 0	Survey question
Ability to Learn (AL)	Years of schooling	Years of formal education achieved by a fisher (YS) Average of all fishers in the sample (μ Sample) Country average formal education (μ Brazil=5.8 ys)	LS < μ Country = 0 μ Country < LS < μ Sample = 0.5 LS > μ Sample = 1	Survey question mec.gov.br
	Fishing Experience	Fishers' age (FA) Fishing time in years (FT)	FE = FT / FA	Survey question

	Awareness of fisheries impacts	Fisher perception of the causes of stock declines (overfishing, sea pollution, lack of governance, religion, predatory fishing and illegal fishing)	Did not know about causes or quoted religion = 0 Quoted only one cause = 0.5 Quoted more than one cause = 1.0	Survey question
Ability to Organize (AO)	Financial Security	Whether the fisher has alternative sources of income (e.g., savings or property)	Yes = 1 No = 0	Survey question
	Fishing Investment	Whether the fisher owned a boat	Yes = 1 No = 0	Survey question
	Migration	Number of years the outside fisher had been living in the community Number of years the fisher had been fishing there	Native fishers and those who migrated to the community during their childhood = 0 Fisher had migrated after adulthood and only then he began to fish there = 1	Survey question
	Association Involvement	Fisher involvement (yes or no) Frequency of a fisher participation in a community organization (low = maximum of once a year, high = > twice year)	No involvement= 0 Low frequency = 0.5 High frequency = 1.0	Survey question
Assets (ASi)	Material style of life	Measured through the proxy "number of home appliances" by household.	Normalization process[a] was used to assign a proportional score to each fisher.	Survey question
Social Resilience at community (SRc)				
Flexibility (FLEc)	Economic diversification	The number of economic activities mentioned by interviewees and managers. The more resilient reserve was the one that had the greatest number of activities, whereas the only economic activity in the least resilient reserve was fishing.	Normalization process[a] was used to assign a proportional score to each community. RDSE Ponta do Tubarão = 5 RESEX Batoque = 4; RESEX Canto Verde = 6	Survey question

Social capital (SC)	Fisher engagement	Percentage of fishers engaged in environmental monitoring in the community	Engaged = 1 Not engaged = 0	Survey question
	Knowledge of management rules	Fisher knowledge of management rules inside or outside MPAs	Do not know the rules = 0 Know only one rule = 0.5 Know more than one rule = 1	Survey question
	Collective action	Demand for MPA creation: local demand (by community) or top-down initiative (by the government)	Local = 1 Top-down = 0	Manager's information
	Social organization	Presence of social and fisheries organizations in the MPA's region	Yes = 1 No = 0	mapaosc.ipea.gov.br
	Fisher participation	Percentage of participation of active fishers in the community organization	Active = 1 Passive = 0	Survey question
Assets (ASc)	Infrastructure	Measured through the presence of the community infrastructure, such as schools, pharmacies, electrical services, banking access, sewage collection and treatment, access roads, food markets, phone services, post office service, security service, health centers, and hotels	Normalization process[a] was used to assign a proportional score to each community. RDSE Ponta do Tubarão = 12; RESEX Batoque = 7; RESEX Canto Verde = 7.	Fieldwork observation
Ecological Resilience (ER)				
Biological sensitivity (BS)	Climate Exposure	Average SST in the year of the sample in the study area and average SST in the period between 1985-2000 in the study area	Low (increase up to 0.5ºC) = 1 Med (increase between 0.6/2ºC) = 0.5 High (increase over 2ºC) = 0	noaa.gov
	Coral Bleaching Risk	Frequency and intensity of coral bleaching	Presence of at least 1 high event = 0 Presence of low/medium event = 0.5 Absence of event = 1	reefbase.org

	Resilience of fish species	Resilience of fish species caught by fishers in the community	Low = 0 Med = 0.5 High = 1	fishbase.org
	Vulnerability of fish species	Vulnerability of fish species caught by fishers in the community	Low = 1 Med = 0.5 High = 0	fishbase.org
Fish Species Exposure (FSE)	Price category of fish species	Price Category of fish species caught by fishers in the community	Low = 1 Med = 0.5 High = 0	fishbase.org
	Threat Level of fish species	Threat Level of fish species caught by fishers in the community	Critical Endagerous / Endagerous = 0 Vulnerable = 0.5 Not threat / Least concern / Data deficient = 1	fishbase.org

[a]Normalization process means a standardization ranging from 0 (least resilient) to 1 (most resilient). To that end, we assigned the higher value of the variable with 1 point and we proportionally calculated the value for each fisher.

REFERENCES

Adger, W. N., N. W. Arnell, R. Black, S. Dercon, A. Geddes, and D. S. G. Thomas. 2015. Focus on environmental risks and migration: causes and consequences. *Environmental Research Letters* 10(6):60201.

Bopp, L., L. Resplandy, J. C. Orr, S. C. Doney, J. P. Dunne, M. Gehlen, P. Halloran, C. Heinze, T. Ilyina, R. Seferian, J. Tjiputra, and M. Vichi. 2013. Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models. *Biogeosciences* 10, 6225–6245.

Cheung. W. W. L., T. J. Pitcher, and D. Pauly. 2005. A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing. *Biological Conservation*, 124: 97-111.

Cinner, J. E., and R. B. Pollnac. 2004. Poverty, perceptions and planning: why socioeconomics matter in the management of Mexican reefs. *Ocean & Coastal Management* 47(9–10):479–493.

Froese, R., and D. Pauly. 2017. FishBase - World Wide Web Eletronic Publication. www.fishbase.org.

Gunderson, L.H., 2000. Ecological Resilience — In theory and apllication. *Annu. Rev. Ecol. Syst.* 31, 425–39.

Marshall, N.A. 2007. Can policy perception influence social resilience to policy change? *Fisheries research*, 86, 216–227.

MMA, Ministério do Meio Ambiente, Brazil. 2014. Portarias Nos. 443, 444, 445, de 17 de Dezembro de 2014. Diário of União Seção 1 2014;245:110 (18 December 2014).

Nayak, P. K., L. E. Oliveira, and F. Berkes. 2014. Resource degradation , marginalization, and poverty in small-scale fisheries : threats to social-ecological resilience in India and Brazil. *Ecology and Society* 19:73.

Suman, D., Shivlani, M. P., and Milon, J. W. 1999. Perceptions and attitudes regarding marine reserves: a comparison of stakeholder groups in the Florida Keys National Marine Sanctuary. *Ocean and coastal management*, 42, 1019–1040.

Appendix 3. Questionnaire

This appendix contains the questionnaire used to interview fishers in the three marine protected areas located on the Brazilian northeastern coast.

Questionnaire

Does the fisher consent to participate in the interview: ( ) Yes ( ) No
(If no, cease the interview.)

Reserve: ___________________________ Community: ______________________

Socioeconomic Aspects

1. Age: _________________ 2. Gender: ( )Female ( ) Male
3. Marital status: ( )Single ( ) Married ( ) Widower ( ) Separate/Divorced
4. Where are you from: ( ) Community ( ) Another village ( ) Outside the community
5. Which community, city, state: ____
6. How many years living in the community: ___________________________________
7. Profession of father: ____
8. Fishing time: ____
9. How long fishing community: ____
10. What do you do in the fishing activity: (Can select more than one option)
( ) Boat owners ( ) Partner fisher ( ) Employee fisher
( ) Boat conductor ( ) Autonomous fisher ( ) Other: _________
11. Do you have any own vessel?
( ) Motorized small boat ( ) Canoe ( ) Boat ( ) Other: _____
( ) *Baitera* (small boat) ( ) Raft ( ) Motorized boat
12. Which fishing gear do you use? (Can select more than one option)
( ) Trawl ( ) *Jereré* (a hand net shaped like a funnel) ( ) Dive
( ) Hook and line ( ) *Manzuá* (semi-fixed bottom trap) ( ) Flashlight
( ) Gillnet ( ) *Espinhel* (hook and line trap) ( ) Casting net
( ) Hand collecting ( ) Seine nets ( ) Others:____

Indicator of Flexibility

13. Do you have others jobs: ( ) Yes ( ) No Which: _________________
14. What is the most important activity as a source of income? ______________________
15. What is the most important activity as the power supply?_______________________
16. Financial contribution of each activity in family income (%): ___________________
17. How many people living in your home: _____________________________________
18. How many people fish in your home: _______________________________________
19. How many people work in your home and what work? _________________________
20. Do you want that your son to be fisherman? ( )Yes ( ) No Why? _________
21. Do you have own house? ( )Yes ( ) No
22. If the fish ran out and you could not to fish anymore, do you think that you could find a job in the community:

( )Yes ( ) No ( ) Maybe Why? ______________________________

23. If the fish ran out and you could not to fish anymore, do you think you are young enough to get another job (apart from fishing) in the community:

( )Yes ( ) No ( ) Maybe Why? ______________________________

24. If the fish ran out and you could not to fish anymore, do you think you are more prone to adapt than other fishers?

( )Yes ( ) No ( ) Maybe Why? ______________________________

25. Would you like to work in another job (apart from fishing):

( )Yes ( ) No ( ) Maybe Which? _______________ Why? ________

26. Do you have wife: ( )Yes ( ) No

27. What is your wife's educational level:

( ) Illiterate ( ) 1 - 3 years of school ( )High school

( ) Only write your name ( ) Literate ( ) Graduate

28. How old is your wife: ____

29. Does she participate in the fishery: ( )Yes ( ) No

30. How frequently does your wife participate in the fishery (daily/weekly/monthly): __

31. Does she have any additional work: ( )Yes ( ) No

32. How many people are supported by the fisher (dependents): ____________________

33. Which resources do you catch besides fish: __________________________________

34. When is the fishery is better and worse: _____________________________________

35. Which resources are more utilized when the fishing is down: ___________________

36. In the reserve, can you exploit everything or there is some rule about the use of resources:

( )Yes ( ) No Which rule: ___________________________

37. Are there some marine resource that cannot be eaten in specific period of year:

Which marine resource: ____

Which period of year: ____

Why it is prohibited: ____

Indicator of Ability to organize

38. Are there any community organizations or fishermen's associations:

( ) Yes ( ) No Which: ______________________________________

39. Do you or someone from your family participate in these organizations:

( ) Yes ( ) No Which: ______________________________________

40. How often do you take part:

( ) Once for week ( ) Once for month ( ) Once for year

41. Do your family take part in decision making processes in the community?

( )Yes ( ) No Why? ______________________________________

42. How are you involved in this process? What do you do? ________________________

43. Is this active or passive participation? ( ) Active ( ) Passive

44. Do you think that you should invest in your fishery (e.g.: new gear or boats)?

( )Yes ( ) No ( ) Maybe How? _________________________________

Why? ____

Other investment: ____

45. Do you have any plans for your financial security?

( ) Any trade ( ) Savings ( ) Other property for rent ( ) Others

If others, which: ____

Indicator of Ability to learn

46. School degree:

( ) Illiterate ( ) 1 - 3 years of school ( )High school
( ) Only write your name ( ) Literate ( ) Graduate

47. Do you think that anything can affect the fish stock? What?

( ) Do not know ( ) Agrotoxics ( ) Industry ( ) Lack of inspection
( ) Water pollution ( ) Tourism ( ) Garbage ( ) Aquaculture
( ) Overfishing ( ) Outside fishers ( ) Crops ( ) Lack of public policies
( ) Predatory fishing ( ) Sewage ( ) Lack of fishery sector

Others: ____

48. Could you do anything to decrease the fish stocks in the ocean? How?

( ) Fishing in reproductive period ( ) Fishing small fishes ( ) Polluting the ocean
( ) Fishing outside of community ( ) Fishing a lot ( ) Predatory fishing

Why? ____

49. Could you do anything to increase the fish stocks in the ocean? What? __________

50. Do you know if there is an organization that implements environmental actions or has supervision over environmental actions in the community? Which? ____

51. Are there some environmental monitoring (about fishes, plants, wood, and others natural resources) in the community? Do you participate?

( ) There is, but I do not participate. ( ) There is, and I participate. ( ) Do not know.

52. How is the environmental monitoring done in the community? ________________

53. Who does the environmental monitoring in the community? _________________

54. Does the community help in environmental monitoring? ____________________

55. Would you like to have some involvement in creating environmental regulations?

( ) I would not like that.
( ) Only on fishery sector.
( ) Yes, but in other work besides fishery.

56. If you could not fish anymore, would you be willing to learn a new activity as a source of income?

( )Yes ( ) No ( ) Maybe Why? ___________________________

Indicator of Infrastructure

57. Are there other income generating activities in your community? ______________

58. Could you suggest any additional income generating activities to be implemented in the community?

59. Which building materials are used in the construction of your house:

( ) Brick and cement ( ) Wood ( ) Branches and straw ( ) Wood and mud

Floor: __________________ Walls: __________________ Roof: _____________

60. Which infrastructure items do you have in your house:

( ) TV ( ) Home phone ( ) Microwave ( ) Satellite dish
( ) Freezer ( ) Mobile phone ( ) Wash machine ( ) Motorcycle
( ) Refrigerator ( ) VCR ( ) Stove ( ) Air conditioning
( ) Car ( ) DVD ( ) Blender ( ) Stereo
( ) Bike ( ) Cable TV ( ) Ventilator( ) Computer

61. How do you describe the house of a wealthy person:

( ) TV ( ) Home phone ( ) Microwave ( ) Satellite dish
( ) Freezer ( ) Mobile phone ( ) Wash machine ( ) Motorcycle
( ) Refrigerator ( ) VCR ( ) Stove ( ) Air conditioning
( ) Car ( ) DVD ( ) Blender ( ) Stereo
( ) Bike ( ) Cable TV ( ) Ventilator( ) Computer

62. How do you describe the house of a poor person:

( ) TV ( ) Home phone ( ) Microwave ( ) Satellite dish
( ) Freezer ( ) Mobile phone ( ) Wash machine ( ) Motorcycle
( ) Refrigerator ( ) VCR ( ) Stove ( ) Air conditioning
( ) Car ( ) DVD ( ) Blender ( ) Stereo
( ) Bike ( ) Cable TV ( ) Ventilator( ) Computer

63. Which infrastructure basic have in your community:

( ) Schools ( ) Hotels ( ) Sewage collection and treatment ( ) Pharmacies ( ) Access roads ( ) Security service
( ) Electrical services ( ) Food markets ( ) Post office service
( ) Banking access ( ) Phone services ( ) Health centers

Ecological Aspects

Fishing gear	Species	Preferred Species

64. How long during your fishery (summer/winter)? ______________________________
65. How much do you catch (daily/weekly/monthly)? ____________________________
About the implementation and management of the reserve:
66. Do you agree with the implementation?
( )Yes ( ) No Why? ____
67. Do you think that fishing was better before or after the implementation?
( ) Before ( ) After Why? ____
68. Do you wish to remain in the reserve?
( )Yes ( ) No ( ) Maybe Why? __________________________
69. Do you know any management rules?
( )Yes ( ) No Which? ____________________________________
70. Are these management rules revised? ( )Yes ( ) No ( ) Do not know
71. When these management rules are revised?
( ) Every year ( ) Requested by community ( ) Only with government change
72. What changes have happened in the management rules? _______________________
73. Why were the management rules changed? ____________________________________
74. Who changed the management rules? ____

Appendix 4: Biological traits of the fish species caught by fishers

This appendix contains the information used to calculate some resilience indicators from the ecosystem level component: resilience of fish species (RES), vulnerability of fish species (VUL), fish price category, and fish threat level (TL).

Table A4.1: List of fish species caught and cited by fishers during the interviews. The Fishbase categories were collected in Fishbase.org. The SERI scores were calculated following the instructions for Biological sensitivity in Section 2 of the manuscript. Some species were not identified (*) and an average value of species that occur in the region was used (using family, order and genus levels). SERI = Social-Ecological Resilience Index, RES = Resilience, VUL = Vulnerability, PC = Price category, TL = Threat level, med = medium, lc = least concern, vu = vulnerable, dd = data deficient, en = endangered, cr = critically endangered, nt = near threatened.

Fish species		Fishbase categories				SERI scores			
Common name	Scientific name	RES	VUL	PC	TL	RES	VUL	PC	TL
Serra	*Scomberomorus brasilliensis*	med	high	high	lc	0.5	0	0	1
Cavala	*Scomberomorus cavalla*	low	high	med	lc	0	0	0.5	1
Cioba	*Lutjanus analis*	low	high	high	vu	0	0	0	0.5
Agulhinha	*Hemiramphus brasiliensis*	med	med	med	lc	0.5	0.5	0.5	1
Tainha*	*Mugil curema*	med	high	med	lc	0.5	0	0.5	1
	Mugil liza	med	med	high	dd	0.5	0.5	0	1
Cação*	*Rhizoprionodon lalandii*	low	med	med	dd	0	0.5	0.5	1
	Rhizoprionodon porosus	low	high	med	lc	0	0	0.5	1
Bonito	*Auxis thazard*	med	low	high	lc	0.5	1	0	1
Bagre*	*Bagre bagre*	low	high	med	lc	0	0	0.5	1
	Bagre marinus	low	high	med	lc	0	0	0.5	1
Moréia*	*Gymnothorax funebris*	low	high	med	lc	0	0	0.5	1

	Channomuraena vittata	low	high	med	lc	0	0	0.5	1
	Gymnothorax moringa	low	high	med	lc	0	0	0.5	1
	Gymnothorax vicinus	low	high	med	lc	0	0	0.5	1
Sardinha	*Opisthonema oglinum*	med	low	low	lc	0.5	1	1	1
Guarajuba	*Carangoides bartholomaei*	high	high	med	en	1	0	0.5	0
Raia*	*Dasyatis guttata*	low	high	low	dd	0	0	1	1
	Gymnura micrura	low	high	med	dd	0	0	0.5	1
	Dasyatis americana	low	high	low	dd	0	0	1	1
	Dasyatis centroura	low	high	low	cr	0	0	1	0
Camurim	*Centropomus parallelus*	med	high	high	lc	0.5	0	0	1
Camurupim	*Megalops atlanticus*	low	high	med	vu	0	0	0.5	0.5
Salema	*Anisotremus virginicus*	med	med	med	lc	0.5	0.5	0.5	1
Voador	*Hirundichthys affinis*	high	low	med	lc	1	1	0.5	1
Galo do alto	*Alectis ciliares*	low	high	med	lc	0	0	0.5	1
Carapicu*	*Eucinostomus argenteus*	med	med	med	lc	0.5	0.5	0.5	1
	Eucinostomus gula	med	med	med	lc	0.5	0.5	0.5	1
	Eucinostomus melanopterus	high	low	med	lc	1	1	0.5	1
Vermelho	*Lutjanus buccanella*	med	high	high	dd	0.5	0	0	1
Carapeba	*Diapterus rhombeus*	high	low	med	lc	1	1	0.5	1
Atum	*Thunnus alalunga*	med	high	high	nt	0.5	0	0	1
Sirigado	*Mycteroperca bonaci*	low	high	high	vu	0	0	0	0.5
Dourado	*Coryphaena hippurus*	high	med	high	lc	1	0.5	0	1
Xaréu*	*Caranx hippos*	med	med	med	lc	0.5	0.5	0.5	1
	Caranx lugubris	low	high	high	lc	0	0	0	1
	Carangoides ruber	med	high	med	lc	0.5	0	0.5	1
Arabaiana*	*Seriola dumerili*	med	high	high	lc	0.5	0	0	1
	Seriola rivoliana	low	high	high	lc	0	0	0	1
Anchova*	*Pomatomus saltator*	med	high	high	vu	0.5	0	0	0.5
	Pomatomus saltatrix	med	high	high	vu	0.5	0	0	0.5

Pescada*	*Macrodon ancylodon*	med	med	med	lc	0.5	0.5	0.5	1
	Cynoscion leiarchus	med	med	med	lc	0.5	0.5	0.5	1
	Cynoscion acoupa	med	high	med	lc	0.5	0	0.5	1
Ariacó	*Lutjanus synagris*	med	med	med	nt	0.5	0.5	0.5	1
Bicuda*	*Sphyraena guachancho*	low	high	med	lc	0	0	0.5	1
	Sphyraena picudilla	med	high	med	en	0.5	0	0.5	0
Palombeta	*Chloroscombrus chrysurus*	med	med	low	lc	0.5	0.5	1	1
Espada*	*Alepisaurus ferox*	low	high	na	lc	0	0	na	1
	Gempylus serpens	high	high	na	lc	1	0	na	1
Biquara	*Haemulom plumieri*	med	high	med	en	0.5	0	0.5	0
Cangulo	*Balistes vetula*	med	med	med	nt	0.5	0.5	0.5	1
Mariquita	*Holocentrus ascensionis*	med	med	med	lc	0.5	0.5	0.5	1
Piraúna	*Cephalopholis fulva*	low	high	high	lc	0	0	0	1
Meca	*Xiphias gladius*	med	high	high	lc	0.5	0	0	1
Garoupa*	*Epinephelus marginatus*	low	high	high	en	0	0	0	0
	Epinephelus striatus	low	high	high	en	0	0	0	0
	Epinephelus morio	med	high	med	vu	0.5	0	0.5	0.5
Coró*	*Haemulopsis corvinaeformis*	high	low	med	lc	1	1	0.5	1
	Conodon nobilis	med	med	low	lc	0.5	0.5	1	1
Sapuruna	*Haemulon steindachneri*	med	med	med	lc	0.5	0.5	0.5	1
Pira	*Malacanthus plumieri*	low	high	high	lc	0	0	0	1
Maria mole	*Paralonchurus brasiliensis*	high	low	med	lc	1	1	0.5	1
Guaíuba	*Ocyurus crysurus*	low	high	med	en	0	0	0.5	0
Pargo	*Lutjanus purpureus*	low	high	high	vu	0	0	0	0.5
Zambaia	*Ablennes hians*	med	med	high	lc	0.5	0.5	0	1
Dentão	*Lutjanus jocu*	low	high	high	en	0	0	0	0
Cururuca	*Micropogonias furnieri*	med	med	med	lc	0.5	0.5	0.5	1
Albacora*	*Thunnus albacares*	med	high	high	nt	0.5	0	0	1
	Thunnus atlanticus	med	high	med	lc	0.5	0	0.5	1

Appendix 5: The hierarchical Bayesian Generalized Linear Mixed Model (BGLMM)

Explanatory variables for the BGLMM

The information used to calculate the explanatory variables was accessed from the data collection survey with fishers in 2011. In addition to the socioeconomic aspects of fisher' households and fisher personal characteristics, we collected data on their fishing activities, including catch, fishing gear, fishing boats, fisheries, fishing crew, and time spent on a fishing trip (to and from the fishing grounds). For the Bayesian model we used fisher age, the household economic dependence on fishing (HD), and the catch per unit effort (CPUE). CPUE was estimated from the fisheries catch (in kg) and effort (days and hours) for each fisher. It was log transformed to approximate normality. The HD variable was measured based on the proportion of people who depend on fishing as an economic activity by household. Table A5.1 below shows these explanatory variables for each of the 100 fishers in the three marine protected areas.

Table A5.1: Explanatory variables of the 100 fishers in the three reserves: Reserva de Desenvolvimento Sustentável Estadual Ponta do Tubarão (RDSE Ponta do Tubarão, N=40), Reserva Extrativista Batoque (RESEX Batoque, N=30), and Reserva Extrativista Prainha do Canto Verde (RESEX Canto Verde, N=30). HD = household economic dependence on fishing; CPUE = Capture per unit of effort.

		Variables		
Fishers	MPAs	Age	HD	CPUE (-Kg/h)
1	RDSE	36	0.143	0.921
2	RDSE	56	0.333	0.398
3	RDSE	48	0.500	0.523
4	RDSE	63	0.556	0.620
5	RDSE	47	0.167	2.125
6	RDSE	32	0.400	0.620
7	RDSE	33	0.333	0.176
8	RDSE	63	0.833	0.444
9	RDSE	45	0.250	0.319
10	RDSE	49	0.500	0.620
11	RDSE	52	0.500	2.243
12	RDSE	36	0.500	1.921
13	RDSE	61	0.400	-0.079
14	RDSE	33	0.250	1.018
15	RDSE	54	0.500	-0.079
16	RDSE	50	0.333	0.699

17	RDSE	34	0.250	-0.380
18	RDSE	58	0.400	1.523
19	RDSE	29	0.333	0.444
20	RDSE	52	0.250	-1.049
21	RDSE	58	0.091	1.301
22	RDSE	27	0.400	0.143
23	RDSE	31	0.250	0.745
24	RDSE	61	0.200	0.620
25	RDSE	59	0.429	0.319
26	RDSE	44	0.400	0.824
27	RDSE	49	0.333	0.620
28	RDSE	22	0.667	0.018
29	RDSE	61	0.143	0.620
30	RDSE	67	0.333	0.620
31	RDSE	46	0.250	0.921
32	RDSE	77	0.500	0.921
33	RDSE	35	0.333	2.243
34	RDSE	67	0.500	0.921
35	RDSE	53	0.333	2.398
36	RDSE	46	0.200	2.097
37	RDSE	41	0.500	1.574
38	RDSE	51	0.200	1.222
39	RDSE	36	0.667	1.570
40	RDSE	43	0.200	0.574
41	RESEX BTQ	38	1.000	0.491
42	RESEX BTQ	43	1.000	0.745
43	RESEX BTQ	41	1.000	-0.255
44	RESEX BTQ	41	0.250	-0.255
45	RESEX BTQ	48	0.250	1.155
46	RESEX BTQ	49	0.250	0.222
47	RESEX BTQ	35	0.333	-0.079
48	RESEX BTQ	47	0.200	-0.380
49	RESEX BTQ	24	0.250	0.620
50	RESEX BTQ	54	0.500	0.456
51	RESEX BTQ	37	0.200	0.667
52	RESEX BTQ	58	0.200	0.416
53	RESEX BTQ	25	0.200	0.699
54	RESEX BTQ	48	1.000	0.143
55	RESEX BTQ	34	1.000	-0.012
56	RESEX BTQ	43	0.333	0.366
57	RESEX BTQ	24	0.333	0.097
58	RESEX BTQ	46	0.200	0.097
59	RESEX BTQ	59	0.500	0.143
60	RESEX BTQ	47	0.143	0.319

61	RESEX BTQ	35	0.333	0.097
62	RESEX BTQ	23	0.333	-0.012
63	RESEX BTQ	47	0.333	1.398
64	RESEX BTQ	37	0.500	0.796
65	RESEX BTQ	25	0.250	1.000
66	RESEX BTQ	39	0.111	-0.283
67	RESEX BTQ	54	0.500	-0.255
68	RESEX BTQ	26	0.250	1.871
69	RESEX BTQ	37	0.333	0.491
70	RESEX BTQ	61	0.333	-0.158
71	RESEX PCV	30	0.333	0.046
72	RESEX PCV	45	0.250	0.972
73	RESEX PCV	66	0.250	0.444
74	RESEX PCV	30	0.333	0.620
75	RESEX PCV	21	0.250	1.146
76	RESEX PCV	44	0.200	0.398
77	RESEX PCV	38	0.750	1.699
78	RESEX PCV	53	0.167	0.620
79	RESEX PCV	35	0.250	0.319
80	RESEX PCV	29	0.250	0.398
81	RESEX PCV	37	0.333	-0.079
82	RESEX PCV	44	0.333	0.699
83	RESEX PCV	60	0.333	1.301
84	RESEX PCV	57	0.750	1.176
85	RESEX PCV	32	0.200	-0.653
86	RESEX PCV	32	0.250	0.289
87	RESEX PCV	31	0.333	0.699
88	RESEX PCV	55	0.667	0.398
89	RESEX PCV	30	0.500	-0.234
90	RESEX PCV	27	0.571	0.491
91	RESEX PCV	23	0.500	0.491
92	RESEX PCV	58	0.500	0.667
93	RESEX PCV	58	0.333	0.871
94	RESEX PCV	43	1.000	1.699
95	RESEX PCV	53	0.125	-0.079
96	RESEX PCV	56	0.500	0.222
97	RESEX PCV	56	0.250	0.222
98	RESEX PCV	48	0.143	1.269
99	RESEX PCV	46	0.200	1.269
100	RESEX PCV	46	0.500	1.187

The beta distribution and the goodness-of-fit measures

Beta distributions have long been used in a wide range of applications involving proportions and probabilities (Gupta and Nadarajah 2004). However, only recently have they been applied to linear regression modelling (Ferrari and Cribari-Neto 2004, Smithson and Verkuilen 2006, Liu and Kong 2015, Paradinas 2016) and time-series analyses (Da-Silva and Migon 2016), to allow for bounded estimates and intervals with model parameters that are directly interpretable in terms of the response mean. For these reasons, the SERI was modeled with a beta distribution $Y_j \sim Be(\mu_j,\varphi_j)$ to avoid non-sensical predictions outside the index limits (between 0 and 1) (Paradinas et al. 2016).

In order to compare the goodness-of-fit between each model, three different measures were computed: (1) the Watanabe-Akaike information criterion (WAIC), (2) the Root Mean Square Error (RMSE), and (3) the adjusted coefficient of determination (R^2). WAIC can be viewed as an improvement to the Deviance Information Criterion (DIC) that is traditionally used in Bayesian models, and is better suited than the Akaike Information Criterion (AIC), which is usually used with frequentist modelling procedures (Spiegelhalter et al. 2002). Unlike DIC, which is conditioned on a point estimate and is not fully Bayesian, WAIC is a fully Bayesian measure and uses the entire posterior distribution to make inference about the parameters; hence, estimations are more precise (Watanabe 2010). RMSE consists in the standard deviation of the residuals and, thus, measures how much the observed values deviate from the predicted values. The R^2 expresses the percentage of variability in the response variable that was explained by the model.

REFERENCES

Da-Silva, C.Q. and H.S. Migon. Hierarchical dynamic beta model. Revstat Statistical Journal, pages 1(17), 2016.

Ferrari, S., and Cribari-Neto, F. 2004. Beta regression for modeling rates and proportions. Journal of Applied Statistics, 31: 799–815.

Gupta, A. K., and Nadarajah, S., 2004. Handbook of beta distribution and its applications. CRC press.

Liu, F and Y. Kong. zoib: an R package for Bayesian Inference for Beta Regression and Zero/One inflated Beta Regression, 2015.

Paradinas, I., M. Marín, M. G. Pennino, A. López-Quílez, D. Conesa, D. Barreda, and María Bellido, J. 2016. Identifying the best fishing-suitable areas under the new European discard ban. ICES Journal of Marine Science, 73(10), 2479-2487.

Spiegelhalter, D. J., N. G. Best, B. P. Carlin, and A. van der Linde. 2002. Bayesian measures of model complexity and fit. *Journal of the Royal Statistical Society*, Series B 64(4): 583-639.

Smithson, M. and J. Verkuilen. A better lemon squeezer? Maximum-likelihood regression with beta-distributed dependent variables. Psychological methods, 11(1):54, 2006.

Watanabe, S. 2010. Asymptotic equivalence of Bayes cross validation and widely applicable information criterion in singular learning theory. *The Journal of Machine Learning Research* 11:3571–3594.

Appendix 6: Sensitivity Analyses

Given that the decisions taken in the process of weighing the indicators equally could be unclear, we ran a sensitivity analysis to check the robustness of our findings. A sensitivity analysis is a repeat of the primary analysis but uses alternative decisions (or weights) to check uncertainty in the output of a mathematical model (Deeks et al. 2008, Nardo et al. 2008). It is also used to prove that the findings are not dependent on arbitrary decisions.

We chose four weighting schemes to check how each component contributes to estimating index values. In addition to assigning the same weight to the three components (equal weight), we also calculated the index by emphasizing one dimension at a time. We did that by assigning a ½ weight to the emphasized component and ¼ to the remaining two. This alternative was run three times: once for each emphasized component. Although the weight variations changed SERI values (Table A6.1), the ordination of the three reserves was similar in the four weighting schemes. In other words, regardless of the weight assigned to the components, the RESEX Batoque was always the least resilient, followed by RESEX Canto Verde and RDSE Ponta do Tubarão (the most resilient).

Additionally, we checked if the SERI average values were statistically different among the three reserves in the four weighting schemes. For that, we ran Kruskal-Wallis tests with pairwise comparisons (Bonferroni post-hoc tests) (Neter et al. 1996) (See table A6.2).

Table A6.1: Components and index values in the weighting scheme: equal weight (same weight among components), Emphasis SRi (SRi component weighing ½ and the other two weighing ¼), Emphasis SRc (SRc component weighing ½ and the other two weighing ¼), and Emphasis ER (ER component weighing ½ and the other two weighing ¼). SRi = Social resilience at individual level; SRc = Social resilience at community level; ER = Ecological resilience; SERI = Index of Social-Ecological Resilience. Highlighting the least resilient reserve in each weighting scheme (bold).

	Components			SERI values			
Reserves	SRi	SRc	ER	Equal weight	Emphasis SRi	Emphasis SRc	Emphasis ER
RDSE Ponta do Tubarão	0.54	0.86	0.47	0.63	0.60	0.69	0.67
RESEX Batoque	0.49	0.59	0.42	**0.50**	**0.50**	**0.52**	**0.47**
RESEX Canto Verde	0.57	0.69	0.48	0.59	0.59	0.62	0.57

Table A6.2: The SERI average values for the four weighting schemes in the three marine protected areas (MPAs) analyzed: RDSE Ponta do Tubarão, RESEX Batoque, and RESEX Canto Verde. The last two columns show the results of the Kruskal-Wallis statistical test. SERI = Social-Ecological Resilience Index. SRi = Social resilience at the individual level; SRc = Social resilience at the community level; ER = Ecological resilience; SERI = Social-Ecological Resilience Index. The least resilient reserve in each weighting scheme is highlighted in bold.

	SERI values by MPA			Statistical test	
Weighting schemes	RDSE Ponta do Tubarão	RESEX Batoque	RESEX Canto Verde	Kruskal-Wallis	p-value
Equal weight	0.63	**0.50**	0.59	40.17	$p < 0.05$
EmphasisSRi	0.6	**0.50**	0.59	21.813	$p < 0.05$
EmphasisSRc	0.69	**0.52**	0.62	67.78	$p < 0.05$
EmphasisER	0.67	**0.47**	0.57	36.16	$p < 0.05$

REFERENCES

Deeks, J. J., J. P. Higgins, and D. G. Altman. 2008. Analysing data and undertaking meta-analyses. *Cochrane handbook for systematic reviews of interventions: Cochrane book series*, 243-296.

Nardo, M., and M. Saisana. 2008. OECD/JRC handbook on constructing composite indicators. Putting theory into practice.

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. Applied linear statistical models. Vol.4, p. 318, Chicago: Irwin.