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# Tracking interactions: Shifting baseline and fisheries networks in the largest Southwestern Atlantic reef system

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## Abstract

1. Increasing evidence has revealed that different fisheries have collapsed around the world. This is generally more evident in countries that can maintain long-term research and fisheries monitoring. When monitoring data are not available, alternative approaches to assess fisheries trends can be used, such as the local ecological knowledge of fishers.
2. To investigate decadal changes in fisheries the local ecological knowledge of small-scale fishers' was evaluated at four sites in Brazil: Porto Seguro, Prado, Alcobaça, and Caravelas. A fisher–fish network weighted by interaction strength was built to indicate the most relevant resources among fishers.
3. The results suggest the occurrence of the shifting baseline syndrome among generations of fishers regarding commercially important fishes such as groupers and snappers. Handline fishers indicated a decline in catch per unit effort over 5 decades.
4. Fisher–fish networks from Caravelas showed greater stability with stronger interaction strength, while Porto Seguro and Alcobaça networks were more fragile, and Prado network showed intermediate characteristics. Overfishing has affected high trophic level species that act as module hubs across the majority of sites.
5. The fisher–fish network approach can be applied in data limited cases, improving the assessments of fisheries' dynamics (in space and time) and declining species.

**KEYWORDS**
Abrolhos Bank, fisheries management, historical ecology, local ecological knowledge, overfishing, reef fisheries, small-scale fishing

## 1 | INTRODUCTION

The global increased demand for seafood has caused the overfishing of multiple stocks and the degradation of ecosystems (Pauly & Zeller, 2016; Pikitch, 2012). Such a scenario is most evident in high-income countries where there are long-term fisheries data (e.g. Fock, Kloppmann, & Probst, 2014; Thurstan, Brockington, & Roberts, 2010). In many low- and middle-income countries, small-scale fisheries represent an important fraction of landings, providing food security, welfare, and livelihoods for coastal communities (Hanazaki, Berkes, Seixas, & Peroni, 2013; Purcell & Pomeroy, 2015). However, these countries have historically suffered from logistical and financial difficulties in implementing strategies to inform fisheries management and monitoring (Jones, 2006; Mills et al., 2011). This scenario makes the stock situation even more uncertain. Alternative approaches have employed historical data, including the empirical knowledge of resource users, as a window into nature's past conditions (McClenachan, Cooper, McKenzie, & Drew, 2015). In Brazil, fishers' local ecological knowledge (LEK) has been widely applied to complement scientific information used in resource management (Herbst & Hanazaki, 2014; Silvano & Valbo-Jørgensen, 2008; Zapelini, Giglio, Carvalho, Bender, & Gerhardinger, 2017).

The lack of long-term data on fisheries may give rise to a false sense that resources are healthy. However, different generations of fishers may perceive resource conservation status differently and use biased information to assess environmental changes, a condition known as shifting baseline syndrome (Pauly, 1995). Studies have documented this phenomenon in small-scale fisheries (i.e. Bender, Floeter, & Hanazaki, 2013; Giglio, Luiz, & Gerhardinger, 2015; Sáenz-Arroyo, Roberts, Torre, & Cariño-Olvera, 2005; Sáenz-Arroyo, Roberts, Torre, Cariño-Olvera, & Enríquez-Andrade, 2005). Some have even revealed that the divergent inter-generational perception of a given resource is independent of the type of fishing gear used and the degree of fisher specialization (Ainsworth, 2011; Bender et al., 2014). However, in order to take account of shifting baselines it is essential that biological change must have occurred in the system and any such perceived changes must be consistent with the available biological data (Papworth, Rist, Coad, & Milner-Gulland, 2009).

The continuous depletion of resources mandates that fishers replace less abundant target species with more abundant ones based on profit (Sethi, Branch, & Watson, 2010). The preference for specific fishing gear and target species will give rise to a fisher–fish interaction network (Erler, Lima, & Schiavetti, 2015). While connected and modular networks are associated with greater stability and resistance to disturbances, nested trophic networks may indicate less persistent structures (Thébault & Fontaine, 2010). In the context of fisheries, a nested pattern would reveal specialist and generalist fishers, while modularity would point to sets of interacting fishers and target species. The effect of disturbances such as overfishing of a species and its potential fishing ban (or extinction) may alter the structure of these interaction networks (Figure 1). Network structure would also reveal how resource users deal with fishing uncertainties (Salas & Gaertner, 2004; Smith & McKelvey, 1986). Thus, the network approach is relevant in the context of fisheries management, revealing patterns of resource users and enabling behaviour prediction in scenarios of resource decline (Erler et al., 2015; Martin, Shizuka, Chizinski, & Pope, 2017).

Here, we investigate the historical fisheries trends in Abrolhos Bank, Brazil, the largest and richest coral reef system in the south Atlantic (Leão, Kikuchi, & Testa, 2003; Moura et al., 2013). Abrolhos Bank was one of the first fisheries sites to be economically explored in Brazil (Bueno, 1998), and fishing still remains as the major economic activity in the region (Freitas, Moura, Francini-Filho, & Minte-Vera, 2011). Today, a mosaic of marine protected areas (MPAs) covers the Abrolhos Bank: a National Marine Park (NMP: full protection, International Union for Conservation of Nature Category II), and two Extractive Reserves (ER; partial protection; Corumbau and Cassurubá, International Union for Conservation of Nature Category VI). Fishers in the municipality of Caravelas, closest to the NMP, are the beneficiaries of the Cassurubá ER, while the municipalities of Alcobaça, Prado, and Porto Seguro are situated in the north of the NMP.

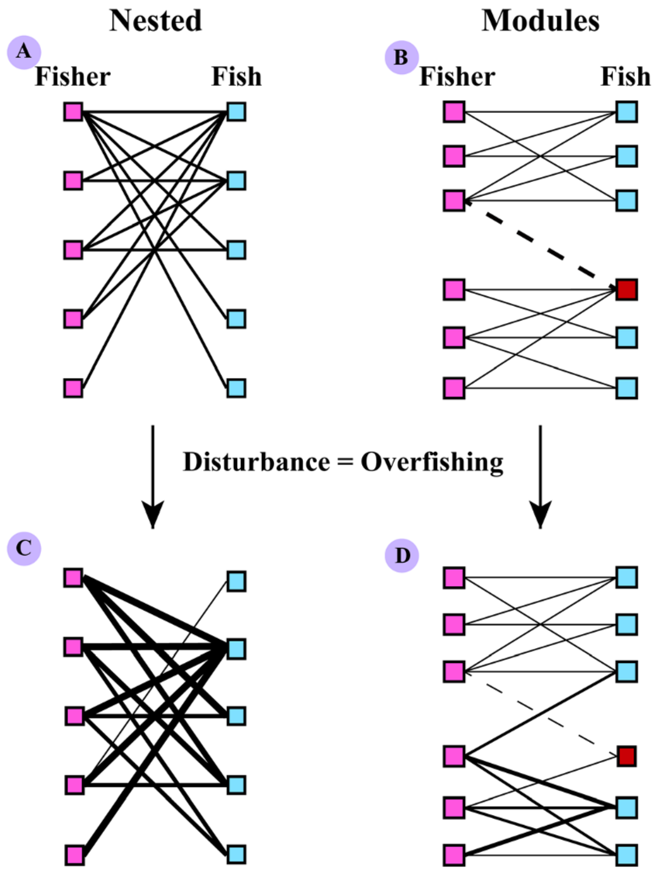


**FIGURE 1** Overfishing effects to fisher–fish network structure. In (a), nested networks, fishers' patterns of resource use characterize generalist (many connections) and specialist (few connections) fishers; while in (b), modular networks there are sets of interacting fishers and fish. The disturbance caused by overfishing with declines in species' abundance can alter network structure. Under this scenario (c), fishers will redirect fishing effort to species that remain in the system, increasing the pressure on species of greater commercial value. The overfishing of a module hubs (vertices in red) in modular networks (d) may alter network structure (indicated by the thinnest dashed line) and initiate extinction cascades. New links can arise between modules leading to a decrease in modularity and increasing network instability. Thick connections indicate more intense fishing effort while thinner connections indicate that fishers have a secondary interest in species. Links between module hubs are represented by the dashed line

In general, the greatest biological benefits come from MPAs where resource exploitation is banned (Edgar et al., 2014). However, partially protected MPAs may also have positive results, including greater biomass and average size of target species relative to unmanaged open areas (Guidetti & Claudet, 2010; McClanahan, Marnane, Cinner, & Kiene, 2006). This suggests that partially protected MPAs can aid in the recovery of fishery resources, influencing fisher–fish relations. In these municipalities, fishers' LEK was evaluated to assess: (i) the historical perceptions of the abundance of fishing resources; and (ii) the structure of fisher–fish networks along fishing communities under different management contexts. While revealing ecosystem changes in a coral reef hotspot, our results provide useful information for fisheries management.

## 2 | METHODS

### 2.1 | Study area

The Abrolhos Bank is an extension of the continental shelf (~46,000 km$^2$) with depths up to 90 m at the shelf break. It presents a diversity of habitats, such as rhodolith beds, seagrasses, seaweeds, and mangroves (Moura et al., 2013). The Abrolhos NMP (913 km$^2$) was created in 1983, comprising two discontinuous portions: Timbebas reef (110 km$^2$), closer to the coast (10 km) and poorly supervised, and Abrolhos Archipelago (803 km$^2$), 70 km from the coast and relatively well-enforced. Among the partially protected coastal MPAs, the Corumbau ER (~900 km$^2$) was created in 2000, and the Cassurubá ER (1,005 km$^2$) was established in 2009 (Figure 2). Both ERs are of exclusive use for beneficiaries from traditional fishing communities that co-manage the area with the Brazilian environmental agency, ICMBio.

In Abrolhos Bank, fishers employ a range of gear, such as handlines, longlines, gillnets, spearfishing, and bottom shrimp trawling (Previero & Gasalla, 2018; Santos Neto, Giglio, & Schiavetti, 2016). During the seasonal closure to bottom trawling, fishers work with other gears, such as handlines and longlines (Musiello-Fernandes, Zappes, & Hostim-Silva, 2017). The main target species are the red grouper (*Epinephelus morio* Valenciennes), the black grouper (*Mycteroperca bonaci* Poey), snappers (e.g. *Lutjanus jocu* Bloch & Schneider, *Lutjanus analis* Cuvier, *Lutjanus synagris* Linnaeus, and *Ocyurus chrysurus* Bloch), and parrotfishes (*Scarus* spp.) (Francini-Filho & Moura, 2008; Freitas et al., 2011).

### 2.2 | Shifting baseline syndrome assessment

Fishers from Porto Seguro, Prado, Alcobaça, and Caravelas were interviewed through a questionnaire containing closed questions. Fishers were interviewed in fish markets, households and ports between

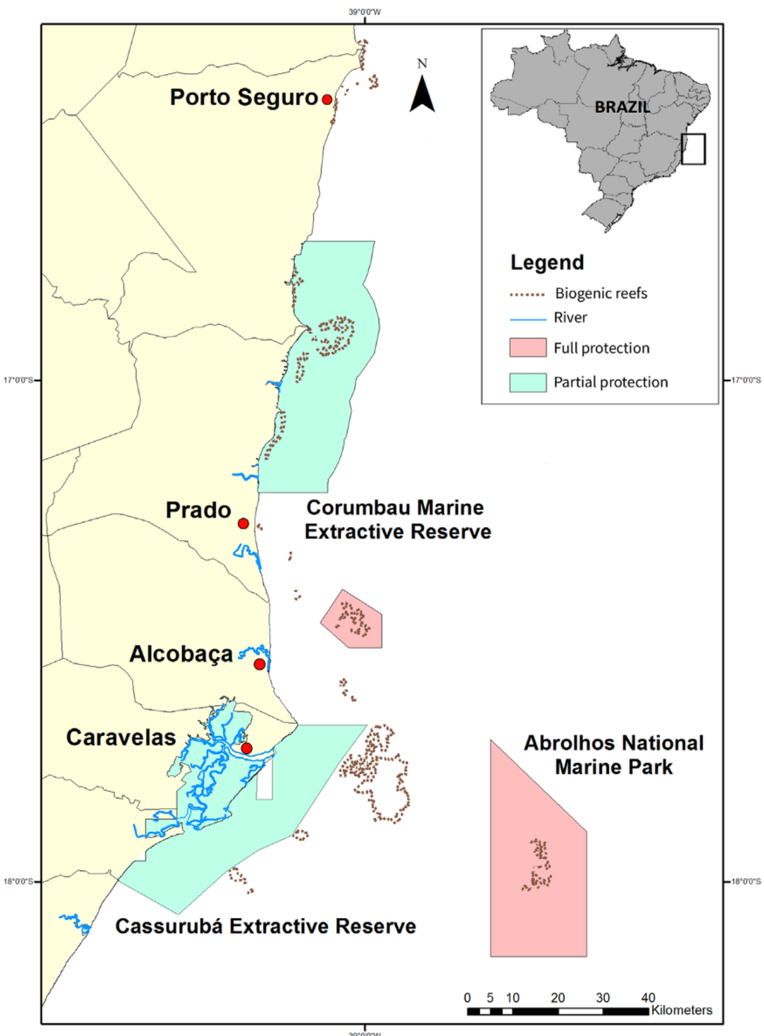


**FIGURE 2** Study sites showing the marine protected areas location

March 2015 and March 2017. Interviews were conducted following previous consent from participants. The majority of fishers interviewed in Prado are not Corumbau's ER beneficiaries, acting outside its limits, while Caravelas' fishers may work inside or outside Cassurubá ER limits.

Each fisher was asked: (i) age and year of the beginning of their careers; (ii) whether fishing sites in the region currently have fewer, equal or greater quantity of fish relative to the past; (iii) if a change has been identified, for how many species that has been the case; (iv) the distance from the nearest and the farthest fishing sites in the beginning of their careers (past) and at the time of the interview (current); (v) the average catch (kg), number of crew members, fishing time (hours) and fishing gear for the past and present periods (see Questionnaire in Supplementary Material). From this information, the catch per unit effort (CPUE; kg.fisher$^{-1}$.h$^{-1}$) per gear for both periods was calculated: $CPUE_{past}$ and $CPUE_{current}$ and, the $CPUE_{past}/CPUE_{current}$ ratio. These ratios represent the perceived changes in resource abundance (PCRA) by each fisher. The relationship between PCRA and the beginning of fishers' careers was verified. In addition, the fishers' perception of the relative abundance of eight target species was assessed (Table 1).

Photographs were used for fish species identification. For each species, fishers indicated their perception for the past and current periods, as described above. Perceptions of abundances were identified as low, medium, or high. Fishers were asked: (i) the largest black grouper specimen (kg) caught and the year that catch was made; and (ii) the largest number of individuals ever caught (n) and year that catch was made. The black grouper is one of the main target species in the region, being listed as Vulnerable in the Brazilian Red List of Threatened species (MMA, 2014). Thus, we verified whether the current species' threat category influences fishers' perceptions, considering that the literature on shifting baselines generally focuses on species of conservation concern (e.g. Giglio et al., 2015; Sáenz-Arroyo et al., 2005).

## 2.3 | Fisher–fish weighting factor

Each fisher was asked which fish species they caught (only for the interview period). This provided a free-list of the species cited by all fishers. Free-list is an approach to identify items in a cultural domain and can accumulate data quickly and easily (Quinlan, 2005). It simply involves listing things in a domain (in this case, fishes) in any order that comes to mind. The resulting list explores local knowledge and its variation in a studied community. The Cognitive Salience Index (S; Sutrop, 2001) was adapted from the free-list to verify the importance of each species. The S refers to a species' citation frequency and the number of times it is cited in a particular citation order and is given by:

$$S = \frac{F}{(N * mP)} * K$$

where S is salience; F, species citation frequency in the free list; N, number of interviewed fishers; mP, mean position in which the species was classified; and K, multiplication factor.

The index ranges from 0 to 1. If a species is often quoted and always in first position of the free-list, its salience tends to 1. By contrast, the salience of species mentioned with low frequency and in the last positions tends to 0. A multiplication factor (K = 1,000) was added to obtain S values always >1. With such an approach, each quoted species obtained an importance value given by its salience. This importance value was used as a weighting factor in fisher–fish network links. Recent network studies have highlighted the importance of including the weighting between vertices: the combined knowledge of network structure and interaction strength allows a clearer understanding of the dynamics and dependence between the nodes (Barrat, Barthélemy, Pastor-Satorras, & Vespignani, 2004; Bascompte, Jordano, & Olesen, 2006; Berlow et al., 2004). The species cited by fishers were identified to the lowest possible taxonomic level.

**TABLE 1** Species considered in the evaluation of relative abundance through interviews with fishers from Abrolhos Bank

| Species | Assessment* | Reference |
|---|---|---|
| *Coryphaena hippurus* (common dolphinfish) | Overexploited | [a] |
| *Epinephelus morio* (red grouper) | Vulnerable | [b] |
| *Lutjanus analis* (mutton snapper) | Slightly overexploited/overexploited | [c, d] |
| *Lutjanus jocu* (dog snapper) | Fully exploited | [c, d] |
| *Lutjanus synagris* (lane snapper) | Slightly overexploited/overexploited | [c, d] |
| *Mycteroperca bonaci* (black grouper) | Vulnerable/overexploited | [b,e] |
| *Ocyurus chrysurus* (yellowtail snapper) | Severely overexploited | [c, d] |
| *Scarus trispinosus* (greenback parrotfish) | Endangered | [b] |

[a]Lessa, Nóbrega, and Bezerra (2004);
[b]MMA (2014);
[c]Klippel et al. (2005);
[d]Frédou et al. (2009a);
[e]Teixeira et al. (2004).
*Assessments are from regional or national scale, as there are no assessments for the local scale.

## 2.4 | Interaction network

The fisher–fish network is represented by a binary matrix, with fishers as lines and fish species as columns. The interaction is given by the value of each cell, with a value of 1 (presence) or 0 (absence). Cells indicating the presence of interaction (= 1) were replaced by the S values of the species, as described above. From this matrix, bipartite graphs were constructed. The vertices (fisher and fish) of the graphs can be generalist (many interactions) or specialist (few interactions) (see Bascompte et al., 2006).

The following network metrics were calculated: (i) *Connectance*, that is, the fraction of all possible connections between vertices that are realized in the network (Dunne, 2006), given by:

$$C = \frac{2L}{S(S-1)}$$

where C is connectance; L, total number of observed interactions; and S, number of possible interactions. (ii) *Nestedness* is formed by a group of specialist vertices that interact only with a subset of the vertices that generalists interact with (Bascompte, Jordano, Melián, & Olesen, 2003). For such an analysis, the matrix was used with its original values (presence = 1 and absence = 0). (iii) *Modularity* is characterized by cohesive groups of highly connected vertices that interact more with each other than with other vertices in the network (Olesen, Bascompte, Dupont, & Jordano, 2007) and is usually found in antagonistic networks that tend to be non-nested (Bellay, Lima, Takemoto, & Luque, 2011; Lewinsohn, Prado, Jordano, Bascompte, & Olesen, 2006). For this analysis, the weighted matrix was used. (iv) *Degree of vertices* (z) and *connectivity between modules* (c) define the position of a vertex compared to the other vertices within its module and how well it connects to vertices of other modules, respectively. Generalist vertices have relevance to maintaining the structure inside and outside their own modules. These highly connected vertices within modules are designated as module hubs and vertices that connect two or more modules are connectors (Guimerá & Amaral, 2005; Olesen et al., 2007). The loss of these vertices (extinction of a species) can lead the entire module or network to fragmentation, shifting the fishing pressure to other vertices (species).

## 2.5 | Data analysis

Fishers were categorized into three age groups: young (≤30 years), middle-aged (31–54 years), and old (≥55 years). Factorial ANOVA was used to verify whether the number of declining species varied among age groups and municipalities, as well as to assess the interaction of these variables. One-way ANOVA was used to evaluate the differences in the distances of nearest and farthest fisheries sites in the past/current periods and between sites. The relationship between the PCRA and the beginning year of each fisher's career was modelled using generalized additive models using Gaussian distribution through the R package *mgcv* (R Core Team, 2018; Wood, 2017).

The qualitative perception of the relative abundance of species received values such as low = 1, medium = 2, and high = 3. This approach has been suggested to avoid possible bias in individual perception with a quantitative approach (Daw, Robinson, & Graham, 2011). Thus, for each species, a general index of individual perception of the fisher was elaborated:

$$P_i = P_{curr_i} - P_{past_i}$$

where $P_i$ is perception of the species *i*; $Pcurr_i$, current perception for species *i*; and, $Ppast_i$, past perception for species *i*.

In this way, there is an ordinal scale with five possible values (−2: extreme decline, −1: decline, 0: no change, 1: increase, 2: extreme increase). An ordinal logistic regression (OLR) model was run using the R function '*polr*' (MASS package, Ripley et al., 2014). The function fits an OLR model with proportional odds for an ordinal response variable. The model was run considering fishers' perceptions at the beginning of their careers. Different link functions (logistic, cloglog, probit, and cauchit) were tested. The choice of the most appropriate model was based on Akaike information criterion values. The OLR model is appropriate to verify the effect of a predictive variable across all levels of ordinal response variables. It does not assume normality and homoscedasticity but requires the assumption of parallel lines across all levels of the categorical outcome (Chen & Hughes, 2004; McCullagh, 1980).

One-way ANOVA was used to verify differences in the weight of the largest black grouper caught and the largest quantity of black grouper caught among fisher generations. Additionally, differences between municipalities considering the same age groups were verified.

The nestedness degree was calculated using the nestedness metric based on overlap and decreasing fill (NODF) (Almeida-Neto, Guimarães, Guimarães, Loyola, & Ulrich, 2008). To test the significance of NODF, random matrices (*n* = 1000) were generated from the original matrix, in which the probability of interactions between fishers and fish was proportional to the total number of interactions (Bascompte et al., 2003; Guimarães & Guimarães, 2006). The proportion of random matrices with NODF values equal to or greater than the observed values indicated a (significantly) higher than expected nested pattern (Erler et al., 2015). Observed NODF values and null matrices were calculated using the Aninhado v.3.0 software (Guimarães & Guimarães, 2006).

Modularity (Q) was calculated using the QuaBiMo algorithm for weighted bipartite networks (Dormann & Strauss, 2013, 2014). To test the significance of observed modularity, random matrices (*n* = 1000) were generated, and their respective Q values were calculated. Subsequently, observed modularity was compared to those from the random matrices (null models). This was done by calculating z-scores:

$$z_Q = \frac{Q_{real} - \mu_{Q_{null}}}{\sigma_{Q_{null}}}$$

where $Z_Q$ is standardized Q value; $Q_{real}$, modularity of the real matrix; $\mu_{Qnull}$, null matrices average modularity; and $\sigma_{Qnull}$, standard deviation of null modularity. Since *z*-scores are assumed to be normally

**TABLE 2** Total number of fishers interviewed, by age group, and average age in each municipality

| Municipality | *N* fishers | Age group Young (≤30 years) | Middle-aged (31–54 years) | Old (≥55 years) | Average age (±SD) |
|---|---|---|---|---|---|
| **Porto Seguro** | 55 | 6 | 30 | 19 | 47.6 (±12.6) |
| **Prado** | 50 | 13 | 26 | 11 | 41.6 (±13.5) |
| **Alcobaça** | 54 | 14 | 33 | 7 | 40.5 (±12.3) |
| **Caravelas** | 51 | 8 | 28 | 15 | 46.7 (±13.1) |

distributed, values >2 were considered to be significantly modular (Dormann & Strauss, 2013).

Degree of vertices (z) and connectivity between modules (c) were calculated according to Guimerá and Amaral (2005). The assumption of OLR parallel lines was verified in SPSS software v.21 (IBM, 2012). All others statistical analyses were conducted in R software at a significance level of 5%.

This study was approved by the Ethics Committee of the Universidade Estadual de Santa Cruz (CEP/UESC, N° 37893014.5.0000.5526, and by the System of Authorization and Information on Biodiversity (SISBIO 43528–1/43528–2).

## 3 | RESULTS

A total of 210 fishers were interviewed, with those from the middle-aged group being the largest number in all municipalities. Fishers from Porto Seguro had the highest average age, while fishers from Alcobaça had the lowest average age (Table 2).

In general, fishers indicated that fishing sites have fewer (82.8%) fish, whereas those that indicated equal (14.7%) or greater (2.4%) were much less frequent. Only the age group was a significant factor, and old fishers mentioned a greater number of declining species (Table 3, Figure S1).

Overall, fishers are fishing farther away than at the beginning of their career. Fishers from Caravelas operate at closer sites than fishers from the other municipalities (Table S1; Figure S2).

Since the late 1950s, there has been a decrease in the perceived change in resource abundance of handline fishers, which means that experienced fishers perceive a steeper decline in catch compared to the perceptions of younger fishers. There was no significant change for fishers using other fishing gear (Table S2; Figure S3).

**TABLE 3** Summary of ANOVA test evaluating the number of species cited in decline as a function of age, municipality, and interaction of factors

| Source of variation | Df | Sum Sq | Mean Sq | F-value | *P*-value |
|---|---|---|---|---|---|
| Site | 3 | 2.3 | 0.78 | 0.26 | 0.85 |
| Age group | 2 | 67.6 | 33.79 | 11.38 | <0.001 |
| Site*Age group | 6 | 14.5 | 2.42 | 0.81 | 0.56 |
| Residuals | 149 | 442.3 | 2.97 | | |

In general, there were different perceptions regarding changes in the relative abundance of species (Figures 3A and 3B; Table S3). Old fishers from Alcobaça reported that the abundance of common dolphinfish has declined compared to the abundance at the beginning of their careers. By contrast, there was a greater tendency of young fishers to report no change in fisheries (Figure 3A-c). For the red grouper (Figure 3A-g) and dog snapper (Figure 3A-o), the perception of Caravelas' old fishers differed from other sites. In Caravelas, young fishers reported an extreme decline of fish relative to the past. In Porto Seguro, the perception of decline in the abundance of mutton snapper (Figure 3A-h) was more pronounced than at the other sites. For the lane snapper (Figure 3B-a–d) and black grouper (Figure 3B-e–h), fishers' perceptions were similar across all sites. For the yellowtail snapper, some old fishers reported greater abundance in the past, but most fishers reported no change, most notably in Caravelas (Figure 3B-l). Finally, the decline in abundance of the greenback parrotfish was more pronounced for Caravelas' old fishers (Figure 3B-o).

There were some inconsistencies between fishers' perceptions and the available landing data. For instance, for the dog snapper, a greater production was verified to late 1990s, albeit with great variation (Figure S4-D). For the black grouper and yellowtail snapper, an increasing trend of production over the years was observed (Figure S4-F, G). However, these comparisons should be viewed with caution considering the different scales (regional/local), data gaps, and lack of landing statistics after 2007; in addition, there are no data on fishing effort.

In Porto Seguro, middle-aged and old fishers captured heavier black grouper than did young fishers (Kruskal–Wallis: $\chi^2$ = 8.9; df = 2; $P$ = 0.01; Figure S5). Among municipalities, a significant difference was verified considering middle-aged (ANOVA: $F_{3,91}$ = 7.11; $P$ < 0.001) and old fishers ($\chi^2$ = 14.4; df = 3; $P$ = 0.002), and fishers from Caravelas captured smaller individuals (Figure 4).

No difference was observed in the largest quantity of black grouper caught between age groups in any municipality (Figure S6). However, there was a difference between municipalities, considering middle-aged ($\chi^2$ = 12.1; df = 3; $P$ = 0.007) and old fishers ($\chi^2$ = 15.5; df = 3; $P$ = 0.001), and Caravelas' fishers captured fewer individuals (Figure 4).

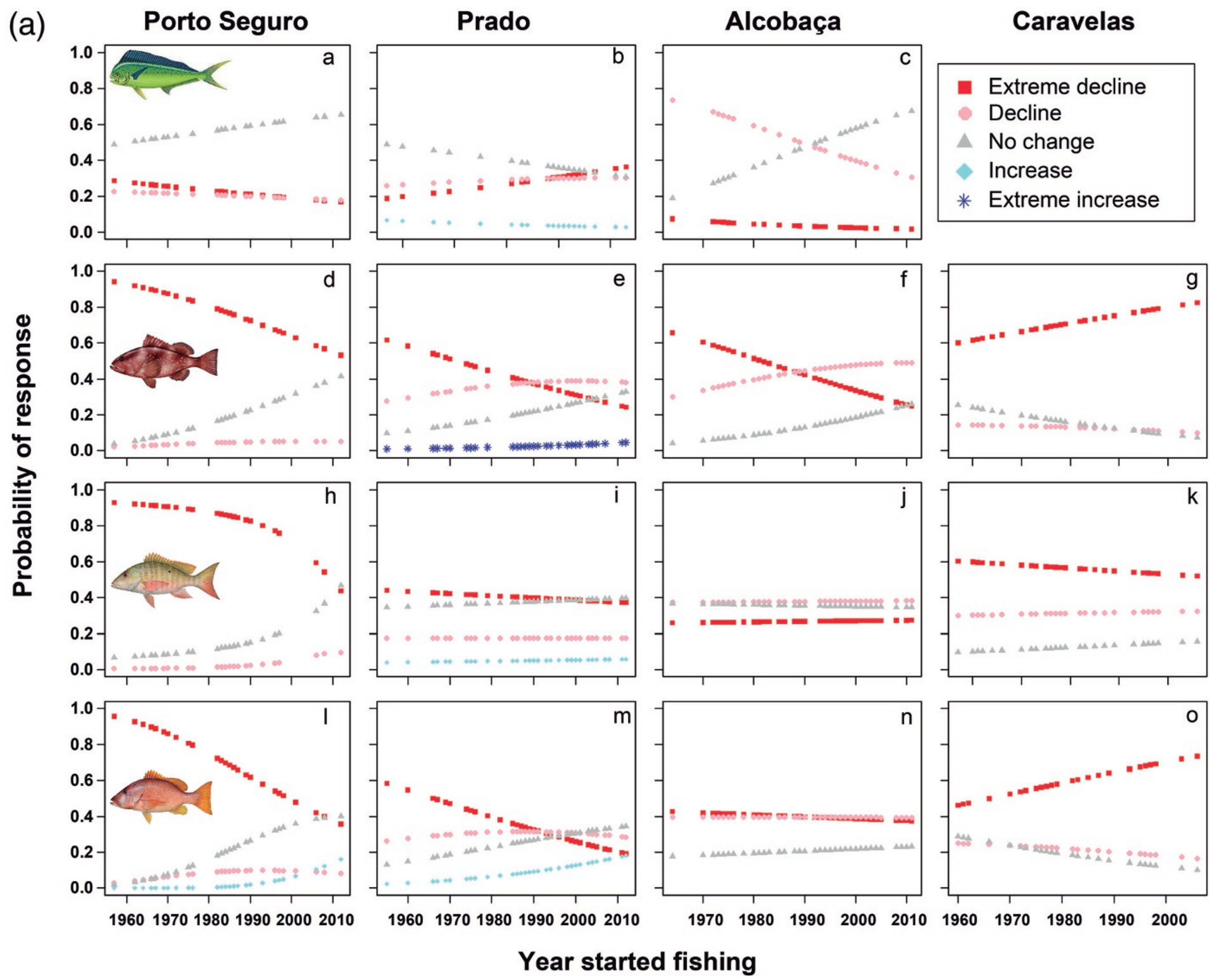


**FIGURE 3** (A) Ordinal logistic regression model adjusted to the perception of change in the relative abundance of common dolphinfish (a–c), red grouper (d–g), mutton snapper (h–k), dog snapper (l–o) in Porto Seguro (a, d, h, l), Prado (b, e, i, m), Alcobaça (c, f, j, n), and Caravelas (g, k, o). In Caravelas, it was not possible to adjust the model for common dolphinfish because the number of fishers involved in fishing was reduced.
(B) Ordinal logistic regression model adjusted to the perception of change in the relative abundance of lane snapper (a–d), black grouper (e–h), yellowtail snapper (i–l), and greenback parrotfish (m–o) in Porto Seguro (a, e, i, m), Prado (b, f, j), Alcobaça (c, g, k, n), and Caravelas (d, h, l, o). The y-axis represents the probability of a fisher indicate a change in relative abundance considering the year of the start of his career (x-axis). In Prado, it was not possible to adjust the model for greenback parrotfish because the number of fishers involved in fishing was reduced

The interaction networks of the four municipalities had significant nestedness and modularity values. Alcobaça exhibits a more nested interaction network. Porto Seguro had the lowest connectance, while Caravelas presented the highest values of connectance and modularity (Table 4, Figure S7). These results suggest that the interaction network of Caravelas presents greater stability, with stronger interaction strength relative to the other networks. By contrast, the Alcobaça network tends to be more fragile due to the greater nestedness and low modularity patterns.

Fishers from Porto Seguro had a more intense relationship with yellowtail snapper, common dolphinfish, and black grouper (Figure 5). In Prado, there were stronger interaction patterns with yellowtail snapper, black grouper, and lane snapper (*L. synagris*). In Alcobaça, the strongest interactions were with yellowtail snapper, black grouper, and red grouper, whereas in Caravelas, these interactions were with Atlantic seabob (*Xiphopenaeus kroyeri* Heller), Serra Spanish mackerel (*Scomberomorus brasiliensis*), and lane snapper. Most fishers are generalists, while a smaller portion is made up of specialists.

The relationship between degree of vertices (z) and connectivity between modules (c) revealed the existence of module hub species in all municipalities (Figure S8), that is, highly connected species within its module. *Ocyurus chrysurus*, *C. hippurus*, and *M. bonaci* were module hubs in Porto Seguro, and the first two species presented greater salience and belonged to the same module. In Prado, *O. chrysurus* and *M. bonaci* were hubs, and the two species presented the largest salience; however, they belong to different modules. In Alcobaça, *M. bonaci* showed the second highest value of salience but was a unique hub. Finally, in Caravelas, *X. kroyeri* presented the highest salience and was the only hub. Such results highlight the critical role that species hubs play in maintaining the stability of networks and the high dependence of fishers on overexploited species.

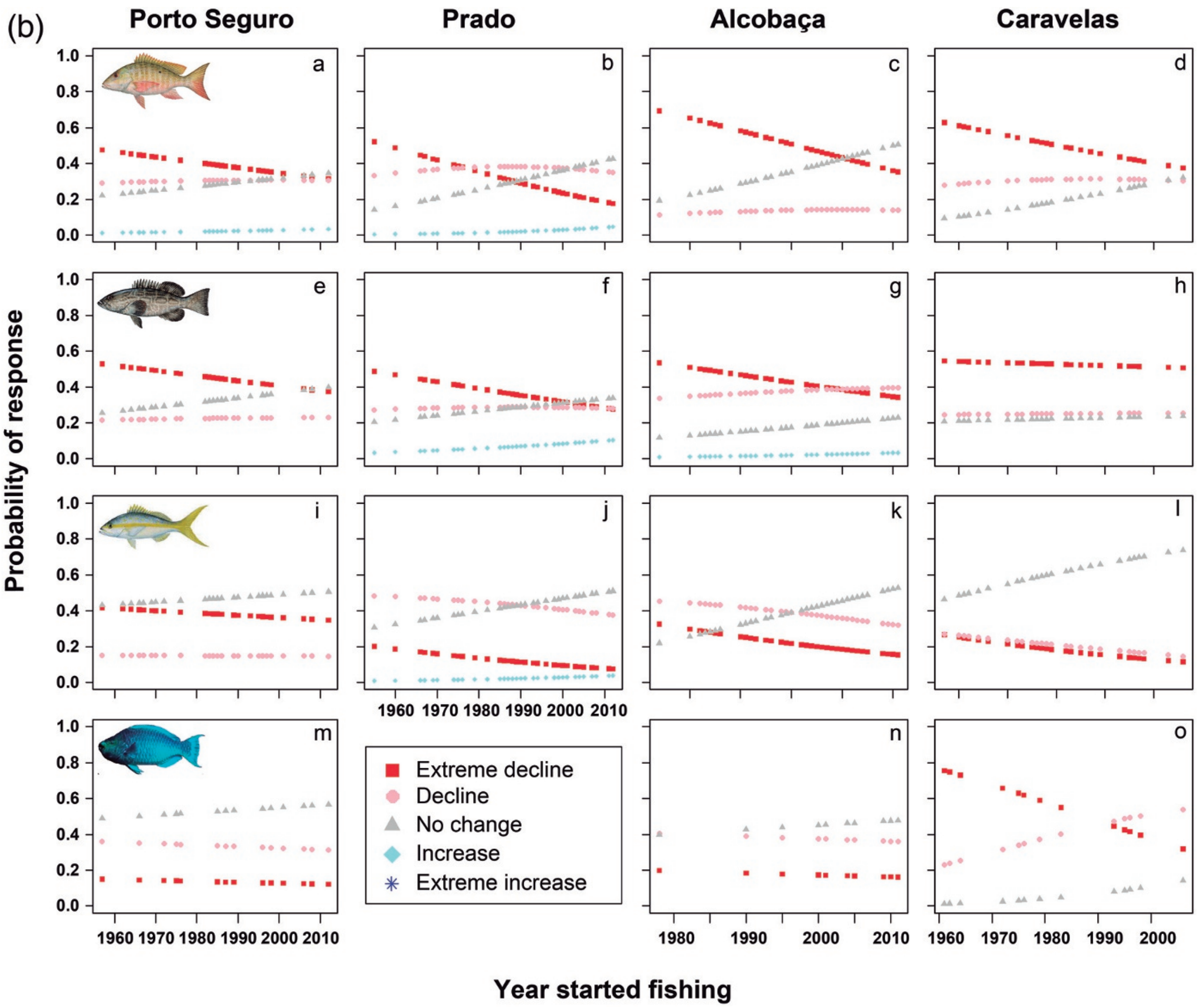


**FIGURE 3** (Continued)

## 4 | DISCUSSION

This study identified differences in the perception of fisher generations regarding overexploited and commercially important species in Abrolhos Bank. In addition, handline fishers have indicated a decline in CPUE across decades. These results have important management consequences, considering that fishers rely on these resources as verified by the interaction networks.

### 4.1 | Occurrence of the shifting baseline syndrome

The Abrolhos Bank has a secular history of fisheries. Although there is a dearth of information on the quantity of fish traded in the past, rough estimates of historical reports by European travellers suggest that approximately 90,000–100,000 specimens of *garoupa* and *mero* (probably the red grouper and the Atlantic goliath grouper *E. itajara*, respectively) were marketed annually from Porto Seguro to Salvador and other Captaincies during the colonial period (Maximilian, 1820). Other records from the early 19th century reinforce the relevance of Porto Seguro as a place of prodigious quantity of red grouper and Atlantic goliath grouper (Vilhena, 1802). Today, red grouper specimens are only occasionally landed in the region (Figure 3A, S4-B) and the lack of effective management tends to perpetuate the current situation.

The yellowtail snapper may follow the historical depletion pattern seen for the red grouper. Between 1979 and 1985, the yellowtail snapper was considered the sixth most important species between Salvador (north of the study region) and Itaipava (south). A few years later, between 1997 and 2000, it became the main target species in the region (Figure 3B; S4-G), now it is being overexploited (Frédou, Ferreira, & Letourneur, 2009a; Klippel, Olavo, Costa, Martins, & Peres, 2005). Some of the interviewees indicated that the species' abundance is stable, similar to the perception of a previous study in Porto Seguro (Bender et al., 2013). Such a pattern indicates the principle by which the handline fleet operates: species are exploited to the point of economic exhaustion and subsequently replaced by another, more profitable species (Klippel et al., 2005). Fishers' knowledge in some instances may be a reliable source of information to understand abundance trends of targeted resources (Sáenz-Arroyo & Revollo-Fernández, 2016; Thurstan, Buckley, Ortiz, & Pandolfi, 2016).

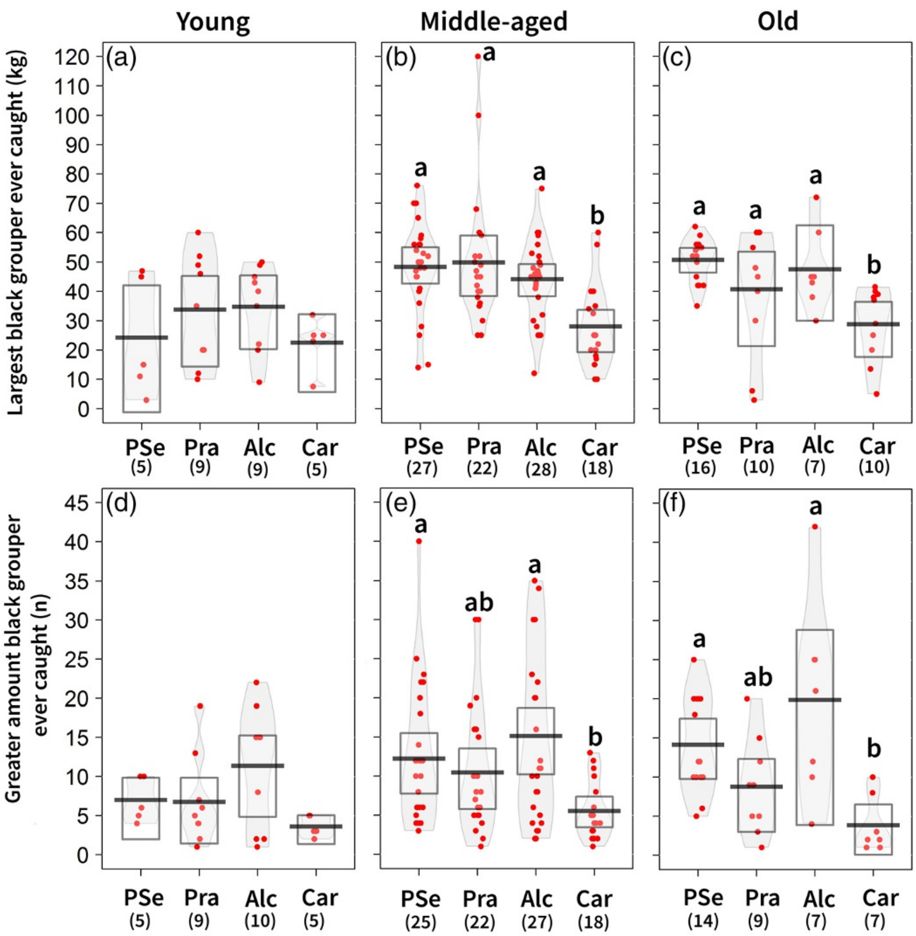


**FIGURE 4** Largest black grouper (a, b, c) and greater amount of black grouper ever caught (d, e, f) in Porto Seguro (PSe), Prado (Pra), Alcobaça (Alc), and Caravelas (Car) considering the fishers generations. Numbers below the abbreviations of municipalities indicate number of fishers. Points are the raw data, black line represents the average, bean is the inference interval. Different letters above plots indicate significant differences (Dunn test, $P < 0.05$)

**TABLE 4** Metrics of fisher–fish interaction networks in the municipalities of Abrolhos Bank. Values in bold indicate statistical significance

| Municipality | *N* species | *N* fishers | Connectance | Nestedness | Modularity |
|---|---|---|---|---|---|
| Porto Seguro | 57 | 52 | 0.0000585 | **20.74** | **0.274** |
| Prado | 46 | 49 | 0.000087 | **26.18** | **0.256** |
| Alcobaça | 34 | 50 | 0.000143 | **31.99** | **0.206** |
| Caravelas | 31 | 50 | 0.000162 | **26.74** | **0.464** |

However, in the study region, it is possible that the abundance of yellowtail snapper has not yet reached the lower limit at which fishers recognize its decline. Further studies focusing on the catch trends of this species may clarify this issue.

The environmental reference of fishers is acquired from their personal experiences and is reflected in perception differences across generations (Bender et al., 2014). Among fishers, there is a widespread notion that resources are not declining but that catches are diluted among the growing number of fishers and vessels. Unfortunately, there are no official and up-to-date data for this perception to be assessed. However, studies point to the high fishing pressure in the region (Frédou et al., 2009a; Frédou, Ferreira, & Letourneur, 2009b; Teixeira, Ferreira, & Padovan, 2004). In addition, the finding that fishers travel greater distances to fish suggests that coastal fisheries sites are depleted. In Caravelas, fishers have smaller vessels, fish closer to the coast, and rely on a governance system based on consensual rules and management measures (Fishery Agreement; Nobre & Schiavetti, 2013). Such co-management systems could mitigate shifting baselines (Campbell, Gray, Hazen, & Shackeroff, 2009), but this has not been the case for Caravelas' local fishers. Clearly, the causes, consequences, and strategies to avoid shifting baselines are complex and may require more than the co-management system.

The fact that older fishers indicate a greater number of depleted species supports the shifting baselines hypothesis across generations: younger fishers assume that species abundance is stable or low. This is not the case for Caravelas, suggesting that: (i) no decline would be occurring at this specific site; (ii) oral transmission of information between generations of fishers on depleted species; or (iii) individual

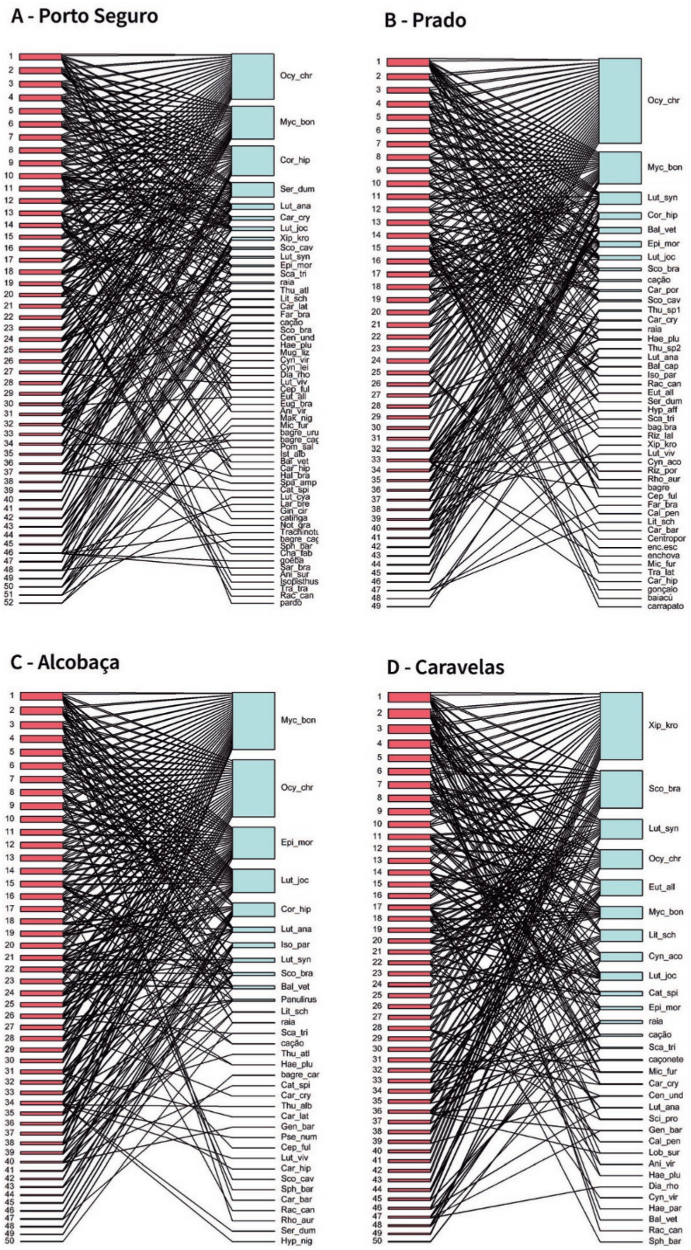


**FIGURE 5** Fisher–fish interaction networks. Blue vertices are fish species; Red vertices are fishers. Links denote the citation of fish as target species by each fisher. Ani_sur: *Anisotremus surinamensis*; Ani_vir: *Anisotremus virginicus*; 'baiacú', 'bagre', bag-bra: 'bagre-branco', 'bagre_cagão', bag-cag: 'bagre_cagapoá', 'bagre_cangatã', 'bagre_urutu'; Bal_cap: *Balistes capriscus*; Bal_vet: *Balistes vetula*, 'cação', 'caçonete'; Cal_pen: *Calamus penna*; Cal_pen: *Calamus pennatula*; Car_bar: *Caranx bartholomaei*; Car_cry: *Caranx crysos*; Car_hip: *Caranx hippos*; Car_lat: *Caranx latus*; Car_por: *Carcharhinus porosus*; 'carrapato'; Cat_spi: *Cathorops spixii*, 'catinga'; Centropomus: *Centropomus* spp.; Cen_und: *Centropomus undecimalis*; Cep_ful: *Cephalopholis fulva*; Cha_fab: *Chaetodipterus faber*; Cor_hip: *Coryphaena hippurus*; Cyn_aco: *Cynoscion acoupa*; Cyn_lei: *Cynoscion leiarchus*; Cyn_vir: *Cynoscion virescens*; Dia_rho: *Diapterus rhombeus*, 'enchova'; enc-esc: 'enchova-escamuda'; Epi_mor: *Epinephelus morio*; Eug_bra: *Eugerres brasilianus*; Eut_all: *Euthynnus alletteratus*; Far_bra: *Farfantepenaeus brasiliensis*; Gen_bar: *Genidens barbus*; Gin_cir: *Ginglymostoma cirratum*, 'goêba', 'gonçalo'; Hae_par: *Haemulon parra*; Hae_plu: *Haemulon plumieri*; Hal_bra: *Halichoeres brasiliensis*; Hyp_aff: *Hypostomus affinis*; Hyp_nig: *Hyporthodus nigritus*; Isopisthus: *Isopisthus* spp.; Iso_par: *Isopisthus parvipinnis*; Ist_alb: *Istiophorus albicans*; Lar_bre: *Larimus breviceps*; Lit_sch: *Litopenaeus schmitti*; Lob_sur: *Lobotes surinamensis*; Lut_ana: *Lutjanus analis*; Lut_cya: *Lutjanus cyanopterus*; Lut_joc: *Lutjanus jocu*; Lut_syn: *Lutjanus synagris*; Lut_viv: *Lutjanus vivanus*; Mak_nig: *Makaira nigricans*; Mic_fur: *Micropogonias furnieri*; Mug_liz: *Mugil liza*; Myc_bon: *Mycteroperca bonaci*; Not_gra: *Notarius grandicassis*; Ocy_chr: *Ocyurus chrysurus*; Panulirus: *Panulirus* spp., 'pardo'; Pom_sal: *Pomatomus saltatrix*; Pse_num: *Pseudopercis numida*, 'raia'; Rac_can: *Rachycentron canadum*; Rho_aur: *Rhomboplites aurorubens*; Riz_lal: *Rhizoprionodon lalandii*; Riz_por: *Rizoprionodon porosus*; Sar_bra: *Sardinella brasiliensis*; Sca_tri: *Scarus trispinosus*; Sci_pro: *Sciades proops*; Sco_bra: *Scomberomorus brasiliensis*; Sco_cav: *Scomberomorus cavalla*; Ser_dum: *Seriola dumerili*; Spa_amp: *Sparisoma amplum*; Sph_bar: *Sphyraena barracuda*; Thu_sp1: *Thunnus.* sp1; Thu_sp2: *Thunnus.* sp2; Thu_alb: *Thunnus albacares*; Thu_atl: *Thunnus atlanticus*; Tra_lat: *Trachurus lathami*; Tra_tra: *Trachurus trachuru*; Trachinotus: *Trachinotus* spp.; Xip_kro: *Xiphopenaeus kroyeri*

amnesia of older fishers. The first hypothesis does not seem possible since there is growing evidence of fish resource depletion in the south-western Atlantic, including the Abrolhos Bank (Bender et al., 2013; Giglio et al., 2015; Zapelini et al., 2017). In the second case, generational amnesia would not be occurring (Papworth et al., 2009), that is, younger fishers would be aware of the previous conditions. However, this situation conflicts with the results regarding the perception of abundance patterns. Therefore, it is hypothesized that some of Caravelas' old fishers may be experiencing individual amnesia and, thus, reported a smaller number of declining species than has actually occurred. This may also explain the unexpected perceptions observed for red grouper and dog snapper, where young fishers indicated a greater probability of decline in abundance than did old fishers.

The decline of high trophic level species triggered the search for new target species, such as the greenback parrotfish. Fishing of this species began 40 years ago and intensified in the past 20 years, mainly with the expansion of commercial spearfishing in the 1990s (Francini-Filho & Moura, 2008). The different perceptions on greenback parrotfish abundance among fishers from Caravelas and Porto Seguro/Alcobaça may be related to the spatial dimension of fleet activity. While fishers from Caravelas are concentrated in coastal areas, fishers from Alcobaça can reach more distant – and probably more productive – fisheries sites (Previero, 2014). This may influence their perception: elderly coastal fishers perceive resource decline, whereas fishers using distant areas see stability. This reveals that the search for different fisheries sites might influence the perception of abundance across generations.

## 4.2 | Interaction networks

The interaction networks reflect fishery characteristics in each municipality, including the patterns of fishing pressure and resource competition among fishers. The result reveals the multispecies nature of reef fishing, where fishers target some species primarily; yet there is a range of secondary species that are also exploited. Presently, the networks present a structure already altered by species overfishing (e.g. red grouper) as verified by shifting baseline syndrome above. Decades ago, possibly the strongest links would be between fishers and red grouper. However, the decrease in its abundance caused a change in the networks. Moreover, current legislation (e.g. MMA, 2014) can also cause changes in the network due to the moratorium that prohibits the capture of species, as is the case of the Atlantic goliath grouper (Zapelini et al., 2017).

The studied networks are simultaneously nested and modular. Modules depict the existence of stronger or more frequent links between vertices within a module and weaker links across modules (Krause, Frank, Mason, Ulanowickz, & Taylor, 2003). Thus, links within a module are stronger and tend to produce greater stability in network relationships (Allesina & Pascual, 2008). The network of Caravelas presented greater modularity and connectance, suggesting a more stable and robust structure. The lower connectance for Porto Seguro interactions might render this network unstable, possibly due to the large number of species cited by fishers (e.g. Dunne, Williams, & Martinez, 2002). In trophic networks, high diversity is related to network instability, and a nested structure can have negative effects on the persistence of antagonistic networks, such as fisher–fish interactions (Thébault & Fontaine, 2010), most evident in Alcobaça.

In mutualistic networks, it has been suggested that nested structures can produce greater resilience to disturbance events (Bascompte et al., 2003; Pawar, 2014). However, this network property can decrease network persistence in antagonistic interactions (Thébault & Fontaine, 2010). Nested structures imply different degrees of specialization. Since specialist fishers preferentially interact with species that are targeted by generalist fishers, this results in high fishing pressure on those species. This is the case for the black grouper in Alcobaça, where many fishers target this already overexploited species. Specialization can bring benefits such as income stability and consistency (Smith & McKelvey, 1986). By contrast, drastic changes in the abundance of a certain resource can destabilize the network. A redirection of fishing pressure on less targeted species can minimize the risk of overfishing; however, such management action is difficult to apply, considering fishers' preference for species with higher commercial value.

Modular systems tend to have a greater niche overlap between their vertices, that is, fishers of a module direct their effort to capture the same subset of available species. By contrast, there is smaller competition with members (fishers) from other modules. This suggests that the reduction of diffuse competition among fishers of different modules in Caravelas can compensate for the greater niche overlap between fishers within the same module, reducing, therefore, the general competition in this site (MacArthur & Levins, 1967; Pianka, 1974). The greater modularity for Caravelas implies greater resistance to disturbance, in this case, overfishing.

In addition, the network in Caravelas presented shrimp as the module hub. Shrimp fishing is a seasonal activity due to the ban of fishing in the closed season; however, fishers can redirect their effort to other resources. This strategy may be a consequence of the overexploitation of the species of greater commercial importance and, at the same time, represents an effort to minimize the risk of changes in income (Anderson et al., 2017), considering the higher aggregate value of lower trophic level species (Sethi et al., 2010). In other municipalities, hubs are carnivore/invertivore species, and their overfishing could trigger trophic cascades (Bascompte, Melián, & Sala, 2005). This could lead to network de-structuring given the synergistic effects of nestedness, lower connectance, and greater diversity of species (Thébault & Fontaine, 2010).

In Caravelas, fisher–fish network structure might reflect the resource governance system of the Cassurubá ER. Caravelas' fishers have exclusive access to resources and this limits competition with non-beneficiary fishers. Personal relationships in co-management systems build a social capital determined by people with common goals (Pretty, 2003). The resulting strong links can be associated with increased confidence and cooperation and this, in turn, encourages fishers to observe fishing rules and practise sustainable fishing (Grafton, 2005).

## 4.3 | An integrated approach

Historical observations and reports from fishers give us a portrait of the past conditions of commercial fish stocks (e.g. McClenachan, 2008; Sáenz-Arroyo et al., 2005; Ulman & Pauly, 2016). The red grouper, a species that once was the region's main resource, is still desirable but scarce, captured as fishers target less valuable but more common species, a practice referred to as opportunistic exploration (Branch, Lobo, & Purcell, 2013). Today's fishers have replaced this fish with more abundant species, such as yellowtail snapper. Except for Caravelas, the species had the highest salience, probably associated with its importance in the export trade, which selects for specimens above 300 g (Costa, Olavo, & Martins, 2005).

The suggestive occurrence of shifting baselines syndrome in Abrolhos Bank emphasizes the relevance of incorporating fishers' knowledge to improve fishing management. Today, target species are being overexploited and might follow the path of the red grouper, which was once the main resource throughout the region. These characteristics may have structured Caravelas' network: less dependence on overexploited fish, more cohesive structure, and strong connections, making it more stable to the disturbance caused by overfishing. By contrast, Porto Seguro's (lower connectance) and Alcobaça's network (higher nestedness) suggest that the network structure in these sites is more unstable, built by weaker relations and more prone to fragmentation caused by overfishing. In this way, we recommend: (i) enforcement of existing norms; (ii) greater control of fishing landings in ports, considering that part of the fleet of Alcobaça, Prado, and Porto Seguro have autonomy to access fishing points on the slope, possible critical reproduction sites of species with high commercial value; (iii) establishment of partnerships with fishers to implement long-term fisheries monitoring, and that these be carried out systematically and at the species level. Our results suggest that the management system of Cassurubá ER may contribute to the resilience of local fisheries, through a network that is more robust to the disruption caused by fishes' overexploitation.


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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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