Title
A Framework For Designing A Network Of Marine Protected Areas In The Abrolhos Bank, Brazil

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Publication Date
2005-06-01

A FRAMEWORK FOR DESIGNING A NETWORK OF MARINE PROTECTED AREAS IN THE ABROLHOS BANK, BRAZIL

by

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A capstone project submitted in partial fulfillment of the requirements for the degree of

Master of Advanced Studies in Marine Biodiversity and Conservation

University of California, San Diego
Scripps Institution of Oceanography

2005

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EXECUTIVE SUMMARY

A FRAMEWORK FOR DESIGNING A NETWORK OF MARINE PROTECTED AREAS IN THE ABROLHOS BANK, BRAZIL

By Fernanda Mazzillo

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The Abrolhos coral reefs are home to the most productive reef fisheries on the entire Brazilian coast and attract tourists each year with their natural beauty. Yet, Brazilians have failed to respect the intrinsic functionality of this unique coral reef ecosystem. The human demand for the unlimited production of goods is leading to the decline of the most diverse coral reef ecosystem in the South Atlantic Ocean.

A network of Marine Protected Areas (MPA) designed to maintain the resilience of this ecosystem is both an achievable and effective solution that

can reverse the decline of the Abrolhos coral reefs. The aim of this study is to identify gaps in knowledge of the Abrolhos coral reef ecosystem and provide a framework for the collection and analysis of data essential for the design of a network of MPAs in the Abrolhos Bank.

The first step towards the design of MPAs is the identification of potential threats. Unfortunately, MPAs cannot eliminate all threats to coral reefs; oil spills and terrestrial runoff will not respect MPA boundaries. Therefore, it is imperative to recognize all present threats so that the design of the MPA network is cost-effective.

The second step is to identify the factors or processes likely to maintain coral reef resilience. Species diversity is one of the most important factors that help an ecosystem maintain its resilience. The main functional groups in reefs are corals and reef fish. As such, a methodology to verify biodiversity patterns of corals and reef fish was designed so that areas with the most diversity of coral and reef fish are identified and included in the network.

Finally, size and distance between reserves must be calculated using dispersal distances of species as a proxy. However, dispersal distances are species-specific, and a model species must be chosen. Dispersal distances of the main coral reef building species *Mussismilia braziliensis* and vulnerable reef fish species will be used to determine size and distance between reserves.

This study also offers recommendations on how to measure the network's success once the sites are selected. The network's aim is to increase coral cover and reef fish biomass with the ultimate goal of increasing coral reef resilience. A baseline is needed to quantify the optimal coral cover and reef fish biomass in both coastal and offshore reefs of Abrolhos. Only a study of the historical ecology of the region will provide an appropriate baseline that indicates measurable goals for restoration and management of the Abrolhos reefs.

Vital to this study's success is a discussion of the obstacles to the implementation of the network of MPAs. Although the need and benefits of implementing a network of MPAs in the Abrolhos coral reef ecosystem may be clear to scientists and environmentalists, the idea of closing areas in the ocean and limiting economic activities does not sit well with many constituency groups. Therefore, the most effective way to phase in the MPA plan is by showing the economic value of coral reef functions and how much desired goods and services depend on the protection of such natural functionality.

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ACKNOWLEDGMENTS

The development of this project would not have been possible without the collaboration and support of my three advisors Dr. Nancy Knowlton, Dr. Enric Sala, and Dr. Jeff Vincent. Nancy's enthusiasm for the Brazilian culture surprised me and encouraged me to develop a conservation project in Brazil. She has been an extraordinarily amazing advisor and professor, teaching me not only sophisticated science, but also encouraging me to always stand up for my beliefs. Enric has also been a great advisor and professor who taught me how to develop this project, from the establishment of the partnership with Conservation International Brazil to the science that underpins the design of marine reserves and the details of the budget. Finally, Jeff Vincent assisted me with the socioeconomics and more practical issues of this project, completing the balance between science and socioeconomics needed for any conservation project.

Thank you to Rodrigo Leão de Moura and Guilherme Fraga Dutra from Conservation International Brazil, who hosted me in Caravelas and exposed me to the reality of Bahia and the difficult conditions of work in a developing, but naturally-rich country.

I would also like to thank my professors Dr. Jeremy Jackson, Dr. Dale Squires, Dr. Lisa Shaffer, Dr. Paul Dayton, Dr. Lisa Levin, and Dr. Heidi Gjertsen who taught me the most critical issues in marine ecology, economics, and policy over the past twelve months. I have learned so much from their incredible knowledge and experience; and I will pursue my conservationist career based on their examples. Dale Squires deserves special thanks for always being so patient and comprehensive in explaining economics to a biologist and Paul Dayton for inspiring me to always work in the field and as a real naturalist. Jeremy Jackson has also contributed remarkably to my education, teaching me the importance of historical ecology among other cutting edge topics in marine ecology and conservation; Lisa Shaffer opened my eyes to the policy issues regarding conservation of marine biodiversity and provided me with the invaluable opportunity to work with students from the UCSD departments of Economics and International Relations during her class. But most of all, I would like to thank this amazing multidisciplinary team of professors for accepting me into this program and giving me the chance to realize a life-long dream of mine. I am truly grateful and will go on in my career fully prepared to work relentlessly for the protection of marine biodiversity in any part of the world.

Furthermore, I cannot forget to thank my MAS colleagues Morgan Richie, Andy Balendy, Loraine Anglin, Greg Wells, and Amy Broulik for supporting me in the difficult times. These five lovely people have become my friends and family. I also want to thank David Kline and the PhD students Marah Newman and Gustavo Paredes for helping me develop critical parts of this study and the prospective MAS student Catalina for her help with the GIS software.

Moreover, my list of acknowledgements must include all the administrative support from Penny Dockry, Jane Weinzierl, Charleen Boyl, Amy Butros from Scripps library and Dulce Dorado from the International Students office.

Most importantly, I want to thank my parents who, although being thousands of miles away in Brazil, have supported me in pursuing my degree and who have never let me down in my entire life. Thank you to my boyfriend Gledson, my three brothers, Andre, Thiago and Felipe, and my grandmother Lucia for understanding that I needed to sacrifice our time together in Rio de Janeiro in order to complete this degree.

1. Introduction

The Abrolhos Bank harbors the most diverse coral reef community in the Southern Atlantic Ocean. However, the Abrolhos reefs are subject to intense human disturbances. Fishing, oil and gas exploration, dredging, and terrestrial runoff act synergistically in the trajectory of decline of corals reefs found in the Abrolhos Bank

The degradation of the Abrolhos reefs limits its functionality and, consequently, its provision of goods and services, potentially leading to drastic implications for the local communities. For example, healthy coral reefs function as a settlement habitat for many target species (Parenti, 1993; Roberts *et al.*, 2003). As such, the degradation of coral reef habitats is likely to decrease the abundance of target reef fish species (Jones *et al.,* 2004). This will reduce fishing catches and, thereby, negatively affect Abrolhos most important economic activity.

The most viable way to reverse the decline of the Abrolhos reefs and to guarantee its long-term persistence and the provision of goods and services is by enhancing coral reef resilience. Resilience of coral reef ecosystems corresponds to their ability to absorb shocks and regenerate after disturbances. Human impacts can alter such ability by removing species, functional groups of species, or even entire trophic levels. The loss of resilience will consequently impair the reefs ability to regenerate after natural or human impacts and, thus, will tend to move to an alternate state of equilibrium (Bellwood *et al*., 2004).

The phase shift from highly productive coral dominated ecosystems to less productive algae dominated systems is vastly documented in the Caribbean reefs and in the Great Barrier Reef (Hughes 1994, Knowlton, 2004). Certainly, the situation of the Abrolhos reefs is not different. Low productive algae dominated reefs have been documented and observed in Viçosa Reef and the fringing reefs of the Abrolhos Archipelago (Amado-filho, *et al.*, 1997; personal observation).

Closing areas in the ocean to human activities by establishing a network of Marine Protected Areas (MPAs) can help maintain coral reef resilience and avoid phase shifts. A network of MPAs designed specifically for the Abrolhos reefs with the goal of maintaining resilience is an effective conservation solution to reverse this trajectory of decline. However, MPA site selection must be based on knowledge of the local threats and ecological processes that support resilience of coral reef ecosystem.

This study identified the gaps in knowledge of the Abrolhos coral reef ecosystem and lays out a much needed framework for the analysis and collection of the data necessary for the design of an effective network of no-take MPAs in the Abrolhos Bank. This project will be implemented in collaboration with Conservation International Brazil (CI-Brazil) lasting for approximately eighteen months and requiring a multidisciplinary team. The results provided will be used in a follow up project that will select areas for the network of MPAs. Therefore, completion of this project is the first step required for the actual design of the network of MPAs in the Abrolhos Bank.

2. Project Objectives

i. Identify main human threats to the Abrolhos coral reef ecosystem
ii. Set specific conservation goals including the creation of the network of MPAs to protect resilience of the Abrolhos coral reef ecosystem
iii. Collect data to achieve conservation goals
iv. Use the results of this project to design a network of MPAs.

3. The Abrolhos Bank Study Area

3.1. The Abrolhos Bank Coral Reef Ecosystem

The northeast coast of Brazil is home to the only true coral reefs ecosystem known in the South Atlantic. Unlike the other coral provinces of the world, the Brazilian reefs exhibit a low diversity coral fauna rich in endemic species. Some of the Brazilian coral reef species have affinities with the modern Caribbean coral fauna, whereas, the endemic coral species are related to Tertiary coral fauna. The Brazilian endemic coral species may have been isolated from the Caribbean Sea by the Amazon River flow, after its reversal due to the elevation of the Andes (Kikuchi *et al.*, 2003).

Particularities of the Brazilian coral reef ecosystems are observed (i) regarding their initial growth form of mushroom shaped coral pinnacles, locally referred to as *chapeirões* (Figure 1), (ii) its remarkably adapted coral fauna able to survive surrounded by or even filled with muddy siliclastic sediments, and (iii) the significant contribution of encrusting coralline algae and zoanthids in the construction of the reef structure (Leão & Kikuchi, 2001).

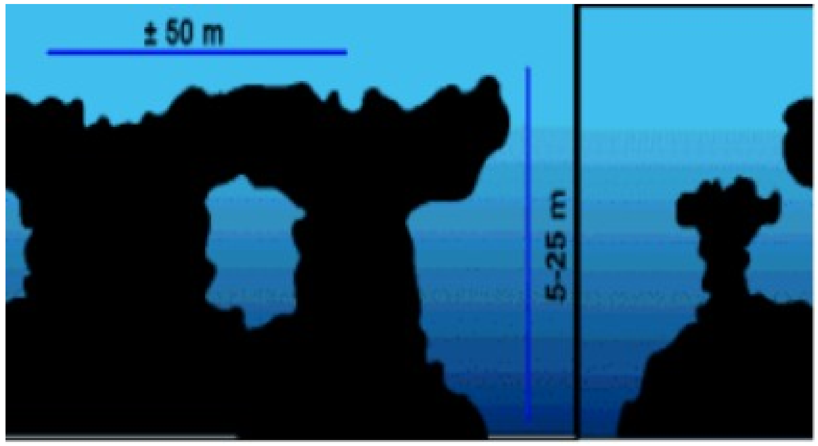

Figure 1: Illustration of mushroom growth form of *chapeirões* (Leão, 1999)

The Abrolhos Bank is located off the southeastern coast of the state of Bahia, where the generally narrow continental shelf stretches to 200km offshore. The bank is limited on the north by the *Jequitinhonha* River delta (15˚ 50'S) and on the south by the *Doce* River mouth (19˚40'S). The *Poço do Jurucussu canyon* divides the bank's northern portion, creating the Royal Charlotte Bank (Castro & Segal, 2001).

The Abrolhos Bank encompasses a mosaic of marine ecosystems (Werner *et al.*, 2000). Besides coral reefs, the bank is home to deep reefs, seagrasses beds, mangrove forests, and sparsely vegetated sandbanks, referred to as *restingas*. The study area for this project will include all these marine habitats found between 16˚ 47'S and 18˚ 09' S.

Seventeen of the eighteen species of Brazilian reef building corals are found in the Abrolhos reefs, representing the greatest biodiversity of coral reefs in the Southern Atlantic Ocean (Leão & Kikuchi, 2001). Forty-one percent of the coral reef species found in these reefs is endemic to Brazilian waters; and one coral species, *Mussismilia braziliensis,* is endemic to the state of Bahia (Table 1).

Table 1: Coral reef building species found in Abrolhos and its range of distribution

Scleractinian Corals	**Geographical Distribution**
Agaricia agaricites	Caribbean, Brazil
Agaricia fragilis	Caribbean, Brazil
Favia gravida	Brazil, Africa
Favia leptophylla	Brazil
Madracis decactis	Caribbean, Brazil, Africa
Meandrina braziliensis	Caribbean, Brazil
Montastrea cavernosa	Caribbean, Brazil
Mussismilia braziliensis	Bahia
Mussismilia harttii	Brazil
Mussismilia hispida	Brazil
Porites astreoides	Caribbean, Brazil, Africa
Porites branneri	Caribbean, Brazil
Scolymia wellsi	Caribbean, Brazil
Siderastrea stellata	Brazil
Hydrocorals	
Millepora alcicornis	Caribbean, Brazil, Africa
Millepora braziliensis	Brazil
Millepora nitida	Brazil

Natural disturbances in the Abrolhos reefs are only related to changes in sea level. The last regression of sea level off the Brazilian coast took place on the Holocene and affected the top of the coral reefs that were exposed to intense erosion and radiation (Leão *et al*., 2003). Small colonies of *Siderastrea stellata* and *Favia gravida* are the only species that survived these conditions. In addition, because of sea level regression the reefs moved closer to the coast and, thus, exposed to greater siliclastic sedimentation.

The Abrolhos coral reefs are presently found in a coastal and in an outer arc, which are separated by the Abrolhos channel (Leão *et al*., 2003). Large reef banks with irregular shapes and dimensions occur in the coastal arc, whereas the outer arc is composed of a set of isolated *chapeirões* and fringing reefs bordering the shores of the five islands that form the Abrolhos Archipelago.

The reefs found in the coastal arc of the Abrolhos Bank appear to be more vulnerable to sedimentation than offshore reefs. A strong permanent and tidal alongshore currents in the nearshore Sueste channel in addition to the topography of *Paredes* reef act as efficient hydrodynamic and geomorphologic barriers to the offshore transport of land-derived material (Leipe *et al*., 1999).

Deep reefs, locally referred to as *buracas*, occurring up to 65m depth, were recently discovered in the Abrolhos Bank (Francini-Filho *et al*., 2005). These reefs are not described in terms of location distribution and geological origin. However, they are known to harbor a diverse community (Francini-Filho *et al.*, 2005). Although the deep reefs are uncharted and unknown to scientists, fishermen were observed fishing in the area (Francini-Filho *et al.,* 2005).

3.2. Southern Bahia Socio Economic Environment

The southern coast of Bahia is locally known as the Discovery Coast since this is where the Portuguese first arrived in Brazil. The colonization of southern Bahia began in the 16th century and it was initially restricted to the coast; this gave rise to the municipalities of Alcobaça, Caravelas, Prado, and Nova Viçosa (Dias, 2001). During this period, the main economic activity was fishing and subsistence agriculture

The total population of these four municipalities is around 108,000 (IBGE, 2004). Approximately 20% of the Brazilians that live in these municipalities and its villages survive with zero or one minimal wage. They are very simple people living with poor health and educational services (Table 2). In addition, the Pataxó tribe inhabits villages of Barra Velha, Aguas Belas and Corumbauzinho of Prado Munincipality (Francini-Filho *et al.*, 2005).

Table 2: Social Welfare Indicators (PRODETUR NE II, 2003).

Municipalities	**Death Rate for Children (number of deaths/1000)**	**Low Income Indicator* (%)**	**Illiterate** (%)**
Alcobaça	60	24	30
Caravelas	60	21	31
Nova Vicosa	60	20	28
Prado	60	23	28
* Percentage of home family income between zero and one minimal wage			
** Illiterate people older than 15 years old			

Tourism and artisinal fishing are the primary sources of income for the communities living near the coastline. Land use focused mainly on timber harvesting and manioc flour production until the mid 20th century. Today main plantation crop is *Eucalyptus,* which is used for the paper and timber industries*;* secondary plantation crops include papaya, coconut, and sugar cane (PRODETUR NE II, 2003).

The establishment of highway BR-101 and development of the timber and paper industries have caused intense clear cutting of the Atlantic forest in the upstream watershed in the last 50 years (Figure 2). It is remarkable if one thinks about how much of an area formerly occupied by the Atlantic forest is now completely replaced mainly by *Eucalyptus* forests.

Figure 2: Rapid loss of Atlantic Forest cover in Southern Bahia in the last 50 years (Projeto Mata Atlântica, 1993)

There are only two National Parks *Monte Pascoal* (125 km^2) and *Descobrimento* (215km^2), protecting the Atlantic Forest. Although the Abrolhos coral fauna is known to be adapted to the influence of siliclastic sediments (Leão & Ginsburg, 1997), one might be shocked by the magnitude of the increased runoff in the last 50 years and how much the Abrolhos coral reef community has been altered since 1950s as a result of the absolute deforestation of the Atlantic forest.

3.3. Management History of the Abrolhos Reefs

MPAs are the major management tool used for protection of marine resources of the Abrolhos Bank. The creation of Abrolhos Marine National Park (AMNP) was proposed in 1969 (Joly *et al*., 1969). The selection of the region was based on its isolation from human threats, the rich fauna and flora, and the infrastructure already provided by the Navy on Santa Barbara Island. The goal was to protect the "diverse, rich marine life of the region for future marine studies" and stop coral harvesting and fishing. However, only in April 1983 was the park finally created. Due to logistical reasons, the area of the park was reduced from what was initially proposed (Figure 3) (IBAMA/FURNATURA, 1990).

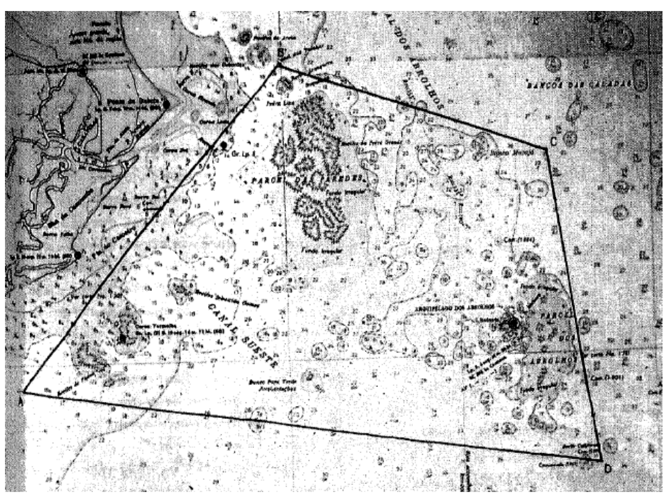

Figure 3: Initially proposed area for the Abrolhos Marine National Park (Joly *et al*., 1969)

According to Brazilian law, the AMNP is designated full protection, which means that only indirect resource uses are allowed. The park includes the *Timbebas* reef in the inner arc ($111km^2$), four islands of the archipelago (the fifth belongs to the navy) and *Parcel dos Abrolhos* ($771km^2$) (Figure 4).

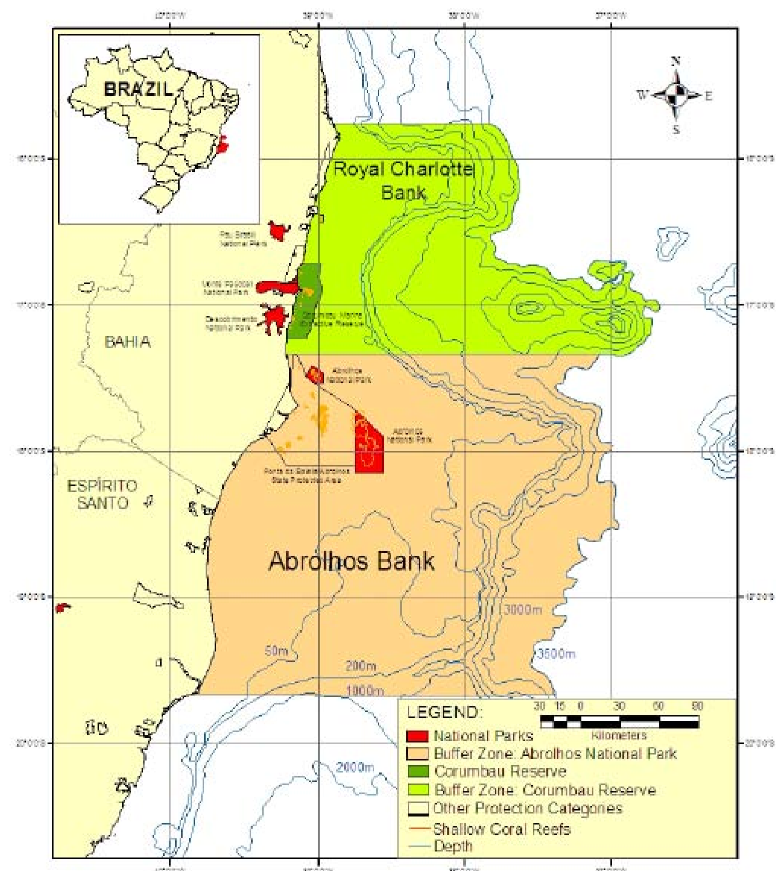

Figure 4: Location of National Parks, Corumbau Reserve, EPA, and buffer zone (Francini-Filho *et al.*, 2005).

The recent establishment of the Extractive Marine Reserve of Corumbau (RESEX -895km^2) in the Abrolhos Bank was a result of the local community initiative seeking to protect their fisheries (Figure 4). RESEX is under the category of sustainable use, meaning that extractive uses are permitted under strict regulations. No-take areas, gear restrictions, species and seasonal catch restrictions were accepted and implemented as management tools to ensure the sustainable use of marine resources.

The State Environmental Protection Area of Ponta da Baleia/Abrolhos (EPA- 3,460km^2) is the largest protected area encompassing all shallow reefs and estuary ecosystems (Figure 4). However, this reserve is a “paper park” since the government of the State of Bahia has not yet hired any staff or provided infrastructure to maintain the reserve.

Current management actions pending governmental approval are: the buffer zone (Figure 4) that would restrict oil drilling activities in the Abrolhos Bank, the Cassuruba Reserve protecting mangrove habitats and the estuarine river system near Caravelas River (Figure 5).

AMNP and RESEX only protect 5% of the shallow coral reef ecosystem. Habitats that contribute to the coral reef functionality such as mangroves and deep reefs are still unprotected. Moreover, the selection of sites for these two MPAs, the buffer zone, and the mangrove reserve was based on limited knowledge of the coral reef community dynamics. The long term persistence of the Abrolhos coral reef community will be compromised if no action is taken to improve the management of the region. Clearly, a network of MPA based on consistent scientific and socioeconomic information is needed.

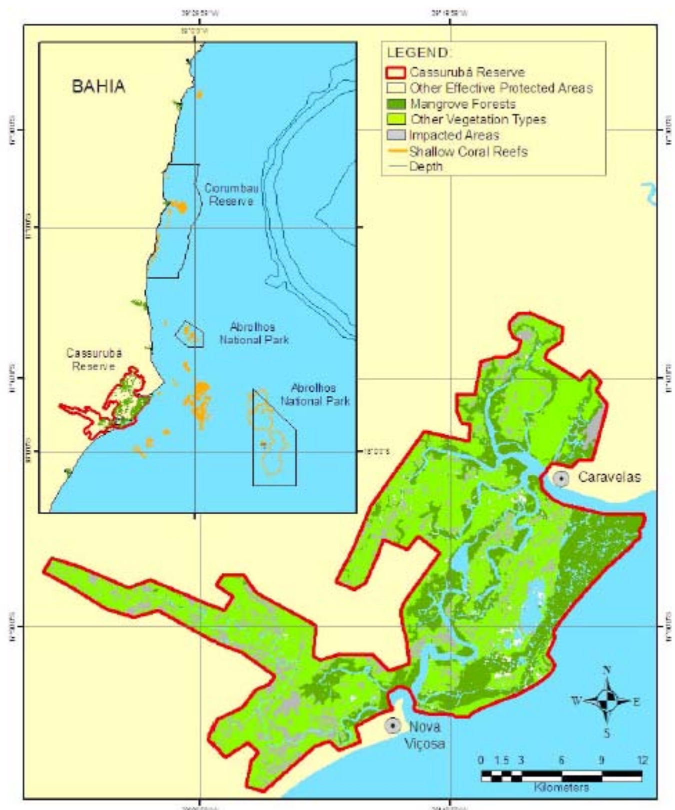

Figure 5: Proposed Cassuruba Reserve protecting estuarine habitats (Francini-Filho *et al.*, 2005).

4. Methods

4.1 Identification of Threats

The main threats in Abrolhos are fishing, exploitation of oil and natural gas, run off and dredging. Unfortunately, MPAs are not a universal remedy. While MPAs can address immediate threats (e.g. fishing), other threats such as oil spills, dredging or run off cannot be eliminated by implementing a network of MPAs. Thus, to design a cost-effective MPA network, areas of the bank with higher risks of being affected by threats beyond MPA protection will be identified and must be avoided in the future site selection.

To avoid the failure of the network due to oil spills, it is necessary to elaborate models of oil dispersion for the region. Fortunately, this has been done in a project developed between CI-Brazil, IBAMA, and the Federal University of Bahia. However, the model was elaborated based on limited knowledge of coastal oceanography. Furthermore, two more rounds have been performed since this project was concluded and new oil blocks have been sold. An update on the present oil blocks being explored will be performed and incorporated in the model. The scenarios for oil dispersion will illustrate areas with the highest or the lowest probability of being affected by an oil spill and, thus, aid in selecting the best areas for the network.

Knowledge of local oceanography is also essential to determine reef areas subject to intense runoff and impacts of dredging. Aerial or satellite images of river plumes during dry and rainy season can also help demonstrate direction of flow and reef being affected by sedimentation. In addition, monitoring of the dredging in Caravelas River estuary is presently being done as a legal requirement from IBAMA. The official information on the impacts of the biannual dredging will be obtained and compiled from IBAMA.

Regarding the fisheries, a strategy is proposed to characterize the impact of fishing in Abrolhos. First, it is necessary to select four main coastal fishing villages where significant landing occur. Second, fishermen will be interviewed about target species, main fishing grounds and fishing gear. Target species can also be identified and quantified through landing surveys in these four villages.

CI-Brazil has begun similar work in four villages where major landing occur: Corumbau, in Prado municipality; Alcobaça; Barra de Caravelas; and Ponta de Areia villages in Caravelas Municipality. Local fishermen were trained to collect data on target species. The results available from this survey describe only groupers and snappers as target species (Francini-Filho *et al*., 2005). All results from this work should be gathered in a database to facilitate analysis and identification of other target species. Moreover, the previous interview conducted with fishermen regarding fishing grounds were focused on the location of spawning aggregations. For the present study, it is relevant to interview fishermen regarding their main fishing grounds and fishing gear. Therefore, the questionnaire used for interviewing fishermen will be reviewed and adapted.

Once all target species are identified, these species will be prioritized for the identification of spawning aggregation sites and nursery habitats (see section 4.4). The selection of MPA sites must consider the spatial distribution of fishing grounds since its location will show which areas are worth being included in the network. Fishermen are the main players in Abrolhos coral reef ecosystem, and their support for the implementation of the network is crucial. Therefore, the design of the network will be balanced with their needs.

4.2. Spatial Characterization of Biodiversity and Ecological Processes

4.2.1. Identifying Areas with Highest Diversity of Scleractinian Corals and Reef Fish

There are two main functional taxa in coral reef ecosystems: corals and reef fishes. The functional contribution of coral species is in the accumulation of carbonate and provision of reef structure, while the functional contribution of reef fish is on energy flow.

Reef systems with greater numbers of species per functional groups are more resilient, since the loss of a species can be compensated by the presence of a species of that same functional group (Bellwood *et al.*, 2004). Thus, to protect processes that secure reef resilience, one strategy will be to identify and protect areas with high diversity of corals and reef fish species in Abrolhos' reefs. Furthermore, Abrolhos' reefs have only seventeen coral species, which are highly adapted to its environment (Leão & Kikuchi, 2001). Therefore, Abrolhos reefs may be functionally compromised and more vulnerable to phase shifts than Caribbean reefs, for example.

A snapshot of the spatial distribution of corals will be estimated by performing point intercept transects (PIT) using SCUBA dive gear to measure coral cover and species richness. PIT is the ideal method since the high turbid waters may hinder the use of video or photographs transects. Moreover, quadrates are not the best methodology to assess cover of the main reef building species *Mussismilia braziliensis* as it present large colonies projected well above the substrate (Segal & Castro, 2001).

The measure of coral cover will be expressed as a percentage and species will be categorized in taxonomic groups and identified to the species level when possible (a waterproof plate will be used for coral species). The transect length will be decided based on logistical reasons (one tank per dive) starting with a 40m transect. Minimal number of transect points (or length of intervals in transect) will be estimated by a species/point curve.

Four replicates of each PIT will be made in all coastal reef banks and offshore reefs. When a coastal reef bank is surrounded by pinnacles, two replicates will be done in each reef formation. Reef banks and pinnacles will be sampled at their top (2m) and walls (6m) (Figure 6).

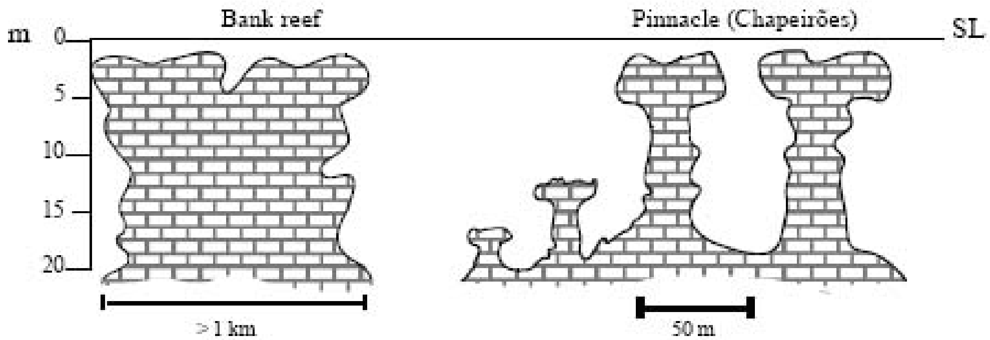

Figure 6: Cross section of reefs found in the Abrolhos Bank. Adapted from Leão *et al.*,(2003).

The precise location of the sites surveyed will be recorded with a GPS and in the regional nautical chart. The GPS location will help in the elaboration of a GIS database with accurate coral cover information.

Visual census to estimate biodiversity patterns of reef fish will be done in the same site of the PIT (visual census will be performed first). A 50 x 5m transect (n = 4) will be performed at 5m and 15m. Individuals will be counted and identified to species level when possible (small fishes may be underestimated in visual censuses). A list of dominant species found in Abrolhos will be taken together with a water proof plate to facilitate species identification. Photographs can be taken if species are not recognized immediately. For species where fish are numerous, abundance categories will be estimated

(English *et al.,* 2004). For each individual species identified, its total length will be visually estimated in order to calculate biomass using the parameters described in Braga *et al*., (2004)

4.2.2. Identification of Different Habitat Types and Benthic Cover in the Abrolhos Bank

Representation of habitats and habitat heterogeneity in MPAs has been suggested as criteria to capture biodiversity value when not enough data on species richness and/or spatial distribution exists (Sala *et al.* 2002; Stewart & Possinghan, 2002; Airame *et al.,* 2003; Roberts *et al.,* 2003). In Abrolhos, data on spatial distribution for most of the species is poor. Habitat representation is proposed to solve this problem and capture biodiversity value.

There are four distinguished types of reef structure in the Abrolhos Bank, which can be classified as main habitat types: the fringing reefs in the Archipelago, reef banks in the coastal arc; offshore pinnacles, and the newly discovered deep reefs. Other main habitat types include estuarine and terrestrial habitats: seagrass beds, mangrove forests, *restingas* (sparsely vegetated sandbanks) and sandy beaches (Creed & Amado-Filho, 1999; Werner *et al.,* 2000).

While shallow water habitats in Abrolhos are well documented, deeper waters (> 30m) are virtually unmapped. However, a current CI-Brazil project located deep calcareous reefs through sidescan sonar surveys and selected information from fisherman. These deep reefs occur up to 65m depth and are yet not described in terms of spatial distribution and geological origin. Deeper reefs are potential sites for spawning aggregations of vulnerable species and those identified so far are located outside the boundaries of present MPAs (Francini-Filho *et al.,* 2005).

Combining sidescan sonar survey of the seafloor with ground truth by scuba diving is the methodology being applied by CI-Brazil to map uncharted deeper reefs. The current effort to map those habitats is a fundamental part of the scientific information needed to select the MPA sites and will be continued.

Estuarine habitat such as the mangrove forests, the seagrass beds, the *restingas* and sandy beaches have also received less attention and are also outside the present MPA boundaries. Area occupied by these habitats will be estimated with satellite images and field surveys to ground truth image data.

Assessment of benthic coverage becomes fundamental to characterize the main habitats of the Abrolhos Bank on a finer scale. Detailed description of benthic cover and species composition is available in the literature regarding the fringing reefs in the Archipelago (Figure 7). This is probably a result of the infrastructure and calm waters in the Archipelago that allow for better field research conditions.

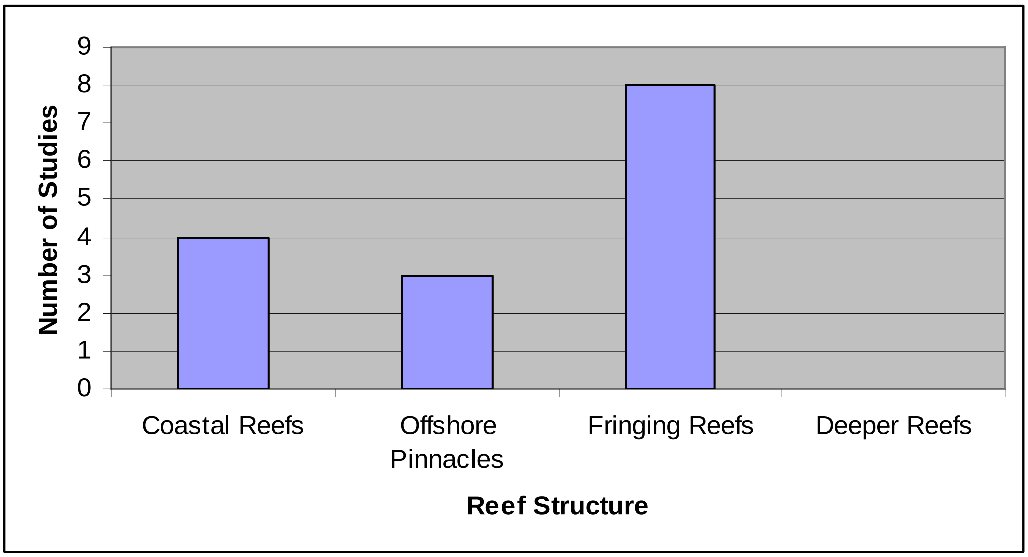

Figure 7: Number of published studies on benthic cover performed in the different reef structures in the Abrolhos Bank.

Coral zones, coralline algae beds, algal zones, and zoanthids zones, have been described as a possible depth zonnation for the fringing reefs of the

Archipelago (Pitombo *et al.,* 1988; Villaça & Pitombo, 1997; Figueredo, 1997). On the other hand, coastal reef banks, offshore pinnacles and deeper reefs are not described in terms of benthic cover. PIT surveys to estimate benthic cover in reefs situated in the coastal and outer arcs will be performed using the same methodology described for assessment of coral cover.

4.2.3. Identifying Spawning Aggregations and Nursery Habitats for Vulnerable Fish

The exchange of propagules (e.g. larvae, juveniles or adults) between reef areas helps maintain the resilience of the coral reef ecosystem by ensuring recolonization of disturbed areas. Thus, in theory, all sources of propagulos must be protected. However, identification of sources and sinks is extremely difficult and may delay reserve establishment since sources and sinks are species specific and subject to temporal variability (Roberts, 1997). In addition, an area that may be a source for one taxonomic group may be a sink for another (Hughes *et al*., 1999).

Nevertheless, spawning aggregations and nursery habitats of reef fish are recognizable sources that contribute to the viability of fish populations if protected (Carter & Perrine, 1994; Gregory, 1996; Roberts, 1997; Domeier &

Colin, 1997; Roberts, 1997; Sala *et al.*, 2003). Protection of sources of target species can also compensate for the loss of fishing area by displaying sustained net export of fish biomass (Sale *et al*., 2005). Therefore, it is urgent to have information about whether spawning aggregations of vulnerable reef fish species occurs in Abrolhos and where nursery habitats are located.

4.2.3.1. Spawning Aggregations

A spawning aggregation is described as an increase in the density of spawning fish greater than three fold (Domeier and Colin, 1997). Vulnerable reef fish species are considered as those targeted by Abrolhos' fishermen (Table 3).

Table 3: Abrolhos' vulnerable reef fish species (Ferreira & Gonçalves, 1999; Francini-Filho *et al*., 2005).

Abrolhos' Vulnerable Reef Fish Species
Snappers (Lutjanidae)
Lane snapper *(Lutjanus synagris)*
Dog snapper *(L. jocu)*
Mutton snapper *(L. analis)**
Cubera snapper (*L. cyanopterus)**
Yellow tail snapper *(Ocyurus chrysurus)*
Groupers (Serranidae)
Black grouper *(Mycteroperca bonaci)*
*Jewfish (Epinephelus itajara)**
Red grouper (*E. morio)*
Parrotfishes (Scaridae)
Green beaked parrotfish *(Scarus tripinosus)*
*Red-listed species

A study to identify spawning aggregations of groupers and snappers in Abrolhos is being currently performed (Francini-Filho *et al*., 2005). Yet, less attention is given to spawning aggregations of herbivores. Although not all herbivores are as vulnerable to fishing as groupers and snappers are, fishing down the food chain can eventually place them in the same vulnerable stage that groupers and snappers are today. For example, Ferreira & Gonçalves

(1999) observed that the green beak parrotfish (*Scarus tripinosus*) is the largest and most abundant herbivore in Abrolhos, and it has recently become a target species due to overfishing of larger carnivores.

Protecting sources of functionally important threatened herbivores is fundamental, because in the absence of herbivores, algae may over grow and eventually kill coral colonies and inhibit coral larvae settlement. As a result, the tri-dimensional structure provided by corals and used by target fish for settlement would be lost.

Previous studies in Abrolhos reefs have identified Scarids and Acanthurids as the main families of herbivore fishes for the region (Kikuchi *et al*., 2003; Ferreira *et al*., 2004). Two species of Acanthurids that occur in Abrolhos are known to form spawning aggregations in the Caribbean (*A. bahianus* and *A. coeruleus*). However, reproductive behavior of the endemic *Scarus tripinosus* and other endemic parrotfishes has not been documented.

Identification of spawning aggregations can demand a huge amount of time and effort (Colin & Clavijo, 1988; Sala *et al.* 2003). As such, before proposing the identification of spawning aggregations of Acanthurids and Scarids, it is reasonable to investigate which species within these two families are being targeted by Abrolhos' fishermen (see section 4.1).

Once target species are identified, information on spawning aggregations will be compiled by interviewing local fishermen (see Sala *et al*., 2003 for detailed methodology). However, fishermen in Abrolhos may provide conflicting information on the existence, location and timing of the spawning aggregations, possibly because the Abrolhos fishing community have not been involved in fishing for a long time (Francini-Filho *et al.*, 2005). To address this problem, studies that have documented spawning aggregations of the same species in other parts of the world may be useful as a back up information.

However, extensive scuba diving surveys on the expected time and sites where the aggregation may occur will still be necessary, especially for the endemic species. Another way to possibly tackle this problem is to analyze the gonads of fished herbivores.

4.2.3.2. Nursery Habitats

A nursery habitat can be characterized by; (i) being a location away from predation; (ii) presenting structural complexity that protects smaller organisms; and (iii) being rich in food supply based on plant detritus and associated microorganisms and small invertebrates (Ogden, 1996).

Visual census of juvenile fish will be done using 50 × 1 m line transects in all coastal and offshore reefs to identify fish nursery habitats. Many reef fish species rely on mangroves or seagrass beds as nursery habitats (Ogden, 1996; Sala *et al*., 2002), and some of them are known to increase their biomass when their reef population occurs next to a mangrove ecosystem (Mumby *et al*., 2004). Thus, assessment of juveniles of vulnerable species will also be performed in mangroves.

Mangrove forests on the Brazilian coast occur in the lower segments of rivers and red mangrove (*Rizophora mangle*) is the dominant species (Leão & Dominguez, 2000). Water turbidity may be high and visual census of juveniles may not be feasible in mangroves. A pilot study on the Corumbau River estuary for sampling juveniles in the mangrove will be performed to determine precisely where, when, and what to sample with.

Prior studies have shown that juveniles use different parts of the mangrove in different stages of life, exhibiting a migration pattern (Cocheret de la Morinie`re *et al*., 2002, Kiso & Mahyam, 2003). Therefore, prop roots of red mangrove (*Rizophora mangle*) found on mangrove fringes will be sampled in the mouth of the main river, along the main river, and in at least one upstream creek. Each of these sites will have three stations.

Sampling will be performed just after the expected spawning season of vulnerable reef fish and should be done during all tides of the day. Different gears will be tested (e.g. small seine, traps or scoop net), and three replicate samples with each gear in each site for each sampling period will be performed. The selection of gear and mesh size will be determined by the juvenile size, depth and logistics.

Species and size will be recorded for juvenile of vulnerable species in all stations. If species is not recognized in the field, one individual will be placed in a plastic container and preserved at the appropriate formalin percentage to be identified later. All the pilot sampling study will have its data carefully entered in a database so that capture efficiency of the each gear can be determined before sampling other four main mangrove estuaries in the Abrolhos bank.

4.2.4. Connectivity

The persistence of populations within the reserves will depend on the reserve size and distance apart, which in turn can be determined based on connectivity patterns. Connectivity is defined here as the rate of colonization of propagulos from local or distant sources. Therefore, knowledge of larvae dispersal distances for coral and reef fish can indicate size and the ideal minimal distance between no-take areas so that they are self-replenishing and connected.

However, dispersal distance is species specific and varies temporally and spatially (Sala *et al*., 2002; DiBacco *et al*., in press). Consequently, assuring connectivity for all species is virtually impossible. To address this problem, distances between reserves in Abrolhos will be estimated based on dispersal distances of model species: vulnerable reef fish and main coral reef building species.

The most practical way to estimate dispersal distance of larvae is by coupling information on life history traits of the model species with local oceanographic data. A review of the literature will be performed to determine life history traits of Abrolhos' vulnerable fish species and the main coral reef building species. The information on life history traits of these species will be coupled with data on local oceanography.

Mussismilia braziliensis is the major reef building species in Abrolhos reefs, and it is endemic to Bahia State (Laborel, 1970; Pitombo *et al.,* 1988; Villaça & Pitombo, 1997). The only information available about life history of *M. braziliensis* is that it is a hermaphroditic and possibly a broadcaster species with spawning periods between March and mid May (Pires *et al.,* 1999). In this case, because of the lack of published data, a review of the literature will probably not be enough. Laboratory experiments will be needed to verify pre-competency period and behavior characteristics (buoyancy, size of egg bundle, etc.).

As for the required oceanographic data, it is known that local near reef circulation is influenced by reef topography resulting in consistent hydrodynamic features (Willis & Oliver, 1990). For that reason, near shore circulation interactions with reef morphology and wind patterns are essential oceanographic information that would need to be gathered during spawning season with the assistance of an oceanographer.

5. Measures of Success of the Network of MPAs in the Abrolhos Bank

The results of this study will be used for the selection of sites of the network in a follow-up study. Recommendations on how to measure the network's success once the reserve sites are chosen are provided in this section. Success can be defined in this case as a resilient coral reef ecosystem. Resilience can only be measured by observing the rate of change when a disturbance occurs. Therefore, I suggest that managers look at coral cover and fish biomass. However, a baseline is needed to quantify the optimal coral cover and reef fish biomass to which the ecosystem must be restored to.

Recent observations of the Abrolhos coral reef ecosystem are unlikely to offer an accurate view of the natural state of those reefs and an accurate baseline. Instead, a reasonable baseline should refer to a period in time when the Abrolhos coral reef ecosystem had not yet suffered major structural changes due to anthropogenic stress. In Jackson et al., (2001) it is clear that archeological, historical, and ecological records powerfully reveal measurable goals for restoration and management of coral reefs and other coastal ecosystems. For example, ecological records from the scientific literature over the past century indicates that coral cover in Jamaican reefs was estimated to be 73%, while if observations were based in recent years, the coral cover of Jamaican reefs would be of 4%.

The fact is that humans have been changing the structure of coral reef ecosystem and what we see today does not correspond to a pristine system (Pandollfi, *et al.*, 2003). If we are to restore coral cover and fish biomass, we ought to know what were the levels of coral cover and fish biomass before intensive exploitation began, so that we do not fail to achieve success.

A good example for Abrolhos was that of a *Millepora* zone described by Laborel (1969) which was not found by Pitombo *et al.*, (1988). The three *Millepora* species that occur in Abrolhos were either absent or in low densities by the time Pitombo (*op.cit*) performed his study in the exact same sites.

It is a fact that fire corals have been subjected to intense souvenir and aquarium trade in Brazil (Leão, 1993), but fire corals are also very susceptible to bleaching. In Panama, two millepores were eliminated after the 1982/83 El Niño (Glynn & Weerdt, 1991). The cause of the elimination of the *Millepora* zone in Abrolhos is unclear, but the fact is that huge biomass of these species has been lost over the past century. Therefore, if we expect to achieve success, the proper coral cover for milleporids should be estimated by looking at historical reports, documents on coral trade, or ecological records from the scientific literature that describes the Abrolhos coral reef ecosystem in the past century to the present. If the rate of exploitation can be estimated from these sources, reasonable quantitative fire coral cover for which we need to restore the system back to can be defined.

Indeed, a historical ecology study of the Abrolhos' reefs would be very useful to estimate an appropriated baseline and also very interesting. Human exploitation of coastal reefs in southern Bahia started in the 16^{th} century. Historical villages in Bahia have monuments built entirely of coral building blocks (Leão, 1999; Leão *et al*., 2003). Coral blocks were also dynamited in the coastal reefs to make mortar (Joly *et al.,* 1969). Moreover, corals were harvested to supply the sugar refineries with lime (lime was used as a clarifying agent in the preparation of sugar cane syrup) (Leão *et al.,* 2003).

Nevertheless, the completion of a historical ecology study cannot hinder the creation of the MPA network. Meanwhile, change of coral cover and reef fish biomass inside and outside the reserve sites should be measured using the results gathered by this research as a baseline (see section 4.2). Statistical analysis will show progress and improvement of coral cover and fish biomass over the short term, but only a historical baseline will tell us if we achieve success.

6. Obstacles and Challenges for Implementing the MPA Network Plan

The long term benefits of a network of MPAs designed to protect coral reef resilience are not evident to fishermen in Abrolhos. As they need to survive, they need to fish. This is an immediate and concrete need. Therefore, the main challenge for implementing this plan is to prove that the network set up to protect the resilience of the coral reef ecosystem will in fact benefit the reef fisheries in the long term. Perhaps an education program will be needed, in order to help them understand some of the facts explained here.

Nevertheless, there are two potential ways to demonstrate the benefits of a MPA network designed to maintain resilience of the coral reef ecosystem. The first is to use the scientific argument that target fisheries species depend on the coral reef habitat to settle, forage, and shelter. Thus, reef fisheries can only be sustainable if coral reef habitats are protected; and the most reasonable way to guarantee the long-term persistence of coral reef habitats is to maintain their resilience. The second way to demonstrate the benefits of the proposed MPA is to assign a monetary value for the resilience of coral reef habitat function.

Fishermen or decision makers are concerned with economic losses. Consequently, the most efficient way to phase in this MPA plan is by assigning a monetary value to the coral reef habitat function or demonstrating the effectiveness of other MPAs that were set up to protect coral reef resilience.

According to Spurgeon (1992), ecosystems that support economic activities can be valued by using the percentage dependence technique. The biological support value will correspond to the value of the supported activity multiplied by an estimated percentage of dependence of that activity on the reef's presence. Hence, the value of the coral reef as a settlement habitat would correspond to the reef fisheries revenue multiplied by an estimated percentage of dependence of that fishery on the reef habitat. The percentage of dependence can be estimated by the number of juvenile target species found exclusively using the reefs as a settlement habitat. Identification of target species juveniles will be performed by visual census and can be used for this type of economic valuation (see section 4.2) and fisheries revenue can be obtained through CEPENE (Bahia Fisheries Institution).

7. Logistics

7.1. Primary Project Personnel

Team members will be experienced and advanced certified scuba divers well trained in the collection of scientific data. One experienced oceanographer with background in the Abrolhos Bank will complete the team.

7.2. Plan of Activities

The activities which will be performed for the completion of this project are divided into field, laboratory, and office research (Table 4). The Scripps Institution of Oceanography will provide office and laboratory infrastructure. IBAMA and CI-Brazil will provide field equipment, including boats, vehicles, and diving tanks. IBAMA's vessel 'Benedito' is fully equipped with radio, radar, global positioning system (GPS) and depth sounders, being regularly used in research activities. The team will be based in Caravelas with free lodging provided by IBAMA, in Prado, in the RESEX facilities, and CI field station in Corumbau.

Table 4: Plan of Activities

Plan of Activities	Required Time	Activities
Initial Office Research	4 months	Compile data of dredging from EIA Compile satellite or aerial images of mangrove area Review literature on spawning aggregation of herbivore target species Review literature on larvae dispersal distance of vulnerable reef fish species
Field Research		
Fisheries assessments	2 months	Compile data on target species previously collected by CI-Brazil Interview fishermen for fishing grounds and gear Interview fishermen for location of spawning aggregations
Scuba Diving Survey	4 months	PIT transects Visual census Juvenile visual census Locating spawning aggregations
Mangrove Survey	2 months	Ground truth mangrove area from satellite images Pilot study in Corumbau estuary
Oceanography Survey	3months	N/A
Laboratory Research	2 months	Analysis of life history traits regarding reproductive behavior of *M. braziliensis*
Final Office Research	2 months	Build database with results Estimate gear efficiency on mangrove sampling

7.3. Budget

The budget covers the salaries as well as the research expenses during the eighteen months duration of the project (Table 5). The project leader will be working full time in field, laboratory, and office research. One oceanographer will be hired to collect oceanographic data required for (i) the development of the oil dispersion model and (ii) the estimation of larvae dispersal distances. His/her payment will be equivalent to the University salary and commensurate to experience. Two dive buddies will help both in scuba diving and mangrove surveys and their payment will be equivalent to two minimum wages in Brazil.

Approximately, one hundred and sixty dives will be done to complete the PIT, the visual census survey, and the search for spawning aggregations. Two dives per day are expected to be accomplished during eighty days of late spring and early summer. The vessel cost is estimated according to the number of days it will be needed for scuba diving surveys and oceanographic survey. Land operations costs include transportation between local villages for fishery assessments and mangrove survey.

The project leader will be traveling from San Diego to Caravelas and travel expenses will be based on current airfare and bus fare rates. A laptop and a digital camera are already available for this project. The main equipment remaining to be acquired is the underwater housing for the digital camera, SCUBA diving equipment, a GPS, and the material for the mangrove survey.

Table 5: Budget covering salary and research expenses

Salary & Benefits	**Monthly**	**Total**
Project Leader (full time)	US$2,000	US$36,000
Oceanographer	US$1,000	US$3,000
Dive buddy 1	US$200	US$1,800
Dive buddy 2	US$200	US$1,800
Research Expenses		
Travel	Airfare and bus fare	US$2,000
Equipment	Underwater camera housing, scuba diving equipment, GPS, scoop net, beach seine, traps	US$4,500
Maritime Operations	Vessel operation and fuel	US$34,000
Land Operations	Fuel for car	US$1,000
Supplies	Underwater paper, paper, printing cartridges, batteries, mail	US$1,000
Total		**US$85,100**

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