FINAL REPORT

the bp conservation programme

ECOLOGY AND CONSERVATION OF REEF FISH SPAWNING AGGREGATIONS IN THE ABROLHOS BANK, BRAZIL

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1. INTRODUCTION

Many reef fishes aggregate to reproduce at specific times, places and moon phases, generally in large numbers, constituting one of the most remarkable biological phenomena in shallow seas (Johannes 1978, Domeier & Colin 1997). The need to understand the biological and economic importance of this phenomenon is becoming increasingly more evident, as reef resources are collapsing worldwide. Aggregations are prime targets for fishers, who often take huge and unsustainable catches of large and commercially important reef fishes such as groupers, snappers and jacks. As a consequence of intensive fishing, many aggregations have been eliminated in the Caribbean and the Indo-Pacific (Sadovy 1994, Sadovy & Eklund 1999, Sala et al. 2001), and many others throughout the tropics are seriously reduced and may soon disappear if not quickly protected (Colin et al. 2003). Eradication of spawning aggregations through overfishing ultimately results in the ecological and commercial extinction of the aggregating species. Thus protection of these aggregations is essential for the long-term preservation of the species and the fisheries they support.

Fisheries management strategies have rarely accounted for the concentrated nature of fish spawning events, and many aggregations have disappeared. In some regions, the aggregations and the fisheries they supported disappeared even before scientists and fisheries managers knew about their existence (e.g., Sala et al. 2004). Within the last decade it has become increasingly clear that, without urgent conservation actions, many more aggregations will decline and some may cease to form altogether, with consequent negative effects for local populations (Colin et al. 2003). To prevent the ecological and commercial extinction of species that reproduce in spawning aggregations it is necessary to locate these aggregations using the best science, and protect them from fishing. Moreover, the creation of successful networks of marine reserves necessarily involves the protection of spawning aggregations of threatened fishes (Sala et al. 2002).

Despite its importance for reef conservation, there is a remarkable lack of consistent information about the existence and location of spawning aggregations along the tropical

southwestern Atlantic (Brazil). The prime objective of this project was to determine the existence and location of spawning aggregations of threatened reef fishes in the Abrolhos Bank, Brazil, the largest and richest reef complex within the entire South Atlantic (Werner et al. 2000). This region comprises a distinctive mosaic of coral reefs, algal bottoms, mangrove forests, beaches and vegetated sandbanks (Leão & Kikuchi 2001, Leão et al. 2003).

At least three red-listed fishes that aggregate to spawn in the Caribbean also occur in Abrolhos, including one Critically Endangered serranid, the jewfish or Goliath grouper (*Epinephelus itajara*), and two Vulnerable lutjanids, the cubera snapper (*Lutjanus cyanopterus*) and the mutton snapper (*L. analis*) (Baillie et al. 2004). Besides the three aforementioned threatened species, several other common species in the Abrolhos reefs, such as the black grouper *Mycteroperca bonaci* and the snappers *Lutjanus jocu* and *L. synagris*, aggregate to spawn in other locales in the Caribbean (Sadovy & Eklund 1999, Carter & Perrine 1994, García-Cagide et al. 2001, Sala et al. unpublished data). If these species also aggregate to spawn in Abrolhos, it is essential that we determine the location and timing of these aggregations, in order to make recommendations for their effective protection.

In the scope of the present project, besides providing a baseline assessment of groupers, snappers, and their fisheries in Abrolhos, we found a yet undescribed snapper species, endemic to Brazil, and also explored and documented several uncharted reefs - some of them with a unique physical structure. It is remarkable that in verge of the 21st Century it is still possible to find undescribed species with commercial importance in some areas of the Atlantic Ocean. This specific finding highlights the importance and lack of basic knowledge about the unique and highly threatened reef complex that thrives in Abrolhos. Although its biodiversity is so far poorly known, Abrolhos remoteness does not ensure its protection, and continued research and conservation efforts are greatly needed.

Notwithstanding our relevant findings, exact locations and timing of most reef fish spawning aggregations in Abrolhos is still ambiguous. However, it is remarkable that the

present project contributed not only to advance the biological knowledge about aggregating reef fish species in Abrolhos, but also to the conservation of such species and their habitats. The lack of adequate representativity in terms of both spawning grounds and nurseries habitats, for several threatened reef fish species, was used to backup ongoing initiatives to establish a functional MPA network in Abrolhos. Our project was integrated into other ongoing research and conservation initiatives that ultimately achieved highly relevant conservation outcomes, which are also described in this report. Additional protection is being achieved for deep reefs that are important spawning grounds, and also to mangrove forests and nearshore habitats that are critical - as nursery habitats, to several threatened reef fishes.

Figure 1. The largest and most biodiverse coral reefs in the entire South Atlantic flourish around the Abrolhos Archipelago, shown in the picture above. Although the archipelago is protected as a National Marine Park, several important adjacent ecosystems upon which the shallow coral reefs depend still lack adequate protection (Photo by Marcelo K. Skaf ©).

2. STUDY SITE

2.1. Brazilian reefs: Priority areas for biodiversity conservation in the Atlantic Ocean

In the Atlantic Ocean, the Caribbean region harbors the largest and richest coral reefs (Spalding et al. 2001), but coral and reef fish communities are also found in the Gulf of Mexico and along the eastern coast of North America, as well as in West Africa (eastern Atlantic) and along the Brazilian coastline (Southwestern Atlantic - SWA). In the western side of the South Atlantic, scleractinian corals extend their distribution from near the Amazon River mouth to Southern Brazil (from about 1° to 26°S), having their southern limit being almost coincident with that of mangroves (Moura et al. 1999). Despite their small area, Brazilian reefs encompass a latitudinal span comparable to that of Australia's Great Barrier Reef.

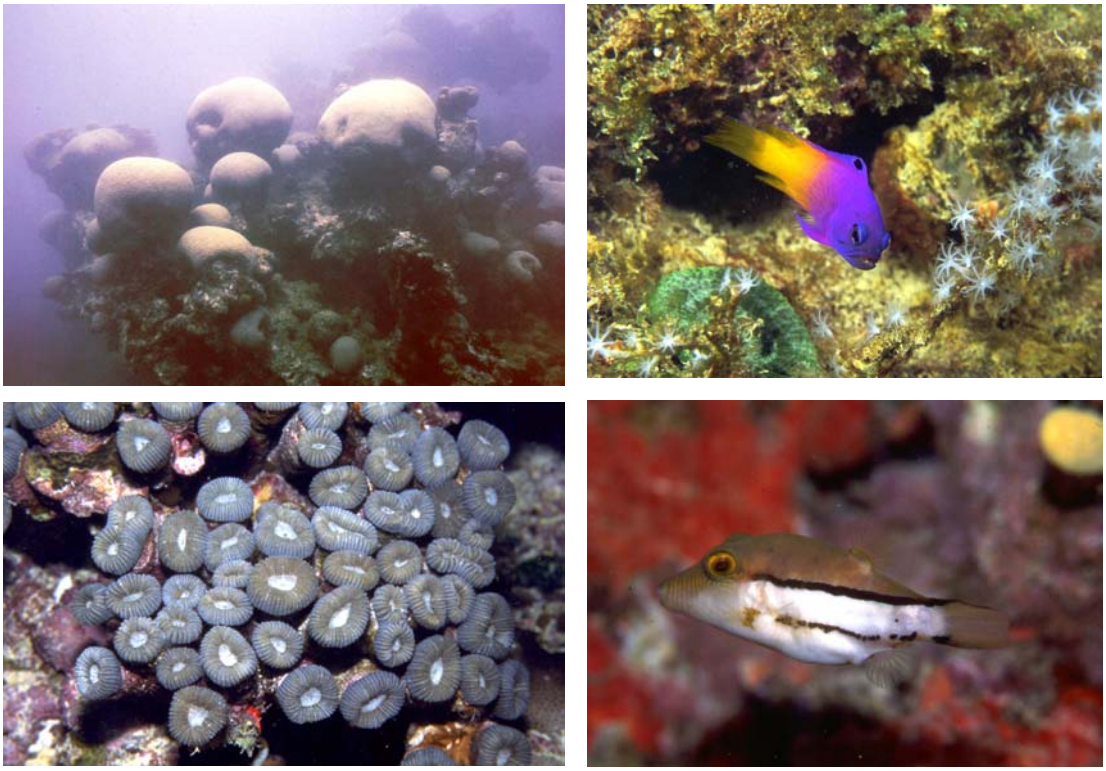

Figure 2. Some examples of the unique biodiversity of Abrolhos, encompassing several Brazilian-endemic reef creatures such as the brain-coral *Mussismilia brasiliensis* (upper left), the Brazilian basslet, *Gramma brasiliensis* (upper right), the coral *Mussismilia hartii* (lower left) and the Figueiredo´s pufferfish, *Canthigaster figueiredoi* (lower right). (Photos by Timothy Werner ©).

In Brazil, coral reefs are concentrated in the northern and northeastern coasts, reaching their maximum expression in the Abrolhos Bank, at about 18°S (Sealey & Bustamante 1999). Brazilian reefs exhibit high rates of endemism (~50% in reef corals and 20% in reef fishes) concentrated in a small area that represents less than 5% of the total reef area of the Western Atlantic (Table 1, Figure 2). High concentrations of endemic species give added conservation significance to some small areas (Myers et al. 2000). Although coral reef research in Brazil is still in its initial stages (Castro & Pires 2001), the region is starting to be recognized as a "hotspot" for marine biodiversity conservation in the Atlantic Ocean (Moura 2002). Endemic-species/area ratios in Brazil four times greater for fishes and, for corals, it is more than three times greater for corals than in the Caribbean (Moura 2002).

Table 1. Summary of characteristics of Brazilian reefs.

Percentage of Global Reef Area	Percentage of Atlantic Reef Area		
0.4%	5%		
Levels of Endemism		Endemic species/area (ratio for 100 km^2)	
Corals	Fishes	Corals	Fishes
50%	15-20%	0.9	6.5

2.2. The Abrolhos Bank

The Abrolhos Bank harbors the largest and richest coral reefs within the South Atlantic Ocean, comprising a unique reef ecosystem that develops in relatively turbid waters, under strong coastal and riverine/estuarine influence. The unique reef type, locally known as "chapeirão", consists of mushroom-shaped pinnacles built predominantly by Brazilian-endemic species, covered with fans of fire coral and round knobs of brain corals, also unique to the Abrolhos Bank. There are 17 species of reef corals in Abrolhos, half of them endemic to Brazil and two endemic to the Bank itself: *Mussismilia braziliensis* and *Favia leptophylla*. In addition, there are three species of hidrocorals (one endemic, *Millepora braziliesis*) and about 300 species of fish.

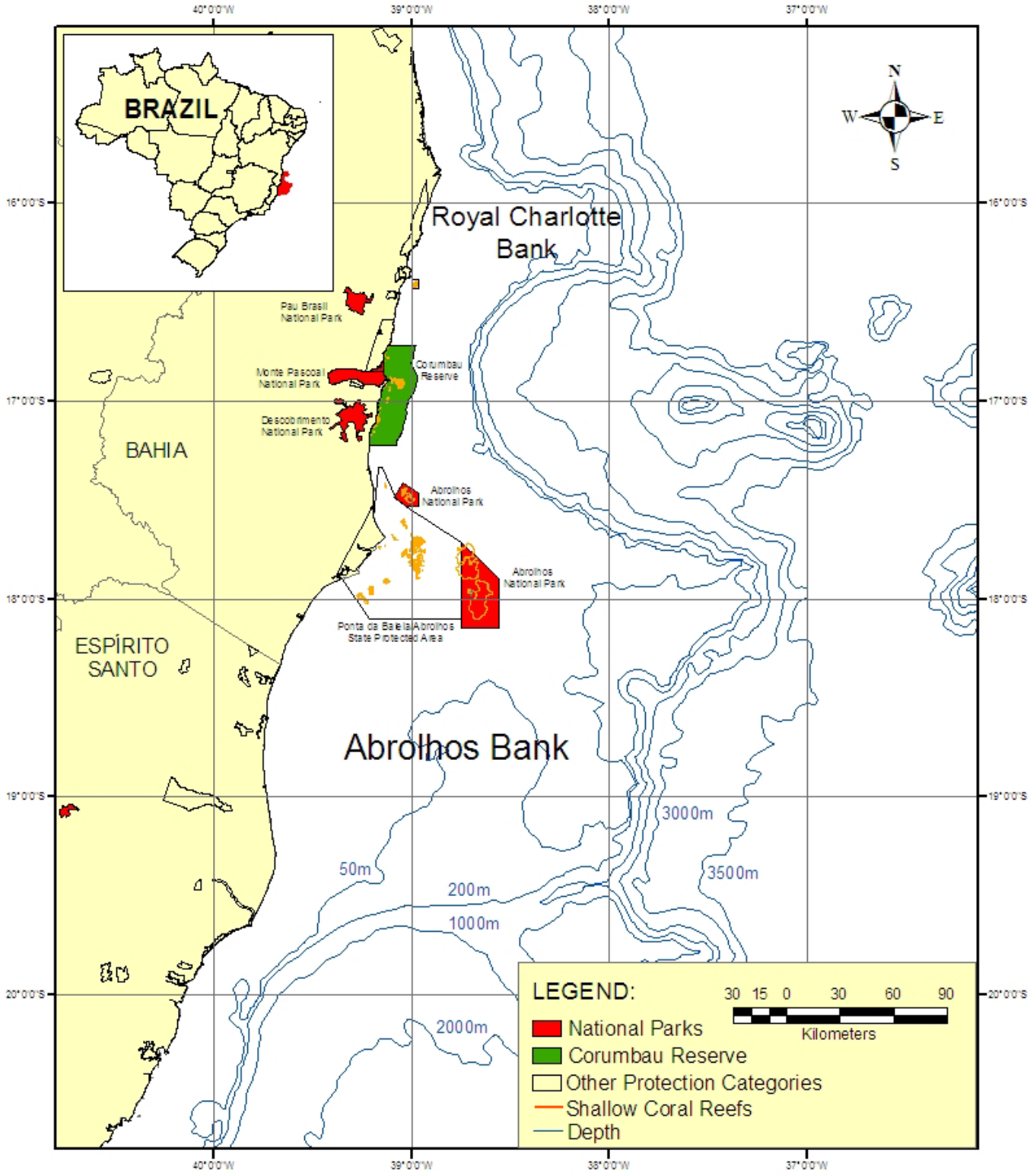

Figure 3. The currently existing network of coastal and marine protected areas in the Abrolhos Bank, Southern Bahia, Brazil. Red areas are fully protected coastal and marine parks and the green area is the multiple-use Corumbau Reserve.

All the commercially valuable species of reef fish in the South Atlantic can be found in the archipelago's surroundings, including red-listed large predatory fish such as the goliath grouper (*Epinephelus itajara*), the cubera snapper (*Lutjanus cyanopterus*), and the mutton snapper (*Lutjanus analis*). Between July and November, Humpback whales, endangered mammals weighting around 30 tons, also visit Abrolhos. The region is the main area in the South Atlantic to which Humpback whales go in order to mate and give birth during the Antarctic winters. Threatened bird species also occur in Abrolhos, including the tropicbird *Phaeton aethereus* and the Royal tern, *Thalasseus maximus*. Three red-listed marine turtles are also present in the region, including the green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), and loggerhead (*Caretta caretta*).

The survey area includes one no-take area (Abrolhos National Marine Park – 882 km^2) and two multiple-use marine protected areas (MPAs), the Corumbau Extractive Reserve (895 km^2) and the Ponta da Baleia/ Abrolhos State Protected Area (3,460 km^2) (Figure 3). Despite the large size of the State Protected Area, it is neither implemented nor has any kind of infrastructure or personnel. Indeed, no State-level protected areas are implemented in Bahia, as they merely represent an attempt of the State Government to increase its governance over marine areas over Federal jurisdiction. The Abrolhos Marine National Park was created in 1983 and is administered by the Brazilian Environmental Agency (IBAMA). The park, located 45 miles off the city of Caravelas, is divided in two separate portions: the Timbebas Reefs (111 km^2) and the Archipelago and Abrolhos Reefs (771 km^2) (Figure 3). Despite its size, enforcement of the National Park regulations is still incomplete, as there is only one larger boat (the 45-foot vessel "Bendito") and a few smaller zodiacs.

The Corumbau Extractive Reserve was created in 2000 and covers 89,5 km^2, being co-managed by IBAMA and a deliberative board of NGOs and members of the local communities. The reserve's goal is to improve local community livelihoods by fostering the sustainable use and management of the fisheries. Although this is a multiple-use reserve, its management plan considers several no-take zones.

Although the existing MPAs play a major role, they are not enough for the long-term biodiversity protection of this unique marine realm, as they represent less than 5% of the entire Abrolhos Bank and are concentrated into a single habitat: shallow and emerging coral reefs (see Figure 3). Most recommendations for conservation of biodiversity and maximization of fisheries yields suggest that a minimum of 20% and an optimum of 30–50% of the total management area be set-aside in no-take reserves (Roberts et al. 2002, Airame et al. 2003, Halpern & Warner 2003). This reserve size allows populations to remain large enough to produce sufficient offspring for maintaining species stability and fisheries needs, while simultaneously leaving enough area open for fishermen to have sustainable catches. Besides their small size, the ecological representativity of the Abrolhos network of MPAs is extremely limited, as there are no fully protected areas encompassing mangroves, and no protected areas encompassing deeper reefs (>20 m depth).

The greatest threats for the long-term protection of the Abrolhos biodiversity and fisheries resources are illegal fishing inside MPAs, uncontrolled fisheries outside MPAs, and uncontrolled exploitation of oil and natural gas near or inside MPAs, as well as large-scale marine transportation (mostly *Eucalyptus* logs and cellulose) near coral reefs and breeding areas of whales. In Abrolhos, fisheries management strategies are largely limited to MPAs, due to the lack of basic life history information for most commercially important species, as well as to the limited traditional knowledge on such resources. As a result, fishing regulations focus only on a few marine resources such as peneid shrimps (season), lobster (season and gear), snook (season) and jewfish (closed till 2007).

The study area is located off the municipalities of Porto Seguro, Prado, Alcobaça, Caravelas, Nova Viçosa and Mucurí, where tourism and artisanal fisheries are still the primary income sources for the coastal population, despite the recent increase in agro-industrial activities related to cellulose production (since the 1980s). Most of the Atlantic Rainforest that once bordered the Abrolhos Bank has been eliminated, although there are a few remnants in two national parks, *Monte Pascoal* (125 km^2) and *Descobrimento* (215 km^2), as well as in three indigenous lands inhabited by Pataxós Indians, *Barra Velha,*

Águas Belas, and *Corumbauzinho*, the former with several Indian fisherfolks that utilize the Corumbau Extractive Reserve as their main fishing area (Figure 4).

Figure 4. There are several remnants of Atlantic Rainforest in the coastal area adjacent to the Abrolhos Bank, including the Descobrimento National Park (upper left – the largest protected remnant of Atlantic Rainforest in the entire Northeastern Brazil). Also, there are several Indigenous Lands inhabited by Pataxós Indians (upper right). Some of the Pataxós at the Barra Velha Indigenous Land, near the Monte Pascoal National Park, are fishermen at the adjacent Corumbau Reserve, whose greater reef, Itacolomis (bottom), had 20% of its area set as no-take by the Reserve's Deliberative Council. (Photos by Jean François Timmers – top and Enrico Marone - bottom ©)

3. METHODS

3.1. Reef fishes in Abrolhos likely to form spawning aggregations

Using the knowledge of the reproductive behavior of groupers and snappers from the Caribbean, and the evidences gathered by one of us (R. B. Francini-Filho) after seven years studying reef fishes in the Abrolhos Bank, we can reasonably expect that the following species form spawning aggregations at specific locations in Abrolhos:

Serranidae (groupers)

Goliath grouper or jewfish, *Epinephelus itajara*: Historically, goliath grouper were found in tropical and subtropical waters of the Atlantic Ocean, both coasts of Florida, and from the Gulf of Mexico down to the coasts of Brazil and the Caribbean. Most adults are found in shallow waters, the deepest records being at about 60 m. Spawning occurs at aggregation sites in July through September over full moon phases (Bullock et al. 1992, Colin 1994). Fish may move up to 100 km from inshore reefs to the offshore spawning aggregations in numbers of up to 100 or more on ship wrecks, rock ledges, and isolated patch reefs along the southwest coast of Florida. Aggregations declined in the 1980's from 50-100 fish to less than 10 per site. Since the harvest prohibition, aggregations have rebounded somewhat to 20-40 fish per site. When goliath grouper are not on their spawning aggregations, they are dispersed along shallow reefs. Historically, they were abundant in very shallow water, often associated with piers and jetties along the Florida Keys and southwest coast of Florida. They are no longer abundant in these shallow areas. T

The goliath grouper occurs along the entire Brazilian coast and in Abrolhos it is particularly abundant at the Itacolomis Reefs, inside the Corumbau Marine Extractive Reserve. The goliath grouper was heavily fished in Brazil, since the 1970’s, but its exploitation was recently (2003) prohibited through a federal legislation. Until 2002, up to 10 large individuals (50-180 cm) were captured per year at Itacolomis Reefs (Figure 5), but now its exploitation has apparently ceased. The young and small adults are frequently

found in the largest estuarine/mangrove system in Abrolhos (Rio Caravelas), which is included inside the recently proposed Protected Area of Cassurubá. Besides the Itacolomis Reefs and the Caravelas estuary, we also recorded the jewfish in other Abrolhos' localities such as Popa Verde, Parcel das Paredes, Timbebas Reef and at the archipelago, the later two within the National Marine Park. These recent records were never frequent nor involved more than two fish at a time.

Figure 5. Jewfish *Epinephelus itajara*, captured at the Itacolomis Reefs in 2000 (Photo by E. Marone©).

Black grouper, *Mycteroperca bonaci*: Although the reproductive cycle of the black grouper has been recently studied in northeastern Brazil (Teixeira et al. 2004), its reproductive behavior has not been published yet, although we know that it forms spawning aggregations. During the winter of 1997-1998, Eklund et al. (2000) discovered an aggregation of black grouper, *Mycteroperca bonaci*, less than 100m outside a newly designated marine reserve. The grouper aggregation included up to 96 individuals just seaward of a no-take area within the Florida Keys National Marine Sanctuary. The black grouper were aggregated in a spatially discrete 100 m² area in 18-28 m of water. In Belize, one of us (E. Sala, unpubl. data) has observed the courtship and spawning of the black grouper in two spawning aggregations of 15 and 100 individuals respectively, in Glover's

Reef atoll, from 1999 to 2004. The aggregations occur around the full moons of December and January. In northeast Brazil, Teixeira et al. (2004) have learned, from the study of gonads of landed fish, that reproduction occurs between June and September. In the Abrolhos Bank, the black grouper is captured mainly from April to June, on deeper and unprotected portions of the Bank, constituting approximately 11% of the total fish catch (Costa et al. 2003; Figure 6).

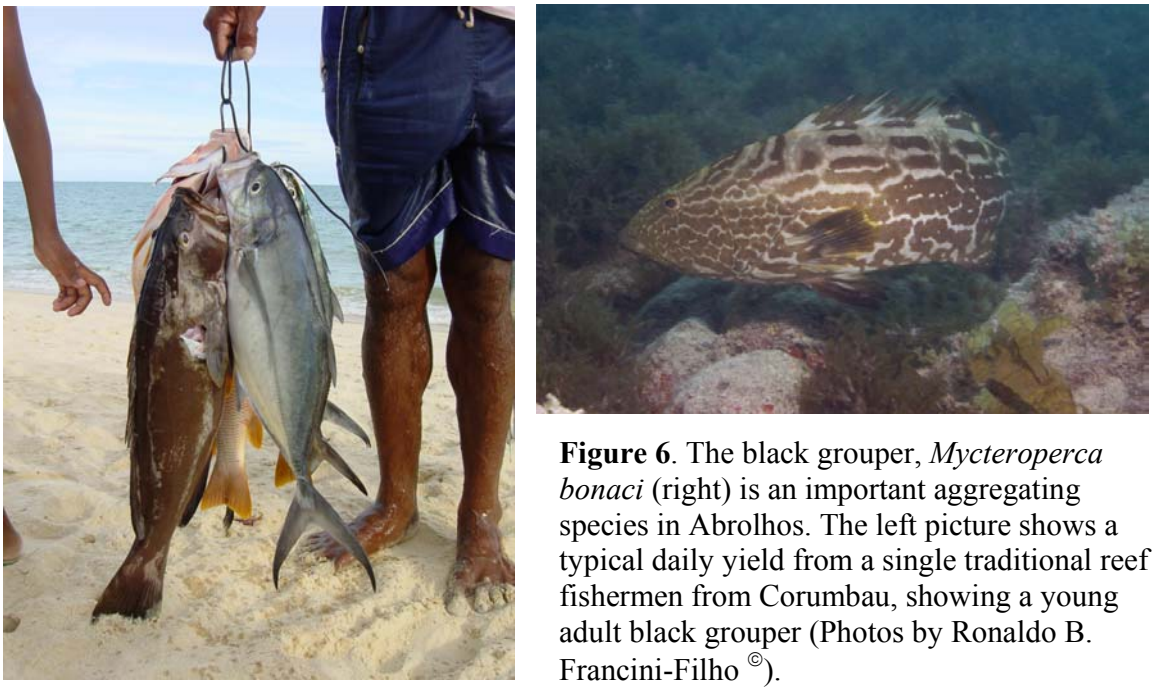

Figure 6. The black grouper, *Mycteroperca bonaci* (right) is an important aggregating species in Abrolhos. The left picture shows a typical daily yield from a single traditional reef fishermen from Corumbau, showing a young adult black grouper (Photos by Ronaldo B. Francini-Filho ©).

Other large serranid species recorded in the Abrolhos reefs

(locally important but not known to aggregate to spawn)

The red grouper, *Epinephelus morio* (Figure7), is another frequent large serranid captured in Abrolhos. Although not known to form spawning aggregations, we included the information we gathered on its fisheries, as well as from underwater surveys and interviews with fishermen, as there are signs of a sharp and recent decline in its populations in Abrolhos. **The coney, *Cephalopholis fulva*** (Figure 7), is a medium-sized serranid with considerable commercial importance. Although not known to form spawning aggregations,

we also included the few pieces of information we were able to gather in Abrolhos. It is rarely found in most coastal reefs and does not occur in the larger Abrolhos reefs such as the Parcel das Paredes and Parcel dos Abrolhos, resulting in negligible catches from small-scale artisanal fishermen (see results under "Traditional Knowledge"). However, catches from the larger and well-equipped fleets that operate in deeper areas are high (pers. obs.) and completely unreported to authorities. Accordingly to the fishermen we interviewed in the larger fishing port of Abrolhos, Alcobaça, coneys are frozen alive onboard, in order to keep their intense coloration. They are then bought by intermediates in Alcobaça and sent directly to the Vitória airport (350 km to the south), from where it is exported. Fisheries and biology of the coney require further attention from scientists and authorities.

Figure 7. The red grouper, *Epinephelus morio* (left and upper right) and the coney, *Cephalopholis fulva* (bottom right) are commercially important serranids in Abrolhos, but they are not known to form spawning aggregations (Photos: Ronaldo B. Francini-Filho ©).

Lutjanidae (snappers)

Dog snapper, *Lutjanus jocu*: Adult dog snappers are commonly found around coral reefs and rocky bottoms at depths of 5-150 meters, from Massachusetts to south Brazil, while the young can be seen in estuaries and have been known to go inshore and swim into rivers. In Belize, they aggregate to spawn around the full moons of March and May, forming aggregations of several thousands of individuals (Heyman 2001). In the Abrolhos Bank, the dog snapper constitutes approximately 4% of the total catch of reef fishes, being more frequently captured from April to June (Costa et al. 2003). The young is also frequently found in the largest estuarine/mangrove system in Abrolhos (Rio Caravelas) witch is included inside the recently proposed Cassurubá Reserve.

Figure 8. The dog snapper, *Lutjanus jocu*, represents the third most important lutjanid in Abrolhos reef fisheries. Although adults are captured in reefs, juveniles are frequently found in estuaries, which still lack adequate protective measures (Photo by Ronaldo B. Francini-Filho ©).

Cubera snapper, *L. cyanopterus*: Cubera snappers live inshore or nearshore. They most often associate with ledges over rocky ledges and overhangs, living at depths to 55 meters. The young typically inhabit inshore mangrove areas and seagrass beds that offer some protection from predators. Small cubera snappers also are known to enter estuaries, mangrove areas, and the tidal reaches of streams and freshwater canals. In the Caribbean, cubera snappers spawn around the full moons of March and April, forming aggregations of up to several thousands of individuals (Heyman 2001). In Brazil, one of us (R. B. Francini-Filho) has observed a large aggregation, including up to 50 individuals, on rocky reefs of Queimada Grande Island, in the southeastern Brazilian coast, in August 2003. In Abrolhos

the cubera snapper is rarely found in shallow reefs located near the coast, possibly reflecting its overexploited status.

Figure 9. The Vulnerable cubera snapper, *Lutjanus cyanopterus*, currently represents a minor proportion of Abrolhos landings, due to the near collapse of its stocks. The cubera is highly dependent on estuaries and nearshore habitats. It was recorded by one of us to form an aggregation in August 2003, in southeastern Brazil (Photo by Rodrigo Moura ©).

Lane snapper, *L. synagris*: The lane snapper inhabits coral reefs although it also frequents the soft bottoms adjacent to reefs, from the surface to 400 m depth. In Cuba, the lane snapper spawns typically 5 to 7 days before the fifth full moon of the year, in late April or early May (García-Cagide et al. 2001), although mature lane snappers have been found until November (Olaechea & Quintana 1975). They form large spawning aggregations that are the target of an important fisheries (Claro et al. 2001). In Abrolhos, the lane snapper is captured mainly from May to August, constituting important resources during this period. It remains unclear whether the larger captures in the Southern Hemisphere autumn and winter are also associated with spawning aggregations, as biological studies are still lacking.

Figure 10. The lane snapper, *Lutjanus synagris*, represents one the two most important aggregating species of Abrolhos (Photo by Ronaldo B. Francini-Filho ©).

Yellowtail snapper, *O. chrysurus*: The yellowtail snapper occurs from Massachusetts to south Brazil and is known to form spawning aggregations in Cuba (Claro 1983a, b). In Abrolhos the yellowtail snapper is considered the main target of reef fisheries, representing approximately 29% of the total catch (Costa et al. 2003). In Cuba it is most intensively captured from April to June, the same period in which it is known to aggregate to spawn in the Caribbean (Claro 1983a, b), but catches decline sharply from November to February. In Pernambuco, Northeastern Brazil, Diehdhiou (2000) found mature yellowtail snapper females all along the year, but suggested that there are two reproductive peaks in that area: one between March and July and other between November and December. Costa et al. (2003), speculates that that the yellowtail snapper is likely to form spawning aggregations in Abrolhos.

Figure 11. The yellowtail snapper, *Ocyurus chrysurus* is the main aggregating species targeted by the larger-scale reef fisheries of Abrolhos (Photo by Rodrigo Moura ©).

Other large lutjanid species recorded in the Abrolhos reefs.

A yet undescribed species of *Lutjanus* was discovered in the Abrolhos reefs, and latter found in other reefs along the tropical Brazilian coast, from which it seems to be endemic. This new species is not known to form spawning aggregations, is largely unreported in catch statistics and is mostly found in estuaries and coastal reefs. We will present it with greater detail in the "Unexpected New Findings"section.

3.2. Selection of survey sites

Maps, satellite imagery, and geographic information systems (GIS). Survey sites were initially assessed from the Brazilian Navy nautical charts. However, as only emergent reefs are depicted in these nautical charts, we also used a recent satellite-imagery survey of Brazilian reefs (Prates 2003) to identify deeper, non-emergent reefs. This was the initial baseline to choose the sites to be sampled with direct observations using scuba diving. The second step was the integration of all baseline data in a Geographic Information System (GIS), where we also included layers of data from interviews with fishermen, sonar side-scanning, and existing Marine Protected Areas (MPAs).

Interviews with fishermen. To locate a spawning aggregation unknown to researchers, fishers are often the best initial resource (e.g. Johannes 1981). We interviewed fishers for four months prior to our field trip in November 2004, using the interview methods developed by Johannes (1981) and the guidelines of the Society for the Conservation of Reef Fish Aggregations (Colin et al. 2003). Our goal was to obtain information on the location and timing of any outstanding catch and/or fish reproductive activity on the Abrolhos reefs. A total of 92 fishermen from four of the main fishing villages within the Abrolhos Bank were interviewed, using a semi-structured questionnaire (Appendix). Interviews included 19 fishermen from Corumbau (Prado Municipality), a *traditional* fishing community that co-manages a 895 km^2 sustainable-use MPA in the northern part of the Abrolhos Bank (Corumbau Extractive Reserve), created in 2000. The other interviews involved fishermen who operate around the Abrolhos National Park, including 27 interviews from Alcobaça Municipality, the main landing spot within the Abrolhos Bank, and 46 interviews from two villages within Caravelas Municipality (Barra de Caravelas and Ponta de Areia).

Side scan sonar and echo-sounding. Due to the limitations of existing nautical charts and satellite imagery, we also performed echo-sounding and sonar side-scanning of the most promising shallow reefs within the Abrolhos National Park. These included the Santa Barbara Island (where most underwater observations were conducted) and the Parcel

dos Abrolhos, deeper reefs that are only partially protected by the National Park (California Reef), and unprotected deep reefs (Buracas). We used an analogical Klein Side Scan Sonar, Hydroscan 531 (100 KHz), and a Skipper 417 echo-sounder. Side scan and echo-sounder images were both paper recorded on board, and latter scanned and geo-referenced with the aid of tracks obtained from a Trimble GPS-III, and a Trimble Pro-XL 12-channel DGPS.

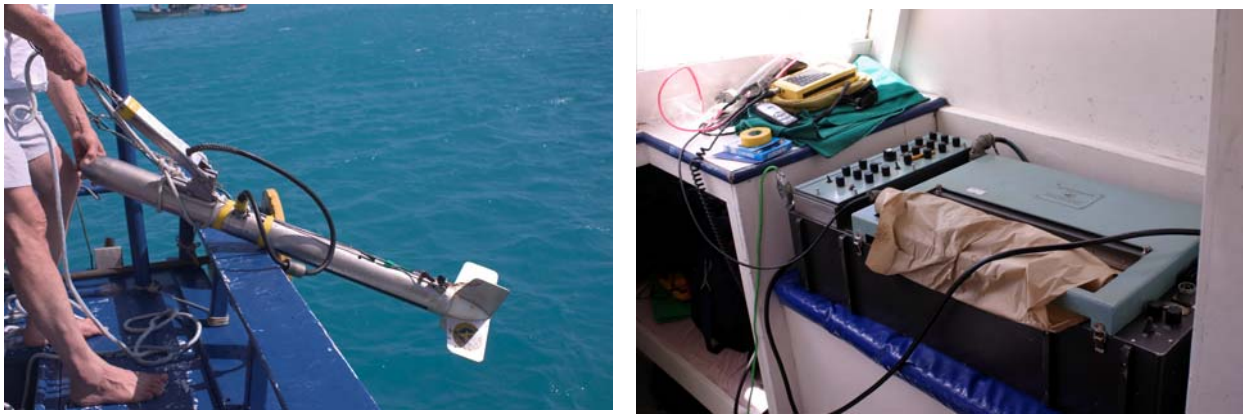

Figure 12. Details of the sidescan sonar operation in Abrolhos in partnership with geologists from the Instituto de Pesquisas Tecnológicas – IPT (Photo by Rodrigo Moura ©).

3.3. Fisheries statistics

Landing surveys. Landing surveys in the municipalities of Alcobaça and Caravelas were used to determine the main species target by fisheries and to detect cycles in maturation of fish gonads, length-weight relationships, length-frequency and catch trends along the year, for the main species. Surveys started in July 2004 and are planned to continue for the next eight months (see Discussion). Two local fishermen were trained to collect the data (Figure 13), and also to preserve female gonads for posterior analyses. Here, we present only the results related to the main species target by fisheries, obtained through the assessment of 64 boat landings, between July and December 2004.

Figure 13. Training of local fishermen to collect fisheries data in landing spots.

Southern Bahia fisheries statistics. To determine peaks in landings, and possible aggregation times for snappers and groupers in Abrolhos, we compiled official data from IBAMA (2002), which is available for all southern Bahia State coastal municipalities.

3.4. Diving surveys

Visual censuses. To quantify the abundance of reef fishes we used two different underwater visual census procedures. At reefs between 35 and 110 meters, we only compiled species lists and semi-quantitative surveys using scuba diving, in order to determine the composition and relative abundance of reef fish assemblages in a cross-shelf (depth) gradient along the Abrolhos Bank. The few deep dives, between 50 and 110m depths (Figure 14), were carried out using mixed-gas techniques, described in detail by Pyle (1991, 1996a, b, 1998).

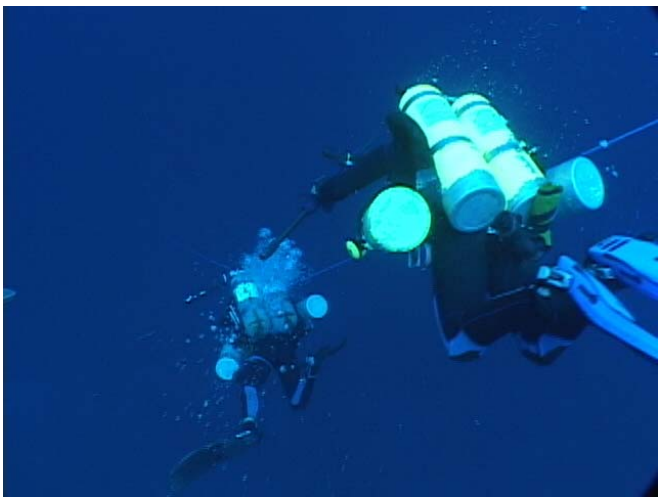

Figure 14. Deep reefs were reached with use of mixed-gas technology, in order to detect which are the species that occur in deeper areas and general characteristics of these largely unknown and unprotected habitats. The picture shows biologists Rodrigo Moura and Ronaldo Francini going down to 105 m in the shelf break of the Abrolhos Bank (Photo by Fábio B. Pereira ©).

In shallower and also in some mid-depth reefs (5 to 40 m), we quantified density, biomass and size structure of all non-cryptic reef fish species, with a methodology modified from Bohnsack & Bannerot's (1986) stationary sampling (also known as point counts), using scuba diving. Point counts were preferred over line transects due to the relative low visibility condition of the Abrolhos shallow reefs. Our modified methods consists in the combined (nested) use of two sizes of stationary cylinders: a small cylinder of 2 m in diameter where all fish of less than 10 cm (total length, TL) are counted, and a larger cylinder of 4 m where all fish above 10 cm TL are counted. Biomass was calculated by using length-weight relationship available in the literature (Froesy & Pauly 2003). We sampled coral reef areas separated by *ca*. 80km: 1) A fully-protected area in the Itacolomis Reefs (~4.5 km^2), within the Corumbau Extractive Reserve (three sites); 2) An area exploited exclusively by local traditional fishers in the Itacolomis Reefs (~20 km^2; seven sites); 3) A fully-protected area within the Abrolhos National Park (~ 100 km^2; three sites); 4) The unprotected area of Paredes Reef, the largest reef complex in the South Atlantic (~300 km^2; four sites), and 5) The unprotected area of Sebastião Gomes Reef (~5 km^2; one site). In each site 30 to 40 samples were obtained totaling about 628 samples. All visual census were made in 2004.

Surveys for Spawning Aggregations. To search for spawning aggregations we followed the protocol of the Society for the Conservation of Reef Fish Aggregations (SCRFA), consisting of interviewing fishers followed by diving studies (Colin et al. 2003). Spawning aggregations generally build over periods of time from days to weeks, and the aggregations can last a few weeks. The abundance of fishes increases dramatically in many cases, and during the spawning period aggregations are very conspicuous and can be easily identified. We conducted several dives per day using scuba diving, and also searched for aggregations during the late afternoon to sunset, as many species spawn during that time (Domeier and Colin 1997, Colin et al. 2003). Apart from the places suggested by fishers and other users of the reefs, we searched on shelf edge areas, reef promontories, pinnacles and passes where many species are known to spawn (Colin et al. 2003).

Between November 25 and 30, we intensively surveyed the rocky reefs of Santa Barbara Island at dusk. Santa Barbara is the largest island in the Abrolhos National Park, and harbors the greatest known grouper and snapper abundance within the entire Abrolhos Bank. We carried out a total of 25 hours of direct underwater observations. Additionally, we surveyed coral reefs in the California Reef and Parcel dos Abrolhos. Surveys for spawning aggregations were carried out by three divers (Enric Sala, Ronaldo Francini-Filho and Rodrigo L. Moura).

Voucher specimens and associated taxonomic studies. Voucher specimens of all known serranid (grouper) and lutjanid (snapper) species that are found in Abrolhos were examined at the Museu de Zoologia da Universidade de São Paulo (MZUSP). This procedure was particularly important not only to ensure correct underwater identifications, but also because we found an unusual snapper that was ultimately diagnosed as an undescribed species endemic to the tropical Brazilian coast. Underwater photographs, as well as a preliminary diagnosis and description of a new snapper species (see Results), is provided in the results section.

Figure 15. Besides scientific research, the project team got involved in a number of community outreach activities, such as meetings with the councilors of Abrolhos MPAs. The picture shows a meeting at the Corumbau Reserve in Caraíva, Porto Seguro Municipality (Photo by Rodrigo Moura ©).

4. RESULTS

4.1. Traditional knowledge on spawning aggregations

An assessment of the existing traditional knowledge is generally used as a first step when scientists start looking for spawning aggregations (e.g., Johannes 1981). In several places around the world, fishermen know the exact places and timing of spawning aggregations, especially those used as fishing spots. Establishing a closer relationship with fishermen is also useful when they are subsequently asked to collaborate in planning and setting protective measures for these long-used fishing spots.

A number of traditional capture techniques and fishing cycles have been described for fishing communities along the tropical and subtropical coast of Brazil (e.g. Forman 1967, Cordell 1974), but the only published information on aggregations of reef fishes is that of Teixeira et al. (2004). These authors have recently described a phenomenon locally known as "correção" (= fish run), in the states of Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, and Northern Bahia, a few hundreds of kilometers to the north of Abrolhos. Fishermen from these areas reported huge concentrations of black groupers, *Mycteroperca bonaci*, during the late Southern Hemisphere winter and spring (from June to September). However, fishermen did not associate these aggregations with reproduction, a fact that was also confirmed by Teixeira and co-authors through the examination of gonads of specimens collected from these aggregations. The exact biological meaning of the "correção" remains unclear, but Teixeira et al. (2004) speculate that it "seems to be a Southward chain reaction and is a feeding aggregation".

In order to assess the traditional knowledge regarding the existence of spawning aggregations we interviewed 92 people in five localities within the Abrolhos Bank, using the methods developed by Johannes (1981) and the guidelines of Colin et al. (2003). Interviews included 19 fishermen from the traditional community that co-manages the Corumbau Reserve (895 km^2), and also 73 fishermen who operate around the Abrolhos National Park, including 26 interviews from Alcobaça (the main landing spot in Abrolhos),

and 47 from other smaller villages (Figure 16). Interviewed fishermen were haphazardly selected, according to their willingness to contribute, but it is remarkable that no one who was approached rejected to contribute.

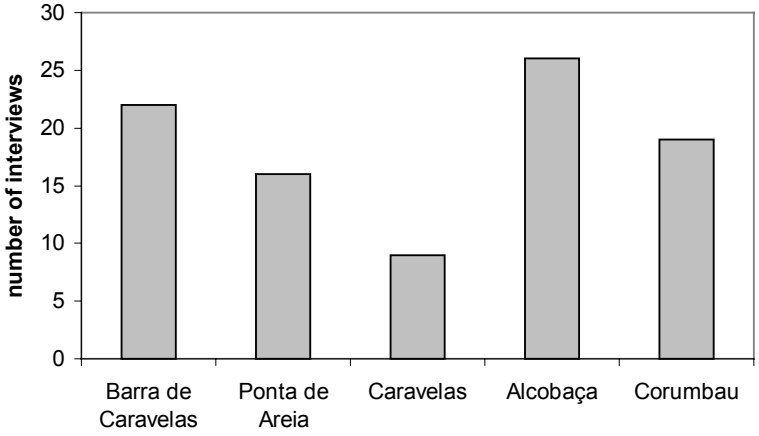

Figure 16. Number of interviews at each Abrolhos fishing community included in the survey.

There is a strong debate, on the biological and social sciences literature, about the concepts and characteristics of traditional fishermen populations (e.g., Diegues 2000), but this contentious discussion lies outside the scope of the present work. However, we do understand and acknowledge that there are differing levels of "traditionality" within the fishing communities of Abrolhos. In one extreme of this gradient there are communities with strong Indigenous (Pataxós) influence, which are also recognized by the Federal Government as traditional communities - such as Corumbau. In the other extreme there are communities in landing spots with large fleets of motorized vessels that come from several Brazilian States, such as Alcobaça. These larger cities also having an associated processing, commercialization and distribution infrastructure, which is lacking in the smaller villages, some of them without electricity and other basic infrastructure. Therefore, while comparing the information from the interviews we frequently used these two extremes, Corumbau and Alcobaça, in order to illustrate the most relevant differences.

Interviewed fishermen were mostly well-experienced and middle-aged men (Figure 17), including 18 fishermen with more than 40 years of daily work in the Abrolhos' reef fisheries (Figure 18). Although there are female fisherfolks engaged in some fisheries in Abrolhos – especially in the mangroves and estuaries, we were unable to find females

working in reef fisheries. The age, sex and experience profile presented in Figures 17 and 18 did not change significantly among the five communities.

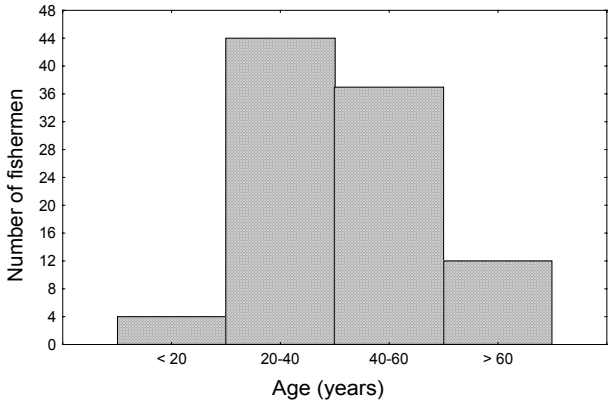

Figure 17. Age profile of interviewed fishermen (all five communities).

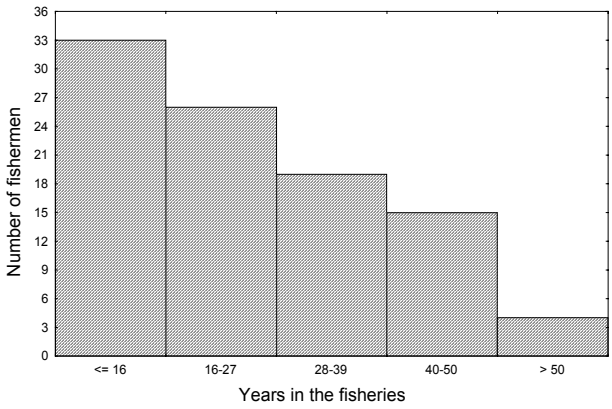

Figure 18. Experience level of interviewed fishermen (all five communities).

There are only smaller differences in the assemblage of fishes captured by the traditional and the larger-scale fishermen. The lane snapper, *Lutjanus synagris*, and the yellowtail snapper, *Ocyurus chrysurus*, are the main aggregating species targeted by both communities, although the former species is slightly more important for the smaller-scale traditional fishermen (Figure 20). The dog snapper, *Lutjanus jocu*, and the black grouper, *Mycteroperca bonaci*, are the next species in terms of relative importance for both communities, followed by the jewfish, red grouper, mutton and cubera snapper. It is noteworthy that the most threatened of the studied species - the jewfish (Critically Endangered) and the muttom and cubera snappers (Vulnerable) occupy the last ranks of importance in the current Abrolhos fisheries. Accordingly to the interviewed fishermen,

some of these rare species, such as the jewfish, were extremely frequent in the recent past (Figure 19).

Figure 19. A photograph from the 1970's showing a large jewfish being landed in Corumbau (unknown author – fishermen's personal archive).

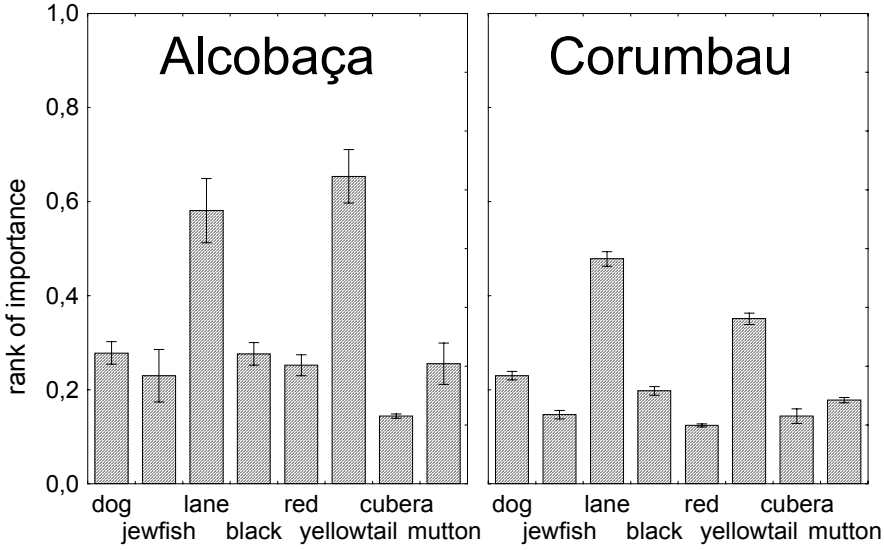

Figure 20. Rank of importance of each potentially aggregating species at the larger fishing village (Alcobaça, left) and at a smaller traditional community (Corumbau, right).

Ranks of importance declared by the fishermen, however, do not imply that the captured volume by each community is similar. Reliable catch-per-unity effort and total catch statistics for the entire Abrolhos Bank are not yet available (see Fisheries Data), but the deeper fishing areas explored by the larger communities are definitely more productive

than the shallower reefs explored by the smaller traditional fishing villages (see Diving Surveys).

One of the most evident discrepancies between the fisheries of the different communities is the depth range of the fisheries (Figure 21). The more traditional fishermen from Corumbau fish the aggregating species in shallower areas than do fishermen from the largest city, Alcobaça. We believe that this pattern is closely connected to the differing fishing powers between larger and smaller fishing communities. Corumbau boats, for instance, are smaller and have fewer navigation (e.g., GPS devices) and overall fishing resources than those from Alcobaça.

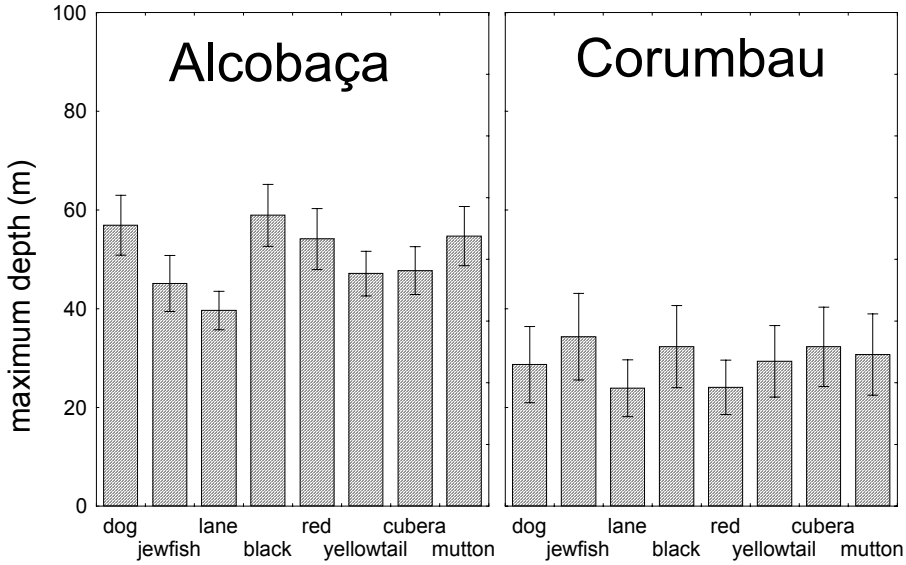

Figure 21. Depth range of fishing areas of all potentially aggregating species at the larger fishing village (Alcobaça, left) and at a smaller traditional community (Corumbau, right).

Costa et al. (2003), who studied some reef fisheries in the northern portion of the neighboring Royal Charlotte Bank, also provide support to the idea that the deeper reefs are still more productive than the shallower reefs. The assemblage reported by Costa et al. (op cit.) is considerably different from the one we studied in Abrolhos, but some of the shared

target species show a clear trend in the relationship between depth and catch-per-unity-effort (Figure 22). As fisheries resources vanish, prices rise and fishermen increase fishing power and move to deeper and yet unexplored areas. Shallower areas are then left to the less empowered smaller traditional communities with low fishing power.

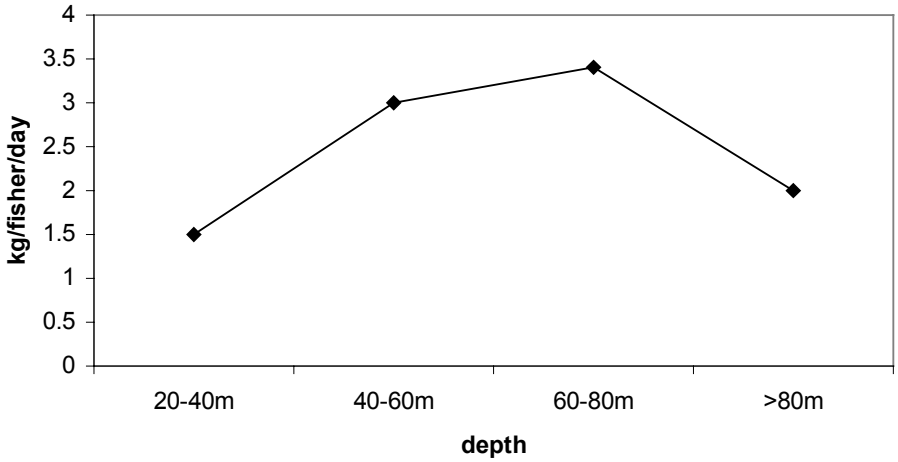

Figure 22. Relationship between depth and catch-per-unity-effort of the black grouper, *M. bonaci*, in the neighboring Royal Charlotte Bank. The graph shows higher values for deeper reefs between 60 and 80m, in which there is no protective measure for aggregating species nor MPAs. (adapted from Costa et al. 2003).

Therefore, a relevant practical aspect of the aforementioned patterns is the fact that the larger and more powerful fleets operate in deeper areas with no fisheries restrictions, while the low-power traditional fishermen explore shallower reefs with lower densities of commercially important fishes where, also, there are multiple-use areas with several fisheries restrictions. It is clear that an accurate sampling design and a larger dataset are greatly needed to subside an adequate fisheries management in the region.

Spawning aggregations information. Most of the interviewed fishermen stated that they didn't know about the existence of spawning aggregations in Abrolhos. With a few exceptions, the remaining interviewees presented ambiguous information about the existence, location, and timing of aggregations, as follows.

Groupers (Serranidae): **Jewfish**: 91% of the interviewees do not know about the existence of spawning aggregations, and the remaining fishermen inform that it aggregates to spawn in the Southern Hemisphere summer. Only 26% of the fishermen who informed about aggregation times were able to indicate the spawning grounds, generally large areas with dozens of kilometers, scattered along the entire Abrolhos Bank. **Red grouper**: 96 % of interviewees do not know about the existence of spawning aggregations, and the remaining fishermen provided conflicting information on spawning periods (2% informed that it spawns in the Southern Hemisphere summer and 2% informed that it spawns in the winter). Only 10% of the fishermen who informed about aggregation times were also able to indicate the spawning grounds, generally large areas with dozens of kilometers, scattered along the entire region. **Black grouper**: 86% of interviewees do not know about the existence of spawning aggregations, and nearly all the remaining fishermen informed that it spawns in the Southern Hemisphere summer (1% informed that it spawns in the winter). Thirty percent of the fishermen who informed about the aggregation times were able to indicate the spawning grounds, also generally informing large areas with dozens of kilometers, scattered along the entire Abrolhos Bank.

Snappers (Lutjanidade): **Mutton snapper**: 92% of the interviewees do not know about the existence of spawning aggregations in Abrolhos, and the remaining fishermen inform that it aggregates to spawn in the Southern Hemisphere summer. Only 6% of the fishermen who informed about aggregation times were also able to indicate the spawning grounds, generally large areas with dozens of kilometers, scattered all along the Abrolhos Bank. **Cubera snapper**: 97% of the interviewees do not know about the existence of spawning aggregations in Abrolhos, and the remaining fishermen inform that it aggregates to spawn in the summer. A negligible 3% of the fishermen who informed about aggregation times also indicate spawning grounds, large area scattered along the Abrolhos Bank. **Dog snapper**: 79% of the interviewees do not know about the existence of spawning aggregations in Abrolhos. Most remaining fishermen believe it spawns in the summer (17%), and only 4% inform that it spawns in the winter. Twenty-one percent of the fishermen who informed about aggregation times were also able to indicate the spawning grounds, but these were also large areas with dozens of kilometers, scattered along Abrolhos. **Lane snapper**: 82% of interviewees do not know about the existence of

spawning aggregations in Abrolhos. The remaining fishermen provided conflicting information on spawning periods, as 10% inform that it spawns in the summer and 8% inform that it spawns in the winter. Thirteen percent of the fishermen who informed about aggregation times were also able to indicate the spawning grounds, but these were also large areas with dozens of kilometers, scattered along Abrolhos. **Yellowtail snapper**: 86% of the interviewees do not know about the existence of spawning aggregations, but the large majority of the remaining fishermen informed that it spawns in the Southern Hemisphere summer (only 3% of the fishermen informed that it spawns in the winter). Twenty two percent of the fishermen who provided information on spawning times also provide information on spawning grounds. However, these were also large and scattered areas.

The lack of unambiguous information about the existence and location of spawning aggregations indicates that such events are currently extremely rare. It is also not clear from the interviews whether spawning aggregations were more common in the past. Older fisherman, however, recall times of greater abundances in the near past, and a progressive decline of all aggregating species, especially the muttom and cubera snapper (Vulnerable), the jewfish (Critically Endangered), and the red grouper (not threatened). The lack of precise traditional knowledge can be partially related to the recent relationship between men and the reef in Southern Bahia. Even the Pataxós Indian fishermen have a recent history of dependence on reef resources (Grunewald 2001). It is also apparent that the migration of a considerable amount of people to reef fisheries is related to the coastal deforestation that only occurred in the last five decades (Figure 23). It was only when forest resources started to fade away that reef fisheries became a widespread activity among Abrolhos coastal populations. Contrary to other coastal populations with a centuries-long history of dependence on reef resources, such as those described by Johannes and other Indo-Pacific and Caribbean researchers, it seems that several remarkable ecological patterns disappeared before being incorporated into the local culture.

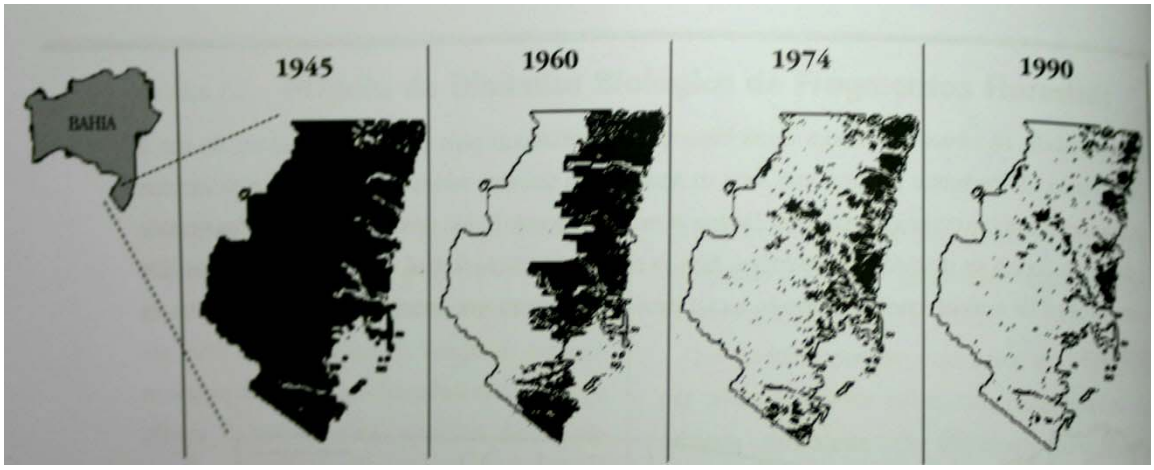

Figure 23. Historical deforestation trends in Southern Bahia. As the forest vanished, coastal populations increased their uses of marine resources. As this is a relatively recent trend, it is remarkable that most fisherfolks' families engaged into reef fisheries only in the last few decades, without accumulating a substantial amount of knowledge about the living resources they depend upon such as Indo-Pacific island communities that rely on reef resources for several centuries (Source: Conservation International).

4.2. Conservation status of the groupers and snappers in the Abrolhos Bank

4.2.1. Fisheries statistics

Data on fish landings showed that the yellowtail snapper, red grouper and lane snapper were, by far, the three species that most contributed to the total reef fish catches during the period of our survey (July-August 2004; Figure 24). Thus, our results highlight the importance of lutjanids and serranids (the main focus of the present project) as one of the main fisheries resources in Abrolhos. The yellowtail snapper accounted for 33% of total fish landings, representing one of the main species target by reef fisheries in Abrolhos. This last result is in accordance to the statistics of IBAMA and the work of Costa et al. (2003). The other species of lutjanids and serranids surveyed were rarely captured (specially the coney, cubera snapper, dog snapper, mutton snapper and the jewfish), possibly representing their overexploited status on shallower and unprotected reefs, where most boats we sampled focus their fisheries. The jewfish, despite being protected by federal legislation since 2002, was also recorded during our fishery assessment (two individuals; Figure 25).

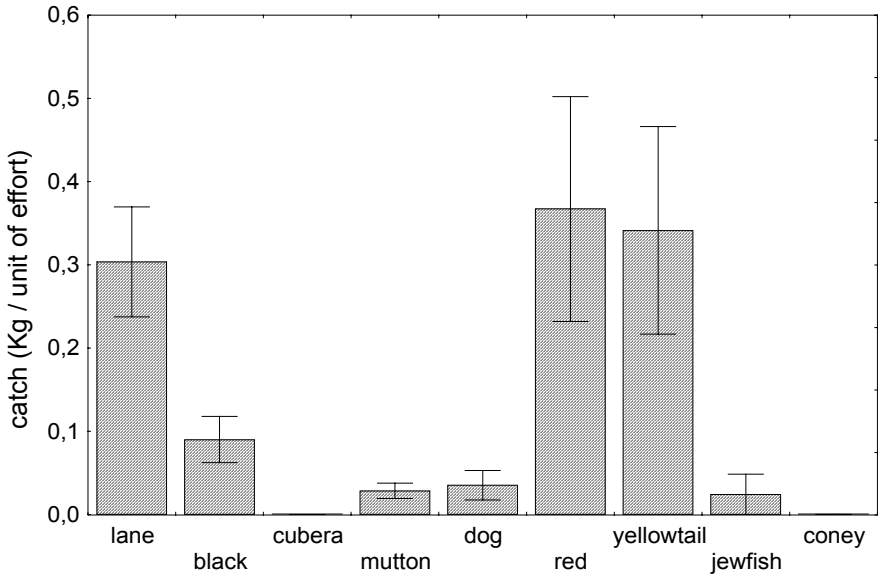

Figure 24. Catch per unit of effort (CPUE; Kg/fishermen/hours of fisheries) of serranids and lutjanids in the Abrolhos Bank, between July and December 2004.

Figure 25. Jewfish *Epinephelus itajara*, a species protected by Brazilian federal legislation recorded during our fishery survey.

Figure 26. A large black grouper, *Mycteroperca bonaci* specimen captured in deep reefs (left), and typical reef fisheries from shallower areas showing, from the top to the bottom, two parotfishes, one dog snapper. *Lutjanus jocu*, and a smaller black grouper.

Official data from IBAMA showed that the yellowtail snapper, black grouper and dog snapper were, respectively, the three main species of reef fishes captured in southern Bahia. The red grouper *Epinephelus morio*, toghether with the jewfish, accounted for a small proportion of the total fish catch (Figures 28 and 29). This difference between our survey's results and the data from IBAMA can be explained by the different sampling periods (our data is more recent) and also by fact that we sampled only two municipalities (Caravelas and Alcobaça), as IBAMA statistics are derived from pooled samples from several municipalities along the coast of Bahia. Another possibility is that the lane snapper has a greater use-value, being mostly locally consumed, and thus lacking from IBAMA's data that is gathered at commercialization points.

Figure 27. Contrary to IBAMA´s official statistics, we found the lane snapper, *Lutjanus synagris*, to be the most captured aggregating species, at least in the smaller fishing communities. See text for discussion.

An important trend, related to the proportional participation of different species, emerged when we considered different municipalities separately. The municipalities with more powerful and larger boats presented higher catches of black grouper and smaller catches of yellowtail snapper, the opposite pattern being recorded for the municipalities with smaller and less powerful boats (Figure 29). This difference can be reasonably explained by the distance these fishing boats may travel to achieve different fishing grounds. More powerful boats (mainly from Alcobaça and Porto Seguro) can travel farther from the coast, while the smaller and less powerful boats (Prado and Caravelas) can not travel far from the coast, thus fishing mainly on shallower unprotected reefs, where the density and biomass of black grouper, and other high-valuable fishes, is smaller (see "quantitative assessment of fish assemblages").

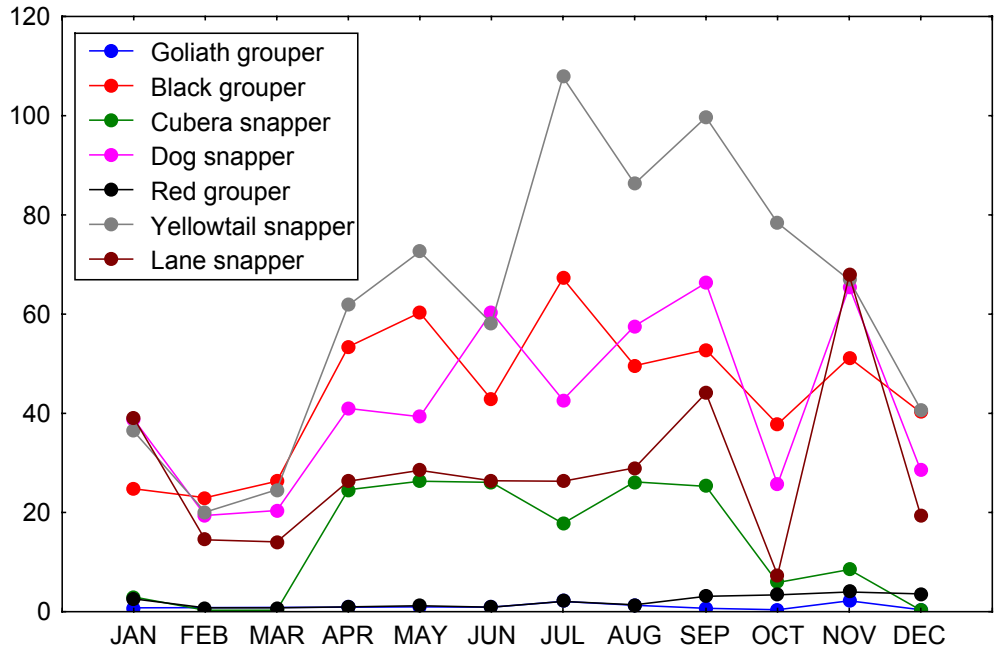

Figure 28. Total catch of reef fishes in southern Bahia along 2002. Source: IBAMA.

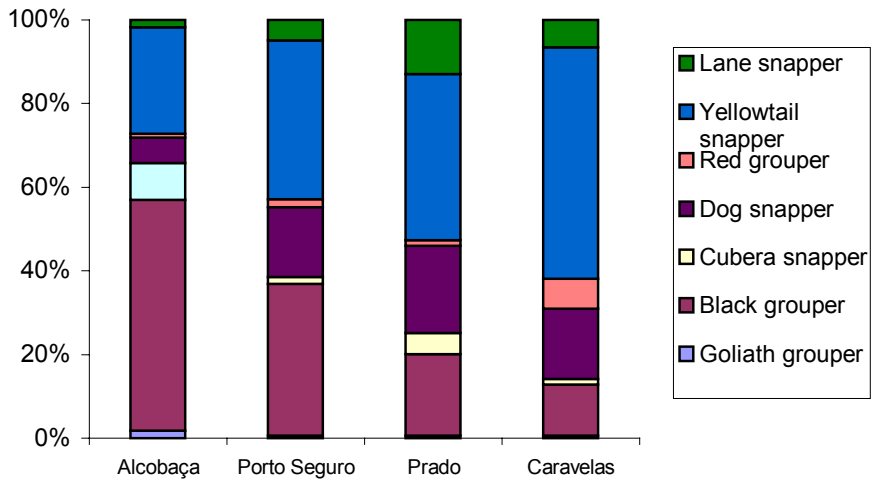

Figure 29. Proportional participation of different reef fish species in the catch of four municipalities in southern Bahia. Statistics for 2002; Source: IBAMA.

4.2.2. Diving surveys

4.2.2.1. Quantitative assessment of fish assemblages

The quantitative assessment of fish assemblages showed that, at least for three species (dog snapper, yellowtail snapper and black grouper), density and biomass on shallow reefs was higher inside protected areas (specially the Archipelago). A summary of the quantitative assessment results is provided in **Figure 30**. Deep and unprotected reefs harbored higher density and biomass of the lane snapper and coney. Density and biomass of black grouper in deep reefs was also high, similar to that recorded on shallow protected reefs. These results support the hypothesis that deeper reefs are less exploited and harbors higher density of high-valuable reef fishes when compared to shallow and more exploited reefs. Thus, larger and more powerful boats can capture fishes on better fishing grounds, while smaller boats have no other choice than to exploit the less valuable species that remain relative abundant on shallower reefs (e.g. yellowtail snapper).

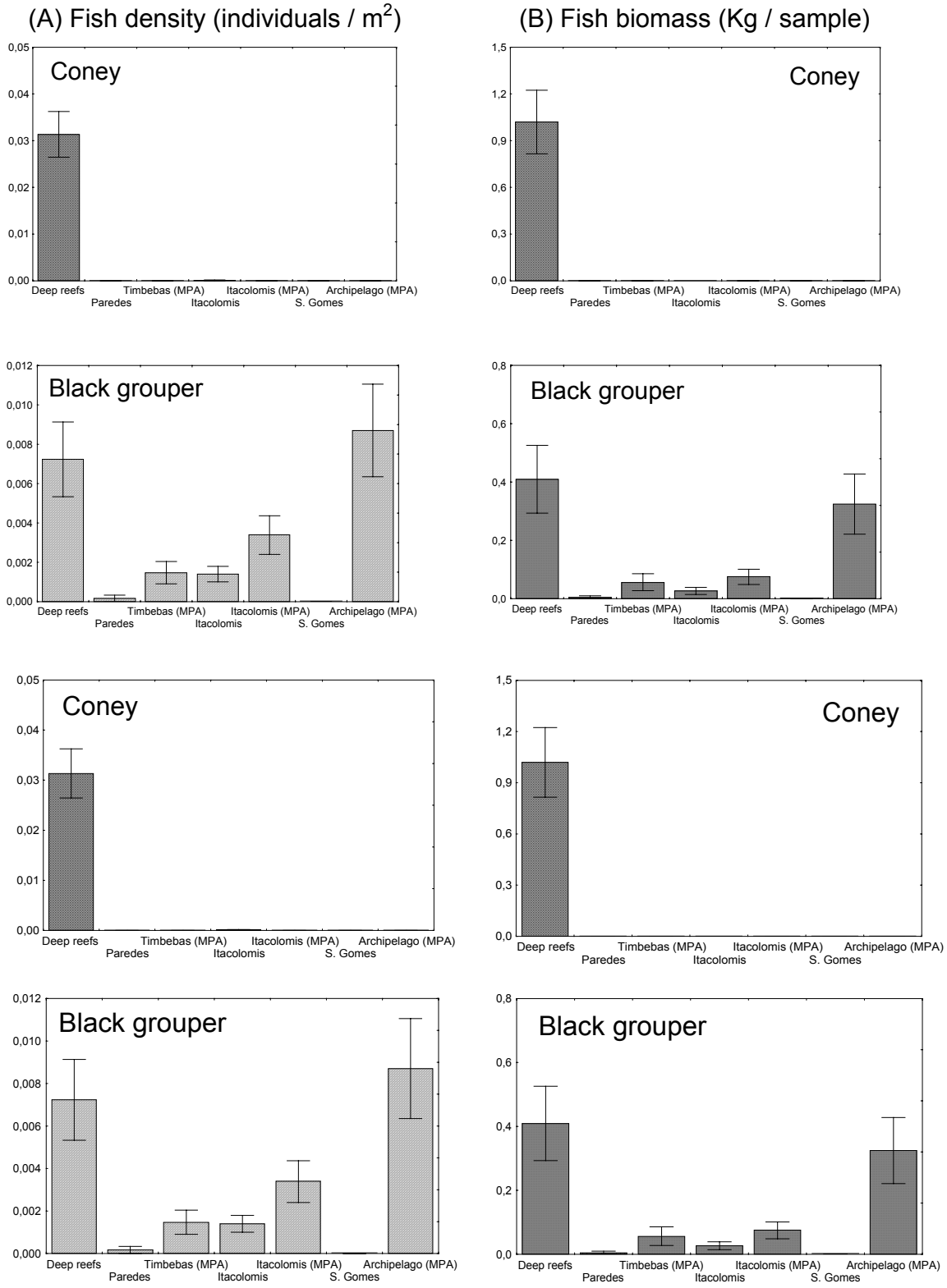

Figure 30. Density and biomass of selected species in protected and unprotected reefs in Abrolhos.

4.2.2.2. Search for spawning aggregations

North Shelf**.** The area surveyed in the north shelf includes lines of calcareous deep reefs in depths to 65m (Point A of Figure 33), and also a large hole (100 m in diameter), known by local fishermen in Abrolhos as "buraca" (Point B of Figure 33). The "buraca" is a nearly circular structure, whose surroundings are covered mainly by fleshy and calcareous algae, with very few and sparse colonies of reef corals, mostly *Montastrea cavernosa*, *Scolymia wellsi* and *Madracis decactis*. In this unusual reef, depth ranges from 25m, in the marginal portion, to almost 50m in its central portion, which is almost completely filled with large and unattached flesh algae. The "buraca" is a site frequently exploited by local fishermen, due to its high concentration of commercially important reef fishes, mainly jacks, barracudas and groupers.

The most abundant fish species (>300 individuals) recorded in this site were, in order of abundance, *Haemulon squamapinna*, *Haemulon plumieri, Anisotremus virginicus*, *Sphyraena guachancho* and *Holocentrus ascensionis*. Very few individuals of serranids and lutjanids were sighted, including the black grouper *Mycteroperca bonaci*, the dog snapper *Lutjanus jocu* and the lane snapper *L. synagris*. Most fishes were concentrated in the marginal areas of the "buraca", where substrate complexity and refuge availability seems to be greater. Despite the uniqueness of this habitat, and relatively high densities of lutjanids and serranids recorded in previous surveys, the "buraca" was not surveyed at dusk (the period when spawning aggregations are likely to occur), since very few individuals of species that are known to aggregate to spawn were sighted during the day.

California Reef. California Reef is located in the central portion of the Abrolhos Bank and it is partially inside the no-take area of the National Marine Park of Abrolhos. Depth ranges between 10 and 40m, and the coral reefs in the area are prominent and characteristic mushroom-shaped pinnacles ("chapeirões" cf. Leão 1982, 1986). However, the pinnacles of California Reefs are more sparse and smaller than the ones present in other coral reef areas in Abrolhos (e.g. Parcel dos Abrolhos). Again, very few individuals of

serranids and lutjanids, such as the black grouper *M. bonaci* and the dog snapper *L. jocu*, were sighted. Consequently, this area was also not surveyed at dusk.

Abrolhos National Park: Parcel dos Abrolhos. The Parcel dos Abrolhos is inside the no-take area of the Abrolhos National Park, and it is constituted exclusively by large and typical mushroom-shaped pinnacle reefs. There is also a big wreck ("Rosalina") where relative large densities of black groupers were recorded. The depth range is between 5 and 25m. During the present survey we recorded a behavioral interaction between two black groupers, but their similar size (about 70 cm in length) and their yellowish pallid coloration suggests they were both females (Figure 31). We could not survey the Parcel dos Abrolhos at dusk because of the bad weather (strong winds) and the subsequent limited water visibility.

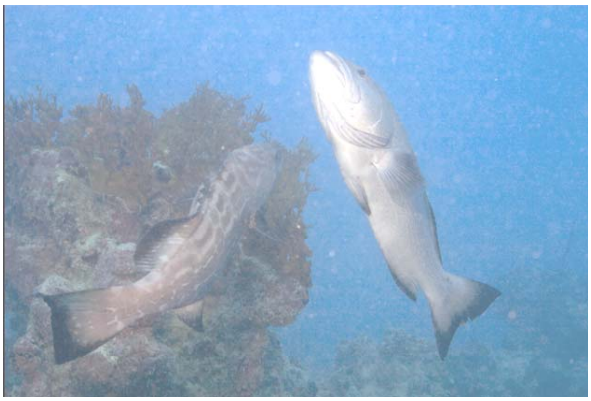

Figure 31. Behavioural interaction between two black groupers, *Mycteroperca bonaci*, at the Parcel dos Abrolhos, within the National Park (Photos by Ronaldo Francni-Filho ©).

Abrolhos National Park: The Abrolhos Archipelago. The Archipelago is the most promising area for the study of spawning aggregations, because of the relatively high densities of black groupers, yellowtail snappers and dog snappers, and calmer sea conditions. Thus, we concentrated most efforts during the final survey in this area. The density and biomass of black groupers and yellowtail snappers in the Archipelago is as high, or even higher than that recorded for deeper and possibly lightly exploited reefs (near Itacolomis Reefs). Yet, the Archipelago harbors the highest density of dog snappers recorded in the Abrolhos Bank (see Figure 30). Observations on groups of black groupers were carried out mainly between 1600 and 1800h, during three consecutive days. However, no spawning activity was recorded. In addition, we observed one solitary jewfish (120 cm in length) and a school of 200 sailor's choice, *Haemulon parra*, at 7 m depth on the southern side of Santa Barbara Island (Figure 32).

Figure 32. The only place we could find large schools of large sailor's choice, *Haemulon parra*, was the Abrolhos Archipelago, within the National Park (Photo by Ronaldo B Francini-Filho ©).

4.2.3. Uncharted deep reefs and unexpected new findings

Mapped coral reefs in the Abrolhos Bank include those in Parcel das Timbebas, Parcel das Paredes, and Parcel dos Abrolhos (Figures 3 and 33). In the nautical charts, there is a vast area east of these large reef formations that is virtually blank. However, this area harbors many deep reefs yet uncharted, in which most fishing occurs, as clearly seen by the depth trends shown in Figure 21.

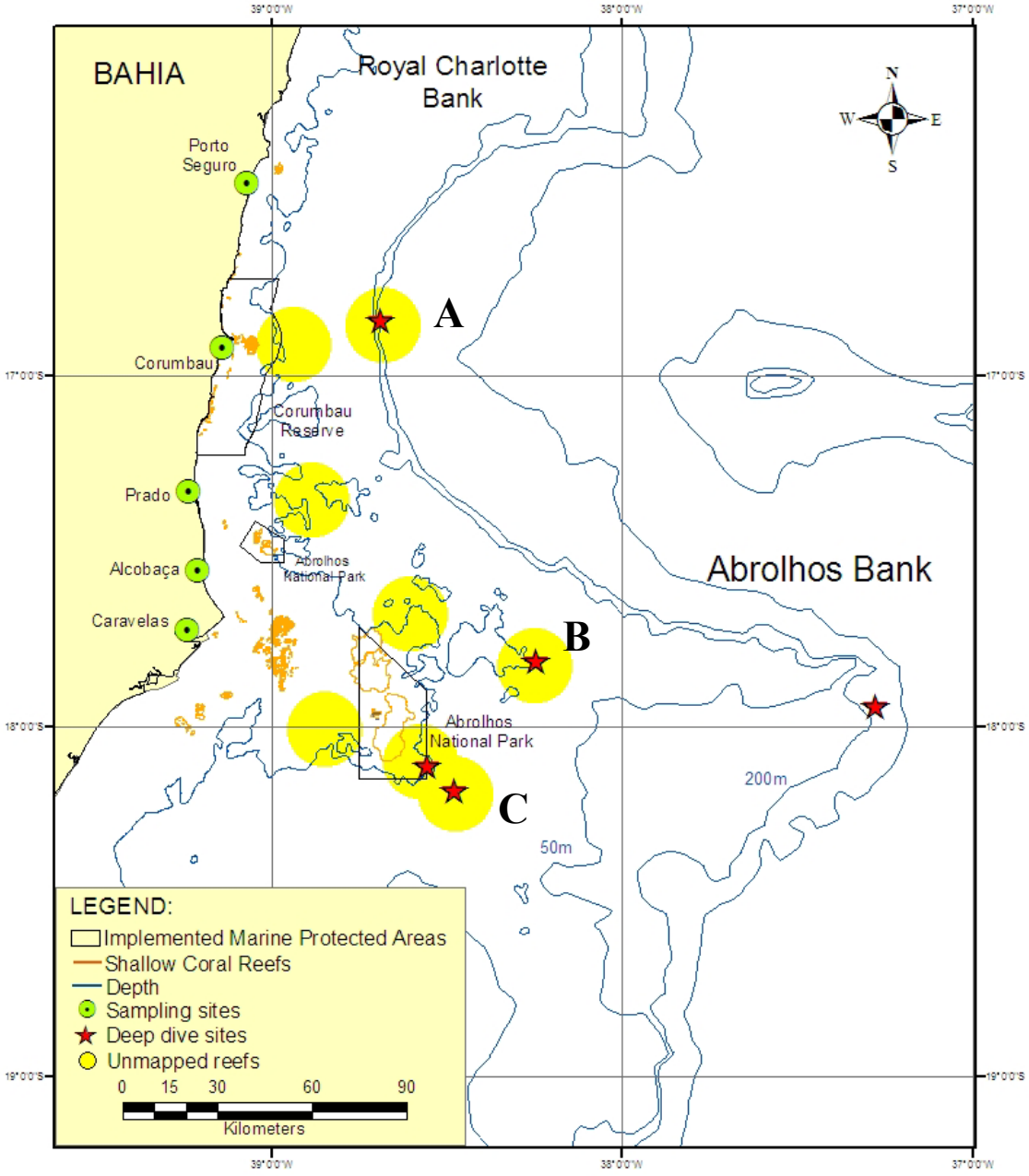

Figure 33. The Abrolhos Bank, showing the currently mapped reefs and several "new" reef formations found during deep dives and sidescan sonar operations. Notice that in only one of the deep dives we were not able to find living reefs, clearly showing that reef mapping is one of the major gaps for adequate zoning and management of Abrolhos reef resources. Another important pattern that emerge from this preliminary survey is the inadequate representativity of the existing MPA network, not covering these rich, unique, and heavily exploited deeper habitats. See Figure 25 for underwater images of the sites marked with letter codes (A, B and C).

We did a series of preliminary sidescan sonar surveys in order to obtain a baseline view of this major gap, allowing us to look for isolated pinnacles and other conspicuous reefal formations that could be promising sites to look for spawning aggregations. Also, from selected information obtained from fishermen, we dove in several fishing spots within this uncharted area. For instance, one boat captain gave us the GPS positions of several "cabeços" (coral heads) out of many he had on a logbook, and found living reefs. These preliminary findings clearly show that there are many of such deep reefs, harboring a rich and diverse marine biodiversity still unknown by scientists (Figure 34).

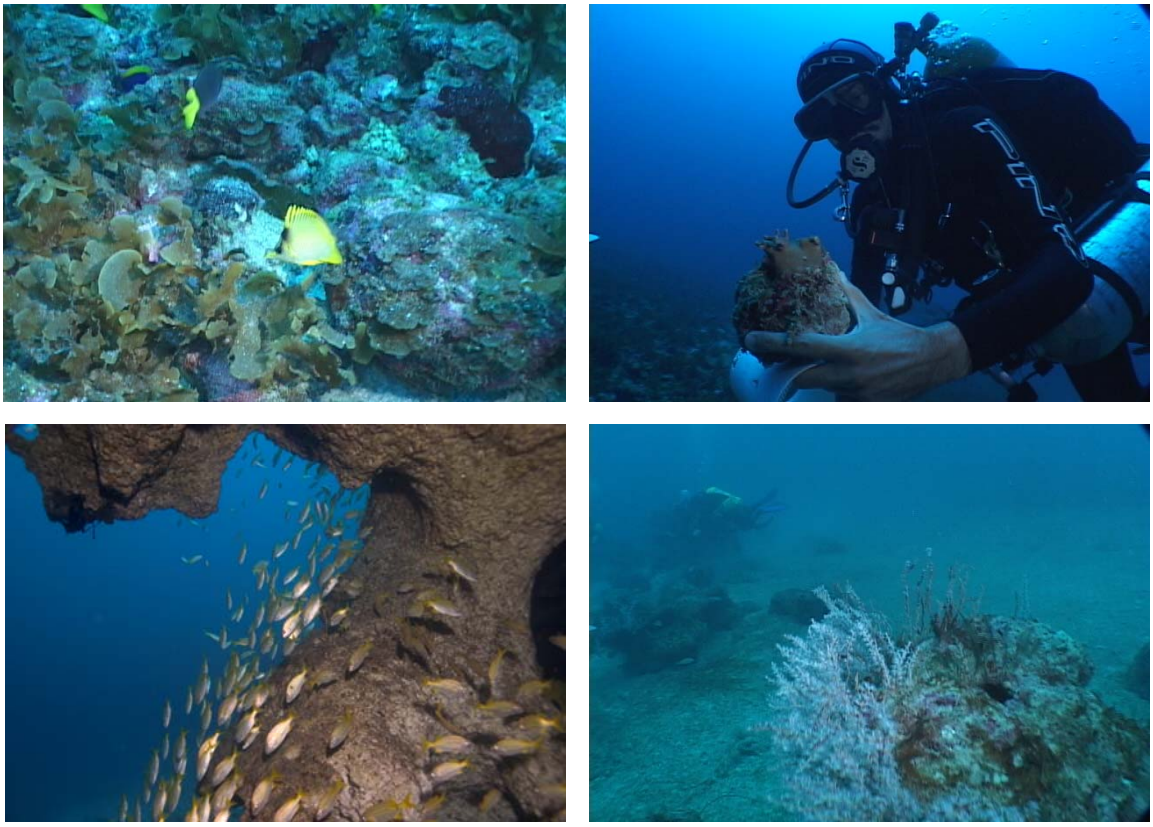

Figure 34. Abrolhos uncharted deep reefs with unique biodiversity. On the **upper left**, a newly recorded butterflyfish in Abrolhos, belonging to a brazilian-endemic species of genus *Prognathodes* (site A of Figure 24). On the **upper right**, the deepest record of a hidrocoral belonging to genus *Millepora*, at 63 meters (site A of Figure 24). On the **lower left**, unique deep reef formations and the Brazilian-endemic grunt *Haemulon squamipinna*, not protected by the Abrolhos MPA network due to its deep-dwelling habits (site B of Figure 24). On the **lower right**, uncharted reefs found from fishermen information (site C of Figure 24) (Photos by Fábio Borges Pereira ©).

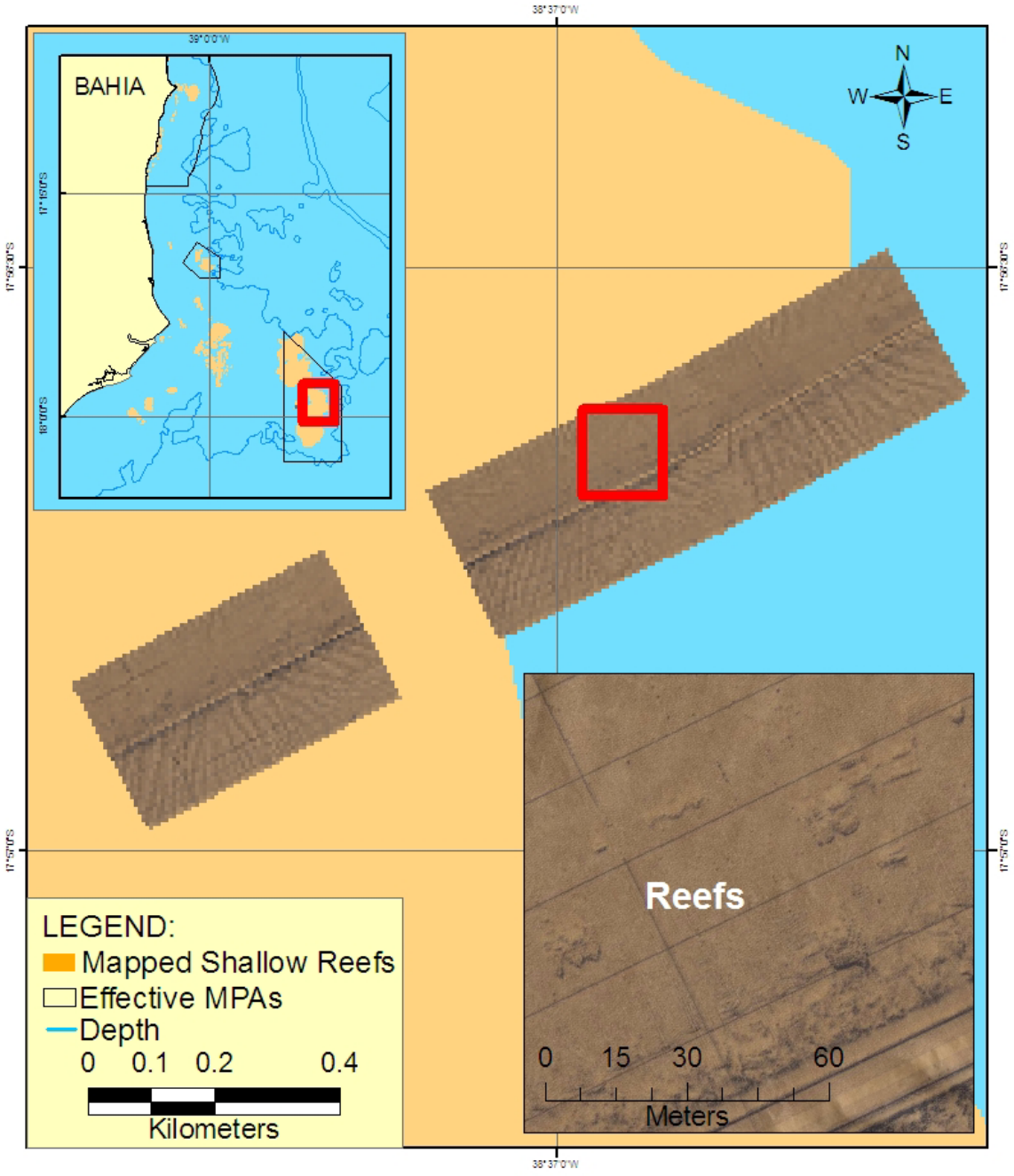

Figure 35. An example of the mapping outputs that are being generated with the sidescan sonar. Figure shows a series of uncharted deep reefs (coralline pinnacles) within the Abrolhos National Marine Park.

Sidescan mapping proofed to be a powerful tool to fill in the knowledge gaps on reef location, distribution, size, and general characteristics. Besides using the sidescan sonar to find the most promising deep diving spots (e.g., Figures 33 and 34), we mapped about 20 miles of uncharted reefs in Abrolhos. This extensive material is being processed in the GIS database of Conservation International, which is shared with the Brazilian Environmental Agency, IBAMA. An example of the mapping outputs that were generated is provided in Figure 35, showing a series of uncharted reefs within the Abrolhos National Marine Park.

***Lutjanus* sp. nov., a snapper new to science**

During our dives on the wreck in the Abrolhos National Park we observed one individual of an unusual snapper yet undescribed (Figure 36). Rodrigo Leão de Moura from Conservation International, and co-workers, are presently working on a scientific publication to describe this new species. Although snappers comprise some of the most important reef fishery resources in the tropical western Atlantic, this new finding makes clear that substantial geographic gaps exist in systematic and ecological information, especially for the least known areas such as the Brazilian coast. Significantly, this snew pecies is relatively common and was often misidentified as *L. griseus* or *L. apodus*. Twelve species of *Lutjanus* are now recognized in the western Atlantic, ten of which occur in Brazil (one endemic).

Figure 36. One of the most remarkable new findings during the Abrolhos´ surveys was the discovery of a large snapper species that is new to science (Photo by Rodrigo Moura ©).

The "buraca," a new type of reef formation in Abrolhos

The "buracas" are holes in the middle of a limestone flat at depths below 25 m (Figure 37). The holes may have more than 45 m depth, and about 100 m in diameter. These formations are found to the east of the National Park (Area B in Figure 33), and are yet undescribed in terms of location, distribution and geological origin. Beside sidescan sonar mapping we did detailed bathymetric surveys in these unique and newly discovered reef formations.

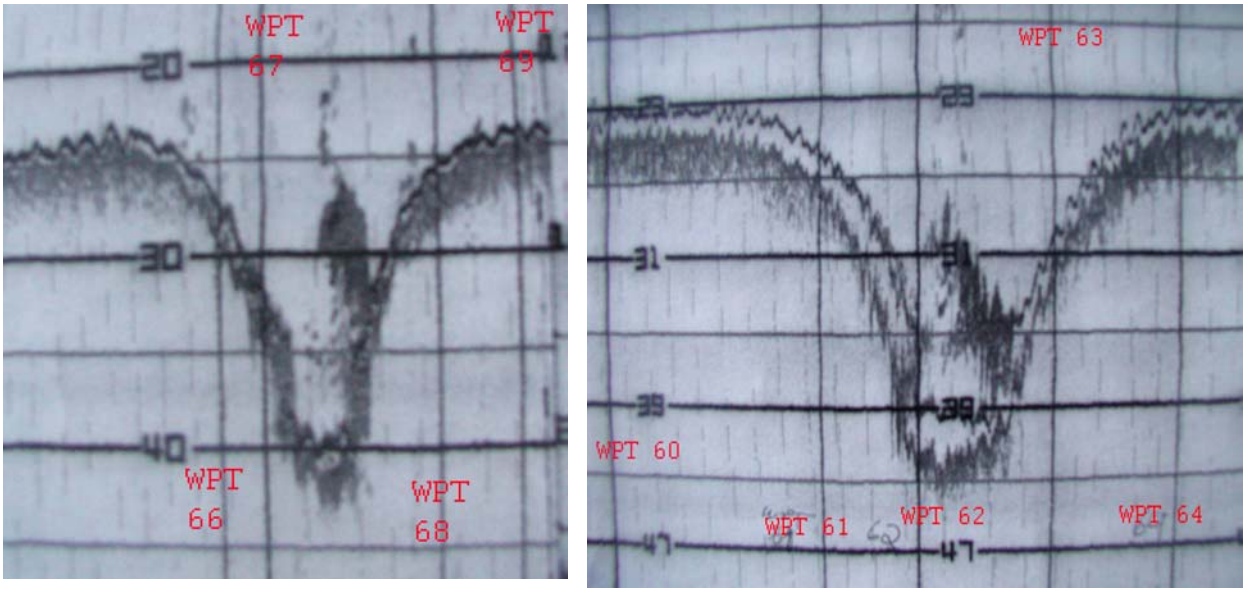

Figure 37. Detailed bathymetric survey of the unique and newly discovered reef formations (horizontal axis represents depths in meters). Notice the abrupt walls and large amounts of decomposing seaweed recorded by the echo-sounder.

The edges of the "buracas" are abrupt and covered by fleshy brown algae (Figure 38). The bottoms of the "buracas" harbor apparently hypoxic sediment, and are covered by a thick layer of decomposing seaweed. Fishes are abundant around and over the buracas. On the edges, the grunt *Haemulon squamipinna* forms large schools of thousands of individuals; other reef species such as the porkfish *Anisotremus virginicus*, are also abundant along the edges of the "buracas." We also observed schools of barracudas

Sphyraena guachancho (up to 200 individuals) and ladyfish *Elops saurus* hovering several meters over the holes. Although the "buracas" are yet uncharted and unknown to scientists, we found a handful of boats fishing in the area. We interviewed one boat captain, who appeared to have GPS positions for several "buracas."

Figure 38. The unique and newly discovered reef formations locally known as "buracas". Schools of *Haemulon squamipinna*, a Brazilian-endemic species that does not occur inside the Abrolhos MPAs but are abundant in deeper adjacent areas (upper left). Edges are abrupt (upper right) and covered by fleshy brown algae (lower left). Schools of commercially important fishes such as barracudas (lower right) are also abundant in these reefs (Photos by Fábio B. Pereira ©).

5. DISCUSSION

5.1. Are there spawning aggregations of reef fishes in the Abrolhos Bank?

We did not find spawning aggregations of reef fishes during this project, although we obtain evidence that there might be. There are several reasons why our efforts were not successful in this sense, but successful in other.

Traditional knowledge vs. ignorance

Biologists typically learn about the existence of spawning aggregations from fishermen who target them. In many cases, the elimination of spawning aggregations by fishing goes unnoticed by scientists and fisheries managers (e.g., Sala et al. 2004). Only in few occasions scientists find unfished aggregations. Fishermen of Caravelas and other smaller villages near the Abrolhos Bank do not have the traditional knowledge of older fishing cultures such as those in Polynesia, Micronesia, and the Caribbean (e.g., Johannes 1981). The information on the location and timing of spawning aggregations of commercial reef fishes obtained during the interviews with fishermen was ambiguous, and sometimes contradictory. This suggests that they do not know exactly about the existence, location and timing of fish spawning aggregations.

An example of this absence of basic knowledge of the natural history of the target species is the inability by the local shrimp fishermen to identify the species they target. The two main groups of shrimp targeted are pennaeids and carids. While carid females carry their eggs on the abdomen, penneid females do not. Fishermen believe that pennaeid shrimp are males (because they do not carry eggs), and that carids are the females of the same species. Moreover, they can distinguish only three out of a total of nine distinct species they catch. Needless to say, this has negative effects on the way landings are recorded, and on the management of the multispecies fishery. This “traditional ignorance” was a surprise to us, and calls for re-evaluation of the paradigm in conservation practice that management has to rely heavily in traditional ways.

Conservation status of commercial reef fishes

Fishing heavily targets all large reef fishes that aggregate to spawn. The Abrolhos Bank is no exception. Although presently protected by a specific law, due to its endangered species status, the jewfish *Epinephelus itajara* is still caught by traditional and artisanal fishermen in Abrolhos (Figure 25). The rainbow parrotfish, *Scarus guacamaia*, is ecologically, if not totally extinct, in Brazilian waters, as its last positive record substantiated with museum specimens tracks back to the nineteenth century. The cubera snapper *Lutjanus cyanopterus* and the tiger grouper *Mycteroperca tigris* are also very rare and cannot support specific fisheries. Only one species, the black grouper, *Mycteroperca bonaci*, is still common in the Abrolhos National Park, although it is depleted outside the park's boundaries. In the Caribbean, elimination of spawning aggregations of groupers has resulted in the collapse of fisheries and local ecological extinctions (Sadovy 1994). In the Abrolhos Bank we cannot determine whether this has been the case. In any way, reduced populations of reproductive adults because of fishing also imply reduced spawning.

Spawning season and weather conditions

As mentioned above, we were not able to identify the exact timing of reproduction of large reef fishes. In the Caribbean, the same species of groupers tend to spawn in the northern hemisphere winter (December – January), snappers in spring (April – May), and the jewfish in July - September (Sadovy et al. 1994, Sadovy and Eklund 1999, Lindeman et al. 2000, Garcia-Cagide et al. 2001). We would expect Brazilian fish to spawn in the equivalent southern hemisphere seasons. Therefore, groupers would spawn in June – July, snappers in October – November, and jewfish in January - March. Indeed, Teixeira et al. (2004) found that the black grouper appears to spawn between June and September.

Our field trip was planned for July 2004, assuming that groupers spawn in the southern hemisphere winter. Unfortunately, a big storm forced us to cancel the trip. We organized a second trip in November 2004, expecting to coincide with the snapper spawning season. The November diving surveys lasted only five days because another storm with strong winds and heavy rainfall hit the Abrolhos Bank. The Abrolhos shelf is

shallow, with a maximum depth of 40 m, and composed of sandy and muddy bottoms above which reefs grow. Sustained winds stir up the sediment and greatly reduce underwater visibility (down to a few meters). Our diving efforts were thus hampered by a combination of rough seas and reduced visibility.

Likelihood of spawning aggregations

Some fish species present in the Abrolhos Bank, such as the black grouper and the dog snapper, have a reproductive strategy that involves spawning aggregations. The information obtained in this project does not point to specific locations or times where they may occur. However, we may speculate where they are more likely to occur. In the Caribbean, most large groupers and snappers aggregate to spawn on fore reefs, typically between 25 and 40 m depth, and near reef drop-offs. The Abrolhos Bank is physically very different from typical Caribbean reefs. It is a shallow and wide (200 km) continental shelf (Figure 3), composed mostly of sandy and muddy bottoms from which reefs arise. Reefs around the Abrolhos archipelago are rocky, and occupy less than 0.5% of the total surface of the Bank. The rest of reefs are endemic coral reef, tower-like formations called *chapeiroes* (Leão 1982, 1986, Leão & Kikuchi 2001). These reefs generally have a cylindrical shape, with diameters ranging from 10 m to 50m, and heights up to 25m. Thus the coral reefs in Abrolhos do not have fore reef and drop-off, but are rather like huge patch reefs in the middle of a shallow soft-bottom shelf.

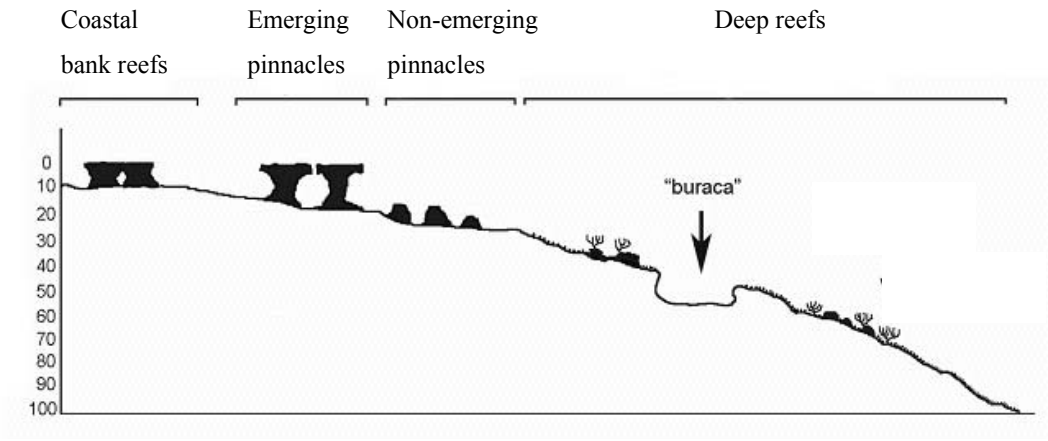

Figure 39. Major Abrolhos' reef types, including the poorly known deep reefs. Horizontal axis represents depth in meters.

The only drop-off occurs at the edge of the shelf, at depths between 60 and 70 m (Figures 3 and 39), but it is not associated with coral reefs. These unique topographic features may change the characteristics of spawning of these reef fishes. In any case, there are abundant pinnacles and channels, which also are preferred spawning sites for reef fishes (Colin et al. 2003).

Juveniles of the black grouper are abundant on all studied reefs. The nearest reefs with abundant populations of groupers outside the Abrolhos Bank are located several kilometers away, and their densities are much lower than those in Abrolhos (Francini-Filho unpubl. data). Because there is an increasing amount of evidence that shows that the dispersal of reef fish larvae occurs mostly at short spatial scales, we could thus assume that black grouper spawning occurs in the Abrolhos Bank and that there is a great deal of larval retention. Where in the Abrolhos bank would they spawn?

The greatest densities of adult groupers and snappers occur in the Abrolhos Marine National Park and in the deep reefs near Itacolomis. The rest of reefs, including those in the Timbebas Marine Protected Area, are depleted. Other species of groupers, such as the Nassau grouper, can swim distances of up to 200 km along continuous reefs in order to spawn (Bolden 2000), whereas they do not leave isolated atolls or swim over large distances over deep waters (Sala et al. unpubl. data). Black groupers could also swim great distances to aggregate to spawn in the Abrolhos Bank, because, although reef complexes are isolated, the maximum depth of the Bank is only 40 m. In any case, the Abrolhos National Park and the deep reefs appear to be the most likely spawning sites. At this point we can speculate that the above is true for other species whose abundance is much greater in the National Park and the deep reefs.

Unexpected new findings

Although we were not able to witness spawning aggregations of reef fishes, our surveys yielded several other exciting new findings, including a species of snapper new to science, a new type of reef formation, and uncharted deep reefs.

6. RECOMMENDATIONS

The main conclusion of this project is that, although we were not able to find spawning aggregations of reef fishes in the Abrolhos Bank, we found evidence that they exist and that they may be essential in replenishing reef fish populations in the region. Based on the information collected during this project, we intend to continue the search for spawning aggregations in the Abrolhos Bank in a more efficient way. The study of reef fish spawning aggregations typically starts with an ethnofishery work, as we intended in this project. However, because the Abrolhos fishermen have not developed a traditional knowledge on fish spawning aggregations, we will need to obtain additional sources of information. We thus recommend the following tasks as a follow-up of this project:

Completing landing surveys

It is essential to complete the landing surveys conducted so far, in order to obtain a comprehensive description of seasonal cycles of fish catches. Large reef fishes that aggregate to spawn usually do so during a specific season, encompassing from one to three months. Seasonal peaks in catches of commercial reef fishes typically coincide with spawning aggregations (Carter et al. 1994). Understanding when these peaks occur will allow us to narrow our search. In addition, the study of the gonads of landed fish will allow us to confirm when reproduction occurs.

Mapping the Abrolhos Bank

There is a need for mapping the reefs in the Abrolhos Bank. Reef fish aggregate to spawn at very specific locations. In the Caribbean, large groupers and snappers spawn on fore reefs at depths of between 25 and 40 m, generally on exposed reef elbows near drop offs (Colin 1992, Carter et al. 1994, Sala et al. 2001). A good map of reef topography, even at a coarse regional scale, can be very helpful for locating potential spawning sites. Although there are nautical charts with bathymetric data, and the Abrolhos reefs appear to be well known, we found that there exists a number of non-emergent uncharted reefs east of the large reef formations of Recife das Timbebas, Parcel das Paredes, and the Abrolhos

Archipelago. These reefs, although known by some fishermen, are poorly known by managers and scientists alike. We thus need to carry out a basic mapping of reefs on the eastern part of the Abrolhos Bank, in order to locate bathymetric features likely to harbor spawning aggregations. Moreover, this improved knowledge of the Abrolhos reefs will be critical for expanding the network of marine reserves in the region.

Continuing the search for spawning aggregations

All the above said, the Marine Program of Conservation International Brasil will continue this research project until spawning aggregations are located. Additional funding from British Petroleum's Conservation Awards program and other funds to be secured in the near future will be used for the mapping study (see above) and additional surveys during the spawning season.

7. CONSERVATION OUTCOMES AND FOLLOW UP: FROM SPAWNING AGGREGATIONS TO MARINE PROTECTED AREAS

The *Reef Fish Spawning Aggregations* project aimed to determine the location and characteristics of spawning aggregations of threatened and commercially important reef fishes, and helped local institutions to back-up proposals for the creation of additional protected areas and specific regulatory measures. This integrated initiative was highly successful in terms of conservation outcomes, contributing to management recommendations that were discussed and supported by the major local stakeholders, and already delivered to the Federal Environmental Agency. These recommendations included the establishment of Ecological Buffer Zones for the Corumbau Reserve and the Abrolhos National Park (Figure 40), including all deep reef formations (totaling 95,500 km^2); and a 350 km^2 multiple-use marine protected area (MPA), the Cassurubá Reserve, encompassing extensive mangrove forests and nearshore habitats that are critical to several threatened reef fishes (Figure 41). Both mangroves and deep reefs were not represented in the previous Abrolhos MPA network of Abrolhos Region.

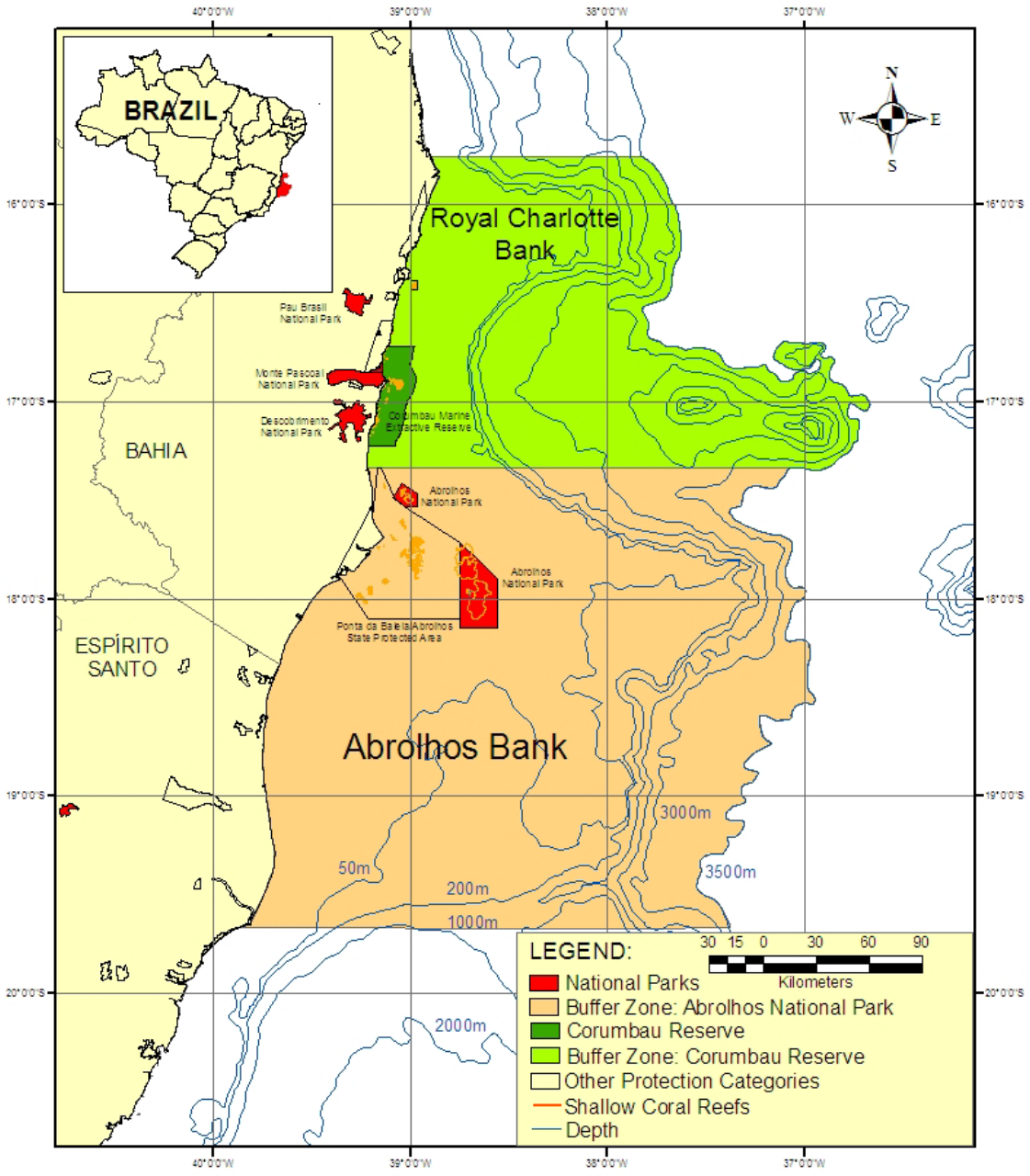

Figure 40. One of the major conservation outcomes produced by our project was the scientific backup to the proposal of Buffer Zones for the Corumbau Reserve and the Abrolhos National Park. Buffer Zones, once established, may work as multiple-use MPAs with Management Plans, with concrete opportunities to increase the number and size of no-take areas within the Abrolhos Bank. The Buffer Zone proposals are already discussed with all major stakeholders, who already sent it to the National Park Administration, Federal Environmental Agency (IBAMA).

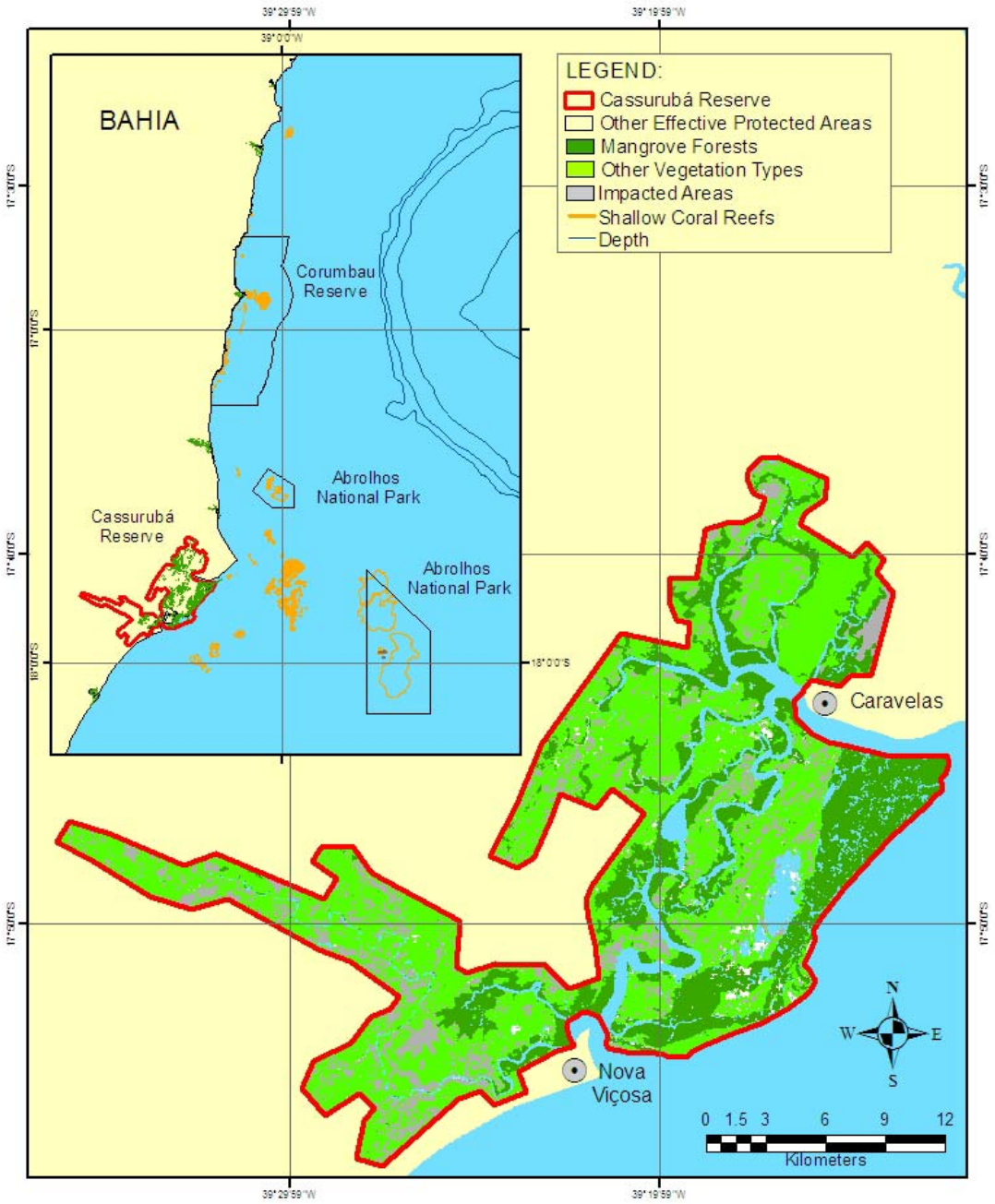

Figure 41. The other objective conservation outcome produced in the scope of the project was the scientific backup to the proposal of a new Marine Protected Area in the larger estuarine area within the Abrolhos Bank (see smaller map showing the other mangrooves/ estuaries), near Caravelas and Nova Viçosa. The new MPA will provide additional protection to critical nursery habitats of the species that aggregate to spawn in the reefs, increasing habitat connectivity. The Cassurubá Reserve proposal is already discussed with all major stakeholders, and is currently being supported by IBAMA's Projeto Manguezal (Mangroove's Project).

The previous surveys, supported by BP Conservation Programme, focusing on spawning aggregations and deep reef habitats, were key in providing useful data for the conservation of threatened species of fishes in the Abrolhos Bank. The aforementioned results play an important role in the interface between science and policy, and are instrumental for planning a marine protected area network in the Abrolhos Bank. The application of science to policy, alongside the work with local communities, have the potential to turn a follow-up initiative into a powerful conservation initiative.

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