Ocean and Coastal Management 154 (2018) 83–95

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Mapping fishing grounds, resource and fleet patterns to enhance management units in data-poor fisheries: The case of snappers and groupers in the Abrolhos Bank coral-reefs (South Atlantic)

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ARTICLE INFO

Keywords:
Small-scale fisheries
Fishers' knowledge
Management units
Coral reefs
Lutjanidae
Epinephelidae

ABSTRACT

In most small-scale fisheries, especially in developing countries, the collection of reliable fishing statistics is not regular, hampering traditional stock assessments. In those data-poor fisheries, a precise knowledge of resources co-occurrence at the ecosystem level, as well as the spatial mapping of fishing activities seem key to support management in a complex fishers-environment context. In the largest South Atlantic coralline reef, the Abrolhos Bank, fisheries are extremely diverse in terms of exploitation capacity, fishing gears, target stocks and operating areas, but any regional fisheries management is currently in place. The aim of this study was to assess, organize, and analyze fisheries of three snappers (*Lutjanus jocu*, *L. synagris* and *Ocyurus chrysurus*), and three groupers (*Cephalopholis fulva, Epinephelus morio* and *Mycteroperca bonaci*) along the Abrolhos Bank, with an ultimate goal of proposing useful management units. Surveys were conducted in the main fishing ports, including fishers' interviews and fish size measures in landings. Data analysis allowed a precise fishing characterization, a grouping of stocks co-occurrence, and the mapping of fishing spots and grounds. Three stocks and seven fishing areas clusters were obtained and defined statistically, suggesting useful management units. Specific fishers' groups per fleet were identified as the main stakeholders to be consulted in fisheries plans. Spatial units based on the occurrence of snappers and groupers stocks were defined, having the "Parcel das Paredes" the greatest number of fishing spots and the lower fish sizes. Overall, findings contain unprecedented fine scale resolution units that clarifies and simplifies the connections among species, fleets, fishing areas and fishers. They should also strength the call for action to implement fisheries management in a broader ecosystem-scale context.

1. Introduction

Small-scale and artisanal fisheries are a source of food, job, income, social and cultural knowledge for coastal communities, particularly in developing countries (Vasconcellos et al., 2007; Gasalla and Castro, 2016). These fisheries are highly complex targeting many stocks, using diverse and low technology gears and vessels, which hinders the clear division of fishing fleets operations and subsequent assessments of fish resources (Salas et al., 2007; Ouréns et al., 2015). The small-scale fisheries are usually data-poor, with non-continuous and unsystematic fisheries monitoring, unknown size range of fish specimens by fleet, inexistent assessments at the stock level, unknown fleets operation patterns and labor relations. As consequence, there are misleading estimates of the fishing pressures (Ramírez et al., 2017) and deficiencies in information required for the management plans (Houk et al., 2017). It hinders and make ineffective any management action, especially at stock level (Pennino et al., 2016).

The coupled human-environment systems approach combines the interactions among them, and helps to understand patterns and processes in the human activities over the natural environment (Liu et al., 2007; Carter et al., 2014). Socio-ecological assessments are important methods for coastal management and environmental planning (Santos et al., 2017). When using participatory approaches, it should help the designing of management plans based in simplification of the complex relations among fishers, resources and the environment (Santos et al., 2017).

Beyond that, proper management units are useful for a successful small-scale fishery management. They may integrate target and by-catch species, vessels, fishing gears and key ecosystem functions (Berkes et al., 2001). Proper management units may also provide information

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https://doi.org/10.1016/j.ocecoaman.2018.01.007
Received 29 March 2017; Received in revised form 25 October 2017; Accepted 8 January 2018

instigating management actions more easily.

Small fishing communities typically develop a traditional culture associated with fishing and a high dependence on natural resources (Diegues, 2001; Santos, 2015). Therefore, for successful fisheries, to know the fishing grounds and the periods when fish are abundant is key to the daily activities of artisanal fishers (Maldonado, 2000; Deepananda et al., 2016). Some studies have demonstrated that fishers' Local Ecological Knowledge has been an effective and a low-cost method to generate information in data-poor fisheries, especially in provide spatial information (Leite and Gasalla, 2013; Shepperson et al., 2014; Aylesworth et al., 2017). Therefore, including fishers' knowledge in studies and in management plans helps to build tools to provide effective fisheries management (Hill et al., 2011; Abreu et al., 2017). For example, fishing areas with high catch density may be key in management actions by maintain fishery productivity and protect vulnerable species (Léopold et al., 2014).

Small-scale coral reef fisheries are adapted to rocky and coral bottoms and generally captures multi-species (Tokeshi et al., 2013) using multi-gear techniques. Nevertheless, coral reef overfishing has been occurring in several areas, affecting the functioning and stability of marine ecosystems, by reducing the fish sizes and the trophic levels in the catches (Bender et al., 2013; Zgliczynski and Sandin, 2017) and increasing the sensitivity to disturbances, which may lead to a phase shift in many reefs (Jackson et al., 2001; Bellwood et al., 2012).

In the largest South Atlantic coralline reefs, the Abrolhos Bank (8844 km^2 of reefs) (Fig. 1) there are widespread reef fisheries (Moura et al., 2013). The catches are composed from several trophic levels, and the snappers and groupers are important reef fishery resources (35.3% of the total fish catch) (MPA, 2013). Currently, approximately 22 species of grouper worldwide are under threat, and the declines are primarily due to the high levels of exploitation not compatible with their life-traits (i.e., long life, late reproduction and sex-changing) (Bender et al., 2013; Sadovy de Mitcheson et al., 2013; IUCN, 2014). The snappers and groupers from Abrolhos Bank are currently classified as “Vulnerable”, “Near Threatened” or of “Least Concern” by the IUCN Red Lists (ICMBIO, 2014; IUCN, 2014). The primary threats to these stocks are overexploitation and lack of management measures (Sadovy de Mitcheson et al., 2013).

Abrolhos Bank fisheries are data-poor, multi-gear, multi-species, have complex relationships among fishers, lack of structured and systematic fisheries monitoring and enforcement. At present, there are no management actions that cover the whole Abrolhos Bank ecosystem neither an organization taking care of its fisheries. Without clear information on fisheries complexity and proper definition of management units, the snapper and grouper fisheries should suffer a greater delay in fisheries management processes, which leads to several losses of ecosystem goods and services. Thus, an in-depth fisheries characterization with some definition of potential management units is an essential step

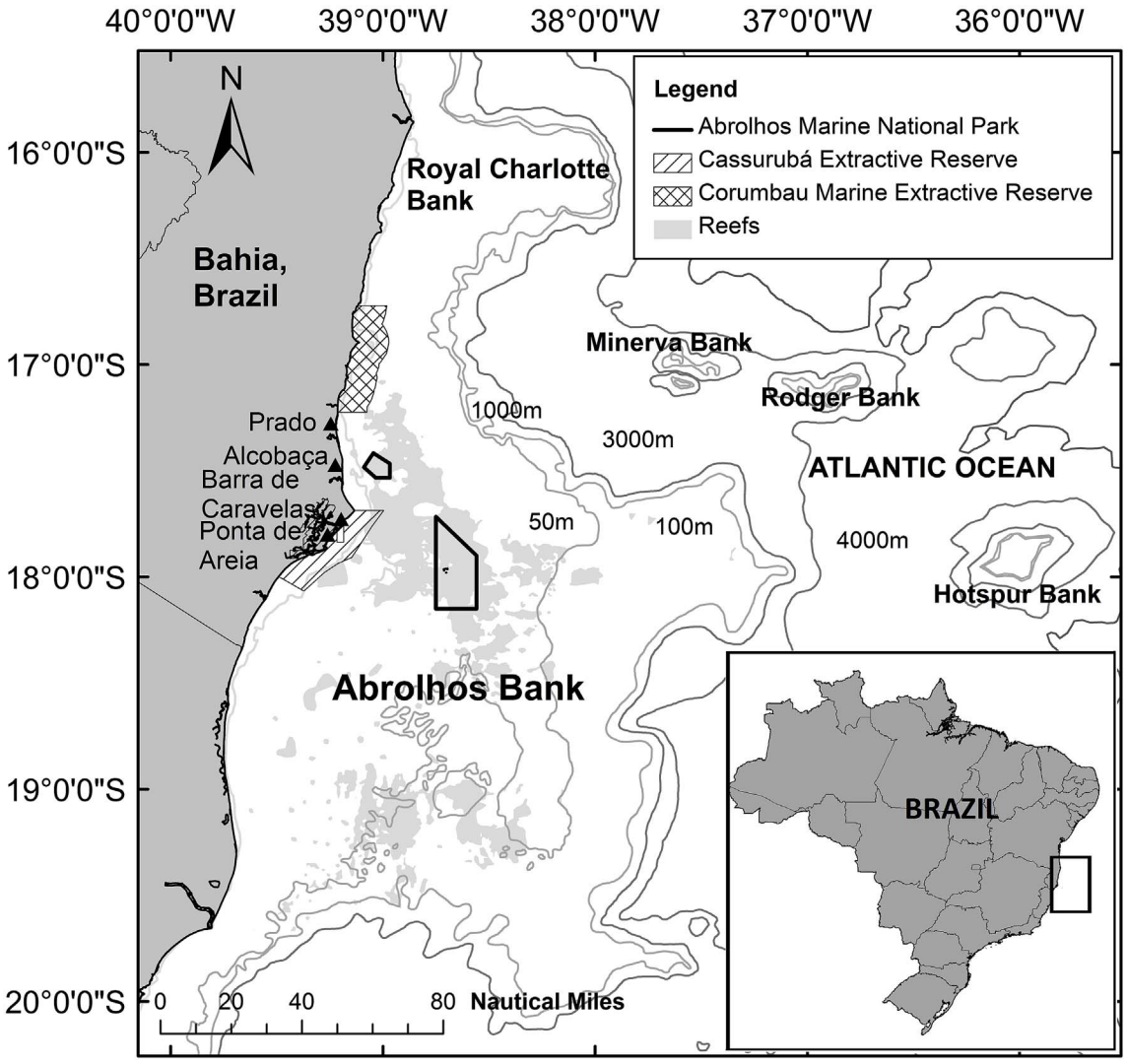

Fig. 1. Map of the study area with the latitudes and longitudes, the location of fishing ports (Prado, Alcobaça, Barra de Caravelas and Ponta de Areia), the reefs and the Marine Protected Areas.

to contribute scientifically to an implementation of fisheries management actions. In the present study, we aimed to assess, organize, and analyze snapper and grouper fisheries along the Abrolhos Bank, mainly in terms of fleet types, fishing gears, fishing trips characteristics (duration, main seasons), labor relations, fishers' profile, groups of stocks in landings, location of fishing spots and fishing grounds.

The fisheries of the following six stocks of the Abrolhos Bank were studied with an ultimate goal of proposing useful management units: the snappers *Lutjanus jocu*, *L. synagris* and *Ocyurus chrysurus* and the groupers *Cephalopholis fulva, Epinephelus morio* and *Mycteroperca bonaci.* The analysis was particularly detailed by (1) characterizing the fisheries, (2) mapping fishing spots and fishing grounds, (3) grouping fish stocks, and (4) clustering fishing areas. The knowledge provided is expected to clarify key management questions besides being applied in spatial and fisheries planning.

2. Materials and methods

2.1. Study area

The Abrolhos Bank is a wide portion of the shallow continental shelf located in the South Atlantic Ocean on Brazil's eastern coast (Fig. 1). The bank is the largest coral reefs complex in the South Atlantic and has a complex benthic habitat mosaic with diverse shapes and dimensions reefs (e.g., *chapeirões* and fringing reefs) (Leão et al., 2003) and 20,904 km^2 of rhodolith beds, in addition to unconsolidated sediments, *buracas*, mangroves and seaweed banks (Bastos et al., 2013; Moura et al., 2013). In this ecosystem there are approximately 18 coral and 280 fish species (Leão and Kikuchi, 2001; Dutra et al., 2005, Moura and Francini-Filho, 2005; Cavalcanti et al., 2013; Previero et al., 2013). In the region, there are Marine Protected Areas (MPAs) of restricted use (Abrolhos Marine National Park) and of sustainable use (Cassurubá Extractive Reserve, Corumbau Marine Extractive Reserve, and Environmental Protection Area Ponta da Baleia).

Abrolhos Bank fisheries are small-scale and the fleets are composed of vessels ranging from 4 to 20 m in length that can fish to a depth of 1200 m and stay at sea up to 30 days (Previero, 2014; Santos, 2015). This region has many fishing landing points with different characteristics and capacities.

It should be mentioned that *Epinephelus morio* and *Mycteroperca bonaci* are currently classified as Vulnerable (VU) following IUCN Red Lists (ICMBIO, 2014; IUCN, 2014). In December 2014, the Brazilian government issued a decree (decree 445/2014) prohibiting the capture, transportation, storage, handling, processing and marketing of species under threat criteria (ICMBIO, 2014). Since then, several problems had occurred due to the lack of discussion with the fishery sector, and also because of legal disputes on the decree's jurisprudence. As a consequence, uncertainties and discussions involving fishers, fish traders, researchers and managers have been common, as well as a weakening of fishers' trust towards environmental managers and researchers.

Moreover, the fisheries face other policies within certain small protected areas, such as the Cassurubá Extractive Reserve (RESEX), a coastal area with mangroves (Fig. 1), where there are some fishing agreements (prohibition of trawling in surrounding areas, and of diving fishing on small size fish) (Moura et al., 2011; Giglio and Freitas, 2013; ICMBIO, 2013).

2.2. Data collection

This study was conducted in four fishing ports (Prado, Alcobaça, Barra de Caravelas and Ponta de Areia), the latter two falling within the Caravelas municipality. These ports have different dimensions and capacities, receive landings from different fishing fleets operating in a complementary manner throughout the study area. The stocks selected for this study (Table 1) are very common in fishing landings in the region, have a high economic value, are carnivorous species, important for the ecological balance of coral reefs, and are very familiar to local fishers. Biological characteristics of these stocks, as well as some general ecological characteristics for the species are compiled (Appendix, Table A.1).

Table 1
The snapper and grouper stocks selected for this study.

Scientific name	Family	Group name	Local name	English name
Lutjanus jocu	Lutjanidae	Snapper	Dentão	Dog snapper
Lutjanus synagris	Lutjanidae	Snapper	Ariocó	Lane snapper
Ocyurus chrysurus	Lutjanidae	Snapper	Guaiúba	Yellowtail snapper
Cephalopholis fulva	Epinephelidae	Grouper	Catuá	Coney
Epinephelus morio	Epinephelidae	Grouper	Garoupa	Red grouper
Mycteroperca bonaci	Epinephelidae	Grouper	Badejo	Black grouper

The data collection was designed based on:

1. Surveys with snapper and grouper fishers. A semi-structured questionnaire was applied to fishers from the Prado, Alcobaça, Barra de Caravelas and Ponta de Areia ports. Surveys were conducted in 2011 and in 2014–2015. The survey addressed the times and places of snapper and grouper catches in the Abrolhos Bank. Fishers marked their fishing grounds by stock on a nautical chart. The ages of fishers and information about the fishing trip and vessels were also registered. For the survey, the most expert fishers were selected according to the 'snowball' method (Neis et al., 1999), and before each interview, we asked each fisher whether he would agree to participate.
2. Compilation and analysis of fisheries monitoring data from the national fishery statistics. Fisheries monitoring data from the years 2010 and 2011 was made available for the four ports studied (MPA, 2013). A program was initiated by the Brazilian government, and designed by the Brazilian Institute of Geography and Statistics (IBGE), where data collection was performed in partnership with NGOs and local citizens who received specific training. Information about the vessels operating and landing in the region was analyzed, as well as the equipment and fishing gear used and information about the fishing trip (such as fishing gear and vessel characteristics, trip duration, fishing periods, hours of fishing per day and number of fishers per vessel), besides the composition of the catches.
3. Records of specimens' lengths at fish landings. Specimens were measured at the fishing ports (Total Length, in cm) between June 2014 and September 2015.

2.3. Data analysis

Three sets of analysis were conducted to consider the objectives:

1. Fishing characterization. The snapper and grouper fisheries in the Abrolhos Bank was characterized based on: fishers' age groups; the most common fleet types; the main fishing gear; the variety of fishing gear per vessel; the sizes of vessels; the number of fishers per vessel; the amount of fishing equipment per fisher; hook sizes; length of specimens by port; the duration of the fishing trip; the distance from shore and depth explored and the better months for fishing.
2. Mappings. Fishing grounds informed by fishers were transformed into fishing spots. For this a map with grids (0º15′00′) was created and one point was plotted, per stock, in each quadrant (15′) in the area reported by each fisher. The density of fishing spots per quadrant was analyzed on a scale of intensity (1–9 or more spots per 15′ quadrant). The quadrants received fictitious names in order for subsequent analyses to be conducted. The fishing grounds that were

locally named by fishers were mapped in order to maintain the original dimensions of the fishers' drawings. The program used to compute the data was ArcGIS 9.3.

3. Groupings. Similarities among fish stocks were grouped based on their co-occurrence in the monitored fishing landings, using a non-metric multidimensional scaling (NMDS) (R-mode). A cluster analysis was performed to identify similarities between the presence and absence of the stocks in the 15′ quadrants (R-mode). Similarities among fishing quadrants were grouped based on the presence or absence of snapper and grouper stocks using a cluster analysis where stocks are the descriptors and the 15′ quadrants are the objects (Q-mode). In grouping analyzes the method used was Unweighted Arithmetic Average Clustering (UPGMA), using binary data transformed into coefficients of Jaccard euclidean distance, using the average method (Legendre and Legendre, 1998). From these cluster results, the most similar areas were mapped in order to facilitate the understanding of spatial similarities between the fishing areas. Clustering analyses were carried out using the language and environment for statistical computation and graphics R (R Development Core Team, 2009).

3. Results

3.1. Fishing characterization

Based on the 82 interviews performed with fishers between 30 and 75 years old, some age patterns were found, being Ponta de Areia fishers the oldest (Table 2), and harpoon diving fishers the youngest. We found 8 different fleet types registered for the snapper and grouper landings based on a combination of fishing gear adopted and the vessel lengths (for Prado and Alcobaça, the only available data) (Table 2). The largest fishing port in terms of number of vessels is Alcobaça (Fig. 2), usually with four fishers per vessel (Table 3). There, the largest vessels were the longline, with the net vessels the smallest, while in Prado the largest vessels operated with hand line and longline, and the smallest operated with nets (Table 2).

The most common fleet for catching snappers and groupers were hand lining, followed by line/longline in Prado, Alcobaça and Ponta de Areia (Figs. 2 and 3). Fishers used from 1 to 10 hand lines each and from 1 to 625 hooks per fisher in the studied ports (Table 3). The greatest variation in hook size was registered in Alcobaça and the smaller hooks were used in Ponta de Areia (Fig. 4). While in Alcobaça the specimens caught were among the largest of the four ports, in Ponta de Areia the specimens landed were the smallest (Fig. 5).

Harpoon diving fishery prevailed in the Alcobaça and Barra de Caravelas ports (Figs. 2 and 3) with differences in the fishing sites, fishing equipment used and trip duration. On one hand, in Alcobaça harpoon diving fishery occurred in deep regions (up to 50 m), approximately 2 harpoons per fisher, often with equipment to assist breathing under water, and in average 10 days fishing trips (Figs. 6 and 7, Table 3). On the other hand, in Barra de Caravelas this fishery occurred in coastal and shallow areas and was performed using one harpoon per fisher and apnea technique in one day trips (Figs. 6 and 7, Table 3).

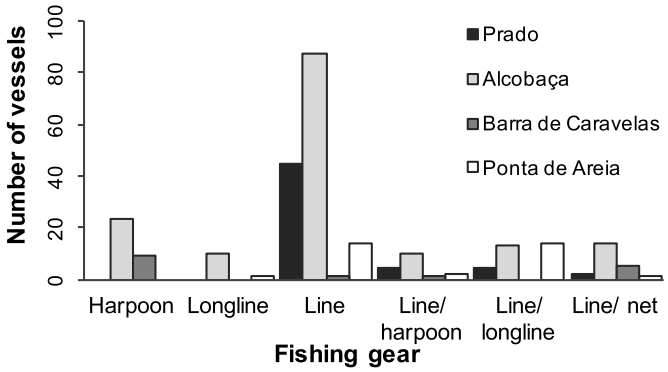

Fig. 2. Fleet size by fishing gear and port in the Abrolhos Bank.

According to the fishers the summer months are the most suitable for catching the six stocks (Fig. 8). The main reasons are the clearest seawater, the stocks are closer to the coast, and the winds have tow intensity. Winter months were also indicated as good for fishing *L. jocu, L. synagris*, *O. chrysurus* and *C. fulva* (Fig. 8).

3.2. Fishing spots and fishing grounds maps

Fishers from Prado and Alcobaça operated around the Abrolhos Bank, Royal Charlotte Bank and Minerva, Rodger and Hotspur banks (Fig. 7). On the Parcel das Paredes region a coastal and focused fishery landed in Ponta de Areia and Barra de Caravelas ports (Fig. 7). High-intensity fishing occurred in the Parcel das Paredes region in which almost all the stocks studied here can be found, also, around the Abrolhos MNP and on northeast of this area toward the continental slope, in the region between the Corumbau MER and the continental slope (Fig. 9). Some of the locally named fishing grounds were marked in different places by different fishers (Fig. 10).

3.3. Clusters

The main groups of stocks observed co-occurring in the fishing landings were "*L. jocu, E. morio* and *M. bonaci*" mainly in harpoon fisheries from Alcobaça, Barra de Caravelas, and "*O. chrysurus* and *C. fulva*" mainly in hand-line fisheries from Alcobaça (Fig. 11). The *L. synagris* was the most distinct stock in fishing landings (Fig. 11).

The grouping of stocks based on cluster analyses highlighted large overlap of *L. synagris* and *E. morio* (south of Caravelas, Parcel das Paredes and Belmonte) and *L. jocu and M. bonaci* (near the continental slope, Parcel das Paredes and around Abrolhos MNP) (Figs. 7 and 12; Appendix, Fig. A.1). Whereas, using the same criteria, *C. fulva* was the most distinct from the other stocks, occurring primarily in the south of Abrolhos MNP (Figs. 7 and 12; Appendix, Fig. A.1).

According to the clustering of quadrants, we identified seven mostly similar fishing areas (Fig. 12; Appendix, Fig. A.2). Among these, there

Table 2
Summary of fishing gears registered and interviewed fishers by studied port on Abrolhos Bank region.

Fishing port	Fleet type based on gears used and in parenthesis vessels average length	Number of interviewed fishers by period		Fisher's age	
		2011	2014–15	Range	Mean
1. Prado	Hand-line (9.42); Hand line and harpoon (10.22); Hand line and longline (11.62); Nets (7.80); Hand line and nets (9.00)	6	4	43–59	49
2. Alcobaça	Harpoon (10.18); Hand line (10.80); Hand line and harpoon (10.28); Hand line and longline (11.55); Nets (7.49); Hand line and nets (8.5)	15	21	31–72	51
3. Barra de Caravelas	Harpoon; Hand line; Hand line and harpoon; Hand line and longline; Nets	15	12	30–75	43
4. Ponta de Areia	Hand line; Hand line and harpoon; Hand line and longline; Nets; Longline and harpoon	4	5	42–66	57

Table 3
Summary of fishing gears, number of fishers and fishing trip duration by fleet type and port on the Abrolhos Bank (mean ± standard deviation).

Fishing port	Fleet type	Mean of harpoons by fisher	Mean of lines by fisher	Mean of hooks by fisher	Mean of fisher by vessel	Mean fishing trip duration, in days	Main stocks	
							Snappers	Groupers
1. Prado	Harpoon	0.40 ± 0.4	–	–	–	6.73 ± 6.1	*L. jocu*	*E. morio, M. bonaci*
	Hand-line	–	1.00 ± 0.7	4.56 ± 3.8	4.30 ± 0.2	10.30 ± 5.1	*O. chrysurus*	*C. fulva, M. bonaci*
	Hand-line/harpoon	–	–	2.50 ± 0.5	4.00 ± 0.6	9.64 ± 7.5	*O. chrysurus*	*E. morio*
	Hand-line/longline	–	–	2.57 ± 1.8	5.70 ± 0.3	15.53 ± 7.4	*O. chrysurus*	*M. bonaci*
	Hand-line/nets	0.66 ± 0.0	–	2.0 ± 0.0	3.00 ± 0.0	8.67 ± 3.6	*L. synagris, O. chrysurus*	*E. morio, M. bonaci*
2. Alcobaça	Harpoon	1.94 ± 0.5	–	–	3.60 ± 0.1	10.84 ± 5.1	*L. jocu,*	*E. morio, M. bonaci*
	Longline	–	–	−440.00 ± 184.9	4.77 ± 0.1	18.26 ± 7.0	*L. jocu, O. chrysurus*	*M. bonaci*
	Hand-line	–	5.33 ± 4.9	28.01 ± 61.1	4.40 ± 1.3	13.40 ± 6.6	*O. chrysurus,*	*C. fulva*
	Hand-line/harpoon	5.20 ± 1.3	–	5.00 ± 3.6	3.90 ± 0.1	14.13 ± 2.4	*L. jocu*	*M. bonaci*
	Hand-line/longline	–	–	3.95 ± 1.6	4.80 ± 0.4	15.76 ± 2.2	*L. jocu*	*M. bonaci*
	Hand-line/net	–	–	9.00 ± 0.0	3.00 ± 0.0	3.00 ± 0.0	*L. synagris*	*M. bonaci*
3. Barra de Caravelas	Harpoon	1.02 ± 0.1	–	–	3.80 ± 0.2	1.06 ± 0.3	*L. jocu,*	*E. morio, M. bonaci*
	Longline	–	–	15.00 ± 0.0	–	–	*O. chrysurus,*	*M. bonaci*
	Hand-line	–	1.50 ± 0.7	3.00 ± 1.4	3.00 ± 0.0	2.00 ± 0.0	*L. synagris*	*E. morio*
	Hand-line/harpoon	–	–	–	–	1.56 ± 0.5	*L. synagris, O. chrysurus*	*E. morio, M. bonaci*
	Longline/harpoon	–	–	–	–	1.00 ± 0.0	–	*E. morio*
	Nets	–	–	–	–	1.00 ± 0.0	*L. synagris*	*E. morio*
4. Ponta de Areia	Hand-line	–	2.03 ± 0.1	3.94 ± 0.4	2.40 ± 0.1	1.26 ± 0.5	*L. synagris*	*E. morio*
	Longline	–	–	–	2.10 ± 0.4	1.39 ± 0.5	*L. synagris*	*M. bonaci*
	Hand-line/harpoon	–	–	–	2.20 ± 0.0	1.56 ± 0.5	*O. chrysurus*	*M. bonaci*
	Hand-line/longline	–	–	–	–	1.00 ± 0.0	*L. synagris*	*M. bonaci*
	Nets	–	–	–	–	2.00 ± 0.0	*L. synagris*	*E. morio*

were fishing quadrants with zero distance (composed of the same stocks in the same amounts) (Appendix, Fig. A.2).

4. Discussion

In this study, we combined different data sources (survey with fishers, fisheries monitoring and biological data) to analyze and classify some snapper and grouper fisheries of the Abrolhos Bank. Fishers' knowledge, fleets, fishing areas and fish specimen's sizes were combined for the application of different analysis (fishing characterization, grouping of fish stocks and mapping of fishing areas). Finally, we explored and defined appropriate management units that would serve in fisheries management in the scale of the Abrolhos Bank ecosystem. Those management units were basically: groups of fish stocks (those caught by similar fishing methods and co-occurring in landings, and stocks co-occurring in one particular fishing ground), and groups of fishing areas (with co-occurrence of fish stocks). All findings were unprecedented and may be useful in regional management plans and helpful to elucidate and simplify complex connections among species, fleets, fishing areas and fishers.

4.1. Diving in fisheries characteristics

In order to provide understanding on snapper and grouper fisheries over the largest coral reef ecosystem of the South Atlantic Ocean, the compilation and analysis of intrinsic characteristics, such as fishers' profiles, fleet, vessel and gear types, duration of fishing trips and fishing areas, were undertaken. Based on the main differences found on these fisheries, the typology proposed by Diegues (2004) in respect to production systems of Brazilian small-scale fisheries may be used. Prado, Barra de Caravelas and Ponta de Areia fisheries would be within the type "Fishing held within the mold of small market production – the small market production of artisanal fishers". Alternatively, in Alcobaça, major fishing would be under the type "Fishing performed in the form of capitalist social organization of production – production of the owners of more than one vessel". Besides that, in Prado and Alcobaça fisheries a 'boss/employee' job relationship predominated, whereas in Barra de Caravelas and Ponta de Areia prevailed the family relationship among fishers in the same vessel (Previero, 2014). Despite Prado being classified as the first type, some characteristics of its fisheries indicate a larger scale than in Barra de Caravelas and Ponta de Areia (employment relation, vessel sizes, offshore fishing spots and larger specimens' size). Nevertheless, none remarkable increasing scale trend was found in Prado, since those characteristics have been previously observed in 2005 by Freitas (2009).

These fisheries classifications are important tools for the elaboration and implementation of fishery management measures since it makes explicit the labor relations. By linking the fisheries classifications and the labor relations to the fishing spots arrangements by port (Fig. 7) we can better understand how the fisheries scale influence the spatial distribution of fishing. On one hand, the most heavily organized fisheries (Alcobaça and Prado) also operated in locations farther from the coast. On the other hand, the smaller scale fisheries (Barra de Caravelas and Ponta de Areia) operated in coastal locations and named small fishing grounds with high precision (Fig. 10). In summary, this classification as well as the understanding of the different scales of each fishery facilitate management proposals in a fine scale and enable a pre-evaluation of the effectiveness of a given management proposal.

Abrolhos Bank fisheries are particularly multi-gears (Table 2, Fig. 3). To achieve management effectiveness in this type of fishery, it is required special attention in considering the different gears and income alternatives (Davies et al., 2009; Hicks and McClanahan, 2012). Thus, we believe this work also contributed to future management plans by explicit which are the multi-gear fleets (their fishing areas, fishing ports and main stocks). Here we also registered diving with equipment that helps underwater breathing, a prohibited practice that occurs in this

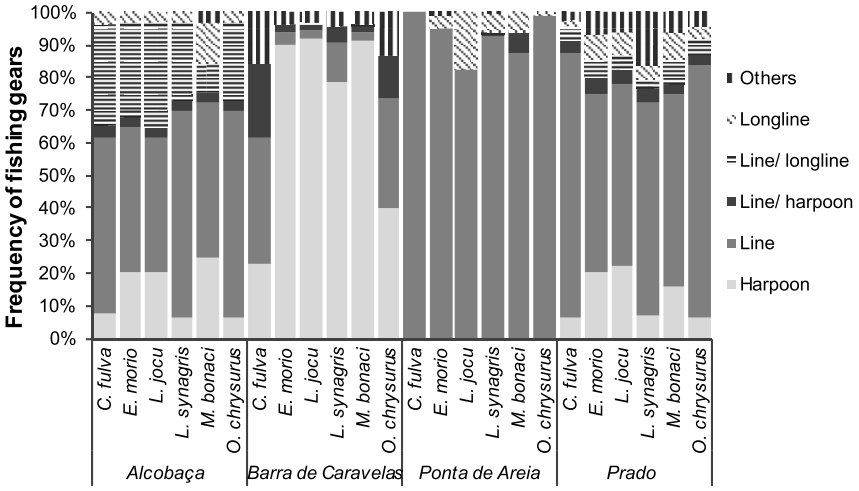

Fig. 3. Frequency of fishing gears used to catch each stock by fishing port. The frequency corresponds to the sum of fishers' citations and landings records.

region, previously reported by Previero (2014). It represents an example of the difficulty to enforce fishing laws in the region, mainly due to the lack of trained staff and financial resources for this purpose.

Data-poor reef fisheries, especially in communities with low income alternatives usually can adapt the fishing gears to explore the various resource size spectra (Tuda et al., 2016). The smallest hooks used in the Abrolhos Bank are from fishers living in Ponta de Areia where the sizes of the specimens in landings were often below their average size at first maturity (Freitas et al., 2011, 2014). As the hand line fishery practiced by fishers from Ponta de Areia occurred in a coastal region (Parcel das Paredes), two hypotheses might explain the smaller size of the specimens: (1) the coastal region was a recruitment site, and (2) the larger individuals were already removed by fishing. Recent studies have shown that such area is a recruitment site (Sartor, 2015). Moreover, the limited navigation equipment, the moon phases and the intensity of the winds makes the smaller vessels to fish closer to the shore and as a consequence can only capture the fraction of the stock living in that area (Tuda et al., 2016), often a fraction of juveniles.

The best times for fishing indicated here were summer and winter (Fig. 8). For *E. morio* and *M. bonaci* the catches were limited in their spawning season (July to October) when they aggregate in areas that remain unknown to most of the local fishers, outside the MPAs existing in the Abrolhos Bank (Freitas et al., 2017). Similar to our findings there is a high occurrence of *O. chrysurus* in winter in the coast of Ilhéus, a town immediately north of the Abrolhos Bank (Cetra and Petrere, 2014). Moreover, to the fishers, fishing grounds away from shore were difficult to explore in the winter because of unfavorable weather conditions for navigation and location of stocks. Southeasterly (SE), south (S), and southwesterly (SW) winds are observed in the region in the autumn and winter months (Teixeira et al., 2013). Regarding the largest catches occurred during the summer months and the fishers observed low winds intensity, Teixeira et al. (2013) found a predominance of northeasterly winds. As a result, under such climatic conditions, many fishers could go out on longer fishing trips and reach fishing grounds farther away. Similarly, fishers in Ilhéus argue that the primary factors influencing the catches are marine currents and climatic factors, with no change in abundance of stocks throughout the year (Caló et al., 2009).

4.2. Groups of stocks as fisheries management units

Three different fish stock groups were found for the two methods employed. The most co-occurring stocks in total catches were "*L. jocu*, *E. morio* and *M. bonaci*" (Fig. 11), and regarding this, we suggest that the management of these three stocks should be carried out jointly, with practices sufficient to protect the three stocks simultaneously. The most co-occurring stocks in fishing grounds were "*L. synagris* and *E. morio*" followed by "*L. jocu and M. bonaci*". Our results highlighted the multi-species fisheries along the Abrolhos Bank, as well as the necessity for considering groups of species rather than individual species for fisheries management actions, since they have greater efficacy (Jennings et al., 2001; Farmer et al., 2016). Furthermore, single-species fishing regulations such as size limits and gear restrictions have shown inadequate to avoid the depletion of fish stocks in multi-species and multi-gear fisheries (Tuda et al., 2016).

Over the fishing ground locally-named *Parcel das Paredes*, we found

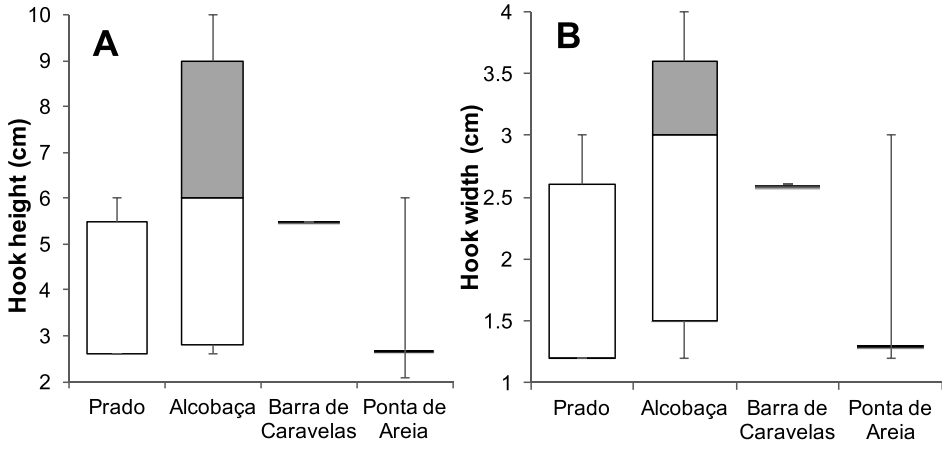

Fig. 4. Hook sizes used in hand line and longline fisheries in the Abrolhos Bank. A- hooks height, B- hooks width. The dark central lines represent the median sizes, the gray box represent 25% of the data above the median value, the white box represent 25% down the median value and the bars indicate the maximum and minimum values.

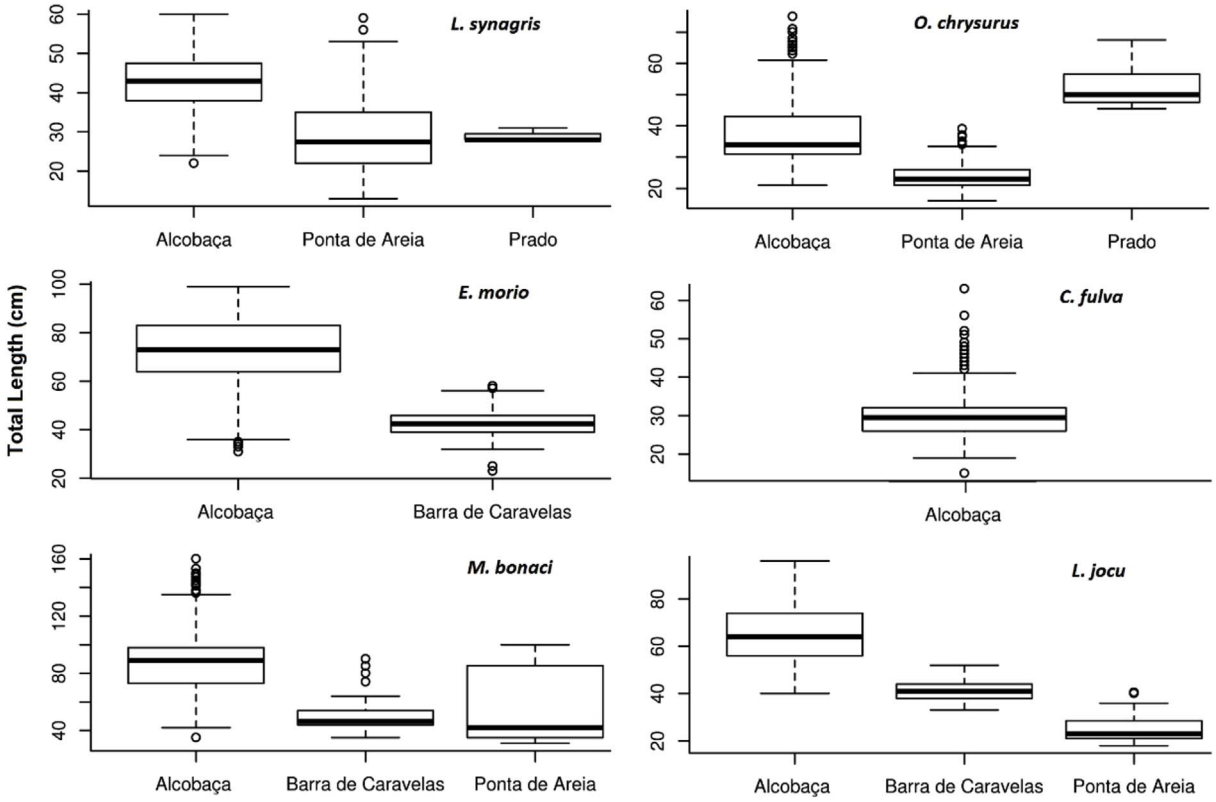

Fig. 5. Fish sizes in landings by port in the Abrolhos Bank. The dark lines represent the median sizes, the box represent 25% of the data above and 25% down the median values and the balls are outliers.

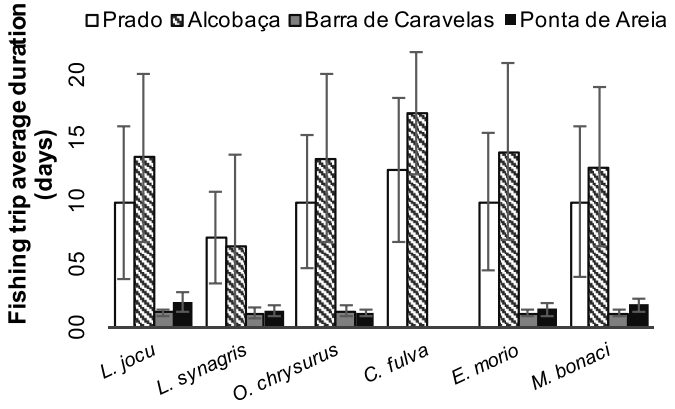

Fig. 6. Fishing trips durations, in days, by stock and port in the Abrolhos Bank. The bars indicate the standard deviation.

large amount of fishing spots mainly from Barra de Caravelas and Ponta de Areia (Fig. 7), the ports with the smallest fish sizes in landings (Fig. 5). Similar to our findings, Sartor (2015) observed an overlap in the recruitment sites for *L. jocu*, *L. synagris, O. chrysurus, E. morio* and *M. bonaci* (Parcel das Paredes) while the *C. fulva* stock recruitment site was observed away from these stocks, near the Abrolhos National Marine Park. Likewise, Martins et al. (2007) also found co-occurrence among *L. jocu*, *L. synagris, O. chrysurus,* and *M. bonaci*, whereas the *C. fulva* stock also occurred in locations different from those of the other stocks. Recalling that in this study, *L. jocu and M. bonaci* were the most similar stocks (Appendix, Fig. A.1), being largely captured near the continental slope (Fig. 7), Pennino et al. (2016) also registered their co-occurrence in other areas along the Brazilian northeast coast. Moreover, they are found together in the "*correção*" phenomenon described by Teixeira et al. (2004), which was also detected by some fishers interviewed in this study.

With respect to the fish ecological characteristics, snappers and groupers are carnivorous, with fish and crustaceans being their primary prey (Randall, 1968). Snappers are usually benthic, occur primarily on coral reefs, with *L. jocu* juveniles found in estuaries, *L. synagris* over mud bottoms in turbid water and vegetated sandy areas and *O. chrysurus* over weed beds (Randall, 1968). Most groupers can change their body color according to the brightness, turbidity, bottom type or activity engaged (DeLoach, 1999). The groupers studied here are usually hermaphroditic, starting the life as females and changing to males at larger sizes (Randall, 1968; DeLoach, 1999), however this sex change has not yet been registered for Abrolhos Bank groupers (Freitas et al., 2017).

When comparing the fishing spots mapped here (Fig. 7) with the seabed map of the Abrolhos Bank (Moura et al., 2013), *L. synagris* occurred primarily on reefs; *O. chrysurus* and *E. morio* occurred mainly on reefs, but also upon rhodolith beds; *C. fulva* catches occurs on reefs, rhodoliths and on unconsolidated sediments; *L. jocu* and *M. bonaci* occurred on both reefs and rhodolith beds. Although *L. jocu* occurs in estuaries, none of the interviewed fishers reported catching this species in that environment, possibly because sizes were uninteresting (juveniles). Regarding the variety of bottoms on which *O. chrysurus* and *L. synagris* occurred (Fig. 7), we assume a high diversity of bottoms in the Abrolhos Bank reefs, being surrounded and even filled with muddy siliclastic sediments derived from river loads and coastal erosion (Leão et al., 2003).

4.3. Fishing areas as spatial management units

There is an increasing trend of applying area-based methods in the management of marine resources and fisheries (Gasalla and Gandini, 2016). In this study, the mapping of fisheries may facilitate and guide future fisheries management actions by using different set of regulations for each fleet (Pennino et al., 2016) and by considering a relevant

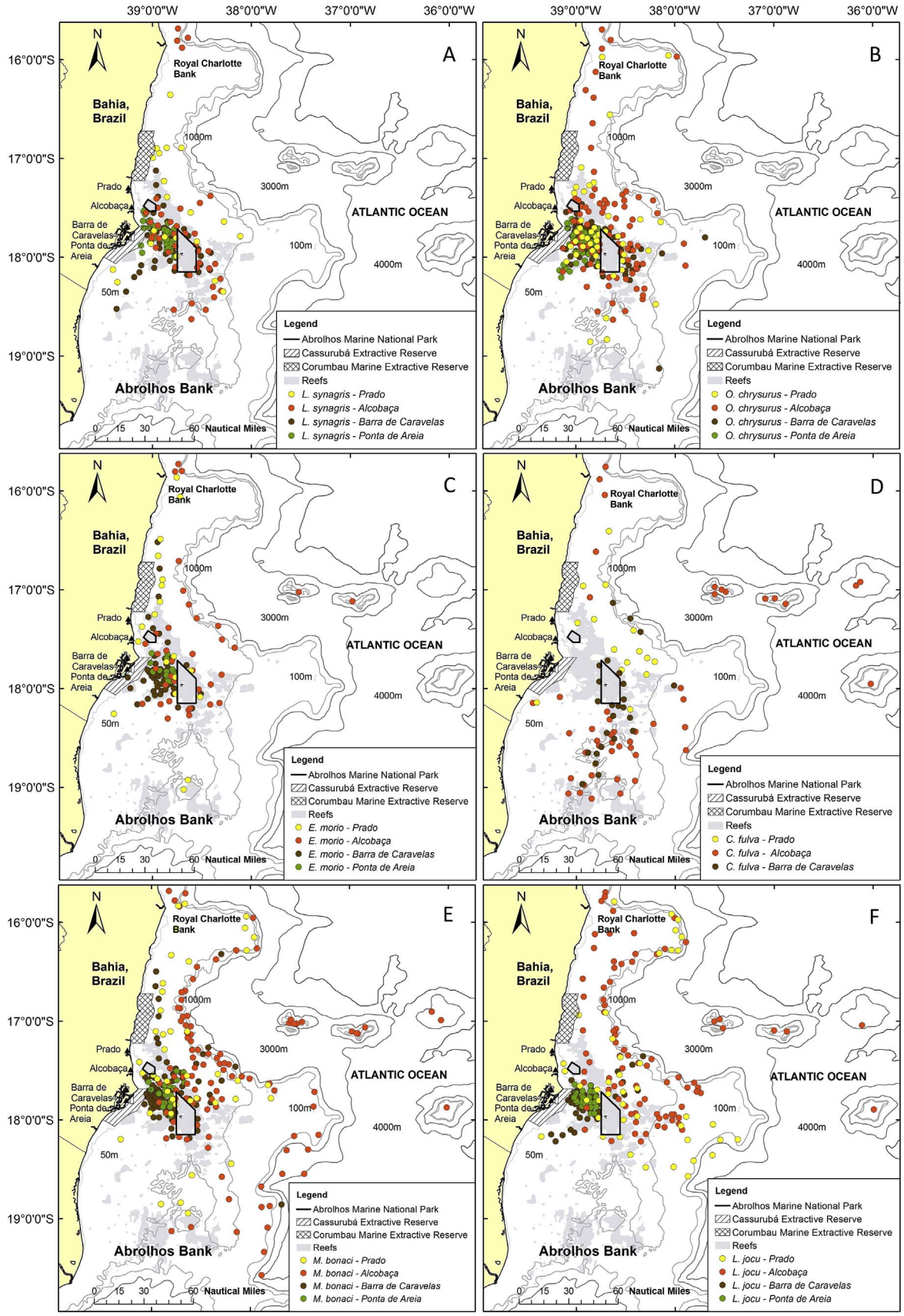

Fig. 7. Maps of fishing spots by stock and port in the Abrolhos Bank. Each map represents one species (A- *L. synagris*, B- *O. chrysurus*, C- *E. morio*, D- *C. fulva*, E- *M. bonaci* and F- *L. jocu*). The fleet of each port have a different spots color (Prado-yellow, Alcobaça - orange, Barra de Caravelas - green and Ponta de Areia – brown). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

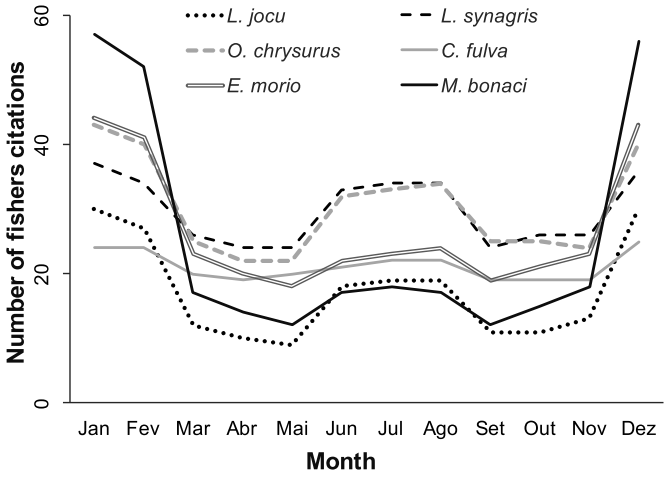

Fig. 8. Better months to catch each stock in the Abrolhos Bank, according to fishers' citations.

scale for area-based management and governance (Léopold et al., 2014; Ouréns et al., 2015).

Previous studies had already shown fishing spots throughout the Abrolhos Bank (Moura et al., 2013). Here we registered and mapped the areas with the highest concentration of fishing spots differentiating it by stock and port (Fig. 7). By this way we could reveal the spatially-structured fisheries, probably related to the spatial arrangements of habitats (Pennino et al., 2016).

Seven mostly similar fishing areas were identified, some of them were composed of the same stocks in the same amounts (Fig. 12). The light blue area clearly corresponds to the highest intensity fishing area (Fig. 9), with fishing spots of all the stocks studied here being exploited by the four fishing ports. The gray area undoubtedly corresponds to "Parcel das Paredes", with the greatest number of fishing spots (Figs. 7 and 10). Therefore, such fishing areas can indicate regions suited to governance by the same fishing regulations, based on the presence of the six stocks of snappers and groupers studied here. Even so special attention to area-based management should be given, the adequate participation of fishers and stakeholders in monitoring fisheries operation seems essential (Tuda et al., 2016).

The method we used here, based on fishers' interviews and mappings provided valuable information for these data-poor fisheries. The creation of maps with the input of fishers to chart the fishing grounds was effective in identifying these sites (e.g., Berkes et al., 2001; Leite and Gasalla, 2013). Many traditional cultures are based on fishing territories, which are places abundant in fishery resources that were either discovered or inherited within the fishing community (Cordell, 2001; Diegues, 2001). To identify these territories and achieve good fishing, the fishers count on the vast knowledge acquired by observing the older fishers and by relying on their personal experiences (Allut,

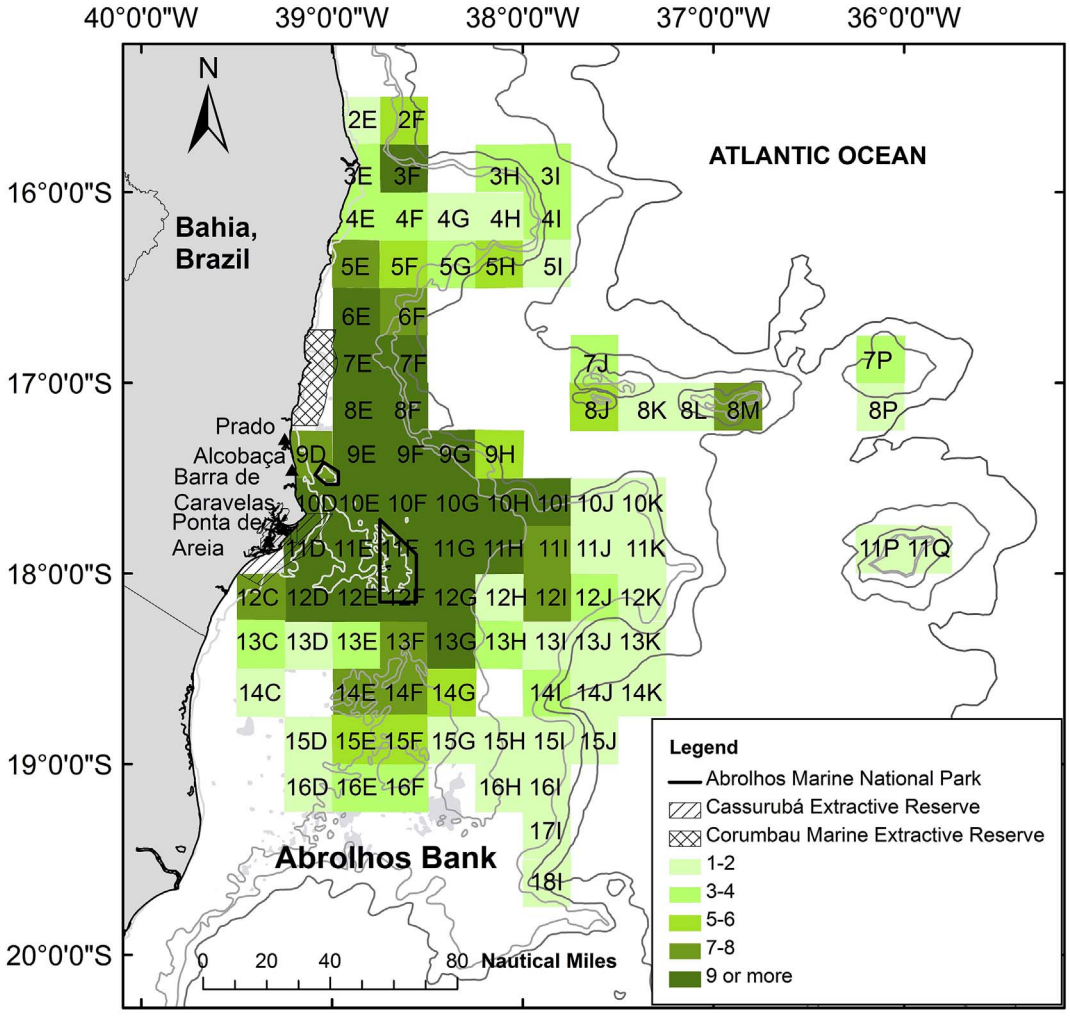

Fig. 9. Map of fishery intensity in the Abrolhos Bank. The colors indicate the number of fishing spots informed by fishers by 15′ quadrants. The codes inside the quadrants are fictitious names used in the cluster analysis. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

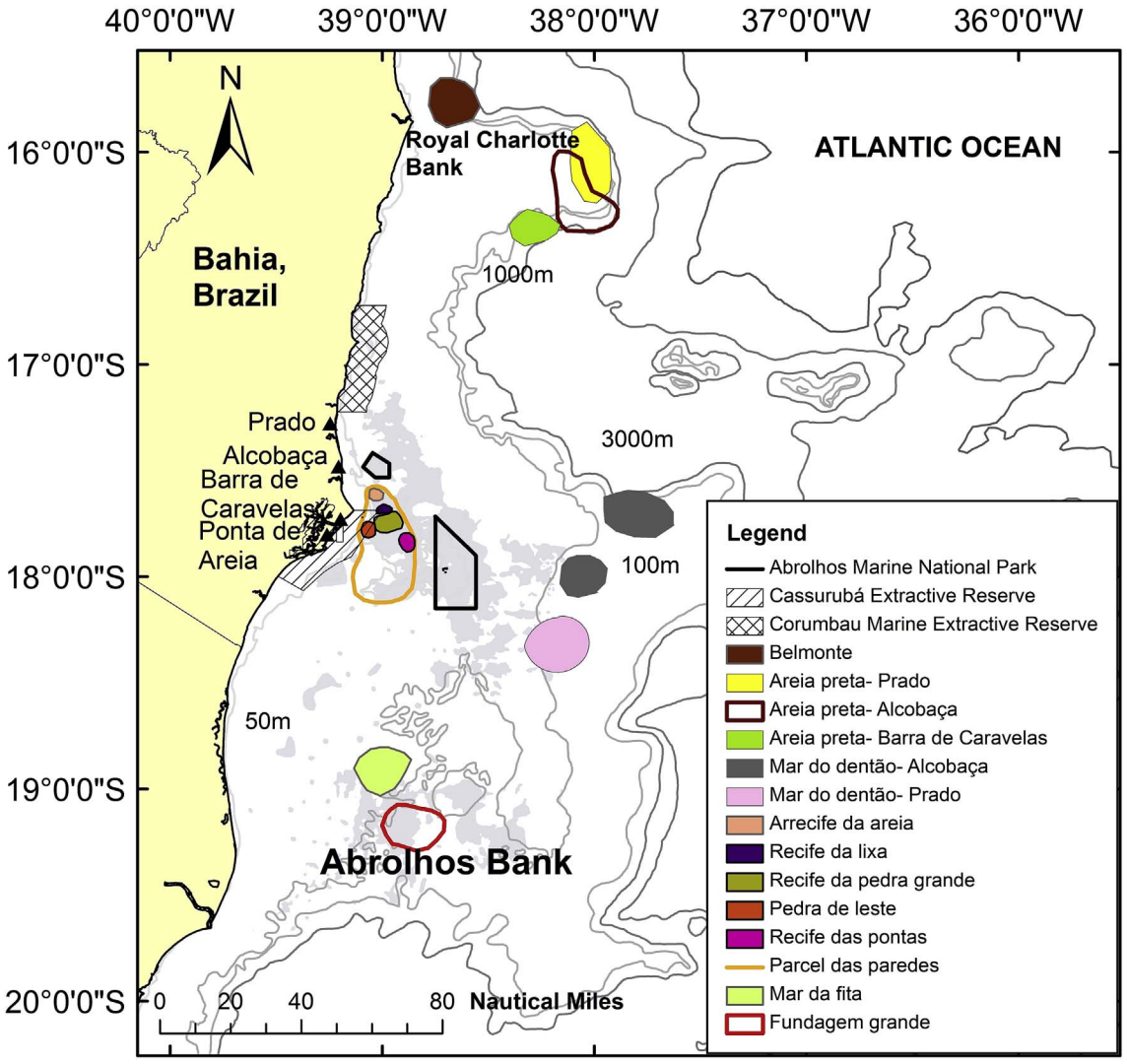

Fig. 10. Map showing the locations and dimensions of the locally named fishing grounds in the Abrolhos Bank.

2000; Diegues, 2000), using a division of the maritime area (Maldonado, 2000). For example, in the Parcel das Paredes region, fishers identified five named fishing grounds (Fig. 10). Because the fishery over this area had an artisanal character, we associated all the fishing ground marks with what Diegues (2000) describes as "a space full of *pedras* and *cabeços* landmarks along the Brazilian northeast coast". In the local context of small-scale fisheries to known these marks represents a prestige of fishers among their peers, because the most knowledgeable fishers are more competent, have greater leadership and catch more fish (Diegues, 2000).

Indeed, in this study, we observed some fishing grounds that received the same name by fishers from different ports and that had different locations on the map. This difference occurred for "Mar do Dentão" and "Areia Preta" (Fig. 10). In offshore spacing this difference is related to the cognitive abilities of fishers resulting from the social and cultural trainings in their communities (Maldonado, 2000), which might differ among the municipalities studied here. Moreover, in this work, the location of the "Mar do Dentão" fishing ground by Alcobaça fishers was similar to the "Buracas" location (Bastos et al., 2013), which are structures in the Abrolhos Bank concentrating snappers and groupers, among other reef species (Cavalcanti et al., 2013). We conclude that these locally named fishing grounds can facilitate communication with fishers in drawing spatial units and contribute to defining accurate management units.

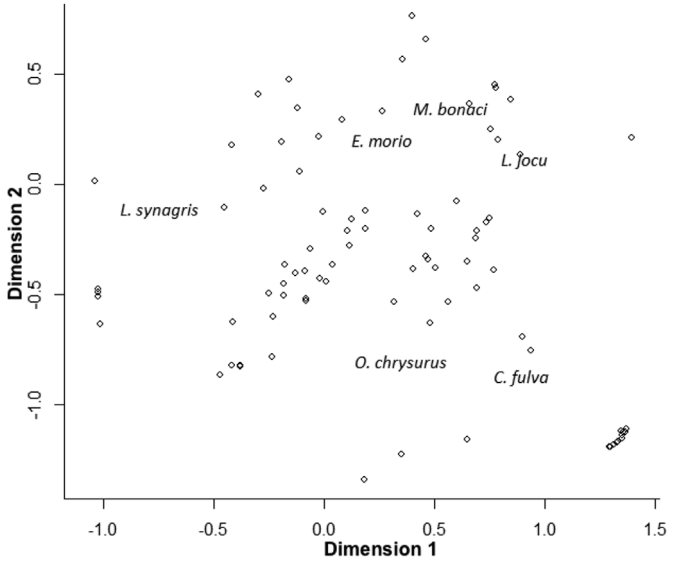

Fig. 11. Non-metric multidimensional scaling of the six stocks according to their co-occurrence in the fishing landings. The nearest stocks in the graphic were landed together more times. Points represent 15′ quadrants.

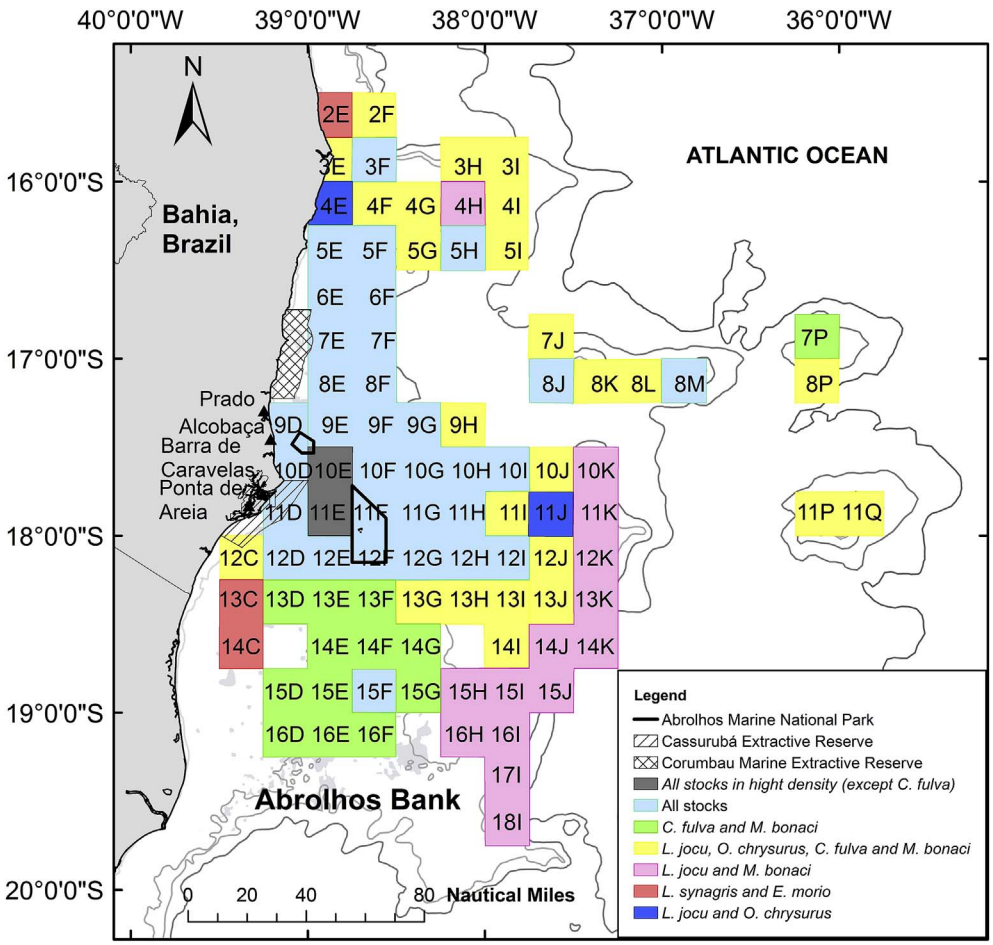

Fig. 12. Map of the most similar fishing areas resulting from the clustering of fishing quadrants. Each area enclosed by a color is similar regarding stocks occurrence. The codes inside the quadrants are fictitious names used in the cluster of fishing quadrants. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

In summary, the mapping of fishing grounds and the seven fishing areas defined as spatial management units may be potentially relevant for both the Ecosystem-Based Fisheries Management (EBFM) and Marine Spatial Planning (MSP) of the Abrolhos Bank. These approaches helped to understand how the fishers use specific coastal areas and fishing grounds (Ehler, 2008; Maina et al., 2016), and may contribute to territorial approaches of access rights and benefits to specific social groups involved (Gasalla and Gandini, 2016).

4.4. Potential management interventions

Based on the findings revealed here, we suggest some potential management interventions. The first one is the consideration of these management units in an EBFM context for the Abrolhos Bank. Second, the definition of management actions for the groups of stocks found here. Third, the use of the fishing areas for the implementation of some fishing restrictions. This study clarifies on the areas used by each fleet and which are the main species by area, and suggests that the Parcel das Paredes (Fig. 10) and the gray area shown in Fig. 12 should be a starting point for fisheries management, that are also juvenile fish areas. In addition, it is an area close to the mainland, which makes inspection actions easier.

5. Conclusions

Two types of management units were defined (stocks and areas groups) and were associated to fleets and fishers. It also helped to identify main stakeholders to be considered and consulted in future fisheries management plans in the region. The stocks groups co-occurring in fishing grounds were "*L. synagris* and *E. morio*" and "*L. jocu* and *M. bonaci*", and the group co-occurring in catches was "*L. jocu*, *E. morio* and *M. bonaci*". Seven areas were suggested as spatial units. Among them, the "Parcel das Paredes" was notable for the many snappers and groupers fishing spots and for the small size of fish caught there. Findings indicate that area is key to implement measures to avoid growth overfishing.

Over the Abrolhos Bank, the primary fleets for snappers and groupers use hand lining and harpoon diving. Each port has particular features and production systems type, with Alcobaça landing the broader-scale fisheries in terms of fishing trip duration, fishing autonomy, number and size of vessels, labor relations and fish sizes. Under the same criteria, Prado, Barra de Caravelas and Ponta de Areia were smaller-scale ports, with Barra de Caravelas and Ponta de Areia placing coastal fisheries from daily trips, catching mainly small size fish.

Finally, the method adopted in the analysis, combining interviews with fishers, monitoring data and size measures, allowed a precise fishing characterization, besides the definition of three stocks and seven fishing areas groups as unprecedented fine resolution management units seems to have clarified and simplified complex interactions among species, fleets, fishing areas and fishers. That methodological approach may help to delineate management units in other small-scale data-poor fisheries elsewhere. Our findings should also help the call for action to implement fisheries management in the scale of the whole Abrolhos Bank ecosystem.

Acknowledgements

We are grateful to the fishers that participated in the surveys for granting part of their time and sharing their knowledge. Additionally,

we are grateful to Dr. Matheus O. Freitas (Universidade Federal do Paraná), Prof. Rodrigo L. de Moura (Universidade Federal do Rio de Janeiro) and Dr. Carolina V. Minte-Vera (Inter-American Tropical Tuna Commission, USA) for their guidance in 2011, to the Brazilian Biodiversity Fund (FUNBIO) by the support in 2011, to Conservation International-Brazil by their support during field trips, and to Rede Abrolhos for the "*shp.files*" database. We are also grateful to the Graduate Program on Oceanography (Oceanographic Institute - University of São Paulo). The Brazilian National Council for Scientific and Technological Development (CNPq) (141622/2014-8) supported this work. Anonymous reviewers contributed significantly to improve the final version.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2018.01.007.

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