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Risk assessment of small-scale reef fisheries off the Abrolhos Bank: Snappers and groupers under a multidimensional evaluation

Marília Previero[1,2] | Maria A. Gasalla[1,2]

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

[2]Graduate Program in Oceanography, University of São Paulo, São Paulo, Brazil

Correspondence
Marília Previero, Fisheries Ecosystems Laboratory (LabPesq), Oceanographic Institute, University of São Paulo, Cidade Universitária, São Paulo, SP, Brazil.
Email: mahpreviero@gmail.com

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Abstract

In the Abrolhos Bank (Southwest Atlantic), multidimensional indicators were used in sustainability assessments and eco-labelling of data-poor reef fisheries. Potential impacts, risks and stocks vulnerabilities were evaluated based on biological, environmental, social and economic aspects by combining both adapted productivity and susceptibility analysis (PSA) and scale intensity consequence analysis (SICA). Data were obtained from local surveys with stakeholders and experts and from literature. A value chain map revealed final consumers at many locations and middleman presence. Vulnerability to overexploitation ranged from low (*Cephalopholis fulva* (L.), *Lutjanus synagris* (L.) and *Ocyurus chrysurus* (Bloch)) to moderate (*Lutjanus jocu* (Bloch & Schneider), *Epinephelus morio* (Val.) and *Mycteroperca bonaci* Poey). While moderate consequences of the catches were observed to *C. fulva*, major consequences were identified to the other five stocks. The main threat to coral reef habitats was found to be mining wastes. Poor governance may constrain fisheries sustainability in the region, while the empowerment of fishers in both governance and post-harvest processes should enhance it.

KEYWORDS

Brazil, Data-poor fisheries, ecosystem-based fisheries management, fisheries value chain, reef fish, sustainability certification

1 | INTRODUCTION

Small-scale fisheries provide broad benefits to both local fishing communities and those involved in the production and consumption chains (FAO, 2005). Despite their socio-economic importance, small-scale fisheries usually lack long-term statistical data, especially in developing countries (Ramírez, Lleonart, Coll, Reyes, & Puentes, 2017). As a consequence, management measures based on stock assessments are frequently unfeasible or inadequate because of incorrect projections or estimates (Salas, Chuenpagdee, Seijo, & Charles, 2007). Nevertheless, the fishery effects go beyond the target stocks and affect other species, habitats and ecosystems (Hobday et al., 2011). Similarly, fishery activities can also be affected by external factors, such as natural or environmental disasters (Gephart, Deutsch, Pace, Troell, & Seekelld, 2017), human disasters (e.g. Fernandes et al., 2016), climate change (Allison & Bassett, 2015; Gasalla & Diegues, 2011), labour and production relation changes (Diegues, 1983) and variations in demand and in fishing profits (Cuetos-Bueno & Houk, 2018). In addition, fishery communities and the whole fishery value chain may be affected at different levels in response to human stresses on the fishery systems. In this sense, in many situations species by species stock assessments do not represent the real threat to all the fishery systems (Cryer, Mace, & Sullivan, 2016).

Fisheries studies encompassing a multidisciplinary approach and considering the fishery ecosystem dimension, such as the ecosystem approach to fisheries (EAF) or ecosystem-based fisheries management (EBFM), can be considered revolutionary (Berkes, 2012). These studies involve management approaches that allow the incorporation of alternative information sources (such as stakeholders and fishers' knowledge) into the assessment models and decision-making processes (Fischer, Jorgensen, Josupeit, Kalikoski, & Lucas, 2015). The multidimensional fishery approaches aim to balance human and ecological well-being under the sustainable development context (Fischer et al., 2015), by incorporating the fishery ecological, social, economic and governance needs into management plans (Long, Charles, & Stephenson, 2017). In practice, EBFM is a relevant step forward for the integrated management of natural resources because it enables a holistic consideration of stakeholder and government questions (Fletcher, Shaw, Metcalf, & Gaughan, 2010). Furthermore, this approach is precautionary and adaptive and is also considered strategic for holistic fisheries management in data-poor situations (Benson & Stephenson, 2018; Fischer et al., 2015).

Risk assessment methods such as the Ecological Risk Assessment for the Effects of Fishing (ERAEF) are practical tools to support the implementation of EBFM approaches (Hobday et al., 2011). These methods are used in planning fisheries research and management activities that use fishery risk assessments and consider a range of activities potentially impacting the target and by-catch stocks, habitats and biological communities (Hobday et al., 2011). Furthermore, in regional contexts, ERAEF can also consider fishery economic aspects (Benson & Stephenson, 2018). This risk assessment method contains a framework that includes a hierarchical structure with different levels of quantification, and a precautionary approach to ecological uncertainty (Hobday et al., 2011). The ERAEF analysis can be qualitative (involving stakeholder participation), semi-quantitative or quantitative. While the less hazardous activities are detected by qualitative analyses, the more hazardous activities are detected by the semi-quantitative and quantitative analyses (Hobday et al., 2011; MSC, 2010). Lastly, the ERAEF is able to screen out the low-risk elements for each analysis type and focus on the potential issues of higher or uncertain risk (Hobday et al., 2011).

Coral reefs are a diverse ecosystem in terms of the number of associated species and geological structures and provide habitat to many fishes (Coker, Wilson, & Pratchett, 2014; Knowlton et al., 2010). They are important in the provision of goods, income and services (such as ecological, social, information, biogeochemical and biotic) (Moberg & Folke, 1999; Teh, Teh, & Sumaila, 2013), and in the livelihoods of many fishery-dependent coastal communities (Burke, Reytar, Spalding, & Perry, 2011). Coral reef ecosystems and the human-dependent populations are in danger as a result of threats such as climate change, pollution, overfishing, invasive species and sedimentation (Arias-González, Johnson, Seymour, Perez, & Aliño, 2011). Along with these threats, many coral reef fisheries are located in less developed countries (Whittingham, Campbell, & Townsley, 2003), where fisheries management and monitoring of environments, biodiversity and commercial landings are scarce (Delaney et al., 2017). Therefore, EBFM in coral reef ecosystems is a key approach used to assess the fishery effects and promote ecosystem recovery (Fenner, 2012).

In Brazil, both small-scale reef fisheries and medium-scale offshore fisheries are not consistently monitored (Miranda, Kinas, Moreira, Namora, & Carneiro, 2016). Typically, the only register is catch data, while effort information is available only for some major stocks, such as for sardines (Freire & Oliveira, 2007). Thus, long-term catch and effort data for marine fish stocks are rare. The major obstacle is the lack of investment and commitment from governments. Currently, several Brazilian marine fish populations are threatened, according to a national assessment done using International Union for Conservation of Nature (IUCN) criteria (ICMBIO, 2014; IUCN, 2014), and stock status in terms of abundance and biomass is poorly known. In this context, an ERAEF approach seems to be a useful alternative to fisheries assessments, which can subsidise future fisheries management.

Along the Brazilian coast, the Abrolhos Bank is the largest coral reef, encompassing complex benthic mega habitats with rhodolith beds and coralline reefs (Moura et al., 2013). Across this region, snappers and groupers are common fishery resources (Martins, Costa, Olavo, & Haimovici, 2006; MPA, 2013), caught mainly by handline and harpoon (Olavo, Costa, & Martins, 2005; Previero & Gasalla, 2018). They are carnivorous species that feed on fish and crustaceans (Freitas et al., 2017), and they play a fundamental role in the trophic equilibrium of the coral reef ecosystems (Rizzari, Frisch, Hoey, & McCormick, 2014). Despite the explicit snapper and grouper economic and ecological importance, their fisheries are not evaluated or monitored. Moreover, the sustainability of these fisheries is unknown as are the impacts from other threatening activities on these stocks. Some of the grouper fisheries are threatened by closures as a consequence of the IUCN status in the last assessment (MMA, 2014), which has caused several conflicts along the Brazilian coast.

In this study, a holistic fishery sustainability evaluation of three types of snappers (*Lutjanus jocu* (Bloch & Schneider), *Lutjanus synagris* (L.) *and Ocyurus chrysurus* (Bloch)) and three types of groupers (*Cephalopholis fulva* (L.), *Epinephelus morio* (Val.) *and Mycteroperca bonaci* Poey) was performed, and the biological, environmental, social and economic components of the fisheries over the Abrolhos Bank were considered. The objectives were to (a) assess the vulnerability or risk of these six target stocks and their by-catch stocks to overexploitation related to the life history and susceptibility attributes of the fisheries; (b) evaluate the fishery sustainability of the six snappers and groupers considering fishery attributes and impacts over the target and the by-catch stocks; (c) determine the main threats to the Abrolhos Bank coral reef habitat and ecosystem; (d) investigate the effectiveness of regional fishing policies as well as fisher relative importance and participation in the construction of such policies; and (d) investigate the economic sustainability regarding the post-harvest characteristics of the six stocks.

2 | METHODS

2.1 | Study site

The Abrolhos Bank is the largest coral reef ecosystem in the South Atlantic Ocean, encompassing a wide portion of the shallow continental shelf on the Brazilian Central coast (Figure 1). Nearly 18

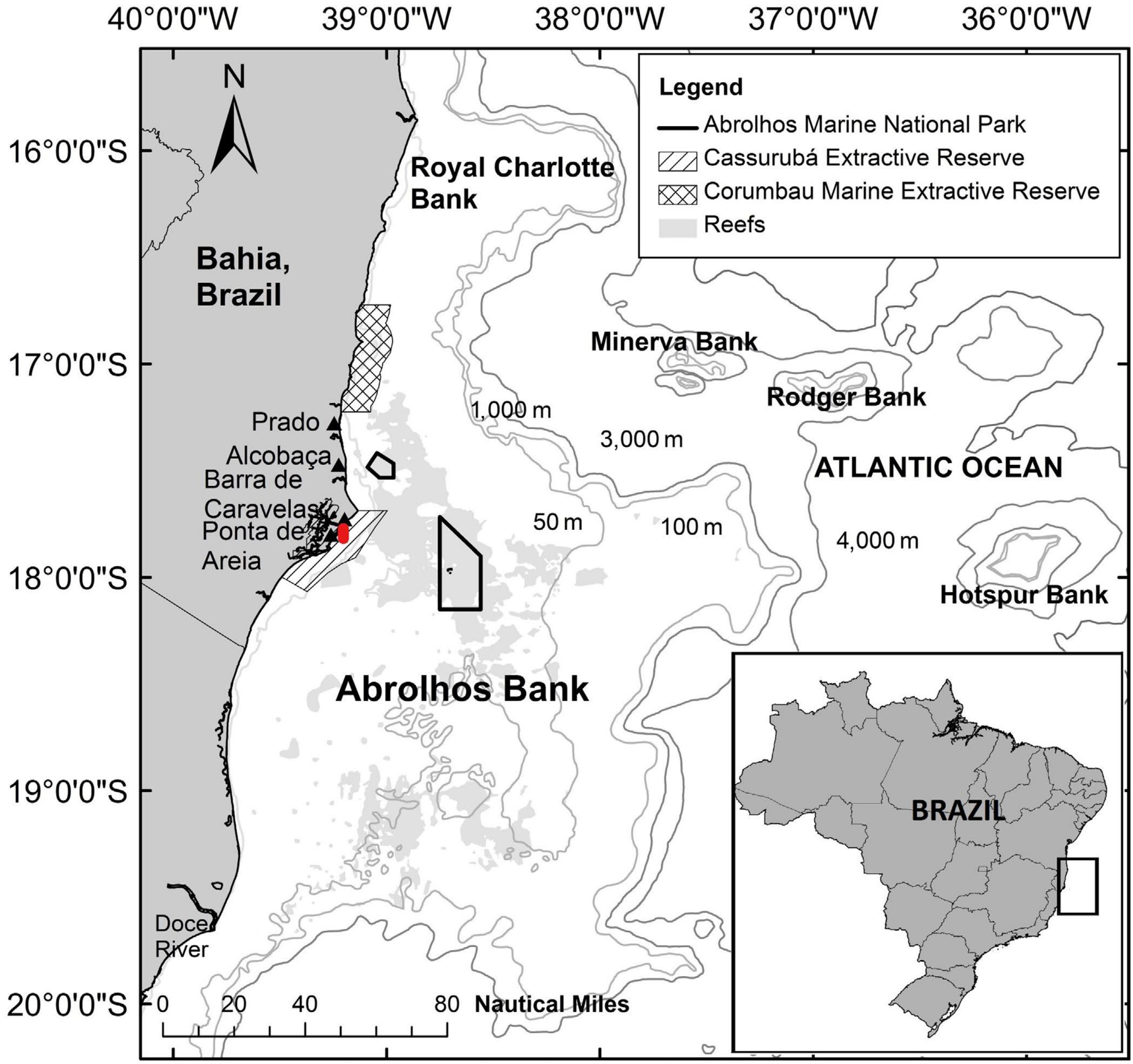

FIGURE 1 Map of the Abrolhos Bank coral reef habitat and ecosystem with the studied fishing ports, the Doce River location and the dredging area (in red)

corals and 280 fish species live in this ecosystem (Cavalcanti et al., 2013; Dutra, Kikuchi, & Leão, 2006; Leão & Kikuchi, 2001; Moura & Francini-Filho, 2005; Previero, Minte-Vera, & Moura, 2013). In the region, there are some marine protected areas (MPAs) with restricted use, such as the Abrolhos Marine National Park, and some with sustainable use, such as the Cassurubá Extractive Reserve, the Corumbau Marine Extractive Reserve and the Environmental Protection Area Ponta da Baleia. Over the Abrolhos Bank, snapper and grouper fisheries operate in the entire area, especially in the coastal area Parcel das Paredes and around the Abrolhos Marine National Park (Previero & Gasalla, 2018). There are also other human activities in this area, such as dredging in the Caravelas River estuary and mining in the Doce River (Figure 1).

2.2 | Data collection

Fisheries information (such as the main fishing areas, main fish stocks, main by-catch stocks, impacts on target and by-catch stocks, impacts over the habitat and over the ecosystem) was obtained by interviews with major stakeholders and experts (fishers, fish processors and researchers). Social information (such as governance, community organisation and empowerment) was obtained through interviews with major stakeholders and experts (fishers, presidents of fisher associations, managers of nearby protected areas and researchers). Economic information regarding the value chain (e.g. vessel, intermediates and consumer prices) was obtained through interviews with fishers, middlemen and fish sellers and by the registration of prices in supermarkets and fairs. Biological information of the stocks (species life-traits) was obtained from a literature review. The surveys with fishers, fish processors, researchers and middlemen were conducted in the years 2014–2015 in the fishing ports of Prado, Alcobaça, Barra de Caravelas and Ponta de Areia (Figure 1). The interviews with researchers were also conducted in other municipalities during research meetings, and the interviews with middlemen and fish sellers were also conducted in nearby municipalities where the fish are traded.

2.3 | Data analysis

To address the objectives, the ERAEF method (MSC, 2010) was applied with adaptations in the by-catch analysis as well as the inclusion of the economic aspects of the six snapper and grouper species. To assess the overexploitation risk to the target and by-catch stocks, a productivity and susceptibility analysis (PSA) (MSC, 2010) was conducted. The stocks were scored from 1 (low risk) to 3 (high risk) in the productivity score, considering the following life-traits attributes: average age at maturity; average maximum age; fecundity; average maximum size; average size at first maturity; reproductive strategy; and trophic level. The final productivity score by stock was obtained by the average of these attributes. The susceptibility score was based on the following attributes obtained from interviews: availability (the overlap of the fishing with the stock distribution); encounterability (the likelihood of a stock to encounter fishing gear); selectivity (the potential of gear to capture or retain individuals of a stock); and post-capture mortality (the survival probability of a fish after the catch). The final susceptibility scores by target stock were obtained by:

$$S=\frac{\left[\left(Av*En*Se*Pm\right)-1\right]}{40}+1$$

where *Av* is the availability, *En* is the encounterability, *Se* is the selectivity, and *Pm* is the post-capture mortality. The susceptibility score for the by-catch stocks was adapted from MSC (2010), being the average of the availability score and the fishery intensity of the by-catch stocks in the studied fisheries (the fishery intensity was the frequency the by-catch/ bait stocks are caught under this condition). The final PSA score was obtained by stock using:

$$PSA=\left(TP^2+TS^2\right)^{0.5}$$

where *TP* is the total productivity by stock, and *TS* is the total susceptibility by stock. In cases for which the biological information was not available for the stock, species information was used. When the information was not available for the species, information from a congener species was used but with a precautionary approach, using a higher score. Detailed information about punctuation is in the Supporting Information (Tables S1 and S2).

To evaluate the fishery sustainability of the three snapper and three grouper stocks and to determine the main threats to the Abrolhos Bank coral reef habitats and to the whole Abrolhos Bank ecosystem, a scale intensity consequence analysis (SICA) (MSC, 2010) was conducted. The SICA risk scores were obtained through interviews and from the literature, following the reference tables from MSC (2010), (Table S3). The values considered were the average of the answers, and the corresponding score was adapted from the reference tables, ranging from 1 (low risk) to 3 (high risk) and integrated as follows: (a) fishery exploitation level of target and by-catch stocks (including baits); (b) risk-causing activities to coral reef habitat; (c) risk-causing activities to the whole ecosystem; (d) social aspects (fisheries management and governance); and (e) fisheries economic aspects (in the post-harvest). First, the fishery was considered as the main risk activity to the stocks and other potentially damaging activities to the habitat and to the ecosystem were listed. Second, the spatial, temporal and intensity scales of each risk activity were scored considering the information obtained from the surveys and literature. During the interviews, a map of the study area was used as supporting material. The temporal scale of the fishery was obtained by interviews with researchers (the average of days the vessels operate during one month was multiplied by 12 (12 months in one year), and this value was multiplied by the number of vessels operating in the region). The result was the total number of fishing days per year, by stock. Third, the main consequence of the risk activities was listed and scored (1 low to 3 high). Finally, a final risk score was calculated (1—low, 2—moderate, 3—high risk), considering also other relevant information about the stocks, habitat and ecosystem exploitation and threats (MSC, 2010). The punctuation values used in scoring process are in the Supporting Information (Table S3).

Regarding the SICA social aspects, the literature (MSC, 2010) was used to investigate the effectiveness of local fishing policies and to list and score some governance attributes: (a) decision-making process on management measures; (b) existence of monitoring and review of management measures; (c) existence of appropriate management measures; (d) compliance and enforcement of management measures; (e) existence of local laws guaranteeing the fisher rights; (f) laws and people trained for law enforcement; (g) fishing incentives; (h) available information on habitats monitoring; (i) effectiveness of fisheries management within MPAs; (j) existence of effective MPAs; (k) fishers participation in fisheries management; (l) existence of studies required to propose management actions; and (m) existence of long-term goals. The governance punctuation was also adapted from MSC (2010), being: 1—good; 2—reasonable; 3—bad.

In terms of the fisheries economic aspects, the economic sustainability of the snappers and groupers in the post-harvest was investigated by evaluation of some indicators: (a) fishers' negotiation power in the value chain (fisher control on the fish selling price; fisher choice of to whom to sell; fisher capacity to store the fish; fisher ownership of the vessel; fisher usually selling the fish in another municipality and obtaining a better price); (b) market chain sustainability (number of links); (c) value chain equity (the percentage that fishers received in relation to the final value and the existence of price speculation); and (d) fish traceability (the ease in tracing a market chain). These attributes were elaborated based on the literature. Each

TABLE 1 PSA table with scores and the corresponding risk category for the six snappers and groupers and their by-catch stocks of the Abrolhos Bank, at top. On the bottom, the rationale with the reference values by species (1—low, 2—moderate, 3—high)

Productivity									Susceptibility							
Stock	Average age at maturity	Average max age (years)	Fecundity	Average max size (cm)	Average size at Maturity	Reproductive strategy	Trophic level (FishBase)	Average score	Availability (%)	Encounterability	Selectivity	Post-capture mortality	Fishery intensity	Final score	PSA score	Risk category name
L. jocu	2	3	2	1	2	2	3	2.14	3	3	2	3	-	2.33	3.16	Moderate
L. synagris	1	2	1	1	1	2	3	1.57	3	3	2	2	-	1.88	2.45	Low
O. chrysurus	2	2	1	1	1	2	3	1.71	3	3	2	2	-	1.88	2.54	Low
C. fulva	1	2	1	1	1	2	3	1.57	2	2	2	2	-	1.38	2.09	Low
E. morio	2	3	1	2	2	2	3	2.14	3	3	2	2	-	1.88	2.85	Moderate
M. bonaci	2	3	1	2	2	2	3	2.14	3	3	2	2	-	1.88	2.85	Moderate
X. kroyeri	1	1	2	1	1	2	1	1.29	1.0	-	-	-	2.8	1.88	2.27	Low
H. plumieri	1	2	1	1	1	2	3	1.57	2.8	-	-	-	2.0	2.34	2.85	Moderate
C. pannatula	1	2	1	1	1	2	3	1.57	3.0	-	-	-	1.8	2.38	2.85	Moderate
K. pelamis	1	2	1	2	2	2	3	1.86	1.5	-	-	-	1	1.25	2.24	Low
Rationale														References		
L. jocu	5	29	NA	96	43	Demersal egg layer	4.4		75	3.7	1.8	2.2	-	Freitas, Moura, Francini-Filho, and Minte-Vera, (2014); Previero et al., (2011)		
L. synagris	3	18	100,000 to 700,000	68	23	Demersal egg layer	3.8		67	3.4	2.8	1.7	-	Freitas, Rocha, Chaves, and Moura, (2011); Aschenbrenner et al., (2017)		
O. chrysurus	5	19	14,102 to 164,756	76	31	Demersal egg layer	3.6		72	3.8	2.8	1.6	-	Araujo et al., (2002); Freitas et al., (2014); Trejo-Martınez et al., (2011)		
C. fulva	2	25	150,000 to 282,000	46	16	Demersal egg layer	4.1		65	3.2	2.8	1.4	-	Araujo e Martins, (2006); IUCN, (2008); Freitas et al., (2014)		
E. morio	11	30	24,300 to 2,322,517	99	47	Demersal egg layer	3.6		79	4.2	2.1	2.1	-	Collins et al., (2002); Freitas, (2017); Freitas et al., (2018)		
M. bonaci	8	34	500,000	160	62	Demersal egg layer	4.5		78	3.8	1.7	2.1	-	Freitas, (2017); Freitas et al., (2018); Randall (1967); Smith (1961).		
X. kroyeri	0.4	1.2	NA	3.8	1.2	NA	1		12	-	-	-	Widespread and frequent	Guimaraes, (2009)		
H. plumierii	2	18	34,000 to 1,000,000	53	22	Demersal egg layer	3.7		77	-	-	-	Occurs at broad spatial scale	Murie and Parkyn, (2005); Hoffmann et al., (2017)		
C. pannatula	4	10	30,000 to 1,500,000	37	22	Demersal egg layer	3.7		90	-	-	-	Occurs at broad spatial scale	Waltz et al, (1982); Gómez-Canchong et al., (2004); Tyler-Jedlund and Torres (2015)		
K. pelamis	1.5	10	255,000 to 1,300,000	108	45	Demersal egg layer	4.5		30	-	-	-	Rare in few locations	Vilela and Castello, (1993); Cox et al., (2002)		

Note: Encounterability punctuation (0 to 5:0–1.5 = low; 1.6–3.5 = medium; 3.6–5 = high). Selectivity punctuation (0 to 5:0–1.5 = low; 1.6–3.5 = medium; 3.6–5 = high). Post-capture mortality punctuation (1 to 3:1–1.5 = low; 1.6–2.1 = medium; 2.2–3 = high).

attribute presented three possible answers, categorised as: 1—good, 2—moderate, 3—bad economic sustainability. The final score of each attribute was the average of answers. Also, a schematic value chain of the six stocks studied was drawn up.

3 | RESULTS

Seventy experts were interviewed, including fishers (32), fish traders (27) and researchers (11), and used to determine the main by-catch

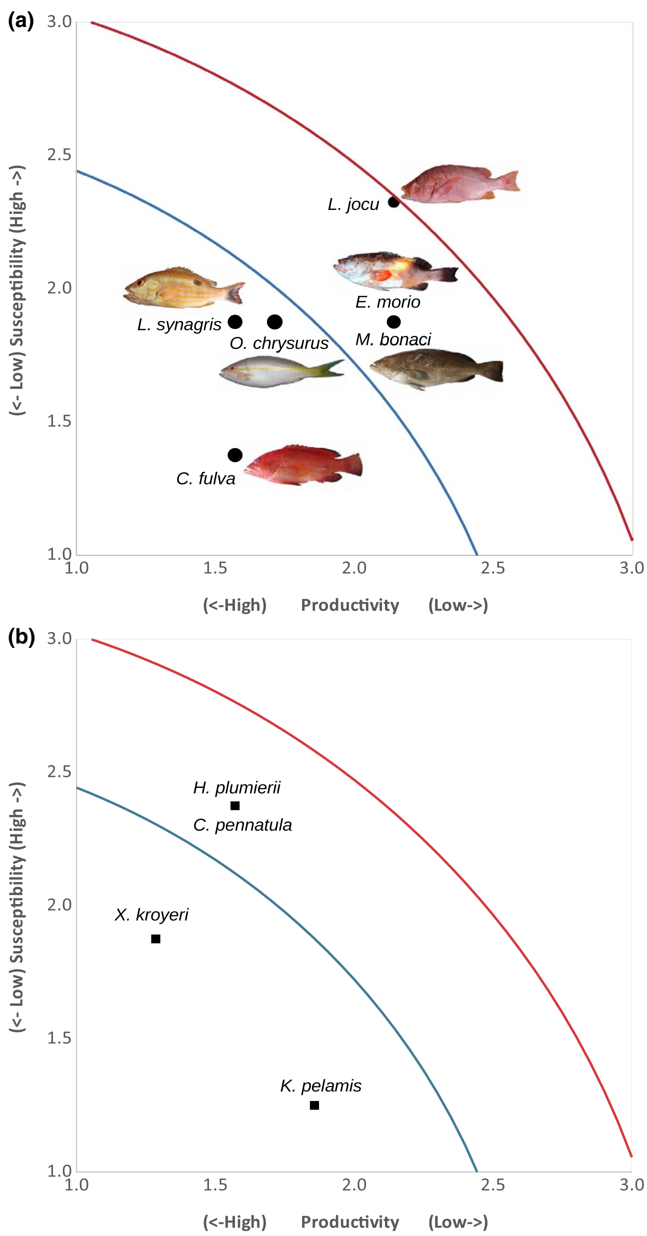

FIGURE 2 PSA result plot. (a) Target stocks studied (three snappers and three groupers). (b) By-catch and bait stocks studied. The closer to the point of origin in the graph, the low risk has the stock. The blue line represents the limit between low and moderate risk stocks, and the red line represents the limit between stocks with moderate and high risk

or bait stocks. While the *Xiphopenaeus kroyeri* (Heller) was usually used as bait in the *L. synagris* and *O. chrysurus* fisheries, *Katsuwonus pelamis* (L.) was used as bait in the *M. bonaci* and *E. morio* fisheries. *Haemulon plumierii* (Lacepède) and *Calamus pennatula* Guichenot were mainly by-catch from the handline fisheries of the six target stocks.

According to the productivity and susceptibility analysis (PSA), the target stocks, *L. jocu*, *E. morio* and *M. bonaci*, had moderate overexploitation risk, and *L. synagris*, *O. chrysurus* and *C. fulva* low overexploitation risk (Table 1, Figure 2a). The main threats are high maximum age as a proxy for low natural mortality, big body-size, high trophic level and fast post-capture mortality (which make it difficult to be returned to the sea and to survive if fish outside the size limits were caught). Regarding the by-catch (and bait) stocks, *X. kroyeri* and *K. pelamis* were at low overexploitation risk, especially because they are used as bait and have a low encounterability score because they do not occur in the same fishing areas (coral reefs) as the target stocks (Table 1, Figure 2b). *Haemulon plumierii* and *C. pennatula* were in moderate risk because they occur in similar target stock areas and their main catches are by-catch (Table 1, Figure 2b).

According to the Scale Intensity Consequence Analysis (SICA), the major risk activity resulting from fishing was direct capture. The fishery spatial scale received the greater risk score to the target stocks because direct capture occurred in almost all of the stock distribution areas (average of 72%, based on interviews) in the Abrolhos Bank (Table 2). This broad fishing distribution is the major threat to such stocks because the fishing restriction areas are a small zone of the region, and their effectiveness is inadequate as a result of lack of oversight. The greatest consequences of direct capture were the reduction in population size and changes in stock ages and size structures. The intensity of these consequences resulted in the major risk score being assigned to five of the target stocks and moderate risk being assigned to *C. fulva* (Table 2). The by-catch stocks received moderate and low-risk scores towards the reduction in population size as a consequence of their use as bait or by-catch (Table 2).

Among the current damaging activities, the major risk was mining waste, followed by dredging, especially because of the time necessary for the recovery and due to the high intensity of these activities (Table 3). Consequently, the loss of habitat quality and loss of ecosystem structure and functioning were the main sources of damage and received a high-risk score (Table 3). In addition to these, there is still the possibility of future petroleum exploration in the Abrolhos Bank (not considered here because exploration has not started).

In terms of governance and fisheries management in the Abrolhos Bank, the most effective activities (low-risk score) were the monitoring and review of management measures, followed by the fishing incentives (Table 4). On the other hand, the less effective activities (high-risk score) were both the management of the marine protected areas and fisheries management (Table 4).

Analysis of the SICA economic aspects regarding post-harvest aspects revealed low fisher negotiation power, lack of means to store fish and high middlemen power in determining the first trading prices, which was the main obstacle to selling the resources in

TABLE 2 Scale intensity consequence analysis (SICA) results of target and by-catch stocks with the attribute punctuation, the greatest risk activity and its consequence, and the final risk score by stock (1—low, 2—moderate, 3—high). Within the parentheses are the SICA scores assigned to the values

Target and by-catch stocks	Risk activity	Spatial scale of activity (%)	Temporal scale (number of fishing days per year)	Intensity scale of activity	Major consequence	Risk score
L. jocu	Direct capture	75 (3)	192 (2)	Major—evidence at broad spatial scale (2.2)	Population size	3
L. synagris	Direct capture	67 (3)	186 (20	Severe—easily and frequent detectable evidence (2.5)	Population size	3
O. chrysurus	Direct capture	72 (3)	186 (2)	Severe—easily and frequent detectable evidence (2.4)	Age/size structure	3
C. fulva	Direct capture	65 (3)	204 (2.5)	Moderate—moderate detection at broader spatial scale (1.5)	Population size	2
E. morio	Direct capture	78 (3)	192 (2)	Major—evidence at broad spatial scale (2)	Population size	3
M. bonaci	Direct capture	78 (3)	204 (2.5)	Major—evidence at broad spatial scale (2)	Population size	3
X. kroyeri	Direct capture	12 (1)	156 (2)	Catastrophic—continual and widespread evidence (2.8)	Population size	1*
H. plumieri	Direct capture	77 (3)	203 (2)	Major—evidence at broad spatial scale (2)	Population size	2*
C. pennatula	Direct capture	90 (3)	226 (2.5)	Major—evidence at broad spatial scale (1.8)	Population size	2*
K. pelamis SICA results of economic aspects of the six snapper and grouper fisheries with the attribute scores by stock (1—low, 2—moderate, 3—high)	Direct capture	30 (1.5)	240 (2.5)	Minor—activity occurs in few restricted locations (1)	Population size	1*

*The final risk score to by-catch was regarding the by-catch or bait fishery.

another municipality (Tables 5 and 6). There was an intermediate level of fish traceability and a reasonable number of links along the market chain (2–6) (Table 6, Figure 3). The final consumers were in 16 different national municipalities and on two other continents (Figure 3). Most of the fish go through a middleman before arriving at the final consumption city. There was no direct marketing between the fishers and the final consumer, nor between the fishers and the middlemen. The fishers always traded within a fish market or sold from a fridge. There was also one processing centre in Itapemirim, ES, from where *C. fulva* was exported to Europe and the United States.

The SICA overall results were compared and revealed that fishing impacts on the target stocks have the highest risk score, followed by the impacts of mining, dredging and fishing on coral reefs and on the entire ecosystem (Figure 4).

4 | DISCUSSION

Semi-quantitative and qualitative tools, such as PSA and SICA, have been crucial in many data-poor fisheries from developing countries to support fisheries management as an alternative to quantitative assessments (Zhou, Hobday, Dichmonta, & Smith, 2016). Although these low-cost approaches were recognised as a first step in identifying stock risk in data-poor situations (Hobday et al., 2011), few studies have used them in Brazil (e.g. Frédou et al., 2017; Previero, 2014). This precautionary ERAEF method was developed by Hobday et al. (2007) and was disseminated by management and advisory bodies (Frédou et al., 2017) and by the Marine Stewardship Council for fishery certification all over the world (MSC, 2010). These certifications, however, are not a reality for Brazilian fisheries (MSC, 2018; Pérez-Ramírez, Castrejón, Gutierrez, & Defeo, 2016), especially due to the lack of knowledge (stocks usually lack necessary data) and lack of investment in fisheries tracking and in the entire certification process (Frédou et al., 2017). In this study, the ERAEF method was applied with some adaptations, such as the inclusion of post-harvest fisheries aspects, which can guide future regional multidisciplinary assessments and certifications. Another adaptation was the evaluation of the by-catch/ bait stocks through the PSA productivity attributes as well as the susceptibility attributes considering the availability and the fishery intensity (the same used in SICA). The main objective was to simplify and make easier the assessment process, considering that

TABLE 3 Scale intensity consequence analysis (SICA) habitat and ecosystem results with the risk activities and the spatial, temporal and intensity scales, the major consequence of each risk activity and the corresponding final risk score (1—low, 2—moderate, 3—high). Within the parentheses are the SICA scores assigned to the values. In temporal scale, "years" refer to a period less than 10 years and "decades" refer to a period between 10 and 20 years

Habitat/ Ecosystem	Risk activity	Spatial scale of activity (%)	Temporal scale (time necessary to recovery)	Intensity scale of activity	Major consequence (loss of)	Risk score
Tropical coral reef	Mining waste	20 (1.5)	Decades (3)	Catastrophic—continual and wide-spread evidence (3)	Habitat quality	3
	Dredging	10 (1)	Years (2)	Major—detectable evidence of activity, reasonably often (2)	Habitat structure and function	3
	Hand line fishery	54 (2.5)	Years (1.3)	Major—evidence at broad spatial scale (1.7)	Habitat structure and function	2
	Harpoon fishery	30 (1.5)	Years (2)	Moderate—moderate detection of activity at broader spatial scale (1)	Habitat structure and function	2
Abrolhos Bank (Including other habitats)	Mining waste	20 (1.5)	Decades (3)	Catastrophic—continual and wide-spread evidence (3)	Ecosystem structure and function	3
	Dredging	10 (1.5)	Years (2.5)	Severe—easily detectable localized evidence of activity (2.5)	Ecosystem structure and function	3
	Hand line fishery	55 (2.5)	Years (1)	Moderate—moderate detection of activity at broader spatial scale (1.7)	Ecosystem structure and function	2
	Harpoon fishery	44 (2)	Years (1)	Moderate—local detection of activity (1.6)	Ecosystem structure and function	2

the evaluation of by-catch stocks in this situation is conditioned to the fisheries of the target species. Furthermore, the vulnerability to overexploitation of the six target stocks and a preliminary risk score of the by-catch stocks were determined. Similarly, the main threats to habitats and ecosystems, the main gaps in effective fisheries management and governance, and the main obstacles to achieving sustainability on the value chains were stated.

4.1 | Vulnerability to overexploitation

4.1.1 | Target stocks

From the six target stocks analysed, three stocks (*L. jocu*, *E. morio* and *M. bonaci*) are classified as substantially threatened, being impacted by intense, constant and dispersed fishery catches that cause reductions in the stock sizes. In addition, these stocks have life-traits putting them under these conditions, such as high maximum age of 29 years for *L. jocu*, 30 years for *E. morio* and 34 years for *M. bonaci* (Freitas, 2014; Previero, Minte-Vera, Freitas, Moura, & Tos, 2011). Major stock susceptibility was from the availability and encounterability indices because the fishing fleets are spread over the Abrolhos Bank, from coastal to offshore areas of approximately 140 nautical miles (Previero & Gasalla, 2018). Thus, suggestions for the management measures for these three stocks are the restriction of the fishing areas to reduce the fisheries overlapping the stocks on the coral reef habitats, and fishing gear regulations to make them more size-selective (Olavo, 2010; Previero, 2018).

The three target stocks that have low vulnerability to overexploitation (*C. fulva*, *L. synagris* and *O. chrysurus*) have also lower body-size and lower maximum ages (18– 25 years) (Araujo & Martins, 2009; Araujo, Martins, & Costa, 2002; Aschenbrenner et al., 2017) than the most vulnerable stocks. According to Zhou et al. (2016), the PSA shows a low sensitivity for the most productive species but relatively high fishing impact. In this case, the productivity attributes related to reproduction (fecundity and reproductive strategy) are similar between the six target stocks. To avoid an increase in vulnerability to overexploitation, periodic assessments of these stocks and continuous fisheries monitoring are necessary.

4.1.2 | By-catch stocks

Xiphopenaeus kroyeri was the main fishing resource in Caravelas in the year 2010 (Minte-Vera & Souza-Júnior, 2014). In this study, as a bait fishery, it is considered low risk, but this is a preliminary risk assessment of the by-catch stocks, and because of its local importance, directed evaluations of this shrimp stock are required. In the study area, *H. plumierii* and *C. pennatula* are usually registered as "mistura", a local fish category encompassing a variety of low-value species traded without identification (Freitas, 2009). As these stocks are classified as medium risk, continuous monitoring and fishing records at the species or ethno-species level are needed (Fischer, 2013; Previero et al., 2013) because the low resolution in fish identification during monitoring may mask a serial depletion (Dent & Clarke, 2015; Kaprov, Haaker, Taniguchi, & Rogers-Bennett, 2000).

TABLE 4 SICA results of social aspects (fisheries management and governance) in the Abrolhos Bank (1—low, 2—moderate, 3—high)

Fishery management and governance policy	Answer	Punctuation (average of answers)	Risk score (average of punctuation)	Justification/ rationale
Decision-making on management measures	good (1)/ reasonable (2)/ bad or missing (3)	1.4		Only inside sustainable use MPAs
Monitoring and review of management measures	good (1)/ reasonable (2)/ bad or missing (3)	0.9		The measures are discussed in deliberative council meetings
The management measures are appropriate	good (1)/ reasonable (2)/ bad or missing (3)	1.3		Even in sustainable use MPAs, the measures are not always appropriate, with failures in the communication between managers and users
Compliance and enforcement of management measures	good (1)/ reasonable (2)/ bad or missing (3)	1.3		The management measures are usually fulfilled but since there is little supervision, some agreements are not complied with.
There are local laws guaranteeing the fishers rights	Yes (1)/ partially (2)/ no (3)	1.7		Besides sustainable use MPAs, few laws guarantee the right of the traditional fishers, being vulnerable to territory losses and conflicts with big companies
There are laws and people trained for law enforcement	good (1)/ reasonable (2)/ bad or missing (3)	2.3		There is a restricted team and few equipment and resources necessary for effective enforcement, with rare inspections.
There are fishery incentives	many (1)/ few (2)/ no incentives (3)	2.2	1.7	There are few incentives, such as a local cooperative for ice production, but not always offers the cheaper prices
There are available information on habitats monitoring	good (1)/ reasonable (2)/ bad or missing (3)	1.3		There are few studies monitoring habitat quality. The information is not easily accessible to local communities.
Effective fisheries management within MPAs	good (1)/ reasonable (2)/ bad or missing (3)	2.3		Management could be more effective with more personal and monetary resources
Effective MPAs management	good (1)/ reasonable (2)/ bad or missing (3)	2.5		Management could be more effective with more personal and monetary resources
Fishers participation in fisheries management	good (1)/ reasonable (2)/ bad or missing (3)	2.2		The fishers and the community participation in fully protected MPAs are very low
There are researches needed to propose management	good (1)/ reasonable (2)/ bad or missing (3)	1.5		There are some scientific researches to support management proposals
There are long-term goals	good (1)/ reasonable (2)/ bad or missing (3)	1.5		The long-term goals are rare or nonspecific

4.2 | Fishery sustainability

4.2.1 | Fishery impacts over stocks

Besides the stocks studied here, the wide spatial distribution of fishing impacts also affects another endangered reef species, the endemic *Scarus trispinosus* Val. (greenback parrotfish) (Previero, 2014). In the Abrolhos Bank, many vessels are small, belong to artisanal fisheries, and are restricted due to adverse weather conditions (Previero, 2014). Therefore, the temporal scale of the fisheries studied is medium. Many fishers from Caravelas claimed that "there is a natural fishing closure" because of the dangers of fishing in adverse weather conditions. For the five stocks for which the main fishery effect is population reduction, fishing targets a broad size range. However, for *O. chrysurus*, the major fishery effect is the change in age and size structure because fishing targets small, immature individuals (Previero, 2018). *Cephalopholis fulva* is the least threatened fishery stock, not only in the SICA but also in the PSA analysis. On the one hand, this stock is an export fishery, for which its fleet has great autonomy and few restrictions due to climatic conditions (Previero & Gasalla, 2018). On the other hand, few vessels operate in these fleets, which confers a low intensity score for this fishery and a medium risk score for *C. fulva*.

The by-catch stocks co-occurring in the target stock area are at a moderate risk, especially because of the wide spatial distribution of the fishery. Both target and by-catch stocks, and also the reef-associated endangered species *S. trispinosus* (Previero, 2014), need fisheries management that mainly addresses total fishing area reduction. A spatial management measure, such as marine protected areas (MPAs) in critical habitats, has been shown to be an option for reef-associated stocks (Moura, Francini-Filho, Chaves, Minte-Vera, & Lindeman, 2011). This measure can promote stock recovery and spill

TABLE 5 Summary of the indicators used to score economic aspects of snapper and grouper fisheries, the specific questions used to score each indicator, and the scores corresponding to the interviewed answers

Indicator	Indicator details	Answer	Punctuation
Fisher's negotiation power	Fishers control the fish selling price	yes/ sometimes/ no	1/2/3
	Fishers choose whom to sell	yes/ sometimes/ no	1/2/3
	Fishers can store the fish	yes/ sometimes/ no	1/2/3
	Fishers have their own vessel	yes/ shared/ no	1/2/3
	Fishers usually sell the fish in another municipality and obtain a better price	yes/ sometimes/ no	1/2/3
Market chain	Number of links	1 or 2/ 3 or 4/ 5 or more	1/2/3
Value chain	The percentage that fishers receive in relation to the final value.	60% or more/ 30–59%/ less than 30%	1/2/3
	There is price speculation	yes/ sometimes/ no	1/2/3
Traceability	The easiness in trace a market chain; with whom the fishers trade	trade with final consumer	1
		trade with fish markets in the region	2
		trade with middlemen from other states or different buyers	3

over to adjacent areas (Francini-Filho & Moura, 2008). MPAs can also support the demographic connectivity of reef fishes, especially if connected as a network (Endo, Gherardi, Pezzi, & Lima, 2019), besides promoting the balance of the whole biological community (Bruce et al., 2012). Previous studies have shown considerable fishing pressure and catches of juveniles in coastal coral reef areas of the Abrolhos Bank (Previero & Gasalla, 2018). There are also areas where some fish families, like Epinephelidae, aggregate for spawning (Freitas et al., 2018; Giglio, Leite, Freitas, & Hostim-Silva, 2016). Such zones are extremely important for several species to complete their life cycle. Furthermore, marine protected areas are a tool to support an ecosystem approach because they may encompass diverse species, ecosystem services, a range of habitats and macro-habitat features (Moura et al., 2013; Seixas & Vieira, 2015). Thus, MPAs can be a management alternative if properly designed and implemented in a spatial planning framework as a network of MPAs (Prates, Cordeiro, Ferreira, & Maida, 2007; Sala et al., 2002).

4.2.2 | Threats to habitat and ecosystem

In this study, the main activities impacting the Abrolhos Bank ecosystem and coral reef habitat were compared and evaluated. It is known that all fishing modalities can cause environmental damage, such as physical damage to habitats and ecological disturbances to the ecosystem by means of changes in food chains (King, 2007). However, hand line and harpoon fisheries are considered to be less harmful to the environment in terms of physical damages and fish size selection (Bjordal, 2002). Considering the spatial distribution of activities impacting the coral reefs, harpoon fishing occurs in restricted areas (only on the shallower coral reefs), while line fishing is the most widespread activity in the region (Previero & Gasalla, 2018). Local dredging began in 2003 to enable the entrance and the exit of barges carrying *Eucalyptus* sp. (Nogueira, 2009). This activity is restricted to the Caravelas Estuary (Moura et al., 2013), a mangrove area that serves as a nursery for several reef fish species (Giglio & Freitas, 2013; Moura et al., 2011), although dredging also has effects on coral reefs closer to the coastline (Dutra et al., 2006), which is a restricted area in the Abrolhos Bank. Local dredging is, however, constant source of problems to the small-scale shrimp fisheries and is responsible for several conflicts between the fishers and the company that conducts the dredging.

The mining waste in the study area comes from the rupture of the mining reject dam of the Samarco Mineração S.A. company on November 5, 2015. About 45 million cubic metres of tailings were discharged into the environment. The disaster occurred in Mariana municipality, in Minas Gerais state, approximately 550 km from the mouth of Rio Doce, in Regencia, Espirito Santo state. The tailings flowed down the Rio Doce and reached the ocean on November 22, 2015, at the southern limit of the Abrolhos Bank. Until this date, mining waste has not been distributed broadly in the study area (LARAMG, unpublished data; Mazzei et al., 2017; TAMAR & ICMBIO, 2017). However, the biological communities, habitats and ecosystem destruction are considerable and require a long recovery period (Fernandes et al., 2016). The main possible damage to the Abrolhos Bank ecosystem includes metal bioaccumulation through food webs, toxic algal blooms, and changes in fish growth, survival and behaviour (Mazzei et al., 2017).

TABLE 6 SICA results of economic aspects of the six snapper and grouper fisheries with the attribute scores by stock (1—low, 2—moderate, 3—high)

Value chain—Target species	Fisher's negotiating power: Controls selling price	Choose whom to sell	Store the fish	Own vessel	Sell in another municipality	Market chain	Value chain	Traceability of fish	Average	Risk score
L. jocu	2.3	2.1	2.4	1.2	2.8	2	1.9	2.0	2	2.5
L. synagris	2.3	2.2	2.3	1.2	2.8	2	1.9	1.9	2	
O. chrysurus	2.3	2.1	2.3	1.2	2.7	2	2.0	1.9	2	
C. fulva	2.1	1.9	2.0	1.3	3.0	2	2.1	2.0	2	
E. morio	2.3	2.0	2.3	1.2	2.8	2	2.1	1.9	2	
M. bonaci	2.3	2.0	2.3	1.2	2.8	2	2.1	1.9	2	

At the beginning of 2019, the Brazilian government authorised petroleum exploration close to the Abrolhos Bank. If such activity occurs, the whole region may be affected by oil spillages (Dominguez, 2002). The impacts may affect many biological communities, habitats and the marine ecosystem (Lemos, Soares, Ghisolfi, & Cirano, 2009; Marchioro, Nunes, Dutra, Moura, & Pereira, 2005). In this sense, the development and implementation of scientific research and technologies capable of rapid response to contain impacts are needed, as well as technologies to eliminate pollutants from the environment before dispersion.

In summary, while fishing operations are widespread in the region, mining waste and dredging currently impact only a portion of the coral reef habitat and of the ecosystem. On the other hand, while the fishing impacts are relatively less intense, as they involve handlines and harpoons, which are ecosystem-friendly fishing gears (Bjordal, 2002), the mining waste and dredging impacts are devastating where they occur, impacting marine organisms (King, 2007) and promoting an absolute loss of habitat and ecosystem structures and functioning (Hadjibiros, Mantziaras, Sakellariadis, Giannakidou, & Katsiri, 2006).

In this sense, the primary management action to protect the Abrolhos Bank reefs is the creation of measures to contain the mining waste with spatially explicit long-term monitoring (Fernandes et al., 2016). Furthermore, measures to prevent future accidents involving mining waste and other damaging activities, such as petroleum leaks, are essential to protect this ecosystem. Another management measure is the containment and reduction of dredging effects by greater control of this activity in the region.

4.2.3 | Fisheries governance problems and challenges

In this study, the review of fisheries management measures in the Abrolhos Bank determined monitoring was the most effective governance activity, but Nobre, Alarcon, Cinti, and Schiavetti (2017) found no regular monitoring of fishery resources in the Cassurubá Extractive Reserve in Caravelas.

Nevertheless, this study found similar results to Nobre et al. (2017) in terms of "local laws guaranteeing the fishers rights" and "fishers participation in fisheries management." According to these authors, there is a need to formalise local laws that ensure long-term user rights and direct fisher participation in fisheries management plans. The lack of enforcement is another characteristic found both by Nobre et al. (2017) and this study, which explains the observed regional demand for people trained for law enforcement. Despite the low effectiveness of MPA management in the Abrolhos Bank, compared with elsewhere, these MPAs have some utility (Edgar et al., 2014). Edgar et al. (2014) found "poor overall performance of MPAs worldwide in terms of recovery of fish biomass," whereas they found the Abrolhos Bank MPAs are classified as medium performance according to the attributes of governance, effectiveness, isolation, size of the area and age.

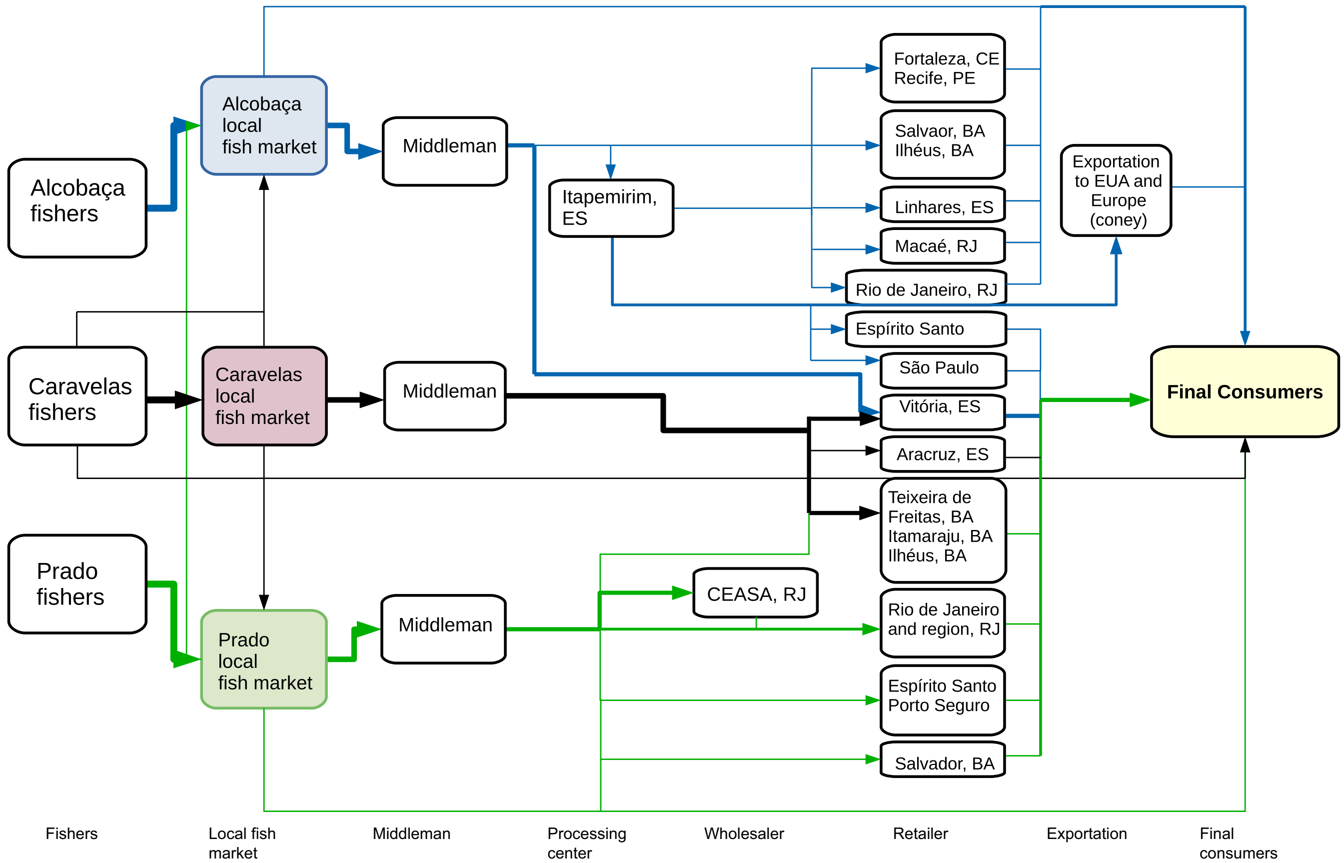

FIGURE 3 Schematic representation of snapper and grouper value chains captured in the Abrolhos Bank and landed in Alcobaça, Caravelas and Prado municipalities. The wider arrows represent the most relevant pathway in terms of number of responses from the interviewees

Governance in the Abrolhos Bank ecosystem presents at least some type of problem in each topic evaluated. The resolution of these issues is mainly through the decentralisation of the entire management and decision-making processes, with an effective increase in fisher and community participation (Garza-Gil, Amigo-Dobaño, & Surís-Regueiro, 2017; Jentoft, 2000; Olavo, 2010). In this sense, fishers need to be empowered and proactive, and have a sense of ownership and independence in the whole process (Nutters & Silva, 2012); in the long term, fishers become guardians or defenders of the resources they can exploit for generations. Moreover, the whole community will feel responsible for the conservation of fishery resources (Garza-Gil et al., 2017). This process is called fishery self-governance and has been successful in many countries (Townsend, 2008). Self-governance is usually implemented by regional community organisations, with governmental oversight, and has communal objectives, targets and paths aimed at effective fishery management (Lee & Midani, 2015).

4.2.4 | Fisheries post-harvest

The scenario of low fisher bargaining power along the value chain is common in several small-scale fisheries in Brazil (Ykuta, 2015),

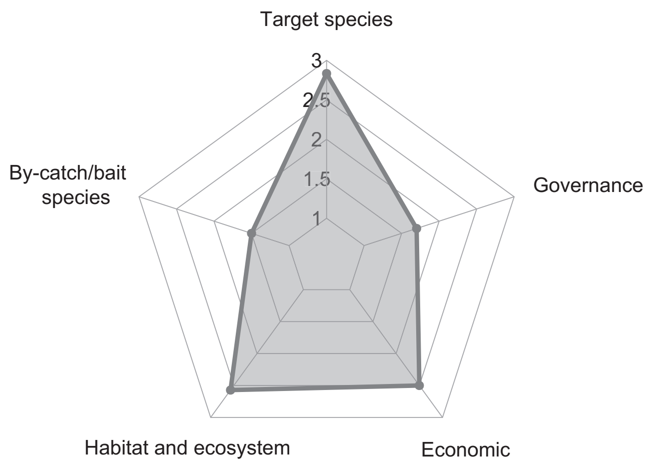

FIGURE 4 Scale intensity consequence analysis SICA overall results comparing the five components average values

and worldwide (Mangubhai et al., 2016; Purcell, Crona, Lalavanua, & Eriksson, 2017). As weighting measures, subsidies to small-scale fishers, such as the provision of infrastructure (ice factories, cold rooms, piers), can strengthen and balance the fishery production chain through fisher empowerment (Ykuta, 2015). When fishers have greater negotiating power, they become more autonomous, selling the fish for higher prices, which is a first step towards a more homogeneous market chain and a more sustainable value chain (Bjorndal, Child & Lem, 2014). Some practical ways to improve the value chain are as follows: (a) the development of fisher cooperatives (Purcell et al., 2017); (b) resource valorisation in landing municipalities; and (c) improve fisher or intermediate competences a different stages of the value chain (with the aim of reducing the number of links in the chain) (Humphrey & Schmitz, 2002).

Despite the value chain map, the fish trajectory from landing to the final consumer is not linear, which hinders good fish traceability. Some benefits of good fish traceability are food security, improvement in food resources management, price control along the value chain and reducing mislabelling and illegal fish marketing (Metref & Calvo-Dopico, 2016; Quinto, Tinoco, & Hellberg, 2016; Stawitz, Siple, Munsch, Lee, & SAFS, 2017). In summary, fish traceability is a tool that is especially used in certifying the resource origin and sustainability (Carvalho & Martinsohn, 2013). The main challenges for the implementation of good fish traceability in developing countries include development of adequate fishing public policies and strong law enforcement. Some tools to improve fish traceability are the collection of fisheries data, the establishment of fishery product legitimacy and the implementation of laws to ban illegal fish commercialisation (Bhatt et al., 2015).

Although the six snappers and groupers exhibited some threatened and overfishing levels (Previero, 2018), the value chain revealed large consumption of these stocks in other Brazilian states. A recognised management option is reduction of the links in the chain, which may maximise profits, especially at the base (fishers), and minimise problems, such as bottlenecks in supply, costs incurred and the time to market (Bjorndal, Child, & Lem, 2014; Shamsuddoha, 2007). The export or distant marketing of threatened species can reduce local fish availability and raise its local price, damaging vulnerable fisher communities (Bjorndal et al., 2014). In addition, when the final fish consumption occurs nearby the locality of production, the value generated along the supply chain remains inside the community, as well as the jobs, which strengthens the local economy (e.g. Bevilacqua, Angelini, Steenbeekc, Christensend, & Carvalho, 2019). In this sense, following suggestions for upgrading value chains described by Humphrey and Schmitz (2002), the functional upgrade, the creation of policies for local fish valorisation can be an alternative. This can be conducted through the promotion of economic development projects based on local cooperatives and the sustainable use of fish and other natural resources, with community engagement. These measures can attract financial resources and generate income for the local communities.

5 | CONCLUSIONS

In this study, semi-quantitative and qualitative approaches were adapted to data-poor situations to understand the whole picture of activities that threaten the Abrolhos Bank ecosystem. Regarding the stocks, the most threatened are *L. jocu*, *E. morio* and *M. bonaci*, classified as substantially threatened, especially because they have life history traits incompatible with current intense fishing levels. Stocks of *L. synagris*, *O. chrysurus* and *C. fulva* are at moderate risk of overexploitation, mainly because the catches occur across most of the stocks' distribution areas, causing major risks to population size reduction and changes in stock age and size structures.

Fishing is a very common activity across the Abrolhos Bank and has moderate risks or impacts on the coral reef habitats and ecosystem. However, the major threat to the habitats and ecosystem is from highly destructive mine waste in the south coast, followed by dredging in the Caravelas River estuary. These activities affect mangroves, estuaries and even coastal reefs, and may lead to loss of habitat quality and structure, and loss of ecosystem structure and functioning.

Regarding economic aspects of the fisheries, the main problems are lack of fisher bargaining power and low infrastructure to support both fishery and post-harvest activities. Furthermore, weaknesses in regional governance have led to failures in the elaboration and implementation of some management measures.

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ORCID

Marília Previero https://orcid.org/0000-0003-2190-5696

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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