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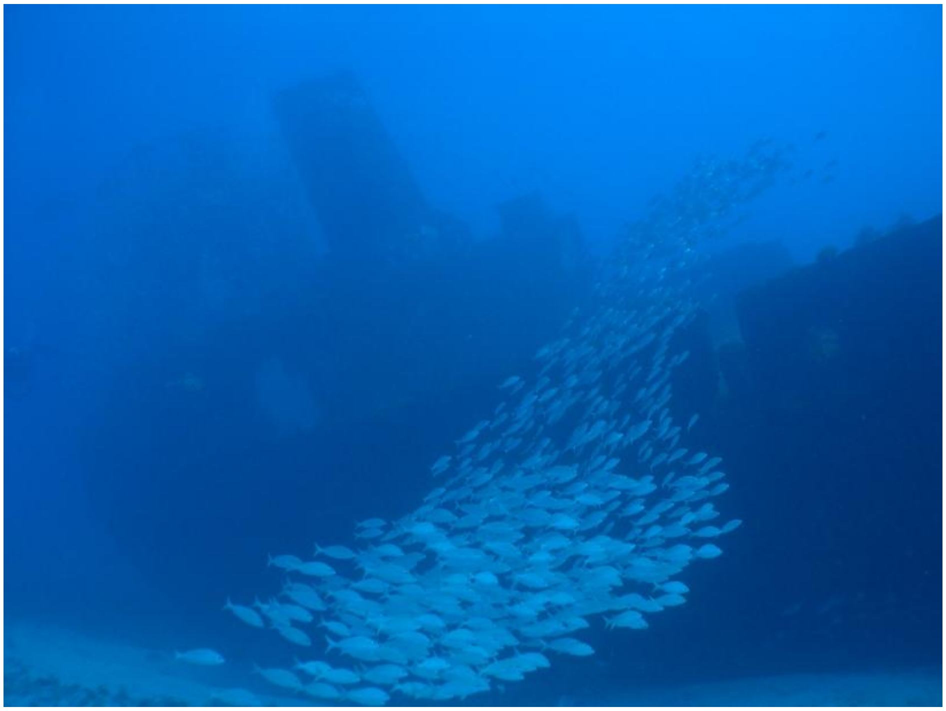
Biological Diversity and Community Structure of the Ichthyofauna on Vessel Reefs in the Coast of Recife (PE) - Brazil



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Dissertação para a obtenção do grau de
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Logic will get you from A to B.
Imagination will take you everywhere.

Albert Einstein

ABSTRACT

As a consequence of the degradation of coastal areas, the use of artificial reefs has become an important tool for the enhancement of habitats and biological resources. In the northeastern coast of Brazil, artificial reefs in the form of vessels have been deployed for recreational diving, with fishing activities being prohibited. The present study aimed at reporting the structure and changes in the fish community present in three recently deployed vessel reefs (Mercurius, Saveiros and Taurus) as well as the colonization process on the first two, including a comparison of these three reefs with other artificial and natural reefs, at shallow, intermediate and deeper areas, in the northeastern coast. For this purpose, monthly dives using visual census were made in all the three vessels, from July 2006 to July 2007. Species were categorized according to their trophic and spatial category and analyses were made regarding their frequency, abundance, diversity and similarity. A total of 87 species were identified in this study. The two structurally identical and deeper vessels, Mercurius and Saveiros, showed a greater resemblance in their community structures, regarding family composition, diversity indices and number of species and individuals, in each trophic guild, than with the shallower and smaller vessel, Taurus. Both the trophic and species composition of Mercurius and Saveiros became more similar over time through the colonization process. Although the three vessel reefs point to a possible stability of the fish community, Taurus presents more evidence of regulating interactions amongst species. A high similarity, >50%, was found amongst all reefs compared in this study. The results obtained showed that the vessel reefs have complete and complex fish communities. Because these artificial reefs are creating new habitats and communities, with local economic benefits, their use should be encouraged, with the employment of some reefs only for diving and others, in a future context, for artisanal fisheries management.

Keywords: Artificial Reef; vessel; ichthyofauna; community structure; colonization; northeastern Brazil; recreational diving.

RESUMO

A degradação dos ecossistemas costeiros por pressões antropogénicas tem tornado o uso de recifes artificiais numa ferramenta importante para o aumento de habitats marinhos e de recursos biológicos. No nordeste brasileiro os recifes artificiais, especialmente em forma de naufrágios, têm sido utilizados para o mergulho recreativo devido às boas condições de temperatura e visibilidade da área. Nesses locais, segundo uma lei estadual existente desde 2001, a actividade de pesca é completamente proibida. Os principais objectivos deste estudo são observar a estrutura da comunidade ictiofaunística, e suas possíveis mudanças, presente em três naufrágios afundados em Maio de 2006 (Mercurius, Saveiros e Taurus), bem como o processo de colonização, para os dois deles, e ainda comparar estes três recifes com outros recifes naturais e artificiais, a diferentes profundidades, na costa nordeste do Brasil. Com esse intuito, foram realizados mergulhos mensais utilizando censos visuais, de Julho de 2006 a Julho de 2007. Devido à estrutura complexa dos naufrágios e ao reduzido tempo de mergulho foi utilizada uma combinação de metodologias, incluindo transectos e busca intensiva, de forma a observar e contabilizar todas as espécies presentes nos mesmos. As espécies foram separadas em categorias com base no seu comportamento trófico (carnívoros, omnívoros, piscívoros, planctívoros, herbívoros territoriais, herbívoros móveis, predadores de invertebrados sésseis e predadores de invertebrados móveis) e espacial (tipo A - espécies que preferem o contacto físico com o recife; B - espécies que nadam à volta do recife, estando associados a este por visão e som; C - espécies que se mantêm na coluna de água; e D - espécies que utilizam a área ao redor dos recifes), analisando-se a sua frequência, abundância, diversidade e similaridade. Foi identificado um total de 87 espécies neste estudo, com 82 para o Mercurius, 68 para o Saveiros e 69 para o Taurus. Os dois naufrágios com características mais semelhantes em termos de tamanho e profundidade, o Mercurius e o Saveiros, apresentaram uma maior semelhança entre si relativamente à composição das famílias de peixes, índices biológicos e número de espécies e peixes encontrados em cada categoria trófica, do que em relação ao Taurus, naufrágio com um tamanho menor e situado a uma menor

profundidade. O Mercurius e o Saveiros também mostraram, através de uma ordenação MDS (MultiDimensional Scaling), que a sua composição específica e trófica se tornava cada vez mais semelhante ao longo do processo de colonização. Os valores mais elevados de diversidade biológica foram encontrados nestes dois naufrágios, com igual valor para a diversidade de Shannon (2.83) e reduzida diferença para a equitabilidade de Pielou (entre 0.83 e 0.82). O Taurus apresentou os menores valores para os índices biológicos, com uma diversidade de 2.61 e equitabilidade de 0.76. Estes valores, juntamente com a análise do log da abundância e percentagem de frequência, e do número de espécies e peixes observados ao longo dos mergulhos, mostram que apesar das comunidades já se apresentarem ricas e tenderem a uma estabilidade, o Taurus mostra evidências de processos mais intensos de interacção entre as espécies, encontrando-se a sua comunidade ictiofaunística ainda em estruturação. Para as análises da colonização foram também utilizadas categorias de distribuição espacial das espécies relativamente ao naufrágio, verficando-se diferenças no potencial de caracterização e evolução da comunidade entre as diversas categorias e especialmente em relação à presença ou não de mergulhadores, uma vez que um dos naufrágios comparados estava fechado para mergulho recreativo, servindo como controle. Foi encontrada uma forte semelhança (> 50%) entre todos os recifes comparados neste estudo pela análise de clusters, utilizando-se a lista de ausência/ presença das espécies. Com esses dados, foi feita uma Análise de Correspondência que separou os locais de acordo com a sua profundidade, agrupando os rasos num grupo, todos os intermédios, incluindo um natural, num segundo grupo e, por último, o recife profundo mais afastado. Ainda em relação às análises de cluster, observaram-se diferentes resultados de agregação entre os recifes consoante o tipo de dados utilizados (e. g. todas as famílias ou só aquelas que mostram certo grau de dependência do recife – Acanthuridae, Chaetodontidae, Labridae, Pomacanthidae, Pomacentridae e Scaridae), nas quais o recife intermédio natural se encontrava agrupado aos restantes recifes intermédios mas artificiais ou aos recifes naturais mas rasos. Os resultados obtidos neste estudo mostram que as comunidades presentes nos naufrágios são características

da costa nordeste do Brasil, tendo presentes todas as famílias mais encontradas em outros recifes costeiros. Nesta última comparação, as diferenças observadas relativamente aos índices de diversidade foram provavelmente influenciadas pelas características estruturais das áreas comparadas e pelas diferenças de metodologia utilizada (e.g. o uso de transecto *versus* censo estacionário, a utilização de ictiotóxico como óleo de cravo). Com a falta de estruturas ou relevos mais complexos na plataforma continental de Pernambuco, uma vez que esta é essencialmente plana com poucas irregularidades até aos 40-50 m, o afundamento de estruturas artificiais funciona como um oásis, para o qual são atraídos peixes de áreas adjacentes. Foi observado um aumento no número de espécies do local para mais 20 espécies em menos de três meses. Pelas análises realizadas com a ausência/presença de espécies foi possível obter um cenário temporal das alterações inerentes ao desenvolvimento das comunidades de peixes recifais, atribuindo uma maior importância à ecologia das espécies do que à dinâmica da comunidade como um todo. Como consequência das limitações intrínsecas à comparação de diferentes recifes neste trabalho, resultantes da escassez de bibliografia e utilização de recifes artificiais no nordeste brasileiro, foi impossível distiguir o verdadeiro factor limitante para a distribuição de algumas espécies, i.e., a profundidade ou o tipo de recife. No entanto, apesar da importância atribuída à configuração de um recife na estruturação da sua comunidade ictiofaunística, este estudo sugere a profundidade como um factor chave neste processo, pois as comunidades observadas nos recifes intermédios mostraram-se mais semelhantes entre si independentemente da localização geográfica e do tipo de recife. Uma vez que os naufrágios criaram novos habitats e comunidades de organismos, trazendo benefícios ecológicos e económicos locais, o seu uso na costa pernambucana deverá ser encorajado tanto para a criação de locais de mergulho como, num futuro próximo, para a gestão de pescas artesanais.

Palavras-chave: Recifes artificiais; naufrágio; ictiofauna; estrutura da comunidade; colonização; nordeste do Brasil; mergulho recreativo.

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INTRODUCTION

BACKGROUND

All the oceans of the world are now affected by human activities which cause severe and widespread ecosystem degradation (Scholes *et al*., 2005). Coastal systems are among the most productive and the most highly threatened in the world. With nearly 40% of the world population living within 100 kilometers of the coast, these systems are experiencing exploitation pressures associated with population growth (Agardy & Alder, 2005). As a result, the demands on coastal areas for shipping, waste disposal, military and security uses, recreation, aquaculture, and even habitation, are increasing and often involve the destruction of coastal forests, wetlands, coral reefs and other related habitats (Agardy & Alder, 2005).

Coral reefs, in tropical coastal areas, are known for their high species diversity and endemism (Sale, 1991; Lowe-McConnell, 1999) and are valued for their provisioning, regulating and cultural services (McKinney, 1998). Reef ecosystems provide values such as tourism, recreation, scientific research and have also great importance at the educational, medicinal and pharmaceutical level (Ahmed *et al*., 2005). These goods and services are an important source of income for local populations, with coastal tourism and diving as the main income generating activities in some areas (Cesar & Chong, 2005).

One of the most dynamic elements of the coral reef ecosystem is the fish community. Its taxonomic richness, diversity in shape and habits, and behavioral and inter and intra relationships (Sale, 1991) make fish communities good indicators of the marine environment and a very interesting class to study.

As a consequence of the degradation of natural reefs, the use of artificial reefs has became an important tool for the enhancement of habitats by increasing natural production of biological resources (Bohnsack & Sutherland, 1985) in countries that rely on marine resources as an essential economic activity (Conceição, 2003).

Artificial Reefs

Artificial reefs – ARs – can be defined, according to the European Artificial Reef Research Network (EARRN), as “a submerged structure placed on the substratum (seabed) deliberately, to mimic some characteristics of a natural reef” (Jensen, 1998) and that “influence physical, biological, or socio-economic processes related to living marine resources” (Sutton & Bushnell, 2007). According to this definition, structures like piers and steel jackets of oil/gas production platforms can be considered as secondary artificial reefs (Pickering *et al.*, 1998). Other man-made structures also considered as artificial reefs are FADs – Fish Aggregating Devices – that have been extensively used, worldwide, to attract commercial and recreational pelagic fish species (Workman *et al.*, 1985). However, in this study, we will only consider bottom structures as artificial reefs.

Until recently, artificial habitats have been widely associated with the establishment of fishing grounds (Nakamura, 1985; Pickering *et al.*, 1998). However, the deployment of ARs now includes several new purposes, such as: ecosystem conservation and management, with the prevention of trawling in seagrass meadows (Relini & Relini, 1989) and mitigation of environmental impacts in seagrass beds (Sánchez-Jerez *et al.*, 2002; Pondella *et al.*, 2006), coral reefs (Abelson, 2006) and kelp forests (Deysher *et al.*, 2002; Reed *et al.*, 2006); aquaculture and marine ranching (James *et al.*, 2007; Relini *et al.*, 2007); biological enrichment of unproductive areas (Stephen & Lindquist, 1989; Walker *et al.*, 2002); and as a possible tool in the management and augmentation of the marine ornamental industry (Wilson *et al.*, 2001). Recreational activities such as SCUBA diving (Milon, 1989; Brock, 1994; Van Treeck & Schuhmacher, 1998; Stolk *et al.*, 2007), mostly in the United States and the Red Sea, and surfing (Burgess *et al.*, 2003), in Australia and New Zealand, are seen as potential circumstances for the use of ARs. These artificial reefs can even act like coastline protection and marine sanctuaries (Bortone *et al.*, 1994; Rousseau, 2006), in a similar way as natural reefs.

With so many different functionalities it is easy to foresee the importance of ARs and the reason why several groups and organizations linked to the use of structures have been funded. Among these are recreational and commercial fishing groups, recreational diving groups, governments (with both agencies for fisheries management and environmental protection), researchers, and community groups (Sutton & Bushnell, 2007). These stakeholders have been found to have a good perception of the benefits (social, economic and environmental) that can result from the deployment of an AR (Milon, 1989; Ramos *et al*., 2007). One frequently used argument for the creation of artificial reefs is the positive economic impact in the local communities, through the increase in tourism and recreational activities (e.g., Pendleton, 2005). These impacts can occur at different levels (local, regional and state) and can be measured in terms of employment, sales, income and tax revenue (Milon *et al*., 2000).

In some countries, artificial reefs have been used as important elements of integrated plans and are considered to be a good investment with long term economic and ecological returns (Santos, 1997). On the other hand, in other countries, especially developing ones, in spite of the prospect for good results in terms of environmental preservation, research and resource exploitation, and besides the great interest of their application for the resolution of coastal conflicts, the use of artificial reefs is still poorly understood as an efficient tool by governmental institutions responsible for the planning and management of natural marine resources (Alencar *et al*., 2003).

Artificial Reefs and Diversity

Artificial reefs provide appropriate substrata for a variety of epibenthic organisms including macroalgae, invertebrates and fishes. Because artificial surfaces create new habitats, which can differ from natural reefs in the same environmental conditions, it is important to carefully evaluate with extreme caution the negative and positive impacts of the modification on the identity and number of species within the considered area (Connell & Glasby, 1999). Thus, the understanding of the regulating mechanisms for the abundance and distribution of the organisms can influence the improvement of reef design, as to better mimic natural reef habitats, and if that is achieved, artificial reefs can help to maintain biodiversity patterns, both locally and regionally (Bulleri, 2005).

Several parameters have been found to influence the diversity of species and density of organisms in artificial reefs, such as reef design and complexity (Walsh, 1985; Brock & Norris, 1989; Hixon & Beets, 1989), size (Jessee *et al*., 1985; Anderson *et al*., 1989; Jordan *et al*., 2005), material (Bailey-Brock, 1989; Nelson *et al*., 1994) and surrounding substrate (Chandler *et al*., 1985; Coll *et al*., 1998), with some studies coming to different conclusions.

One of the main reasons for the deployment of artificial reefs is the assumed limitation of habitat, and its importance as shelter and food source for fish species, and this raises the main divergent point regarding the use of ARs, the 'Attraction versus Production' debate (Bohnsack, 1989). While the *attraction hypothesis* states that ARs simply redistribute fishes without augmenting production, and that the larger densities sometimes found in artificial reefs are the result of attraction to a new habitat, (Wilson *et al*., 2001), the *production hypothesis* relies on the assumption that artificial reefs can increase the carrying capacity in a saturated environment and, as a result, enhance the abundance of species (Bortone *et al*., 1994; Wilson *et al*., 2001). The effect that ARs will have in the dynamics of fish communities will depend on their degree of attraction as well as the strength of density dependence (Osenberg *et al*., 2002), with the most susceptible species to a possible biomass increase being the ones that present habitat-limited population control, reef dependency, demersal and territorial behavior (Bohnsack, 1989).

The use of Artificial Reefs

Just as reef applications vary, reef materials also differ between countries. The most used materials are concrete, followed by natural stone and rock, offshore platforms and FADs, tires, stabilized ash, plastic and even old structures like vessels and automobiles (Baine, 2001). However, the deliberate use of some of these materials, such as platforms, vessels and tires, is one of the most controversial aspects related to the creation of ARs (Baine & Side, 2003). In Europe and Japan, concrete is the preferred material, whilst in Australia, Jamaica and the Philippines, tires have been successfully used as artificial reefs (Pickering *et al*., 1998).

Regarding vessels, several countries are sinking decommissioned ships, as artificial reefs, for the enhancement of fisheries, sport angling, diving activities and eco-tourism (Jones & Welsford, 1997; Baine, 2001; Pendleton, 2005). Vessel-reefs have been subject to several studies, such as environmental and structural influences on biological communities (Chandler *et al.,* 1985; Sanders Jr. *et al*., 1985; Bayne & Szmant, 1989; Lindquist & Pietrafesa, 1989), fish assemblages (Stephan & Lindquist, 1989; Arena *et al*., 2007), social, economic and environmental benefits (Pendleton, 2005; Leeworthy *et al*., 2006) and even volunteer programs (Parnell, 2005; REEF, 2007).

In the Brazilian coast, several states have been deploying artificial reefs from the 90's on. Paraná is the state with the largest AR project with more than 2.000 concrete structures, including anti-trawling reefs and reefs for fisheries enhancement and conservation, followed by São Paulo with the initial deployment, in 1997, of 100 concrete structures and 30 made of steel, and a posterior enlargement of the project in 2000, with the immersion of another 160 structures, 100 made of concrete and 60 of steel (Alencar *et al*., 2003). The state of Rio de Janeiro, associated with the largest number of AR related scientific publications (e.g., Godoy *et al*., 2002; Zalmon *et al*., 2002; Brotto *et al*., 2007), has used several materials from tires to concrete structures, vessels and old oil tubes (Alencar *et al*., 2003). In the state of Ceará, a project to aid local fisheries and also avoid the proliferation of *dengue* by redistributing old tires, has installed more than 20.000 tires in 35 artificial reefs throughout the coast of the state (Conceição, 2003). Another use for artificial reefs in Brazil is recreational diving, with vessel reefs being deployed in states such as Espírito Santo and Pernambuco. In the former, only one vessel reef (Victory-8B) has been deployed, while in Pernambuco nine vessels have been purposefully sunk.

In Pernambuco, the first vessel deployed as an AR was Marte, in 1998, followed by Gonçalo Coelho, two years later. After that, in 2002, three vessels, Servemar X, Minuano and Lupus, were deployed off the coast off Recife, followed by Servemar I, in 2004 (Santos & Passavante, 2007). In 2006, three decommissioned ships were donated to the AEMPE (Associação de Empresas de Mergulho de Pernambuco), and were sunk in May, also in Recife's coast, with the purpose of creating the Parque de Naufrágios Artificiais de Pernambuco (PNAPE) – Pernambuco Artificial Wreck Park (Santos *et al*., 2008).

AIMS AND STRUCTURE OF THESIS

Few studies have been conducted on artificial reefs on the Brazilian coast, with even fewer on vessel-like structures, resulting mostly in congress abstracts (Silva *et al*, 2003; Miranda *et al*, 2004; Amaral *et al*., 2007). This study intends to increase the knowledge of fish communities and the biological and colonization processes on recently deployed vessel-reefs off Recife, in the northeastern tropical coast of Brazil.

Recife is the capital city of the state of Pernambuco and it is known as the Brazilian capital of shipwreck diving, with more than fifty shipwrecks along the coast. The warm temperature and high visibility of the water makes recreational diving an important source of income and promotion of Recife coastal habitats attributes. The diving facilities together with the existence of a state law 23.394/2001 (Pernambuco, 2001), which prohibits spear and hook and line fishing in the vicinity of the sunken vessels, make the coast of Recife an excellent location for the development of projects and studies on biodiversity, colonization, succession, productivity and other artificial reef related subjects.

A comprehensive study of the effects and benefits of an artificial reef is a long and complicated endeavor. It is a multidisciplinary work involving different areas of knowledge, from the habitat's abiotic and biological and ecological characteristics of the organisms linked to the reef, to the social and economic aspects of the deployment of an artificial reef.

The aim of this thesis is to quantify and evaluate the changes in the fish community that took place during the first year of the deployment of three derelict vessels in the coast of Recife (PE), Brazil, comparing it with similar natural and artificial reefs off the northeast coast of Brazil. The specific aims of this work were divided in three main chapters, structured as follows:

- Chapter 1 lists the fish species associated with three vessel reefs (Mercurius, Saveiros and Taurus) and aims to characterize and compare the ichthyofaunal communities present on these reefs through quantitative and qualitative analyses at frequency, trophic and spatial levels;
- Chapter 2 studies the ichthyofaunal colonization and succession of two similar vessels, Saveiros and Mercurius, with differential usage (i.e. open VS closed for recreational diving), by the use of trophic guilds and spatial distribution categories. An evaluation of the visual census methodology on different spatial categories is also done;
- Chapter 3 compares the community of reef fishes found in several different reefs (shallow, intermediate and deep; natural and artificial) and groups species according to their distribution pattern.

The final items of this thesis summarize the major points highlighted in the three chapters and discuss the performance of the recently deployed vessel reefs as *true* reefs, at an ecological and trophic level.

CONTEXT OF THE STUDY

This study was part of a project called PNAPE – Pernambuco Artificial Wreck Park, in which three decommissioned tug boats (Mercurius, Saveiros e Taurus) were sunk for commercial and scientific purposes. The project was a cooperation between the State Association of Dive Companies and two federal universities in the state of Pernambuco (Universidade Federal Rural de Pernambuco – UFRPE, and Universidade Federal de Pernambuco – UFPE). The main objectives were to have an opportunity to study the colonization process of these recently deployed structures since the very beginning, while simoultaneously promoting the diving tourism industry in Pernambuco, by creating new diving alternatives (Santos *et al.*, 2008).

The project was a multidisciplinary research that included the study of physical (currents), chemical (hydrology), geological (morphology and sediments), and biological (colonization and succession of benthos and ichthyofauna) characteristics related to the vessel reefs. The logistic was made possible due to the support of dive companies, in particular Aquáticos which made all the arrangements for the monthly monitoring of the three vessels during the two years of the project.

The data for this study was collected during the first year after the deployment of Mercurius, Saveiros and Taurus, by a scientific group of post and undergraduate students, from two laboratories in the aforementioned universities (LOP – Laboratório de Oceanografia Pesqueira in UFRPE, and IMAT – Grupo de Ictiologia Marinha Tropical in UFPE), aiming at the study of reef fish communities and their interactions in the vessel reefs.

STUDY AREA

This study was carried out on the coast of Recife (PE) in northeastern Brazil (Fig. 1). The three vessel reefs sampled were Taurus, Mercurius and Saveiros which are located at a distance of about 6, for the first, and 7 nautical miles from the port of Recife. Taurus (08°04,193’S and 034°45,196’W) is the closest from shore, being located at a depth of 25 m, whilst Saveiros (08°04,517'S and 034°44,327'W) and Mercurius (08°04,725'S and 034°44,022'W) are near the 30 m isobath, being 700 m distant from each other. The two deeper vessels are very similar with a total length of 29 m and with a vertical relief of about 10 m, with Saveiros open for recreational diving and Mercurius closed for any activity other than research dives. Taurus is smaller, with only 26 m total length and a vertical relief of about 8 m, which is related to its inclined bow at an angle of 25º, rather than its real height (Fig. 2).

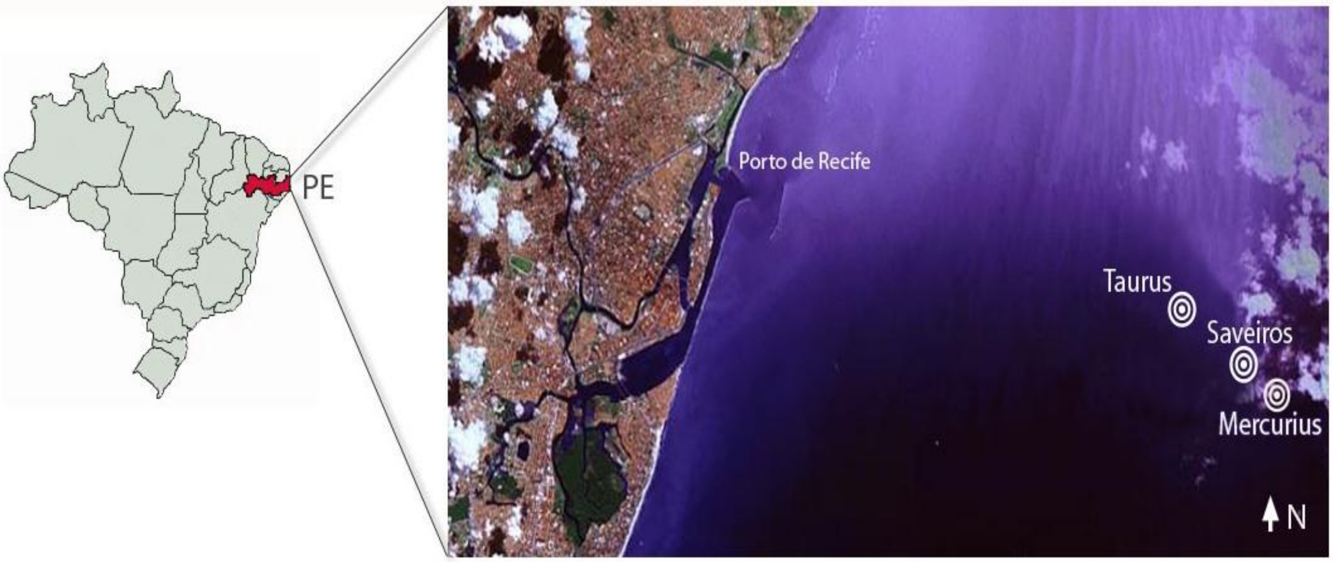

Figure 1. Map of the study area and location of the vessel reefs Taurus, Mercurius and Saveiros.

The continental shelf of Pernambuco has a reduced width of about 35 km and a relatively shallow depth, and is largely flat, from the shore to the continental slope, which begins at 50 or 60 m (Manso *et al.*, 2003).

The northeastern continental shelf presents three distinct regions: a) the internal shelf (0 to 20 m), with soft slopes and regular terrain, mainly constituted by quartz sand; b) the medium shelf (20 to 40 m), with some irregularities in relief and a predominance of sand and gravel with a high percentage of calcium carbonate (>90%); and c) the external shelf (from 40 m on) with irregular terrain and predominance of gravel and biodetritic sand and muds, with a large abundance of *Halimedas* sp. and an amount of calcium carbonate superior to 75% (Cunha, 2004).

The constancy of the shelf and the influence of the South Equatorial Current contribute to the stability of environmental parameters such as salinity, temperature and water transparency, creating ideal conditions for the development of algae, especially *maerl* – red coralline algae (Mabesoone *et al*., 1972 *in* Cunha, 2004). Also associated with these carbonate rich sediments are large quantities of benthic foraminifera (Cunha, 2004) that contribute to the bioclastic portion of the substrate. These algae, which are one of the main components of the substrate, are usually from the genus *Lithothamnium* and the upper limit of their growth is related to the boundary of the terrigenous influence, at 20 m, while the lower is situated from 80 to 100 m deep. Green algae from the genus *Halimeda, Udotea* and *Penicillius* are also an important source for biogenic sediments of the continental shelf (Coutinho, 1976; Pereira *et al*., 2007).

SAMPLING METHODOLOGY

Due to the high visibility of the coastal waters of Recife, its reduced impact on the environment and its easy application, the visual census was chosen as the sampling methodology for the study of the ichthyofauna. The artificial reefs were monitored monthly with SCUBA equipment, from July 2006 to July 2007, with no dives occurring in June due to rough sea conditions. As the vessel reefs have a complex topographical relief and the dives are limited to 20 minutes, visual census were used with a combination of methodologies (Watson & Quinn II, 1997): transect (Brock, 1954; Buckley & Hueckel, 1989) and intensive search methods (Bortone & Bonhsack, 1991). According to Bortone *et al.* (1989), when there is a known area and a time limit to do a survey, it is advisable to sample the number of fishes by transect of a pre-determined length and width, counting every occurrence on both sides of the diver (Labrosse *et al*., 2002).

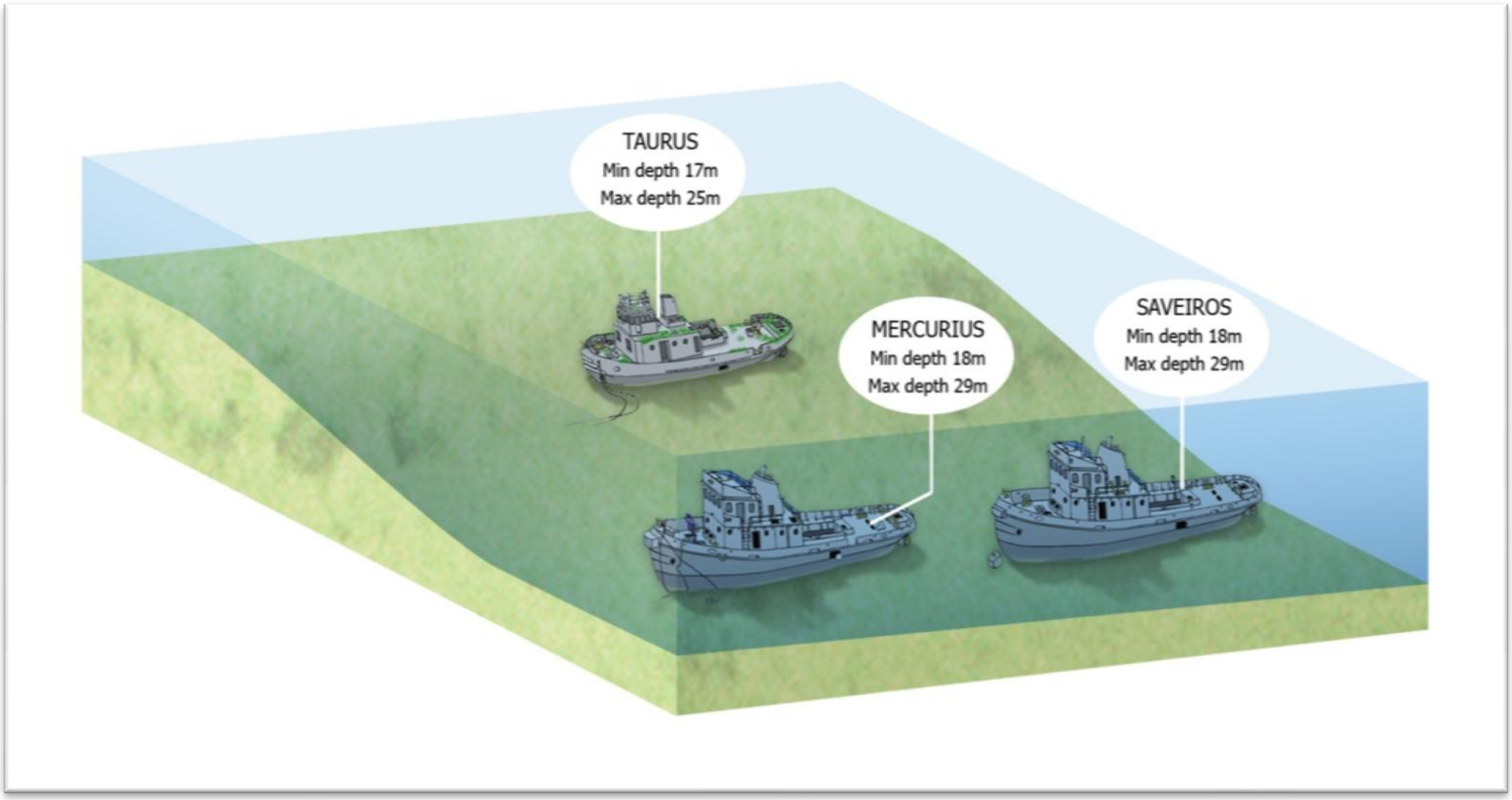

Figure 2. Configuration of the vessel reefs, Mercurius, Saveiros and Taurus with minimum and maximum depths.

Each sampling consisted of a team of four divers who performed the transect survey simultaneously, with two divers near the bottom and two at the height of the cabin, on the port and starboard sides, at a constant swimming speed. Every fish occurring in a 2 m distance on each side of the imaginary line was registered. The swimming velocity for the transect was slow, from 6 to 10m/min, and allowed sporadic stops to cautiously examine the area (Colvocoresses & Acosta, 2007). Upon finishing the transect, an intensive search was performed, in the cabin area, in an effort to minimize the underestimation of cryptic species, which is known to be a limitation of visual census methodology (Brock, 1982; Hobson, 1980; Kulbicki, 1990). This intensive search consisted in taking note of every species observed in the study area.

Fishes were identified to the species level, according to Carvalho-Filho (1999), Humann & DeLoach (2002), and also Fishbase (www.fishbase.org), with data on the abundance being also registered. Recent changes in the classification of the Serranidae, with the restoration of the Epinephelidae as a family, such as proposed by Craig & Hastings (2007), were adopted.

The data were thus collected through visual census, underwater photo and video and direct observations by the divers in 44 scuba dives, resulting in a sampling total time of 880 min (Table 1). During the dives, observations on behavior and photographic records for posterior confirmation of the identification of the species were made with the use of a Sony Cybershot DSC–W5 5.0 MP with MPK–WA housing. The vessels were sampled on a monthly basis, with the dives always taking place between 10 am and 3 pm, to maximize sunlight and visibility and to avoid the natural differences of fish activity between day and night (Gray *et al*., 1998; Nagelkerken *et al*., 2000a; Unsworth *et al*., 2007).

DATA ANALYSES

According to the different objectives of the study, the data were treated and analyzed using a variety of different techniques and softwares, as described in the following three chapters.

Table 1. Diving dates for the three vessels, with the corresponding total number of dives and sampling time in minutes.

Mercurius		
	Dive	Day
2006	1	6-Jul
	2	2-Aug
	3	23-Aug
	4	20-Sep
	5	4-Oct
	6	11-Oct
	7	6-Nov
	8	4-Dec
	9	18-Dec
2007	10	8-Jan
	11	23-Jan
	12	7-Feb
	13	27-Feb
	14	7-Mar
	15	24-May
	16	19-Jul
Total (dives/min)		**16/320**

Saveiros		
	Dive	Day
2006	1	6-Jul
	2	2-Aug
	3	23-Aug
	4	4-Sep
	5	20-Sep
	6	4-Oct
	7	11-Oct
	8	6-Nov
	9	21-Nov
	10	4-Dec
	11	18-Dec
2007	12	8-Jan
	13	7-Feb
	14	27-Feb
	15	28-Mar
	16	11-Apr
	17	17-May
Total (dives/min)		**17/340**

Taurus		
	Dive	Day
2006	1	4-Sep
	2	14-Nov
	3	21-Nov
	4	18-Dec
2007	5	23-Jan
	6	27-Feb
	7	28-Mar
	8	11-Apr
	9	17-May
	10	24-May
	11	19-Jul
Total (dives/min)		**11/220**

CHAPTER 1. COMMUNITY STRUCTURE ON VESSEL REEFS OFF THE COAST OF RECIFE (PE) - BRAZIL

INTRODUCTION

Nearly 40% of the known fish species occur in tropical waters, in association with coral reefs (Moyle & Cech, 1996), which are among the world's most complex marine ecosystems, offering endless ecological niches and containing the most colorful and diverse fish communities (Sale, 1991; Lowe-McConnell, 1999).

The centre of reef fish diversity in the Atlantic is the Caribbean (Floeter & Gasparini, 2000), with its richness decreasing from tropical to temperate latitudes (Ebeling & Hixon, 1991). The reef ichthyofauna of the southwestern Atlantic is one of the least known (Floeter & Gasparini, 2000) and only recent efforts have been undertaken to compile and describe the species and communities occurring in the Brazilian coast (Rocha *et al*., 1998; Floeter *et al*., 2003) and offshore reefs (Rosa & Moura, 1997; Feitoza *et al*., 2003). Together with those studies, several descriptions of new fish species, similar to the Atlantic congeners but endemic to the Brazilian coast, have been reported (Moura, 1995; Rocha & Rosa, 1999; Floeter & Gasparini, 2001; Moura *et al*., 2001; Moura & Lindeman, 2007).

Fishes are important elements in the reef environment, structuring communities through processes such as predation, competition and territoriality (Choat & Bellwood, 1991). As mentioned by Sale (1991), "coral reef fishes are an excellent system to work in" due to the mobility, accessibility and temporal and spatial scale of processes they undergo added to their diversity of forms, habits and relationships.

A *guild* is a group of species that exploit the same environmental resources in a similar way, and one advantage of the use of this concept is that it focuses on sympatric species that are involved in a competitive interaction, regardless of their taxonomic relationship (Root, 1967). Because the same guild, such as feeding groups, may be represented in several different communities, it can be very useful in the comparative study of different biotopes or communities (Root, 1967). Similarly to the use of guilds, the calculation of biological indices allows for the analysis and comparison, in a systematic way, of different communities, as well as for the evaluation of their evolution (Magurran, 2004).

To evaluate the reef fish community present in the three vessel reefs after a year of deployment, the fish assemblages structure was characterized using species abundance and frequency of occurrence, trophic guilds and biological indices (species diversity and evenness), and were compared amongst them, using other reef areas in the northeastern coast of Brazil as reference.

DATA ANALYSIS

Diversity Indices

According to Magurran (2005), community’s diversity should be divided in two main components: species richness (number of species) and the distribution of these species (relative abundance of each species). Therefore, in this study the following indices were calculated: Shannon-Wiener’s diversity (**H’**) and Pielou’s evenness (**J’**).

- Shannon-Wiener’s diversity index (**H’**)

This index (**H’**) is frequently used and its value is affected by the community’s specific richness and the distribution of the individuals among species (Krebs, 1999). It is calculated by the equation:

$$H' = -\sum_{i=1}^{S} pi \ln pi \,,$$

with *pi* as the proportion of individuals of species *i*.

- Pielou’s evenness (**J’**)

Evenness reflects the abundance distribution among every species of the community. Its value ranges from 0 to 1, resulting in lower values (approaching 0) if a species abundance is much higher than that of the others (Krebs, 1999). Its equation is:

$$J' = \frac{H'}{\ln(S)} \,,$$

where ***H’*** is Shannon’s diversity index and *S* the number of observed species.

For the estimation of the biological components, the number of fish in large schools of some frequently occurring species (e.g., *Haemulon aurolineatum*, *H. squamipinna*, *Pempheris schomburgkii*) or of species that occurred only occasionally but had a large schooling behavior (e. g. more than 200 individuals) were not recorded. This decision was based on the problems associated with sampling large schools due to their geometry, size and species composition (Bortone & Bohnsack, 1991).

Frequency and abundance

To describe and compare the community among sites, frequency of occurrence (f.o.) and relative abundance (r.a.) were also determined, using the following equations:

$$f.o. = \frac{T_i}{T_t} x\,100 \text{ and } r.a. = \frac{N_i}{N_t} x\,100 \text{, respectively,}$$

with T_i as the number of transects in which the species *i* was registered, T_t the total number of transects, N_i the number of individuals belonging to species *i* recorded for each vessel reef, and N_t the total number of individuals in that vessel. Species and families were analyzed based on pre-determined abundance classes (adapted from Feitoza, 2001) (Table 1-1).

Table 1-1. Frequency of occurrence and abundance classes used for Mercurius, Saveiros and Taurus.

Frequency of occurrence (f.o.)		Relative abundance (r.a.)	
Very common	f.o. > 80%	Very abundant	r.a. > 10%
Common	f.o. = 51-80%		
Occasional	f.o. = 21-50%	Abundant	r.a. = 2-10%
Uncommon	f.o. = 11-20%		
Rare	f.o. < 10%	Low abundance	r.a. < 2%

Trophic Guilds

Species were trophically classified, based on available literature (Randall, 1967; Cervigón *et al.*, 1993; Feitoza, 2001; Dominici-Arosemena & Wolff, 2005; Halpern & Floeter, 2008) and following Ferreira *et al.*, (2004), as: Carnivores (C), Mobile Invertebrate feeders (MI), Omnivores (O), Piscivores (P), Planktivores (PL), Roving Herbivores (RH), Sessile Invertebrate feeders (SI) and Territorial Herbivores (TH).

Analysis

For the analysis of the diversity indices (**H’** and **J’**) and comparison of the frequency classes and abundance of trophic guilds between vessels, the non parametric Kruskal-Wallis test was used, after a non normal distribution (Lilliefors test of normality; $p<0.05$) was found for both Taurus and Saveiros. For the comparisons of the diversity indices in each vessel reef throughout the study periods, a chi-square test was used. All tests had a 95% of Confidence Interval and were computed using BioEstat 3.0 software.

RESULTS

Structure of the fish community

In this study, 87 species belonging to 41 families and 64 genera (Appendix 1) were registered in 44 dives for the three vessel reefs. The most species-rich families in the vessel reefs (Figure 1-1, Appendix 1) were: Labridae, with seven to eight species; Epinephelidae, varying from three to five species; Haemulidae with five species in the three reefs; Lutjanidae with four to five species; and Pomacentridae, with five and three species. Carangidae and Scaridae were represented by a maximum of four species, while three species each were recorded for Acanthuridae, Pomacanthidae and Gobiidae. The other families registered in the study were only represented by one or two species.

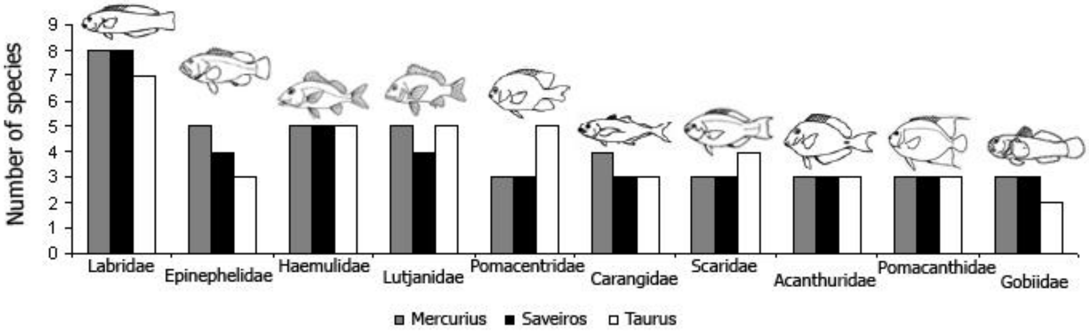

Figure 1-1. Number of species by family in each of the vessel reefs (Mercurius, Saveiros and Taurus).

Most families were represented by a larger number of species in Mercurius, with the exception of the pomacentrids and scarids, which showed higher numbers in Taurus (Fig. 1-1). Saveiros showed a family distribution close to Mercurius, except for Epinephelidae, Lutjanidae and Carangidae, that had a smaller number of species. In Taurus, the distribution of species was different, especially for the serranids, with only three species, and for pomacentrids and scarids, with the occurrence of five and four species, respectively, having thus a higher number of species than the other two vessel reefs. Haemulidae, Acanthuridae and Pomacanthidae were similar regarding the number of species in each reef, with five species for the first and three for the latter two. Gobiids were represented by two species in Taurus and by three species in Mercurius and Saveiros (Fig. 1-1).

Concerning the resemblance of species, 55 species (63.2%) were common to the three vessel reefs (Taurus, Mercurius and Saveiros), six species (6.9%) were only found in the deeper reefs (Mercurius and Saveiros) and 20 species (22.9%) were recorded in only one vessel. Three species (3.4%) were common to the Mercurius (deeper) and Taurus (shallower), and another three to Saveiros (deeper) and Taurus (shallower) (Fig. 1-2; Appendix 1).

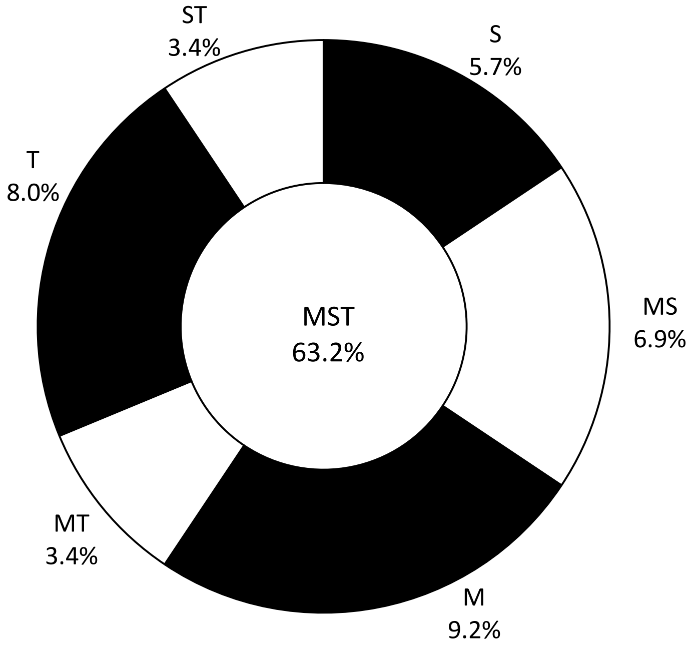

Figure 1-2. Percentage of species found among the vessel reefs Mercurius (M), Saveiros (S) and Taurus (T).

Regarding the diversity indices (Fig. 1-3), the mean value for **H'** was the same for Mercurius and Saveiros (2.83), with the latter having a little higher evenness, 0.83, than Mercurius (0.82). Taurus had a lower **H'** and **J'**, with 2.61 and 0.76, respectively. Using Kruskal-Wallis test, no significant difference was found for Shannon's diversity between vessels (H=4.24, p=0.12) but there was a significant difference for the evenness between the two deeper vessels and Taurus with H=11.66 and p<0.05.

No significant differences were found among the classes of frequency of occurrence among vessel reef (Table 1-2), with the exception of "very common species" between Mercurius and Saveiros and Mercurius and Taurus and of “common species” between Mercurius and Taurus.

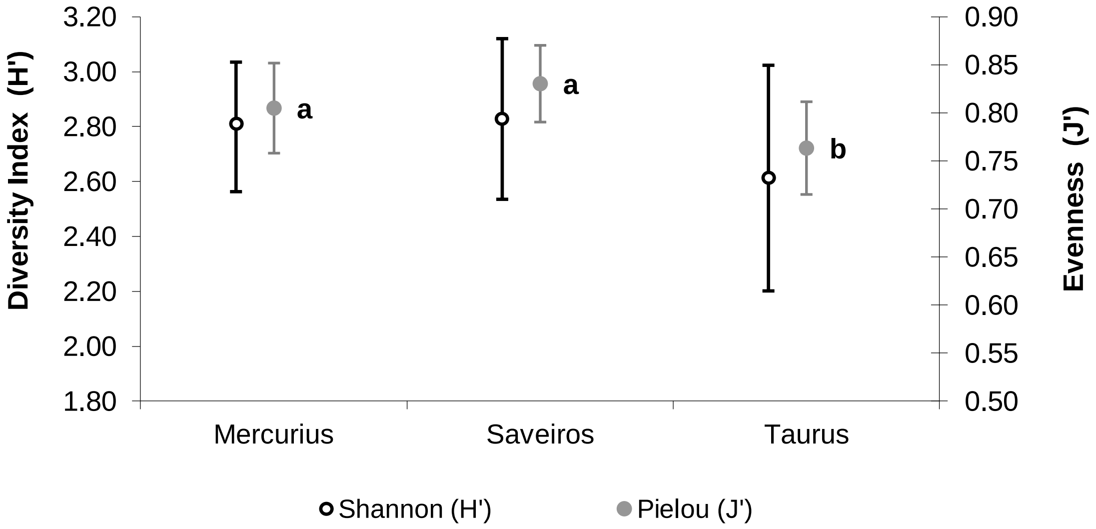

Figure 1-3. Mean values of Shannon’s diversity (H’) and Pielou’s evenness (J’) for Mercurius, Saveiros and Taurus. Different letters represent significant differences.

Table 1-2 - Kruskal-Wallis results for frequency of occurrence classes in Mercurius, Saveiros and Taurus, with test value, H, and p-value. * means significant difference.

		Very common	Common	Occasional	Uncommon	Rare
Mercurius/Saveiros	H	17.24	3.71	0.22	0.08	0.53
	p	**<0.05***	0.54	0.64	0.78	0.47
Mercurius/Taurus	H	15.26	6.97	0.33	0.55	0.23
	p	**<0.05***	**<0.05***	0.56	0.46	0.63
Saveiros/Taurus	H	2.57	1.10	0.61	0.16	0.08
	p	0.11	0.30	0.43	0.69	0.78

There was a linear decline in the ranked log abundances from the most common to the rarer species observed in the three vessels (Appendix 2). However, the pattern for the decline observed in frequency percentages did not show the expected shape (as shown in Appendix 3) with the frequency patterns being similar in the three vessel reefs, with only minor differences between the reefs (Fig. 1-4). Saveiros and Taurus had a similar pattern in the frequency of species, with occasional species (28 and 29%) followed by the very common (26 and 25%), the common and the rare species with the same percentage (17 and 19%) and the uncommon species as the least frequent class (12 and 7%, respectively) (Fig. 1-4). For Mercurius, the very common (31%) were followed by the occasional (25%) and the rare species (22%), with the common and the uncommon being the least frequent species (with 13 and 10%).

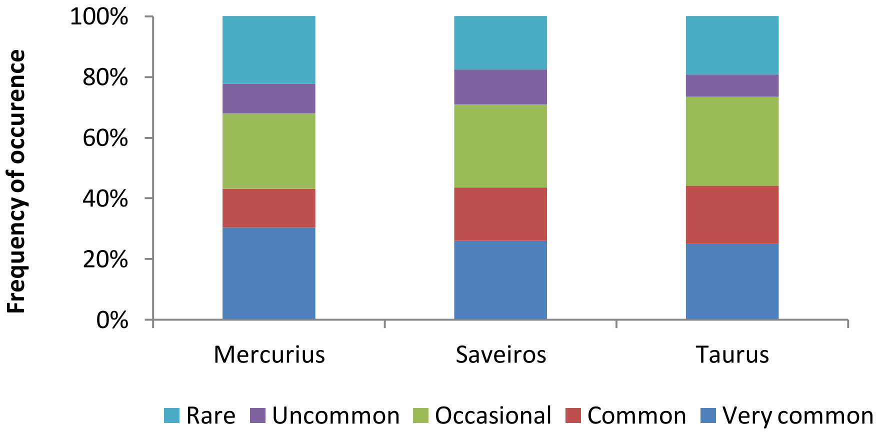

Figure 1-4. Species frequency of occurrence distribution on Mercurius, Saveiros and Taurus.

Regarding trophic distribution, a more similar pattern was observed between the two deep vessels than with Taurus both for number of species and number of individuals (Fig. 1-5 and 1-6).

For the relative abundance on the number of species (Fig. 1-5), mobile invertebrate feeders (26 and 28%), carnivores (24 and 22%) and omnivores (13%) had a larger number on Mercurius and Saveiros than in Taurus (25, 18 and 12%, respectively). Planktivores and roving herbivores species were more represented in Taurus (15 and 12%) than in the deep vessel reefs (12 and 10% for Saveiros and 10% for Mercurius), while sessile invertebrate feeders had the same number of species in the three vessels

(6%). Piscivores and territorial herbivores had a more similar abundance of species in Mercurius and Taurus (10 and 3%) than in Saveiros (9 and 1%) (Fig. 1-5).

However, when using Kruskal-Wallis test on the number of species, per dive, in each trophic guild for the different vessel reefs, the only significant differences found were for the territorial herbivores between Mercurius and Taurus, and Saveiros and Taurus (H=10.79, p<0.05; H= 10.30, p<0.05).

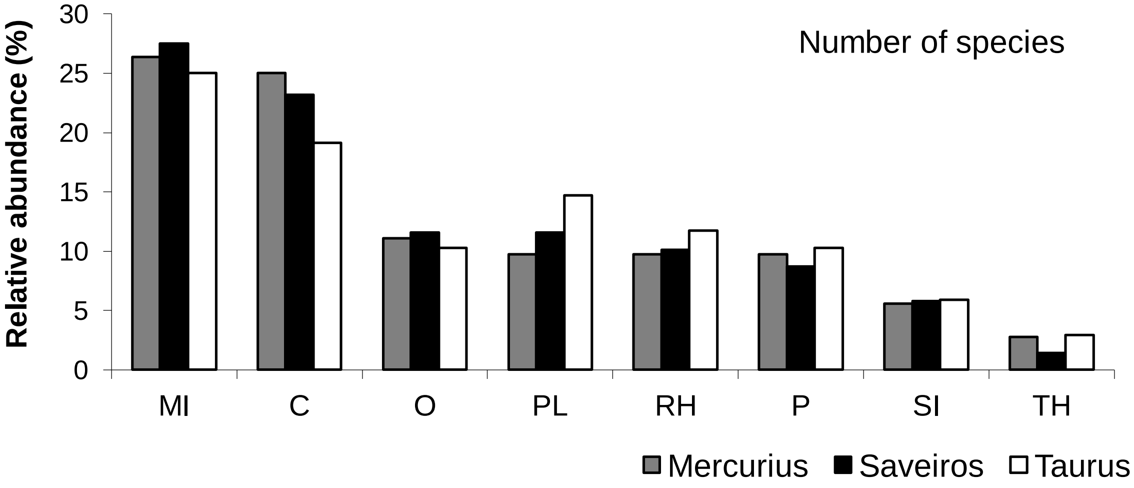

Figure 1-5. Relative abundance of the number of species belonging to the different trophic guilds for Mercurius, Saveiros and Taurus. Trophic groups: Territorial Herbivores (TH), Sessile Invertebrate feeders (SI), Roving Herbivores (RH), Planktivores (PL), Piscivores (P), Omnivores (O), Mobile Invertebrate feeders (MI) and Carnivores (C).

Regarding the relative abundance of the number of individuals (Fig. 1-6), the most represented trophic guilds were mobile invertebrate feeders and planktivores for the three vessel reefs, with the first group being more abundant in Taurus (43%) than in Mercurius and Saveiros (30%), and the planktivores being more abundant in the two deeper reefs (37%) than in Taurus (24%). The carnivorous group showed closer values for the three vessels, varying from 11% in Mercurius to 15% in Saveiros. The roving herbivores and sessile invertebrate feeders also showed low variation between the three vessels, being equal to 8, 7 and 6%, and 2, 2 and 1%, for Saveiros, Mercurius and Taurus, respectively. The omnivores were more abundant in number of individuals in Mercurius (11%) than in the other two vessels, where they accounted for only 4% in each. Both piscivores and territorial herbivores had a greater abundance in Taurus, 9 and 1% respectively, than in the deeper vessel (4 and <0,2%).

The results of Kruskal-Wallis test, on number of individuals, per dive, in each trophic group showed significant differences in the omnivores between Mercurius and Saveiros ($H=6.65$, $p<0.05$) and Mercurius and Taurus ($H= 4.61$, $p<0.05$). Regarding the territorial herbivores, significant differences were found between Taurus and Mercurius ($H=18.52$, $p<0.05$), and Taurus and Saveiros ($H=8.90$, $p<0.05$).

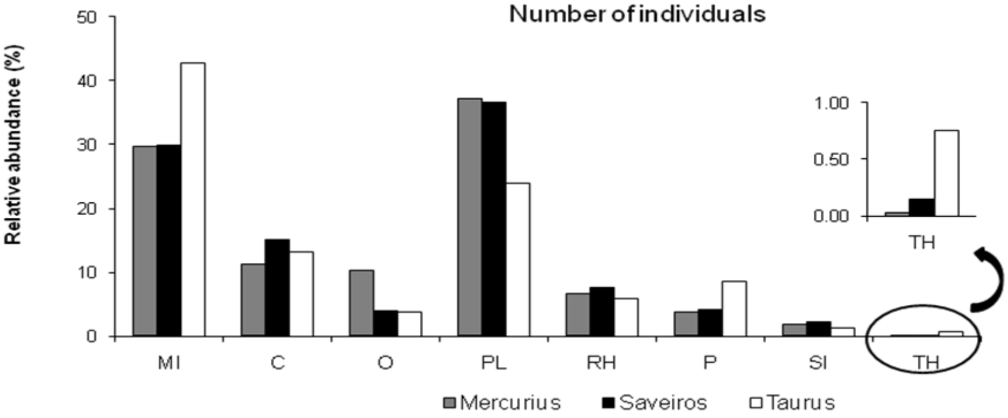

Figure 1-6. Relative abundance of the number of individuals belonging to the different trophic guilds for Mercurius, Saveiros and Taurus. Trophic groups: Territorial Herbivores (TH), Sessile Invertebrate feeders (SI), Roving Herbivores (RH), Planktivores (PL), Piscivores (P), Omnivores (O), Mobile Invertebrate feeders (MI) and Carnivores (C).

Fish community of Mercurius

A total of 72 species were identified for Mercurius, in 16 dives, belonging to 56 genera and 35 families (Appendix 1). The 10 families represented by three or more species in Mercurius (Fig. 1-7) were: Labridae, with eight species; Epinephelidae, with five, Haemulidae and Lutjanidae, with five, Carangidae, with four, and Acanthuridae, Gobiidae, Pomacanthidae, Pomacentridae and Scaridae with three species. Most of these families were abundant (>2%), with the exception of Gobiidae and Pomacanthidae, with only 0.6 and 1.4% of relative abundance, respectively (Fig. 1-7). Four other families, Scaridae, Scianidae, Holocentridae and Pempheridae, represented by two or only one species, had an abundant presence in Mercurius with the other 24 species only accounting for 6.2% of all the vessels' abundance.

During the dives, 5185 individuals were counted in Mercurius, with the exclusion of the large schools, more than 200 individuals, of *Mulloidichthys martinicus*, *Opistothonema oglinum*, *Haemulon aurolineatum* and *H. squamipinna*.

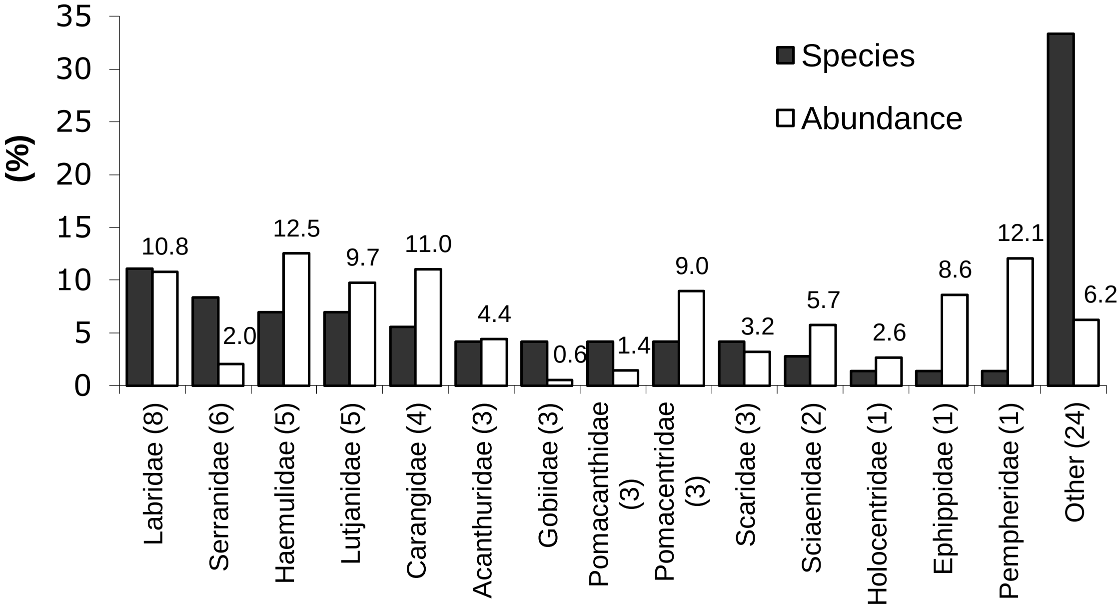

Figure 1-7. Most representative families in number of species and relative abundance for Mercurius. Numbers in parenthesis correspond to the number of species per family and the black bars its percentage.

The 12 more abundant families (Fig. 1-7) accounted for 4759 fishes, which represent about 92% of the total number of individuals. The most abundant families were: Haemulidae with 649 individuals (13%); Carangidae with 571 (11%) in which *Decapterus macarellus* and *Carangoides bartholomaei* were responsible for 65% and 29% of the family abundance; Labridae with 560 fishes (11%), with two of the eight species, *Bodianus rufus* and *Thalassoma noronhanum*, together accounting for 54% of the abundance; Lutjanidae with 505 fishes (10%), with *Lutjanus alexandrei* and *Ocyurus chrysurus* accounting for 91% of the family and Pomacentridae with 465 individuals (≈9%) and *Chromis multilineata* representing 60% of the family. The families Ephippidae (9%), Pempheridae (12%) and Scianidae (6%) despite only being represented by one or two species had a high abundance due to their schooling behavior, ranging from a few dozens to up to about 150 individuals, especially *Chaetodipterus faber* and *Pempheris schomburgkii*.

The serranids, although with a large number of species (6), were responsible for only 2% of fish abundance in Mercurius being surpassed by the acanthurids, 5%, and scarids, 3%, with three species, and by the holocentrids with one species, *Holocentrus adscensionis*, totaling 3% of the vessel fish abundance (Fig. 1-7).

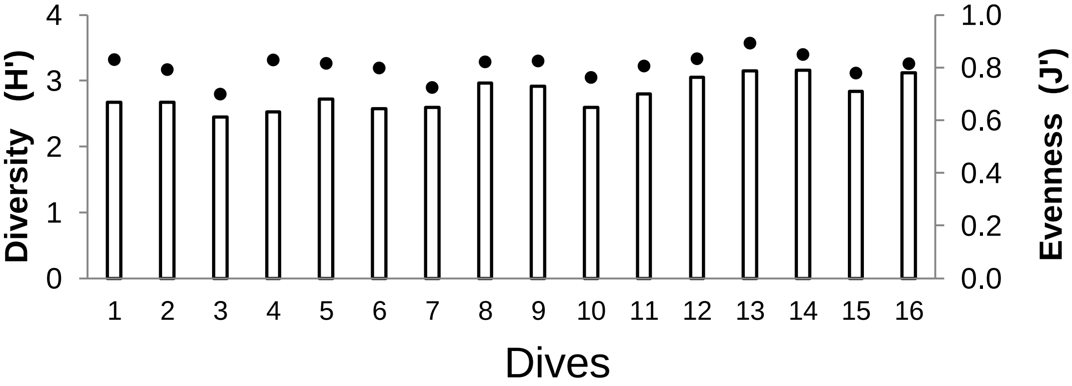

Figure 1-8. Diversity indices Shannon - H' (□) and evenness - J' (●) for Mercurius.

It was possible to observe fluctuations in the values of the diversity measures obtained for Mercurius (Fig. 1-8). However, no significant differences were found based on the chi-square test for the two indices throughout the study (**H'**: χ^2=0.30, p=1.00 and **J'**: χ^2=0.04, p=1.00). Highest values for the Shannon index were registered in the 14th and 13th dives, 3.16 and 3.15, respectively. The maximum value for evenness, 0.89, was recorded on the 13th dive. The minimum values for Shannon and evenness were found in the 3rd dive with 2.45 and 0.70, respectively.

The number of fish and species richness (Fig. 1-9) showed a more varied pattern during the first part of the study until the 11th dive, with the minimum values occurring on the 11th dive (163 individuals) for the number of fish and on the 1st and 6th dives (27 species) for the richness. From the 12th dive on, corresponding to February 2007 or the 10th month after vessel deployment, a more constant pattern was observed, with the highest values obtained in the last dive, with 506 individuals and 48 species.

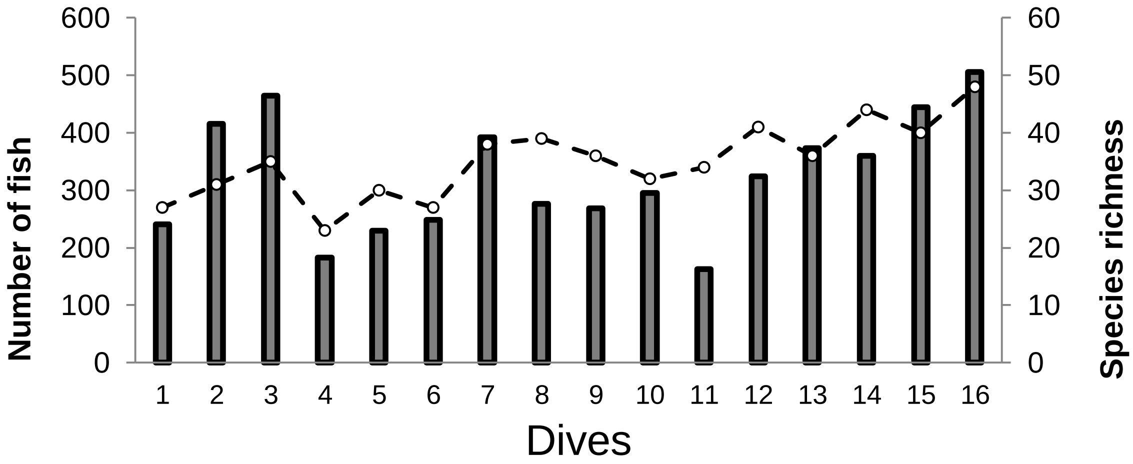

Figure 1-9. Number of fishes (■) and species richness (○) in Mercurius.

Of the 87 species registered in this study, eight were only found in Mercurius where they were classified as rare due to their low frequency of occurrence, 6.25% (Table 1-3).

Table 1-3. Rare species found only in Mercurius.

Family	Scientific Name
Clupeidae	*Opisthonema oglinum*
Epinephelidae	*Epinephelus itajara*
Serranidae	*Serranus baldwini*
Echeneidae	*Echeneis naucrates*
Rachycentridae	*Rachycentron canadum*
Carangidae	*Elagatis bipinnulata*
	Clepticus brasiliensis
Bleniidae	*Ophioblennius atlanticus*

Fish community of Saveiros

In Saveiros, 69 species were catalogued belonging to 53 genera and 34 families (Appendix 1). Like for Mercurius, only 10 families were represented by three or more species in Saveiros (Fig. 1-10). The Labridae was by far the most species-rich family with eight species, followed by Haemulidae with five. Lutjanidae and Epinephelidae had four species with the remaining families (Acanthuridae, Carangidae, Pomacanthidae, Pomacentridae, Scaridae and Gobiidae) having three species. Four families with two

(Holocentridae, Mullidae and Scianidae) and one species (Pempheridae) had also an abundant presence in Saveiros.

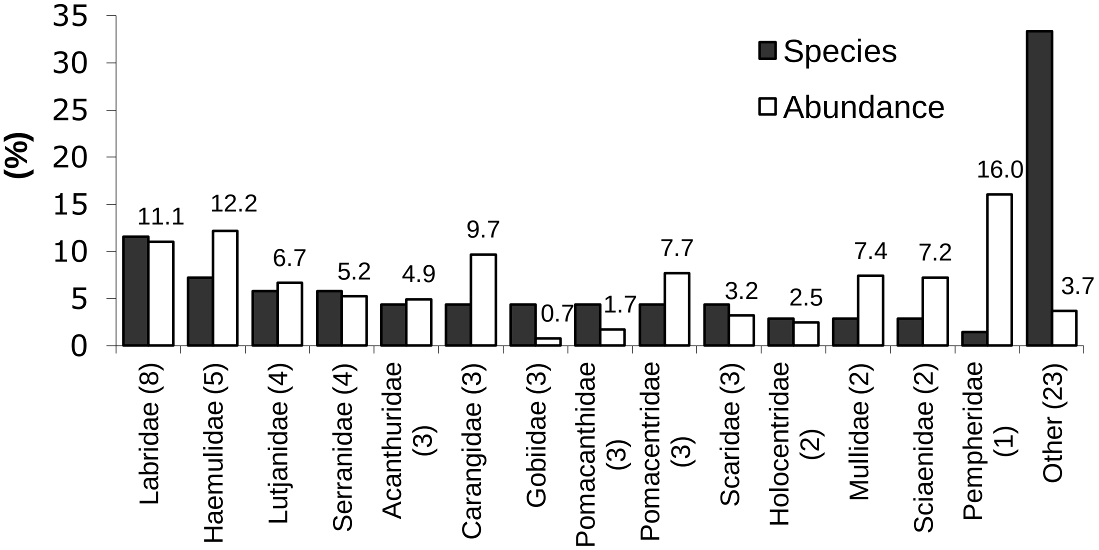

Figure 1-10. Most representative families in number of species and relative abundance for Saveiros. Numbers in parenthesis correspond to the number of species per family and the black bars its percentage.

In Saveiros, 4270 individuals were counted, not considering the large frequent schools of *Haemulon aurolineatum* and *H. squamipinna* and one of *Decapterus macarellus*, with an estimated 300 individuals.

Similar to Mercurius, the 12 most abundant families (relative abundance >2%) accounted for up to 94% of Saveiros' total abundance. The most abundant families were: Pempheridae (16%) with 685 individuals of only one species, *Pempheris schomburgkii*; Haemulidae with 520 individuals (12%); Labridae with 472 individuals (11%), in which *Thalassoma noronhanum* accounted for 40% of the family abundance; Carangidae, 414 individuals (10%), with *Decapterus macarellus* representing 60% and *Carangoides bartholomaei* 36%, as the two more abundant species of the family and Pomacentridae with 330 (8%), with *Chromis multilineata* and *Abudefduf saxatilis* being responsible for 98% of the family abundance. The lutjanids had nearly 7% of the total abundance in Saveiros, 284 individuals, with *Lutjanus synagris* being the most abundant species of the family, followed by *Ocyurus chrysurus*, with both accounting for 90% of the family abundance. With 7.4% of total vessel abundance was the Mullidae family, with *Pseudupeneus maculatus* showing a 93% dominance in the family, whereas

Odontoscion dentex and *Pareques acuminatus* had a similar abundance (3.5% each) completing the 7% of the Sciaenidae family. The serranids, although being represented by four species, accounted for only 5% of the vessel's total abundance (Fig. 1-10). The acanthurids, scarids and holocentrids had a similar pattern to the one found in Mercurius with 5, 3 and 2%, respectively, with the most abundant species in the family following the same pattern between vessels (e.g. *Acanthurus bahianus*, *Sparisoma axillare* and *Holocentrus adscensionis*). The other 23 species of Saveiros accounted for only 3.7% of the total fish abundance of the vessel reef.

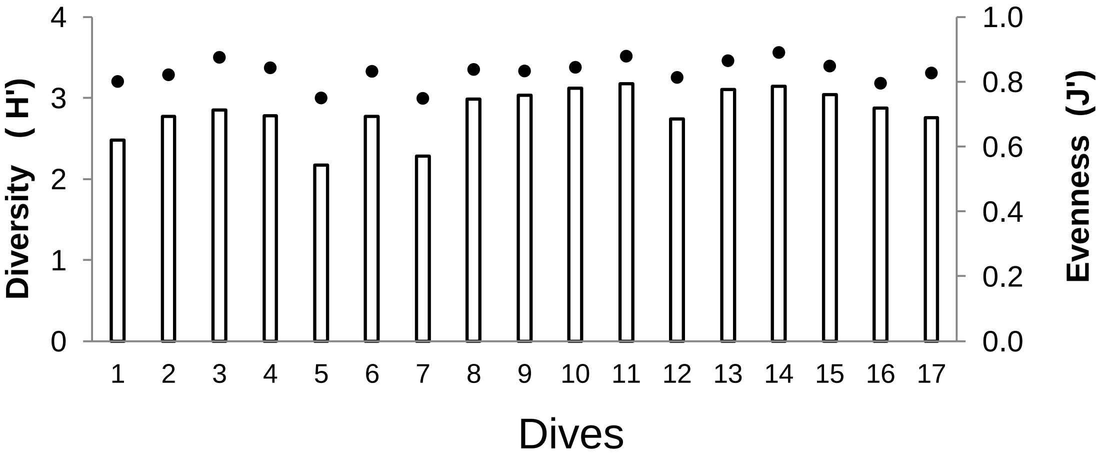

Figure 1-11 – Diversity indices Shannon - H' (□) and evenness - J' (●) for Saveiros.

Although there was some variation in the diversity indices over the course of the dives, no significant differences (**H'**: χ^2=0.48, p=1.00 and **J'**: χ^2=0.03, p=1.00) were found in Saveiros (Fig. 1-11). The highest values for the indices were obtained on the 11th dive for Shannon (3.18) and on the 14th for Pielou, 0.89. Shannon's diversity index showed the lowest values in the 5th dive (2.17), whereas Pielou's evenness had the minimum value, 0.75, in the 5th and 7th dives. The 5th and 7th dives also achieved the lowest values for the number of fishes and species richness, 129 and 141 individuals and 20 and 23 species respectively (Fig. 1-12). The greatest richness was obtained in the 10th dive, with the 9th being the most numerous one.

Of the total number of species accounted for in this study, five were only found in Saveiros, with their frequency varying from uncommon to rare (Table 1-4).

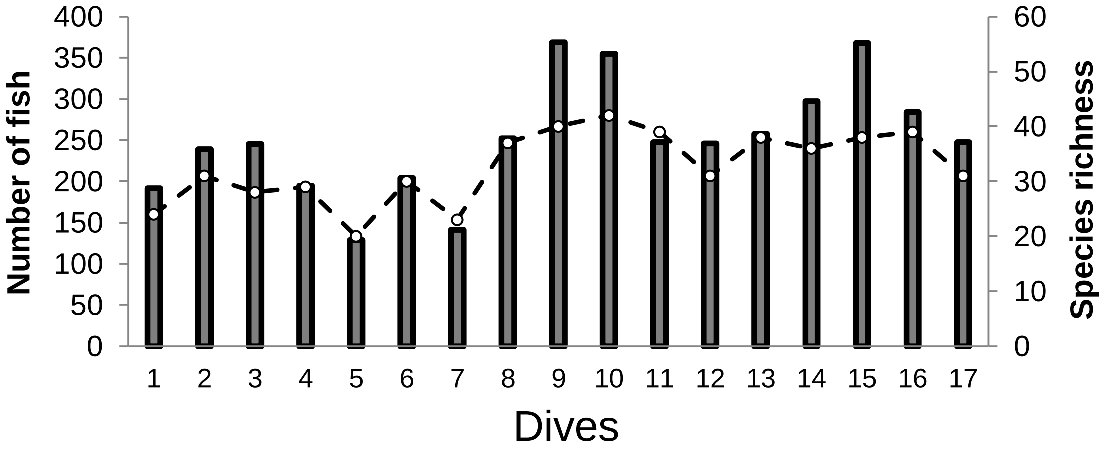

Figure 1-12. Number of fishes (▣) and species richness (○) in Saveiros.

Table 1-4. Species found only in Saveiros and corresponding frequency of occurrence.

Family	Scientific Name	Frequency of occurrence (%)	
Muraenidae	*Gymnothorax vicinus*	Uncommon	11.76
Antennaridae	*Antennarius multiocellatus*	Rare	5.88
Scorpaenidae	*Scorpaena plumieri*	Uncommon	11.76
Labridae	*Xyrichthys splendens*	Rare	5.88
Scaridae	*Sparisoma radians*	Rare	5.88

Fish community of Taurus

Taurus, despite being located closer to the coast than the other two vessel reefs, had a smaller number of dives, 11. During these dives, 68 species were registered belonging to 50 genera and 33 families (Appendix 1), of which only nine families were characterized by three or more species (Fig. 1-13). Labridae was the most represented family with seven species, followed by Haemulidae, Lutjanidae and Pomacentridae, with five species each. The scarids were represented by four species with the other five families (Acanthuridae, Carangidae, Pomacanthidae, Pomacentridae and Serranidae/Epinephelidae) having only three species. Holocentridae, Sphyraenidae, Mullidae and Scianidae, with two species, and Pempheridae, with only one species, were also abundant in Taurus.

During the study period, 3586 individuals were counted in Taurus, with the exclusion of large schools of *Haemulon aurolineatum* and *H. squamipinna*.

The 12 abundant families (relative abundance of more than 2% of the total vessel abundance) totaled 92% of the reef abundance, with the other 28 species, including scarids and pomacanthids, accounting for the remaining 8% (Fig. 1-13).

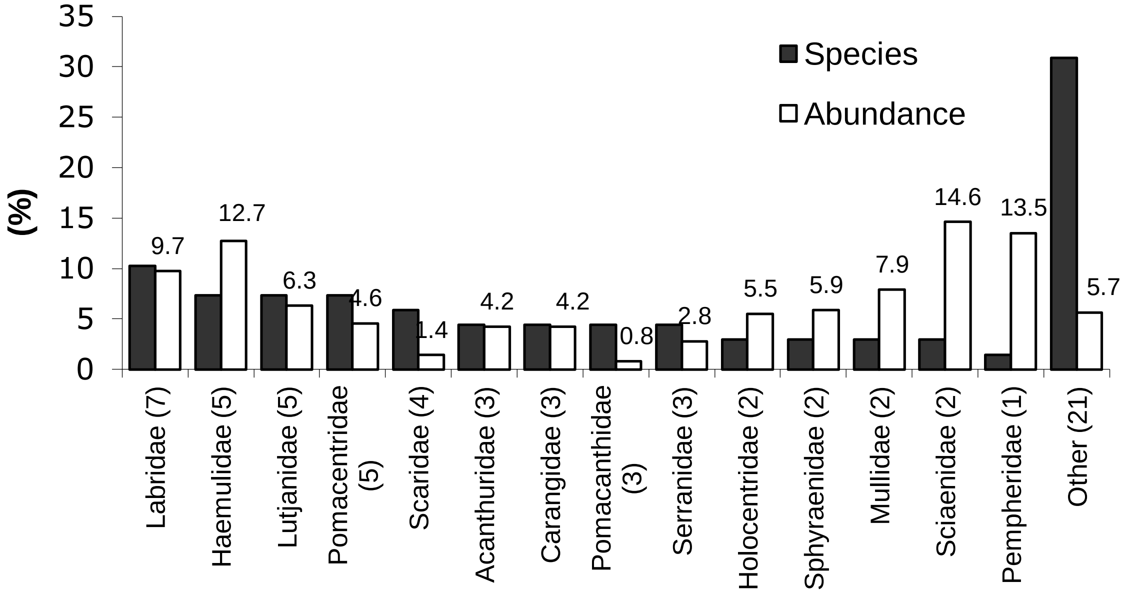

Figure 1-13. Most representative families in number of species and relative abundance for Taurus. Numbers in parenthesis correspond to the number of species per family and the black bars its percentage.

The most abundant family in Taurus was Scianidae, with 520 individuals (≈15%), with *Pareques acuminatus* being responsible for 74% of the family abundance. The three other families that predominate were: Pempheridae (13.5%), represented exclusively by *Pempheris schomburgkii*; Haemulidae with 457 individuals (12.7%) and Labridae with 349 fishes (10%), with *Thalassoma noronhanum* and *Bodianus rufus* being responsible for 40% and 20% of the family abundance. Mullids accounted for nearly 8% of Taurus abundance, with 384 individuals, being dominated by *Mulloidichthys martinicus*, differently from Mercurius and Saveiros, where *Pseudupeneus maculatus* had a stronger presence. The lutjanids had an abundance of 6.3%, with *Lutjanus synagris* and *Ocyurus chrysurus*, with nearly 50% and 36%, respectively. The Sphyraenidae family, with 6% of total reef abudance, was represented by only one barracuda, *Sphyraena barracuda* and 200 estimated southern sennets, *Sphyraena picudilla*. Holocentrids accounted for 5.5% of the total abundance, with *Holocentrus adscensionis* being responsible for 90% of the family, just like in Saveiros. The pomacentrids presented more species in Taurus than in any other vessel reef, with 164 fishes (4.6%), with 17% of the family being accounted by *Stegastes fuscus* and *S. pictus* and the remaining mostly by *Chromis multilineata* and *Abudefduf saxatilis* with 45% and 37% of the family abundance. Acanthuridae and Carangidae had 4% of the total abundance in Taurus, with about 150 individuals each. As observed in the other two vessels, the serranids, although having a different number of species in each vessel, also displayed a low abundance in Taurus, 3%, with most of them being *Cephalopholis fulva*.

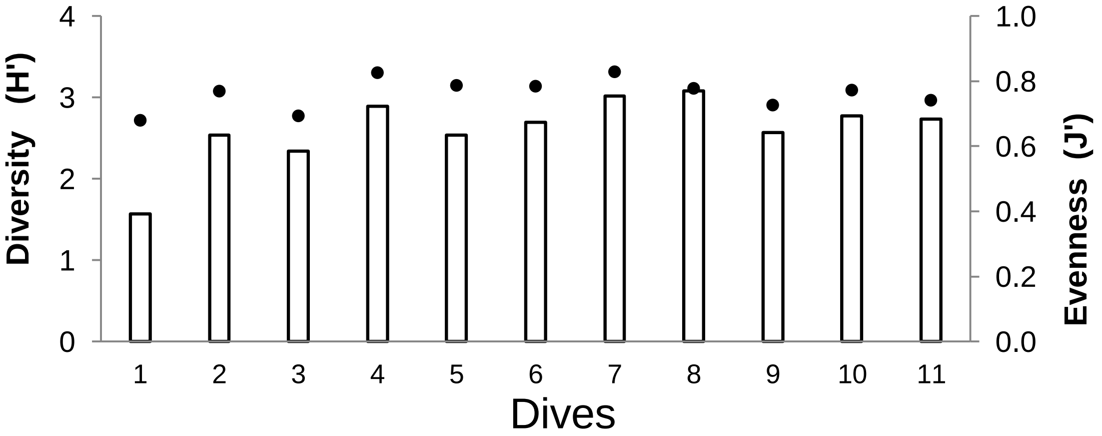

Figure 1-14. Diversity indices Shannon - H' (□) and evenness - J' (●) for Taurus.

The diversity indices for Taurus, like for the other two vessels, did not show any significant difference with the chi-square test (**H'**: χ^2=0.65, p=1.00 and **J'**: χ^2=0.03, p=1.00). However, a weak correlation was found by the Spearman test between Shannon's diversity and Pielou's evenness (rs=0.66, p=0.03). The highest values for diversity and evenness were registered in the 8th and 7th dive, 3.08 and 0.83, respectively (Fig. 1-14). All the minimum values for Taurus were recorded in the 1st dive, **H'** with 1.57 and **J'** with 0.68, and species richness and number of fish with 12 and 59, respectively. This dive occurred in September, corresponding to the end of the rainy season which explains the low visibility, especially in shallower waters, due both to wind and rain.

For the first five dives, occurring from September to January, the values for species richness and number of individuals were lower than in the second half of the dives, when both maximum values were registered with 54 species on the 8th dive and 521 individuals on the 6th dive (Fig. 1-15).

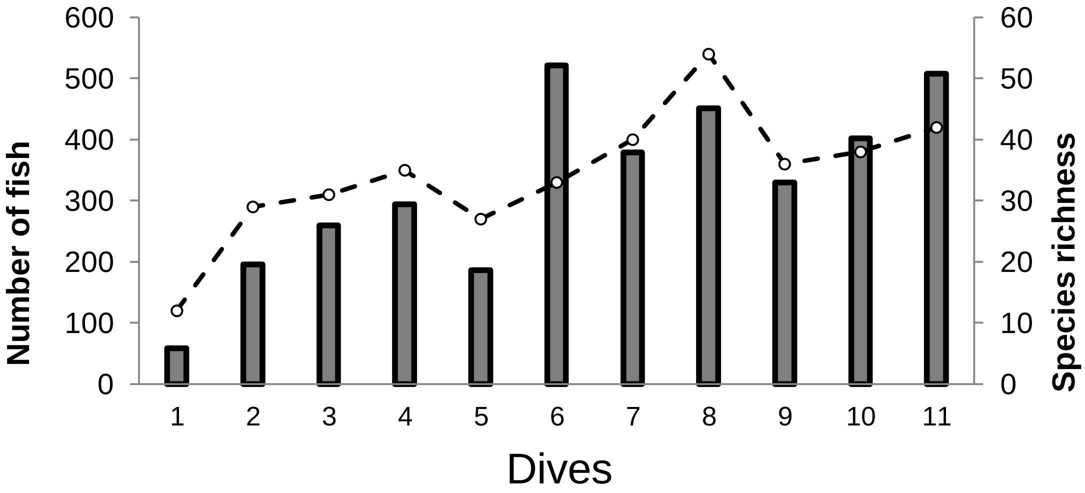

Figure 1-15. Number of fishes (▨) and species richness (○) in Taurus.

In Taurus, seven unique species occurred with their frequency varying from very common to rare (Table 1-5). Interestingly, *Stegastes fuscus* and *Gramma brasiliensis*, had a good frequency of occurrence in most of the dives, being always found in the exactly same spot.

Table 1-5. Species found only in Taurus and corresponding frequency of occurrence.

Family	Scientific Name	Frequency of occurrence (%)	
Grammatidae	*Gramma brasiliensis*	Occasional	45.45
Pomacentridae	*Chromis jubauna* *Stegastes fuscus*	Rare Very Common	9.09 81.82
Scaridae	*Scarus trispinosus*	Uncommon	18.18
Sphyraenidae	*Sphyraena picudilla*	Uncommon	18.18
Balastidae	*Balistes vetula*	Rare	9.09
Monacanthidae	*Aluterus scriptus*	Rare	9.09

DISCUSSION

Community structure

The development and equilibrium of the reef fish community in the vessel reefs can be inferred by the presence of all the 10 families typically considered reef families (Robertson, 1998; Bellwood & Wainwright, 2002). According to Bellwood & Wainwright (2002), these families (i.e. Acanthuridae, Apogonidae, Blenniidae, Carangidae, Chaetodontidae, Holocentridae, Labridae, Mullidae, Pomacentridae and Scaridae) can be found in any reef, regardless of its biogeographical location or coral richness.

Aburto-Oropeza & Balart (2001) and Pérez-España *et al*. (1996), Fariña *et al.* (2005) and McKenna Jr. (1997) observed that the best represented families found in the Gulf of California, Venezuela and México, respectively, were: Serranidae (with the Epinephelidae included), Labridae, Pomacentridae, Lutjanidae, Haemulidae and Scaridae, which is the pattern observed in this study for the most species-rich families. Haemulidae and Labridae are known to be abundant families, in terms of species, in the northeastern coast of Brazil (Floeter *et al*., 2001).

As far as the Brazilian coast and oceanic islands are concerned, the most representative families remain almost the same, with a large importance of: the Carangidae family in Parcel Manuel Luiz (Rocha & Rosa, 2001), Porto de Galinhas (PE) (Engmann, 2006), Tamandaré (PE) (Ferreira *et al*., 1995), Arraial do Cabo (RJ) (Ferreira *et al*, 2001), Atol das Rocas (RN) (Rosa & Moura, 1997) and Trindade Island (ES) (Gasparini & Floeter, 2001); Gobiidae, Serranidae with the Epinephelidae groupers, and Muraenidae in Risca do Zumbi (RN) (Feitoza, 2001) and Coast of the Paraíba state (Feitoza, 1999; Rocha *et al*., 1998) with this last family also showing more species in Maracajaú (RN) (Feitosa, 2005; Feitosa *et al*., 2002). In a study made by Floeter *et al.* (2001), on the geographical variation of reef fish communities along the Brazilian coast, Muraenidae, Holocentridae and Chaetodontidae were found to be among the 10 most representative families. However, this was not the case in the present study, with these families represented by two or only one species.

Comparing the number of species and families found in the present study with other studies carried out nearby, some similarities can be found. In two studies that took place in Porto de Galinhas, a beach 70 km south of Recife, Engmann (2006) registered 89 species belonging to 41 families, while Silva (2006) only found 74 species in 36 families. These differences can be a result of different methodologies used. Although both studies applied the transect, the first author used SCUBA dives while the second, despite using intensive search, relied on snorkeling to sample the area. Even though the number of species varied between these two studies, 89 and 74, the results obtained for the vessel reefs were close, varying from 68 to 72. In Tamandaré, also in the south of Pernambuco, some 100 km from Recife, Ferreira *et al.* (1995) found 103 species in 43 families. However, their study site was located between two river mouths, which clearly influenced the composition of the recorded species, with some species associated with shallow and even brackish waters (e.g., Gerreidae and *Hippocampus redi*).

Diversity, Frequency and Abundance

The diversity indices calculated for the present study were somewhat higher than those obtained for other sites along the Brazilian coast. The mean values for Shannon's diversity ranged between 2.61-2.83, with the lowest value for the shallow vessel and the highest values for the two deeper vessels which, when compared to the values found in Porto de Galinhas, 1.2-2 (Engmann, 2006), Maragogi, 0.8-0.93 and Maracajaú, 2.02-2.63 (Feitosa, 2005), and Arquipélago dos Currais, 2.26-2.46 (Pinheiro, 2005), indicates a much more diverse fish community in the recently deployed vessel reefs. Interestingly, the area and height of the reef has been found to influence species richness (Molles, 1978) which could be noted in our study with the highest values of Shannon's diversity found in the larger vessel reefs, Mercurius and Saveiros, than in Taurus that is smaller both in size and height. Also, the higher diversity observed for the deeper reefs can reflect the importance of depth in the fish diversity and abundance as it has been previously reported (e.g., Roberts & Ormond, 1987; Pinheiro, 2005)

The Shannon results from this study also showed that the diversity found in the vessel reefs was greater than in two marine protected areas: Parcel Manuel Luiz, 2.31, (Rocha & Rosa, 2001) and Atol das Rocas, 2.08 (Rocha & Moura, 1997). As mentioned by Feitoza (2001), this is probably due to two factors: firstly the number of species in an oceanic island is smaller than in coastal reefs due to isolation and typically small shallow water area (Floeter *et al*., 2001) and secondly, the complications in the employed sampling technique can result in sub or overestimation. The Shannon index value found by Feitoza (2001) in Risca do Zumbi, 2.95, was higher than the ones found in this study, and this difference is probably related to the type of methodologies used by that author, who used stationary point counts with several replicates in different areas, resulting in a much longer sampling period and also clove oil to collect the most cryptic species. The dimension and variety of sampled environments (e.g., caves and marine plateaus), as seen in Feitoza's study, can also influence the results obtained for a determined study area.

The almost linear decline of the log abundances observed for the three vessels reflects, according to Bohnsack & Bannerot (1986), an undisturbed and highly diverse community. However, in this study Shannon's diversity and Pielou's evenness values were higher and more stable for Mercurius and Saveiros than for Taurus. This suggests two possibilities: a) that the reef fish in Taurus are under a more intense process of community regulation, which is reflected in the variability of the number of species and individuals in the vessel, or b) Taurus, as one of the most visited new "shipwrecks" in the coast of Recife has been subjected to an intense diving tourism (PNAPE, unpubl. data) and the divers impact in settling communities can be reflected in the indices and in the number of rare and uncommon species of the vessel reef. One example of the probable dynamics of the process of regulation of the fish community can be ascertained by the non-occurrence of *Ophioblennius trinitatis* in Taurus. This territorial herbivore is abundant both in shallow and intermediate reefs in the northeastern coast and in our study area was only present in one of the deep reefs, when logically it should be registered in the shallower one. Many factors affect the founding of herbivore territory, such as the abundance of competitors for space and for food resources (Ceccarelli, 2007). In Taurus, the presence of two species of damselfish, *Stegastes pictus* and *S. fuscus*, might be affecting the establishment of a new species, *O. trinitatis*, due to their territorial nature. Nonetheless, other studies have also found larger values for diversity and evenness in greater reefs (e.g., Friedlander & Parrish, 1998) and found it to be related with different physical and biological characteristics of the sampled habitats.

One of the universal characteristics of ecological communities is that some species are extremely abundant, some are moderately common and the remaining, usually the majority, are rare (Magurran, 2005) represented by only a few individuals. In this study the results suggest that the communities, despite having good values for diversity and evenness, are eventually still adjusting to changes in their ecological structure probably caused by predation, competition and recruitment in the new deployed reefs**.**

Trophic patterns

The number of species belonging to each trophic group was close in the three vessels. However, the abundance of the different trophic guilds showed a distinct pattern for omnivores, planktivores, mobile invertebrate feeders and territorial herbivores.

The higher abundance of omnivores found in Mercurius is a direct result of using data of medium schools of common species, in this case four events of more than 50 individuals of *Chaetodipterus faber* that accounted for more than half of the total omnivores in this vessel reef. This might prove that the use of data from large schools of frequently found species in the vessels (e.g., *Haemulon aurolineatum* and *H. squamipinna*) not only can be very biased for the estimation of large number of individuals but also masks the importance of much lower abundance species that have, nevertheless, an important ecological function in the community's structure.

In this study, the planktivores were one of the most abundant groups in the vessel reefs, which is in agreement with other studies about vertical relief on artificial reefs (e.g., Rilov & Benayahu, 2000; Lindquist & Pietrafesa, 1989; Stephan & Lindquist, 1989). Arena *et al*. (2007) found significant differences in the abundance of planktivores in vessel reefs and natural reefs. However, in a study at natural reefs in Zumbi, in the northeastern coast of Brazil (Feitoza, 2001), planktivores were also the main trophic group.

The deployment of a vessel in an area with significant currents can cause horseshoe vortexes and thus ressuspension or scouring of the sediment on the reef bottom (Lindquist & Pietrafesa, 1989), which in turn causes recycling and regeneration of nutrients near the reef. As observed in a previous study on phytoplankton in two older vessel reefs in Recife, the abundance of these organisms was higher in the area around the vessel than in the middle and upper water column (Santos, 2006). This probably reflects the preference of these species for gathering in places with higher food resources and thus explains the main aggregation of diurnal planktivores (e.g., *Chromis multilineata*, *Thalassoma noronhanum*, *Decapterus macarellus*) that remain at a depth near the vessel and not near the surface. Several planktivorous species, like *Chromis*, tend to aggregate in mid-water above and/or around the artificial reefs (Jessee *et al*., 1985) which can also be a reflection of the quantity of organisms associated with the open sand plains, which according to Hobson & Chess (1986) can be rich and abundant and can be exposed by burrowing or feeding habits of species such as *Dasyatis americana* and *Pseudupeneus maculatus*.

In this study, although a higher number of planktivorous species were found in the shallower vessel, a higher abundance of fish were observed in the deeper reefs, Mercurius and Saveiros, which matches the results obtained in a study on artificial reefs in the south coast of Brazil (Pinheiro, 2005), in the deep reefs in Marshall Islands (Thresher & Colin, 1986) and in coastal reefs in Hawaii (Friedlander & Parrish, 1998). In the latter study, the authors found that planktivores had a positive relationship with depth, being more abundant along the deep reef slope and that their distribution pattern must be related to the abundance of their major prey in deeper waters (Hobson & Chess, 1986). This concurs with findings by Santos (2006) in which the values for chlorophyll *a* found in the deeper vessel reef were superior to the ones found in a shallower vessel nearer the shore of Recife.

Mobile invertebrate feeders are usually, by far, the most important fraction of benthic invertebrate predators, being equally important at inshore, midshelf and outer shelf reefs (Jones *et al.*, 1991). These animals usually feed on high caloric food resources, like crabs and mollusks, which are abundant on hard and soft substratum (Harmelin-Vivien, 2002; Jones *et al.*, 1991). As found in a complementary study, a part of the PNAPE project (Costa *et al.*, *in prep*), the sediments on both sides of the Mercurius and Saveiros are mainly composed of very coarse to medium sand with some granules. This supports the idea of re-suspension and displacement of the bottom material in our study area resulting in the exposure of small burrows in the substrate surrounding the vessels, which allied to naturally existing small rocks, attract fishes and invertebrates. Some fishes use them for shelter and, in some cases, feeding grounds. Examples are diurnal planktivores, such as *Ptereleotris randalli* or *Opistognathus aurifrons*, and carnivorous species like *Scorpaena plumieri*. The distribution and abundance of benthic macroinvertebrates is mostly related with the type of substrate and the frequency and intensity of disturbances in the habitat, with stable environments (e.g., tropical waters) presenting the most diverse fauna (Sanders Jr., 1968). Regarding the type of substrate, in a study conducted in the southernmost state of Brazil, Capítoli & Bemvenuti (2004) found the highest diversity of benthic invertebrates in areas of highest substrate diversity, with the dominance of sand, gravel and some mud, at depths of 20-30m. Using this information, it can be thought that the greatest occurrence of mobile invertebrate feeders in the shallower vessel is probably a reflection of the complexity of the substrate around the vessel which lodges a great variety of invertebrate (occurring with all three vessels) and the intermediate level of disturbance of the substrate by currents which is more intense in shallow depths.

In a study in the Caribbean, Dominici-Arosemena & Wolff (2005) observed that mobile invertebrate feeders tended to increase their abundance and diversity from the sheltered to the exposed areas, which can be the case in this study for Taurus, as it is smaller than the other two vessel reefs, thus originating less available shelter for the fishes. However, in the individual species analysis it could be observed that the highest values of mobile invertebrate feeders in Taurus, when comparing with the other two vessels, were due to the presence of larger numbers of *Haemulon plumieri*, *H. parra* and *Mulloidichthys martinicus*. There may be two main reasons for this: in the two deeper vessels enormous schools of *H. aurolineatum* and/or *H. squamipinna* that almost cover the entire vessels are constantly present while in Taurus the schools are somewhat smaller, which can result in a "camouflage" effect of these large schools in species that look alike (e.g., *Haemulon squamipinna* with *H. plumieri* and *H. aurolineatum* with *M. martinicus* and *H. parra*). On the other hand, *H. parra* and *H. plumieri* do not school in such large numbers as *H. aurolineatum* and *H. squamipinna*, probably due to their larger sizes, and therefore their numbers are probably not so biased in Taurus as they could be in Mercurius or Saveiros.

Submerged vegetation creates an availability of resources, such as shelter and food, affecting the distribution patterns of herbivores, invertebrate feeders and omnivores who prey on the associated epifauna (Anderson, 1994; Garpe, 2007). Regarding the herbivores, two patterns arose from the comparison between vessel reefs: Taurus presented more roving herbivore species than the deeper vessels which in turn had a larger number of fishes even when comparing the mean number of herbivores per dive; and Taurus showed the same number of territorial herbivorous species than another deeper vessel, Mercurius, but a much larger number of individuals.

The roving herbivores dwell on reefs and migrate during the day to seagrass beds for feeding (Ogden & Zieman, 1977). This may allow a larger distribution pattern and result in a small dependence on the development of algae and other organisms in which they feed on the reef, for they can forage for food in nearby vegetation. On the other hand, territorial herbivores remain in their protected area for shelter and feed (Jan *et al.*, 2003; Letourneur *et al.*, 1997) and although territory size can vary between species and locations (Ceccarelli, 2007) it is logical that the type and abundance of food resources will affect the number of these small fishes. The fact that a larger number of territorial herbivores were present in Taurus than in the deeper vessels is probably related to the more abundant macroalgae coverage and diversity at depths around 20 m than near the 30 m isobath, as shown in a study on the Gaibú, just south of Recife (Pereira *et al.*, 2007), meaning that a greater amount of algae is available in Taurus than in Mercurius and Saveiros. As the numbers and abundances of roving herbivores were somewhat similar in the three vessel reefs, it suggests that food is not as limiting for these species as their need for shelter. Dominici-Arosemena & Wolff (2005) found that herbivores, like scarids, increased their numbers in sheltered zones which helps to explain that one important factor for the regulation of their abundance is their dependence for shelter. This can be observed in our study by the larger abundance of roving herbivores occurring in Mercurius and Saveiros which have a larger size (29,1 m x 7,4 m) than Taurus (26 m x 7 m), with size also acting as visual/audio stimulant and spatial reference for fish (Anderson *et al.*, 1989; Jessee *et al.*, 1985).

Several factors have been related to the distribution of fish species on coral reefs like substrate complexity, food and shelter availability, presence of currents, etc. (Williams, 1991). Reef morphology however seems to be one of the main factors that determines the organization of the reef fish communities (Letourneur, 1996) because it determines the existence of adequate shelter for some important species. The availability of large inner open spaces in the reef, although ideal for some nocturnal planktivores species that tend to aggregate (e.g., *Pempheris schomburgkii* and *Odontoscion dentex*), might constitute a limiting factor for other species that prefer more “customized” elements in the reef (e.g., small openings or holes with sizes near the fish’s own size) and vessels, concrete pieces and the so-used *Reef Balls*® are known to have a poor surface/area ratio and complexity (Figley, 2003).

In the present study, some families did not present the *expected* patterns in terms of species number (e.g., muraenidae and gobiidae) probably due to two main factors. Muraenids are known to remain hidden in holes and crevices during the day, foraging at night (Randall, 1967) and therefore one of the main reasons for the low counts of Muraenidae species registered in all three vessel reefs was probably due to the lack of appropriate holes for the size of these fishes. This might suggest that shelter from predation can be more important than food, in determining the presence and abundance of some species (Hixon & Beets, 1989). Supporting these results is the fact that the taxonomic lists obtained in several studies in the northeastern coast of Brazil (Engmann, 2006; Rocha *et al*., 1998) report Muraenidae as a species-rich family. The low number of gobiidae species in the vessel reefs, and surrounding area was due to the type of methodology used. In a previous study carried out in the coast of Paraíba, the state just north of Pernambuco where this project took place, Feitoza *et al.* (2005) registered 10 species of gobiids inhabiting intermediate coastal waters and this author also found 6 species of this family in intermediate reefs of Zumbi, in the coast of Rio Grande do Norte, the state north of Paraíba (Feitoza, 2001). These results show that a larger number of gobiids could probably be found in our vessel reefs but were not identified as a result of the census techniques employed, as both the studies mentioned above used fish anaesthetics to collect and identify specimens.

Although there were some differences observed, between the vessel reefs and other natural reefs in northeastern Brazil, the structure of the artificial reefs fish communities was mostly similar to the patterns observed in the natural ones. The main differences found (e.g., biological indices values) were probably influenced by the structural characteristics of the compared areas and differences regarding the used methodologies (e.g., the use of transect versus stationary point counts; the use of clove oil). In spite of this, the vessel reefs showed a diverse community, and although regulation processes are still taking place, especially in the shallower artificial reef, the reefs prove themselves capable of offering shelter and food to most of the typically found species in the area.

CHAPTER 2. COLONIZATION AND ECOLOGIC SUCESSION IN TWO VESSEL REEFS ON THE COAST OF RECIFE (PE) - BRAZIL

INTRODUCTION

Any newly available patch of habitat is subject to colonization by organisms, which are prepared to colonize unoccupied environments (Valiela, 1995). The colonization of a reef is the result of the dispersion and settlement of pelagic larvae and/or immigration of juveniles and adults (Matthews, 1985; Carr & Hixon, 1997). According to Solonski (1985), individuals from suboptimal habitats may move to more optimal areas when new habitat or food becomes available, and this type of colonization may occur from species living in nearby natural reefs or those without a territory. These movements will depend on the diversity and health of the local ecosystem and on the populations it shelters, for that will determine the pool of available species to colonize the new habitats (Caley & Schluter, 1997; Belyea & Lancaster, 1999).

It has been suggested that inter and intra specific interactions pose as the main limits for the coexistence and diversity in natural communities (e.g., MacArthur & Levins, 1967). However, it is now accepted that the structure and dynamics of these communities is the outcome of both interactions of biotic and environmental factors (Menge & Sutherland 1976; Dunson & Travis 1991). Thus, as a consequence of the complex interactions among species (e.g competition, predation, facilitation) and temporal and spatial stochastic variations (e.g., recruitment), the structure of fish communities in different locations cannot be predicted (Doherty, 1991; Hixon, 1991; Sale, 1991). According to Munday *et al*. (2001), different combinations of resource overlap, competitive abilities, and competitive outcomes are expected to be found in communities where species coexist.

It is possible to compare artificial reefs relying on the list of species that inhabit them, as the presence/absence of certain species might provide an indication of the nature of these habitats (Bortone & Bohnsack, 1991). Several reasons, such as the reefs' geometric configuration, the behavioral features and abundance of species present and even possible variations between the ability of different observers to see and identify some species, may determine the chances to register the occurrence of a given species, so caution must be taken when using this approach (Harmelin-Vivien *et al.*, 1985; Bortone & Bohnsack, 1991), both in sites subject to human interference or not.

Tourism is one of the most remarkable socio-economic phenomena of the twentieth century, with earnings from international tourism reaching US$ 476 billion which is larger than the export value of any other single category of product or service, including petroleum products (Neto, 2002). “Diving has become a booming branch of the tourism business”, and differently from the general tourism, this activity targets small coastal areas in tropical countries, mostly with poorly developed economies (Van Treeck & Schuhmacher, 1998). Several studies have been conducted in coral reefs to determine the impacts of the diving activity (e.g., Hawkins *et al.*, 1999; Tratalos & Austin, 2001; Uyarra & Côté, 2007) with many regarding only the effects on the coral community. Although it has been found that coral reefs endure physical contact by divers, this impact is reflected in the loss of large massive corals (Hawkins & Roberts, 1993). Regarding fish communities, however, no significant impact has been found, although studies using electronic devices have reported the avoidance reactions of several fish species to the presence of divers (e.g., Stanley & Wilson, 1995; Schmidt & Gassner, 2006). Nevertheless, in the northeastern coast of Brazil, two studies on the impact of marine tourism, both on trampling and diving, have concluded that the main factor influencing the fish community was the offer of food by tourists, which could be attracting some “opportunistic” species, thereby changing the overall trophic structure of the communities (Feitosa, 2005; Engmann, 2006).

In order to identify the influence of recreational diving on the colonization process of reef fish in artificial reefs, two identical vessel reefs, one open to recreational dives and the other only to scientific dives done within the framework of the present study, were compared after a year of deployment, through the characterization of the fish assemblages by the use of trophic guilds and spatial categories. A brief evaluation and comparison was made on the visual census methodology used, observing the influence of divers’ presence in the studied spatial categories.

METHODS

Study site

The data for this study were collected from two vessel reefs, Mercurius and Saveiros, located on the coast of Recife (PE) in northeastern Brazil (Fig. 2-1), as mentioned earlier (see *Study area*). The two vessels were chosen for their similarity in terms of size and deployment area, sampling similarity (e.g., the number of dives and the beginning of the sampling period) and differential usage, with Saveiros open for recreational diving and Mercurius only available for research dives.

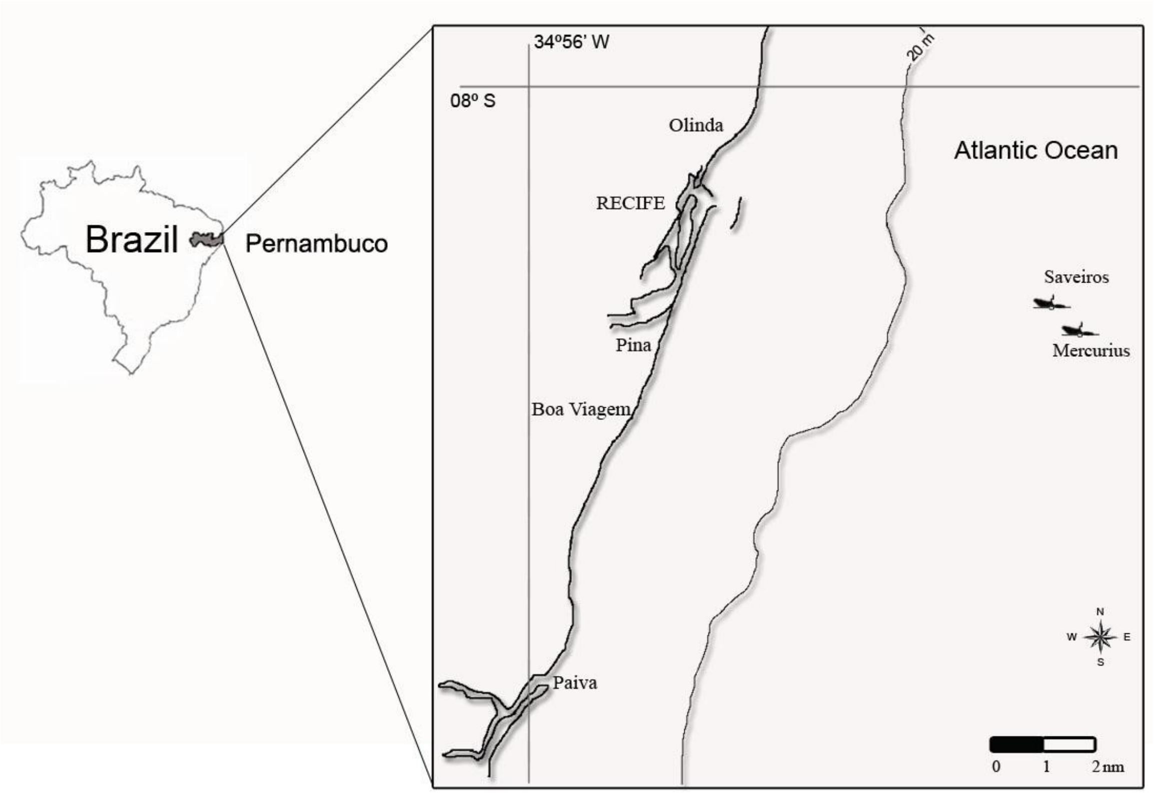

Figure 2-1. Map of study site, with the location of the two vessels, Mercurius and Saveiros.

Data analysis

To confirm if the sampling period was adequate, a cumulative curve was plotted with the number of species registered throughout the dives. According to Begon *et al.* (2006), sampling is considered adequate when the cumulative number of species stabilizes.

For the analyses of colonization, each fish species registered during the dives was assigned to a category according to its spatial distribution (adapted from Nakamura, 1985 and Okubo & Kakimoto, 1991), with: A – species that prefer physical contact with the reef; B – species that are associated to the reef by vision and sound; C – species that remain in the water column; and D – species that use the area/surroundings of the reef (Fig. 2-2). . This allows the study of specific groups that share functional relationships, allowing the comparison of similarities of unrelated species.

To compare differences between the number of species belonging to each spatial category, throughout the study period, a chi-square test was used.

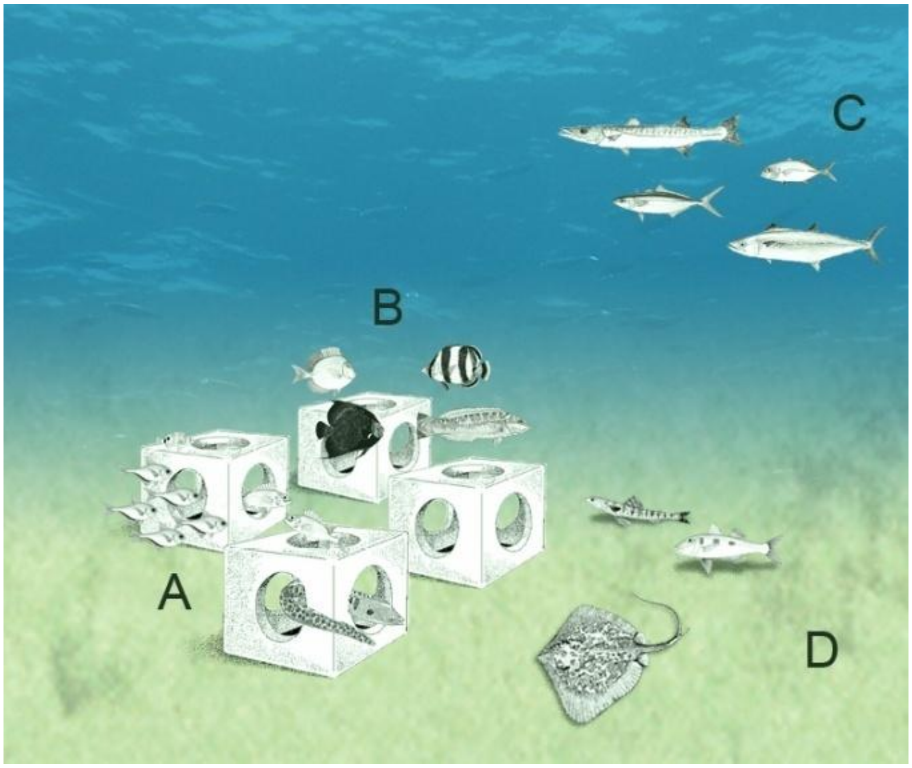

Figure 2-2. Schematic representation of the relationship of species with the artificial reef (adapted from Nakamura, 1985 and Okubo & Kakimoto, 1991).

Species were also assigned a trophic category based on visual observations and available literature (Randall, 1967; Feitoza, 2001; Dominici-Arosemena & Wolff, 2005; Halpern & Floeter, 2008). The eight trophic groups, following Ferreira *et al*. (2004), were: C – Carnivorous; O – Omnivores; MI – Mobile Invertebrate feeders; P – Piscivores; PL – Planktivores; RH – Roving Herbivores; SI – Sessile Invertebrate feeders and TH – Territorial Herbivores. Frequency classes were also used with: very common (VC) - >80%; common (C) – 51-80%; occasional (O) – 21-50%; uncommon (U) – 11-20% and rare (R) with <10% of occurrence.

Hierarchical cluster analysis, using the Bray-Curtis similarity index (Bloom, 1981) based on a presence/absence matrix was used to evaluate the colonization process and resemblance between reef fish assemblages. Presence/abundance data was used as it confers the same weight to abundant and rare species (Clarke & Warwick, 2001). A non-metric multidimensional scaling ordination (MDS) was also used to evaluate spatial and temporal differences in the communities (Field *et al*., 1982) between both vessel reefs.

One-way ANOSIM (Analysis of Similarity) and SIMPER (Similarity Percentage Analysis) routine were used to examine the potential differences in the studied assemblages among sites and dives and to identify the species responsible for the dissimilarity between the obtained groups. All the multivariate analyses were conducted using the PRIMER 6β ® software (Clarke & Warwick, 2001).

RESULTS

From July 2006 to July 2007, a total of 80 species were registered, with 72 for Mercurius in sixteen dives and 69 for Saveiros during seventeen surveys (Appendix 4). The cumulative curves for the number of species were similar for the two vessels (Fig. 2-3). In the first dive on July 2006, 27 species were found in Mercurius and 24 in Saveiros. For Mercurius, the number of species increased sharply in the first two months of sampling, four months after the deployment of the vessel, with a subsequent moderate but steady increase from September to March reaching 68 species. From March on, there was only the addition of one or two species per dive. For Saveiros, a constant increase was registered, from July to February, when the number of species reached 68. From March on there was only the addition of one new species until July 2007. From September to March, Saveiros had a greater number of recorded species than Mercurius, with a difference ranging from 1 to 6 species.

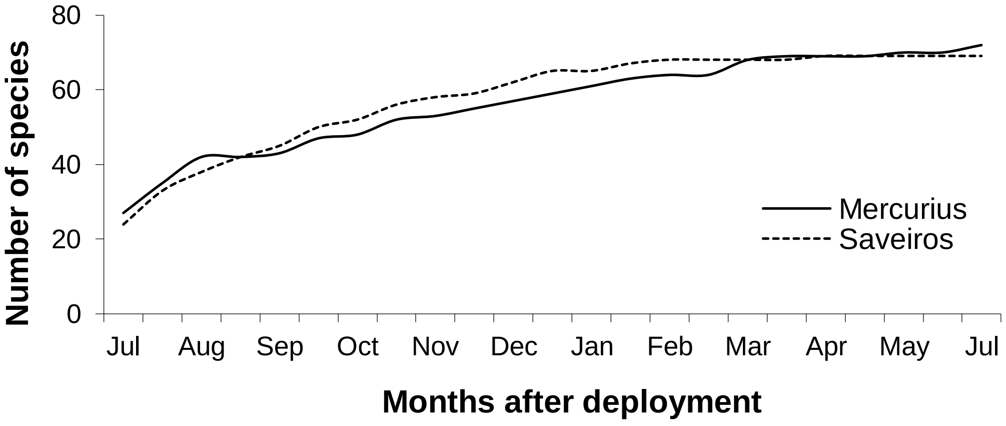

Figure 2-3. Cumulative curve of number of species observed in Mercurius and Saveiros.

During the study, a differential increase in the different trophic categories (Fig. 2-4) was observed. It was possible to distinguish a sharper increase in the number of omnivores, carnivores and mobile invertebrate feeders, with a rise varying from eight to 10 species in each category. The sessile invertebrate feeders, piscivores and planktivores started with few species (one to three species), and by the 11th month had attained four species, for the former group, and an increase of four to six species for the other two. The roving herbivores were recorded from the beginning with five and three species, and gained two and four species, reaching seven species by the 7th month, for both vessels. The territorial herbivores were the last species to appear, with *Stegastes pictus* and *Ophioblennius trinitatis* in Mercurius and only *S. pictus* in Saveiros.

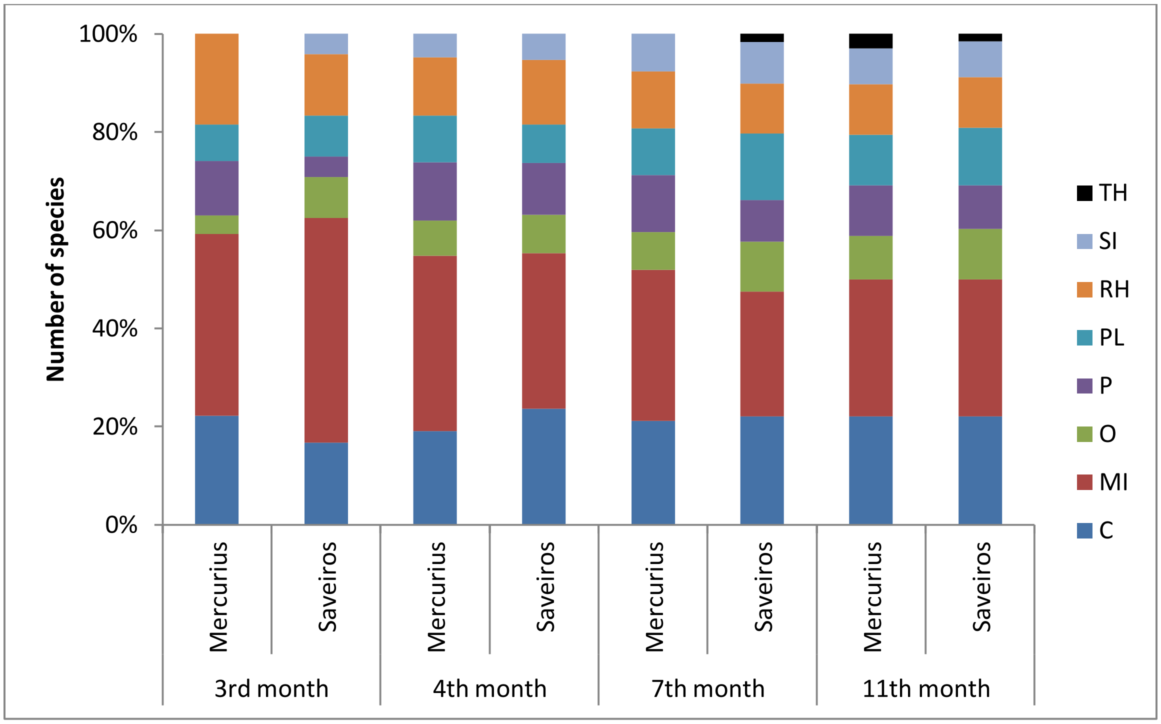

Figure 2-4. Proportion of the cumulative number of species by trophic group, in Mercurius and Saveiros, at the 3rd, 4th, 7th and 11th month. Trophic groups: Territorial Herbivores (TH), Sessile Invertebrate feeders (SI), Roving Herbivores (RH), Planktivores (PL), Piscivores (P), Omnivores (O), Mobile Invertebrate feeders (MI) and Carnivores (C).

Regarding the spatial distribution of the species, the ones belonging to type B were the most numerous, 39 and 38, followed by the type A, site attached species, with 13 and 14 species, respectively, at Mercurius and Saveiros. For Mercurius, there were more type C, pelagic, species (12) than D, substrate related, species (8), while for Saveiros the opposite was found, with 10 type D species and only 7 type C species (Appendix 4). The number of species in each spatial category, throughout the sampling period, was very similar for the two vessels (Table 2-1), with no significant differences between the two (p>0.05). Almost every frequency class was observed in every spatial category (Fig. 2-5 and 2-6), for Mercurius and Saveiros, with the exception of type C that excluded the very common species.

Table 2-1. Number of species of each spatial category registered for Mercurius and Saveiros and result of the Chi-square test, χ^2, degrees of freedom, D.f., and p-value. Spatial categories: A – species with physical contact with the reef, B – species associated to the reef, C – species on the water column and D – species in the surroundings of the reef.

Spatial Category	3rd month		4th month		7th month		11th month	
	Mercurius	Saveiros	Mercurius	Saveiros	Mercurius	Saveiros	Mercurius	Saveiros
A	3	3	4	7	5	13	11	13
B	18	18	26	24	33	33	39	38
C	4	2	7	3	8	6	11	7
D	2	1	5	4	6	7	7	10
Total	27	24	42	38	52	59	68	68
χ^2	0.83		2.42		3.49		1.60	
D.f.	3		3		3		3	
p	0.84		0.49		0.32		0.66	

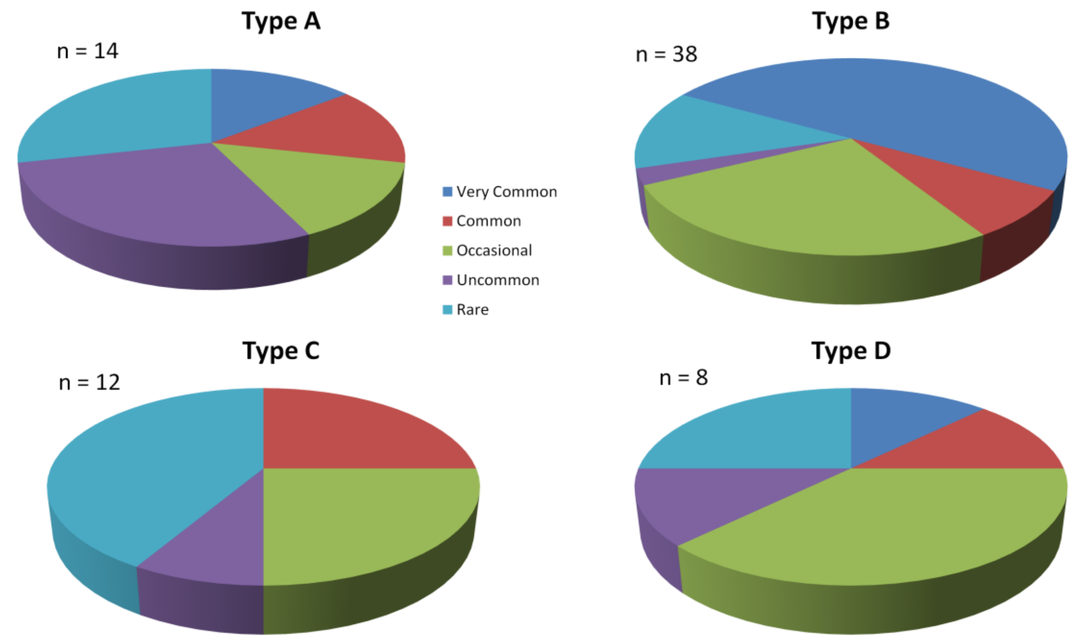

Figure 2-5. Pie charts for the abundance of species belonging to each frequency class, for all spatial categories in Mercurius. N is the total number of species belonging to each spatial category.

For types B or reef associated species, and D or substrate related species there was a very abundant spatial group (very common for the first and occasional for the second) followed by a second abundant group (occasional and/or common for B and rare for D). For group B, the rare and uncommon species were better represented in Saveiros than in Mercurius, and common, uncommon and very common species for type D, in both reefs. Type A, or reef attached, species were represented very differently in the vessel reefs, with uncommon and rare as the more abundant classes followed by very common and occasional for Mercurius while for Saveiros, the most abundant classes were occasional followed by uncommon and then common and rare with the same number. The distribution observed for type C, or pelagic, species was not satisfactory due to the absence of very common species, which represented 25-30% of the total number of species (Chapter 1) and the lack of a pattern for the frequency classes, showing an almost opposite pattern of species frequency classes in the two vessels.

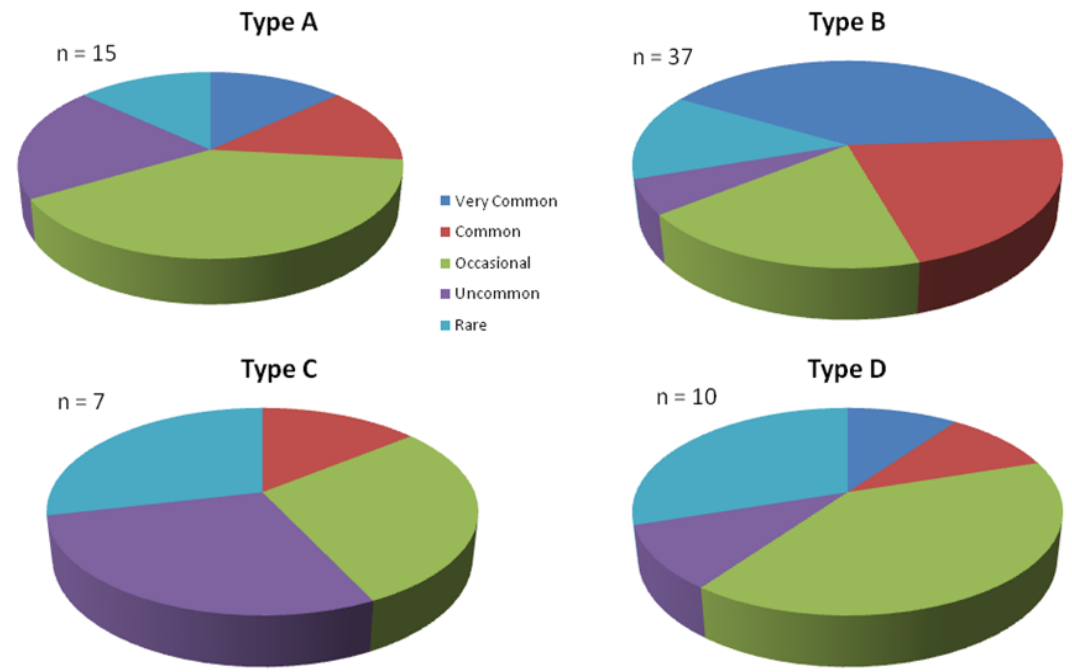

Figure 2-6. Pie charts for the number of species belonging to each frequency class, for all spatial categories in Saveiros. N is the total number of species belonging to each spatial category.

As expected, not all spatial categories are well represented in every trophic group, due to the relation of some feeding habits to predetermined spatial movements. From the eight trophic groups three (mobile invertebrate feeders – MI, omnivores – O and Planktivores – PL) were observed in all spatial categories, one (piscivores – P) in three categories, one (roving herbivores – RH) in two categories and two trophic groups (sessile invertebrate feeders and territorial herbivores) in only one spatial category (Table 2-2). Regarding the remaining trophic group, the carnivores, they were present in all spatial groups in Mercurius but in Saveiros, although carnivorous species were observed in type A, B and D groups, there was no record of pelagic carnivores.

Table 2-2. Number of species belonging to each spatial category and trophic guild, for Mercurius and Saveiros. Spatial categories: A – species with physical contact with the reef, B – species associated to the reef, C – species on the water column and D – species in the surroundings of the reef.

		Carnivores	Mobile Invertebrate feeders	Omnivores	Piscivores	Planktivores	Roving Herbivores	Sessile Invertebrate feeders	Territorial Herbivores
Mercurius	A	7	2	1	1	1	-	-	2
	B	7	14	4	-	3	6	4	-
	C	2	1	1	5	2	1	-	-
	D	1	2	3	1	1	-	-	-
Saveiros	A	7	2	1	1	3	-	-	1
	B	6	15	4	-	2	6	4	-
	C	-	1	1	3	1	1	-	-
	D	2	1	3	2	2	-	-	-

Based on the qualitative analysis, most species showed a similar colonization pattern, with several species that were first registered in one vessel occurring in a brief interval, up to two months, in the other one (Appendix 4). From a total of 80 species, only 13 (16.3%) showed a different pattern in the colonization of Mercurius and Saveiros, with the greatest disparity concerning *Epinephelus adscensionis* and *Gnatholepis thompsoni* that were registered in the 4th month and 6th in Saveiros and only in the 15th and 11th month in

Mercurius, and *Mulloidichthys martinicus* that was listed in Mercurius six months before it appeared in Saveiros.

The 2-dimensional MDS, despite the great similarity (>50%) found among every sample, distinguishes Mercurius from Saveiros (Figure 2-7). The differences found in the 4th dive in Mercurius and the 5th and 7th dive of Saveiros were mostly due to the smaller number of species observed in those dives, ≤22, than in any other which was always superior to 24 species. Although the R-statistic generated by the ANOSIM, R = 0.203, implied little segregation between the two vessel-reefs, the p-value of < 0.05 showed that there was a significant difference between Mercurius and Saveiros.

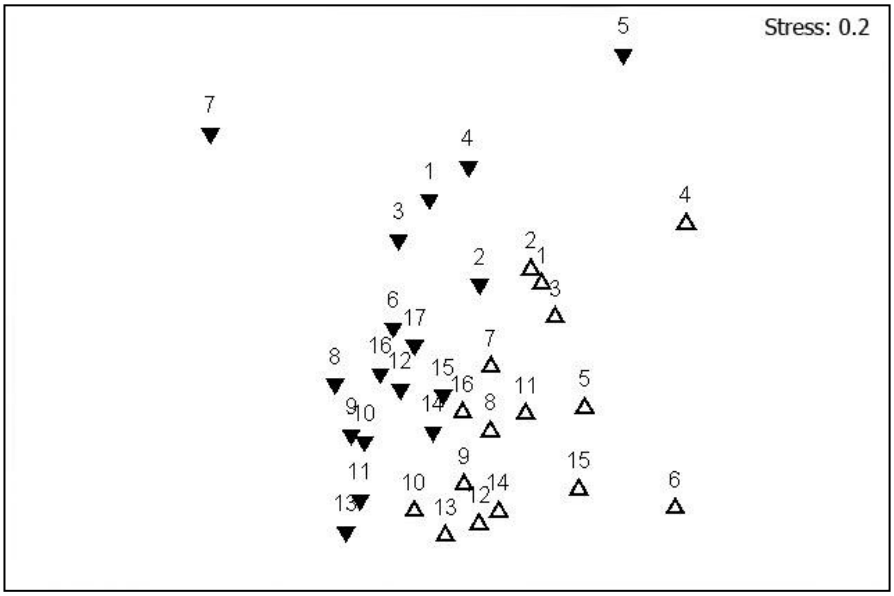

Figure 2-7. The 2 dimensional MDS configuration for the dives (numbers) made in Mercurius (△) and Saveiros (▼).

From the cluster analysis for both vessels (Figure 2-8 and 2-9) it was possible to observe the different capacity of each spatial category to describe the dives throughout the study period. In the clusters using all species, it can be observed that almost every dive for Mercurius and Saveiros showed a similarity of more than 60%, with the exception of dives #5 and 7 in Saveiros, for the above mentioned reason. It can also be noted that in both vessels, the first four dives are separated from the rest (Figure 2-8 – I, II and Figure 2-9 – III, IV).

Type A, reef attached species, presented a similarity of about 50% for most dives in both vessels, with the exception of dive #5 in Saveiros. For type C, pelagic species, there was a similarity of 20% in Mercurius in all dives and about 15% for Saveiros, without dives #5, 13 and 14 for the latter (these represented by IX in Figure 2-9). However, for Mercurius, types A and C showed a gradual separation between dives while for Saveiros there was a more clustered distribution of the dives, showing groups of samples. Type C species showed a different pattern for each of the vessel reefs. For Mercurius, it was possible to see a good connection between most dives, with 12 dives (75%) with a similarity of about 45%, with a similarity among all dives of ≈20%. In Saveiros, with a smaller number of C species, the difference between clusters was larger with three dives (#12, 13 and 14) showing a resemblance of 0% and the similarity for 75% of all dives of only ≈25%. For type A, reef attached, species there was a somewhat different pattern between vessels, with Mercurius showing a gradual separation of the dives, with about 80% of the dives having a similarity of ≈60% and Saveiros presenting the groups in clusters, with a reasonable temporal continuity for the dives, with nearly 80% of the samples showing a similarity of ≈50%.

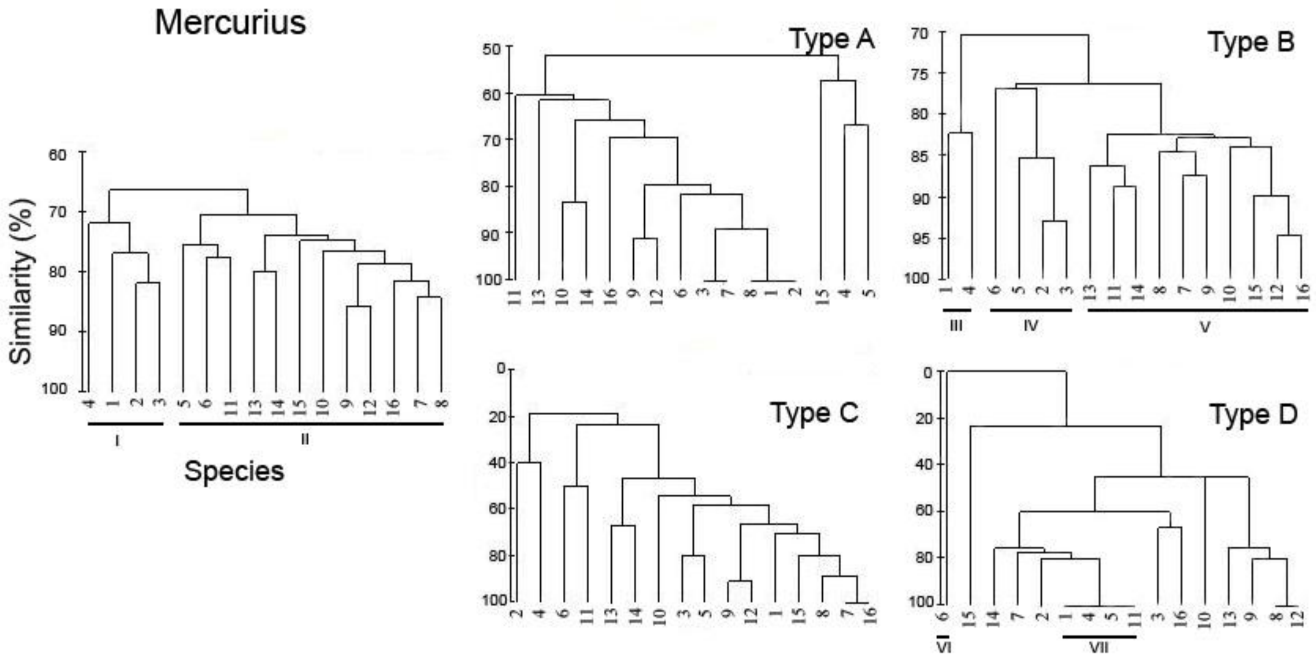

Figure 2-8. Cluster analysis for Mercurius, for all species and type A, B, C and D species.

The cluster analysis for type D showed an extremely high similarity between many of the samples, with Saveiros having more type D species than Mercurius, and both showing complete similarity for some of the dives (Figure 2-8 – VII and Figure 2-9 – X).

Type B species, for Saveiros, distinguished the first dives in one cluster and the last dives in another (Figure 2-8 –VII, VIII), with the exception of dives #5 and 7 as mentioned above, showing a strong similarity of more than 65% between all dives. For Mercurius, despite the similarity of about 70% between every dive, it is possible to see three groups (Figure 2-8 – III, IV, V). By comparing the cluster analyses using every species and type B species, it is possible to see the resemblance of both plots on the distribution of the dives in the study period, with an almost complete match for Saveiros (Figure 2-9 – I, II, III, IV with V, VI, VII, VII) and a small difference but with very good similarity between the groups of Mercurius (Figure 2-8 – I, II and IV, V).

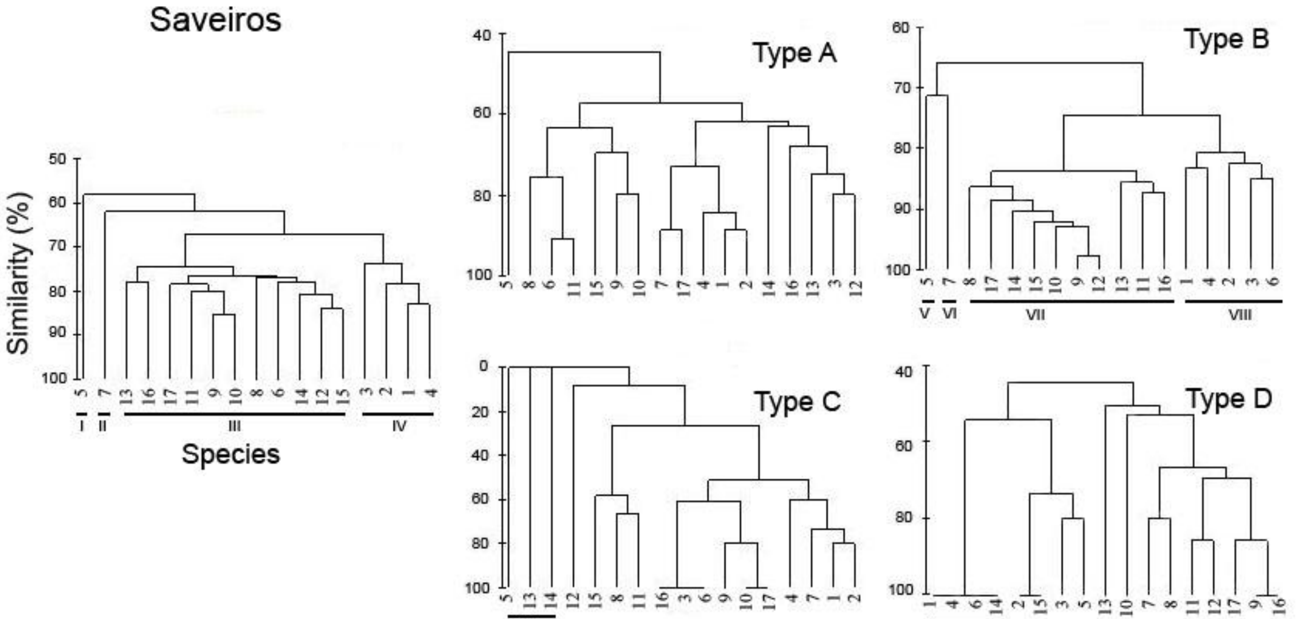

Figure 2-9. Cluster analysis for Saveiros, with all species and type A, B, C and D species.

DISCUSSION

Species colonization

The fish colonization in both vessels was similar, with a rapid increase in the first months and a more moderate growth in the following months for Mercurius and a constant increase throughout the study period for Saveiros. Less than one year after deployment, the fish assemblages in both vessels appear to have reached stability within a timeframe already observed both in tropical and temperate environments (Randall, 1963; Ogden & Ebersole, 1981; Golani & Diamant, 1999; Jardeweski & Almeida, 2005; Leitão *et al.*, 2008;).

The two vessel reefs presented similar results regarding trophic and spatial distribution, with the main difference being found regarding the species present in each reef. This agrees with Sherman *et al*. (2001) who found that different results may be obtained for artificial reefs within the same geographical area.

In a study conducted by Randall (1963) on an artificial reef in the U.S. Virgin Islands, the author registered all species arriving on the reef until the 10th month, but from then until the 14th month no increase in the number of species was observed, with only a change in the number of individuals and a “reduction in the number of small fishes and an increase in the larger ones” (Randall, 1963; Ogden & Ebersole, 1981).

The results from the present study were compared to those of Randall (1963) due to their resemblance regarding climatic conditions, as both studies were located in tropical areas, and deployment time, with Randall Reef being deployed in April and our vessels in May. Although it was not possible to sample the artificial reefs in the initial period of the study, due to bad sea conditions and water visibility, the reefs were compared from the third month on. The species encountered in the first months in the vessel-reefs were mostly the same, with *Holocentrus adscensionis*, *Pseudupeneus maculatus*, *Ocyurus chrysurus*, *Chaetodon striatus*, *Alphestes afer*, *Halichoeres poeyi*, all the three species of Acanthuridae, and even *Thalassoma noronhanum*, the sister species of *T. bifasciatum* (Costagliola *et al*., 2004) being registered from the beginning of the dives, just as described by Randall (1963). Despite the similarity in the pattern observed in Randall Reef and our reefs, some species showed a marked difference in the time of arrival to the new habitat (e.g., most *Halichoeres* and *Ophioblennius trinitatis*).

The Labridae are an interesting case, with the appearance of *H. poeyi*, the generalist wrasse found both in inshore reefs and seagrass beds (Randall, 1967), in the beginning of both studies, which in our case is probably related to its high frequency of occurrence and abundance in the northeastern coast of Brazil (Feitoza, 2001; Feitosa, 2005; Engmann, 2006), where it occurs from shallow to intermediate-deep reefs (Feitoza, 1999).

Another species with the same early arrival, for the same reasons as *H. poeyi*, was the reef-specialist *H. brasiliensis*, with its sister species *H. radiatus* (Rocha *et al*., 2005) being the last *Halichoeres* to arrive in Randall Reef. An inverse pattern was observed with *H. bivittatus* and *H. maculipinna* which were present in Randall Reef from the 1st and 2nd month but that only arrived in both our vessel-reefs in the 8th and 6th months. It is believed that this difference in arrival time is related with the distribution of these species and especially in the location of the reef, because Randall Reef is situated at depths of around 9 m and our reefs are at a distance of more than 5 nautical miles from the coast and at a depth of nearly 30 m. *Halichoeres bivittatus* was reported as having a smaller abundance than other species of the genus *Halichoeres* in both coastal reefs of Pernambuco (Engmann, 2006) and in 15 m deep shipwrecks in Paraíba (Feitoza, 1999). Even though it is a generalist species occurring in reef and non-reef habitats (Rocha *et al*., 2005), this species is probably not able to compete with the already established *H. poeyi* and *H. brasiliensis*, only succeeding after settlement of the other *Halichoeres* species. As shown by Nagelkerken *et al*. (2000b), the utilization of the biotope is very specific to different species and even closely related species seem to have a clear spatial separation resulting from avoidance of competition.

The early presence of *H. maculipinna* in Randall Reef can be due to the fast colonization of their preferred benthic invertebrate prey, polychaetes (Randall, 1967) on the artificial reef, which has been shown to begin as soon as two weeks after the deployment of concrete modules in a study in Hawaii (Bailey-Brock, 1989), with environmental variables (e.g., depth and grain size) affecting polychaete species composition (Fukunaga & Bailey-Brock, 2008). In our study, its pair sister species *H. penrosei* (Rocha, 2004) was only observed from the 6th month on, which could be due to misidentification in the first dives of juveniles of *H. penrosei* and of *Thalassoma noronhanum,* which have a great resemblance in their color pattern.

The late appearance in the deep vessel-reefs of *Ophioblennius trinitatis,* a hard bottom and crevice associated species (Ferreira *et al*., 1995), and *Stegastes pictus*, a damselfish that usually inhabits cold and deep waters (Ferreira *et al*., 1998; Feitoza, 1999), is probably due to their limited mobility and small home range often associated with territorial herbivores (Labelle & Nursall, 1985; Osório *et al*., 2006). However, their arrival in the reefs was probably related to the patches of algae existing in the substratum, that can provide shelter for many marine invertebrates and small fishes (Parrish, 1989) and allow them to forage in unvegetated areas, acting thus as “sheltered bases” (Orth *et al*., 1984).

Trophic patterns

From the continuous analyses of the number of species belonging to each of the trophic groups, it can be observed that the numbers of mobile invertebrate feeders and roving herbivores decrease in total relative abundance as can be expected for these species that are usually associated with sand and algae beds and can swim large distances, up to several kilometers, to forage (Hobson, 1973). Even so, the number of mobile invertebrate feeders increased more than the number of roving herbivores, which is probably related to the increase in the number of mobile invertebrate species (e.g., shrimps, sea urchins) due to the continuous formation of sand cavities on the base of the reef by currents and by the enhancement of the surface area for benthic organisms that provide shelter for both fishes and mobile invertebrates (Bohnsack *et al*., 1994; Burgess *et al*., 2003; Figley, 2003).

The eight species of roving herbivores recorded in this study represent most of the known species for the northeastern coast of Brazil, with the pelagic species

Kyphosus sectatrix, the whole Acanthuridae family and four of the seven species of Scaridae (Moura *et al*., 2001) being present. The scaridae *Cryptotomus roseus*, *Scarus trispinosus* and *Sparisoma amplum* had not arrived in the two vessel reefs after one year of study. The absence of *C. roseus* can be explained by its preference for waters deeper than 30m (Feitoza, 1999), proved by their lack of occurrence in shallow coastal reefs such as Porto de Galinhas – PE (Engmann, 2006), Tamandaré – PE (Ferreira & Maida, 2006) and Maragogi – AL (Feitosa, 2005). On the other hand, the lack of *S. trispinosus* and *S. amplum* is probably time related. This shows that this trophic guild was well represented in our study. An interesting observation is that juvenile scarids usually use the algae beds, in the vicinity of the vessel reefs as both shelter and feeding grounds with these sites acting as nurseries, as has been observed by Ogden & Zieman (1977) in St. Croix, Virgin Islands.

The strong initial presence in the vessel reefs and gradual decrease during the course of the study, of both mobile invertebrate feeders and roving herbivores, shows that these species probably used the reef and were important in the colonization process, having a fundamental role in the energy transfer to the reef. Mobile invertebrate feeders, such as haemulids, holocentrids and scianids, are known to be important commuters that shelter on/near the reef and forage in the surrounding areas, acting as transport agents of nutrients to the reef (Parrish, 1989; Meyer *et al*., 2000; Beets *et al*., 2003).

The trophic groups that showed an increase in relative abundance were the omnivores and the planktivores. This increment in the number of species was probably related to greater food availability in the vessel reefs over time, with both plant and animal material for the omnivorous species and with an increase in the biomass of phytoplankton available in the water column above the reefs, for the planktivores. Large planktivorous feeding aggregations have been associated to the increase of nutrients in the vicinity and in reefs, by providing the nutrients that potentially limit the growth of macroalgae and also as part of the food web by feeding mobile invertebrates (Bray & Miller, 1985). According to Kingsford & MacDiarmid (1988), planktivore biomass can also sustain populations of piscivorous fishes. However, in our study the relative abundance in the number of piscivorous species decreased over time, but this is probably more related to the fact that most of these species (>50%) are pelagic (e.g., Carangidae and Scombridae) and their sighting can be considered, most of the times, occasional, as reported by Bohnsack & Bannerot (1986). Nevertheless, as pointed out by Campos & Gamboa (1989) and Herrera *et al*. (2002), artificial modules can act as aggregation points for pelagic species such as carangids.

All four species of sessile invertebrate feeders were already present by the 7th month, with *Holancanthus tricolor* being the last species to arrive, probably due to the fact that it is not very abundant in coastal reefs of the northeastern coast of Brazil, with no quantitative data of its presence in the coast of Pernambuco, such as at Porto de Galinhas and Tamandaré (Engmann, 2006; Ferreira & Maida, 2006;). However, in a study in the coast of Rio Grande no Norte, Feitoza (2001) observed that in every habitat he sampled *H. tricolor* was always the least abundant species of three species of Pomacanthids.

Spatial categories and census detection

The use of visual census have been proved cost-effective for estimates of biodiversity and abundance of reef fish communities (Bohnsack *et al*., 1999) and has been assumed as the best non-destructive method for population assessment (Brock, 1982) being superior to several other techniques in habitats of great heterogeneity (De Girolamo & Mazzoldi, 2001). Nevertheless, the data gathered by this method has to be accepted, most of the time, without an independent confirmation through another technique (Smith-Vaniz *et al*., 2006) and several sources of bias have been identified, such as observer presence and speed (Lincoln Smith, 1988) and fish behavior (Russell *et al*., 1978; Kulbicki, 1998; Willis *et al.*, 2000). As previously mentioned, visual census techniques also tend to underestimate the number and abundance of cryptic species (Kulbicki, 1990; Willis, 2001; Ackerman & Bellwood, 2002; Smith-Vaniz *et al*., 2006) and also of nocturnal species, such as Holocentridae and Apogonidae, that tend to remain hidden during the day (Kulbicki, 1990), which in our case was inside the cabin and deck, making them difficult to detect and count. As a result, we have evaluated the biological community by a mixture of visual census methodologies that we found to be suitable for the studied reefs in order to reduce the inherent error associated with simple techniques. The monthly sampling was proven satisfactory for our methodology, allowing us to observe the shaping of the community structure (Brotto *et al*., 2007) throughout the study period.

In this study, we chose to add another category to the Nakamura classification because even though there are some resemblances between type A and type D species, we noted that most species were found consistently in one habitat (vessel reef or the surrounding area) making it necessary to separate such species for a better analysis.

Through the cluster analysis for each vessel it was possible to observe a pattern in the distribution of the dives. In an individualist analysis, we saw that clusters of type A and type C species indicate a similar pattern regardless of their similarity between dives, which is probably related to their behavior pattern at a diver's approach, with type A species hiding in crevices/holes and type C species fleeing the site. This creates a larger chance to observe these species, during a sampling dive in a known vessel reef area, than type C species that can easily disappear in the water column, returning only after the last diver has emerged.

The clusters for type C species obtained for both vessels were not very satisfactory for the colonization process because although they created groups of dives, those dives did not have a temporal continuity. However, an interesting pattern arose with Saveiros, open for recreational diving, having not only a smaller number of pelagic species but a lower similarity between dives than Mercurius. This shows that although it is easier to identify and register pelagic species in non impacted sites such as Mercurius, in neither reef is the use of pelagic species as an indicator of the colonization desirable. It has been previously reported that several highly mobile pelagic species (e.g., Carangidae) can be erroneously enumerated by underwater visual census (Buckley & Hueckel, 1985; Kulbicki, 1998) or avoid divers in locations with some degree of anthropogenic impact, most usually regarding fishing (Russell, 1977 *in* Russell *et al*., 1978; Guidetti *et al*., 2008).

Type A species were consistently more numerous in Saveiros than in Mercurius throughout the study period, and even species that were similar to both vessel reefs were always registered first in Saveiros, with the exception of *Ginglymostoma cirratum* and some species that arrived at the same time in the reefs. The cluster analysis for this group shows a different pattern for each of the studied vessels, even though they started with the same number of species. Whilst in Saveiros there was the partitioning of the dives in two main clusters, in Mercurius although there were also two clusters, there was a more gradual separation of the dives. The fact that there is no temporal continuity in either vessel is probably related to the large number of species observed only after six months (approximately 50%) and also to the stabilization of the community, composed by these species, both with the appearance of new species and the restructuring of the old ones.

In type A species we included: (1) species that use complex spaces in the reef for shelter, such as *Holocentrus adscensionis*, *Myripristis jacobus*, *Pempheris schomburgkii* and *Odontoscion dentex* that can be found hiding or aggregating, for the two latter, in large enclosed spaces; (2) species like *Pareques acuminatus* and *Apogon americanus* that hide very well in crevices of the reef (Randall, 1963); (3) species that show a strong dependence of the reef such as *Amblycirrhitus pinos* that rests upon hard substratum (Randall, 1967) or *Stegastes pictus* and *Ophioblennius trinitatis* that forage in small areas; and (4) ambush predators that can remain in the reef for long periods of time, such as *Epinephelus spp*. and Muraenidae, (Heemstra & Randall, 1993; Juanes *et al*., 2002). Although these species can often be observed in pre-determined sites in the reef, for the first two types, others that are usually in a more exposed location can easily hide from view using either the reef structure or benthic cover, mostly for the two latter. This presents a whole array of detection possibilities, the outcome of which is not only related to the recognition ability of the diver and chosen census methodology, but also to the chance that the species is actually there. The fact that some of the species included in this category, such as *O. trinitatis* have a very limited home range (estimated forage area is 4 m^2 (Mendes, 2006)) or *S. pictus* with an area of approximately 2 m^2, and taking into account that it probably has a similar foraging pattern as its substitute in shallow depths *S. fuscus* (Osório *et al*., 2006), probably indicates a slower process of colonization of the intermediate vessel reefs by these and similar species.

Regarding type D species, it was possible to see strong similarities for both vessels, with larger number of species and similarities for the dives in Saveiros than in Mercurius, and a similar pattern for the two. This type of species is characterized by substrate related behaviors, associated with protection, such as burying in the sand, digging holes or even hiding themselves in burrows made by other organisms and feeding. All species in this group obtain their food by close association with the substrate, either by directly foraging for invertebrates or animal/plant material, like *Pseudupeneus maculatus* or *Dasyatis americana* and gobiids; by preying upon fishes venturing too near, like *Synodus intermedius* or *Scorpaena plumieri*; or even by hovering above their burrows feeding on zooplankton, such as *Opistognathus aurifrons* and *Ptereleotris randalli* (Randall, 1967; Gasparini *et al*., 2001). Type D species show the greatest cryptic patterns, due to their coloration pattern and escaping means, being the least abundant group, with the exception of pelagic species for Saveiros. Also, the stronger resemblance between the first dives is explained by the lower number of species which suggests the possibility of either a fairly long period for their arrival in the vessel reefs or underestimation of the real number of species due to their cryptic habits.

Many type A and D species are well camouflaged and tend to hide at the approach of an observer. According to Kulbicki (1998), in disturbed areas the detection of cryptic species (e.g., Serranidae and Synodontidae) tends to increase because fishes tend to move and become conspicuous, instead of remaining still and concealed by their color and behavior. This finding can be applied to this study with some species, such as *Synodus intermedius*, *Epinephelus adscensionis*, *Amblycirrhitus pinos* and *Stegastes pictus*, which were recorded in Saveiros before being observed in Mercurius, an undisturbed area with restricted number of divers. This can also, to some extent, justify the presence of *Scorpaena plumieri* and *Antennarius multiocellatus*, two mimic species known for their sedentary nature (Randall, 1967).

The major group of species, type B, was the best represented of the fish community throughout the study, having not only the greatest similarity but also a good temporal aggregation for most dives, in both vessels. These species are linked to the reefs but normally do not hide or flee in the presence of divers for which they have been considered as “neutral fishes’’ by Kulbicki (1998) who studied the behavior of some species in the presence of divers and the implications in terms of bias. He considered these fishes to be conspicuous by their shape or color (e.g., acanthurids, chaetodontids and scarids) and not affected by the presence of a diver, neither positively in the case of “curious fishes” nor negatively by “shy fishes”. By having representatives of most trophic guilds, with the exception of piscivores and territorial herbivores, and with a full range of frequencies of occurrence, this group has proven to be quite capable of showing possible changes in the community structure, especially in artificial sites where sampling can be complicated, as in the case of vessel reefs that have a complex structure and are located at intermediate depths that do not allow long periods of immersion using SCUBA for accurately sampling the whole reef and the surroundings.

Regarding the differences between the vessel reefs, this study indicates that the impact caused by divers is not perceptible, at least, during the first year of immersion of the reefs, for the two communities have a large resemblance in terms of trophic categories and overall community structure. It is important to highlight, though, that an advanced level of diving skills (e.g., Advanced Open Water Diver in PADI certification) is needed to dive in these reefs due to the depth of the sites. This probably influences the possible impact that the divers can have, both in benthic and fish communities. Although there is no consensus about the difference of impact between inexperienced and experienced divers, a greater negative influence of the first in the surrounding area has been reported (Schaeffer & Foster, 1998). According to Rouphael & Inglis (1997), the chances of a diver to come into contact with reefs is determined by personal attributes, such as its technical competence as a diver, the activities he pursues whilst at the diving site (e.g., photography, exploration) and his awareness of the environmental consequences of his actions.

The main goal of this chapter was to assess the main species in terms of trophic group and spatial category, in order to better understand the colonization process in the coast of Pernambuco, tropical southwestern Atlantic. As expected, with the lack of structural reefs for the enrichment of the continental platform, the deployment of vessel reefs can work as oasis in attracting/producing reef fishes, increasing the number of species present by at least 20 species in less than three months. By the presence/absence analysis we could comprehend the temporal changes inherent to the reef community development, allowing a greater focus on the species ecology rather than group or quantity dynamics.

CHAPTER 3. COMPARATIVE STUDY BETWEEN DIFFERENT REEFS IN THE NORTHEASTERN COAST OF BRAZIL

INTRODUCTION

The Brazilian coral reefs have a unique character, which is the relatively low diversity of their coral fauna, although they are rich in endemic species, including the southernmost reef communities of the Atlantic Ocean. The northeastern coast (between 5 and 12º S) presents several types of reef structures with coastal isolated bank reefs of different shapes and dimensions, forming up to three lines of reefs along the coasts of Rio Grande do Norte, Paraíba, Pernambuco and Alagoas (Leão & Dominguez, 2000).

The tropical fish fauna of the western Atlantic is distributed from 35° N to 28° S, with a considerable part included in Brazilian waters, mostly from below the Amazon River mouth at Manuel Luiz Reefs (0°52'S) to Santa Catarina State (27º30' S) (Ferreira *et al*., 2004; Floeter *et al*., 2001). Several studies have described the differences in reef fish communities along latitudinal gradients in Brazil (e.g., Floeter *et al*., 2001; Ferreira *et al*., 2004; Floeter *et al*., 2004), using diverse characteristics such as trophic or feeding strategies, spatial use and mobility, resulting in the recognition of the northeastern coast as a region with a distinct species composition.

Few, if any, fish families are obligate coral reef dwellers (Bellwood, 1998), with many species having a larger distribution associated with hard substrata and even sand plains, mangroves and seagrass beds (Lowe-McConnel, 1999). However, the concept of the existence of some key reef families is widely accepted. The major taxa that constitute this group are the chaetodontid fishes (Chaetodontidae and Pomacanthidae), the acanthuroids (Acanthuridae and the Indo-Pacific families Siganidae and Zanclidae) and the labroids (Scaridae, Pomacentridae and Labridae) (Choat & Bellwood, 1991).

Although the evaluation of the performance of an artificial reef should vary according to the purpose for which it was built, a comparison of these structures with natural reef systems, preferentially undisturbed, in local and regional scales is always useful (Carr & Hixon, 1997). According to these authors, this type of comparison can not only increase the knowledge on the fish communities present in the area but also determine the spatial scales over which artificial structures act to attract reef species.

To understand the dynamics and resemblance between natural and artificial reefs in northeastern Brazil, a comparison was made among different reefs (shallow, intermediate and deep; artificial and natural), using reef fish species inventoried in several different studies.

DATA ANALYSIS

Data collection

For this study the list of species observed, by visual census, in reefs from several locations in the northeastern coast of Brazil was assembled from the available literature (Table 3-1) and compared to the results obtained by the present study from three artificial reef vessels (Taurus, Mercurius and Saveiros). Species sampled in other studies by other means than visual census (e.g., clove oil) were not included.

Table 3-1. State, distance from the shore, depth and type of the compared reefs in this study, and corresponding census methodology (from available literature).

	State	Distance (km)	Depth (m)	Type	Methodology
Porto de Galinhas **Engmann, 2006**	PE	< 0.2	2-9	Natural	Transect
Maragogi **Feitosa, 2005**	AL	3.5	1-5	Natural	Stationary
Picãozinho **Souza *et al.*, 2007**	PB	1.5	6	Natural	Intensive search
Maracajaú **Feitosa, 2002**	RN	7	1-4	Natural	Stationary
Zumbi **Feitoza, 2001**	RN	24	9-15	Natural	Stationary
Pirapama **Maranhão *et al.*, *in prep***	PE	6	23	Artificial	Transect
Vapor de Baixo **Maranhão *et al.*, *in prep***	PE	5	23	Artificial	Transect
Servemar X **Maranhão *et al.*, *in prep***	PE	7.5	25	Artificial	Transect
Marte **Véras, unpubl.**	PE	12	33	Artificial	Transect/ Intensive search
Reboque Florida **Maranhão *et al.*, *in prep***	PE	14	33	Artificial	Transect
NE deep reefs **Feitoza, 1999**	PB	-	> 40	Natural	Stationary
Taurus **This study**	PE	5	24	Artificial	Transect/ Intensive search
Saveiros **This study**	PE	8	28	Artificial	Transect/ Intensive search
Mercurius **This study**	PE	8	28	Artificial	Transect/ Intensive search

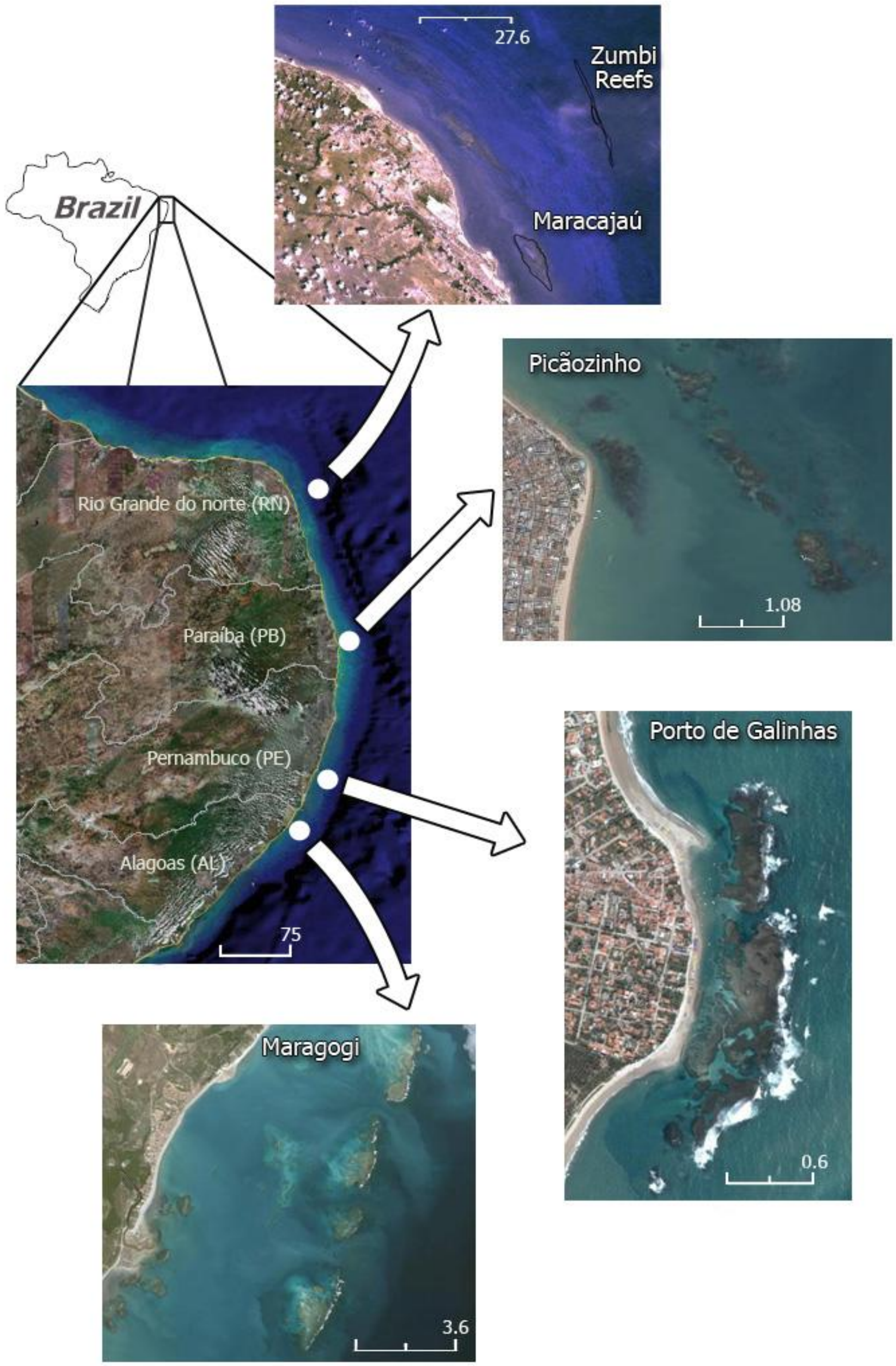

Figure 3-1 – Location of the several natural reefs compared in this study, with the shallow/coastal reefs, Parrachos de Maracajaú, Picãozinho, Porto de Galinhas and Galés de Maragogi and the intermediate natural reef, Zumbi.

For shallow and/or coastal reefs, depths up to 10 m, Porto de Galinhas - PE, Maragogi – AL, Maracajaú – RN and Picãozinho were used (Fig. 3-1). For the deeper reefs, > 40 m, the list of species was obtained from a study in the coast of Paraíba (Feitoza, 1999). Regarding the intermediate depth reefs, from around 20 to 30 meters deep, two geographical zones were used: Recife's coast with artificial vessel like reefs (Fig. 3-2) and Zumbi's natural reefs from available literature (Fig. 3-1). The eight vessel reefs used were: Marte; Pirapama, Servemar X, Vapor de Baixo and Reboque Florida; and Mercurius, Saveiros and Taurus, with lists compiled during the current project (Table 3-2).

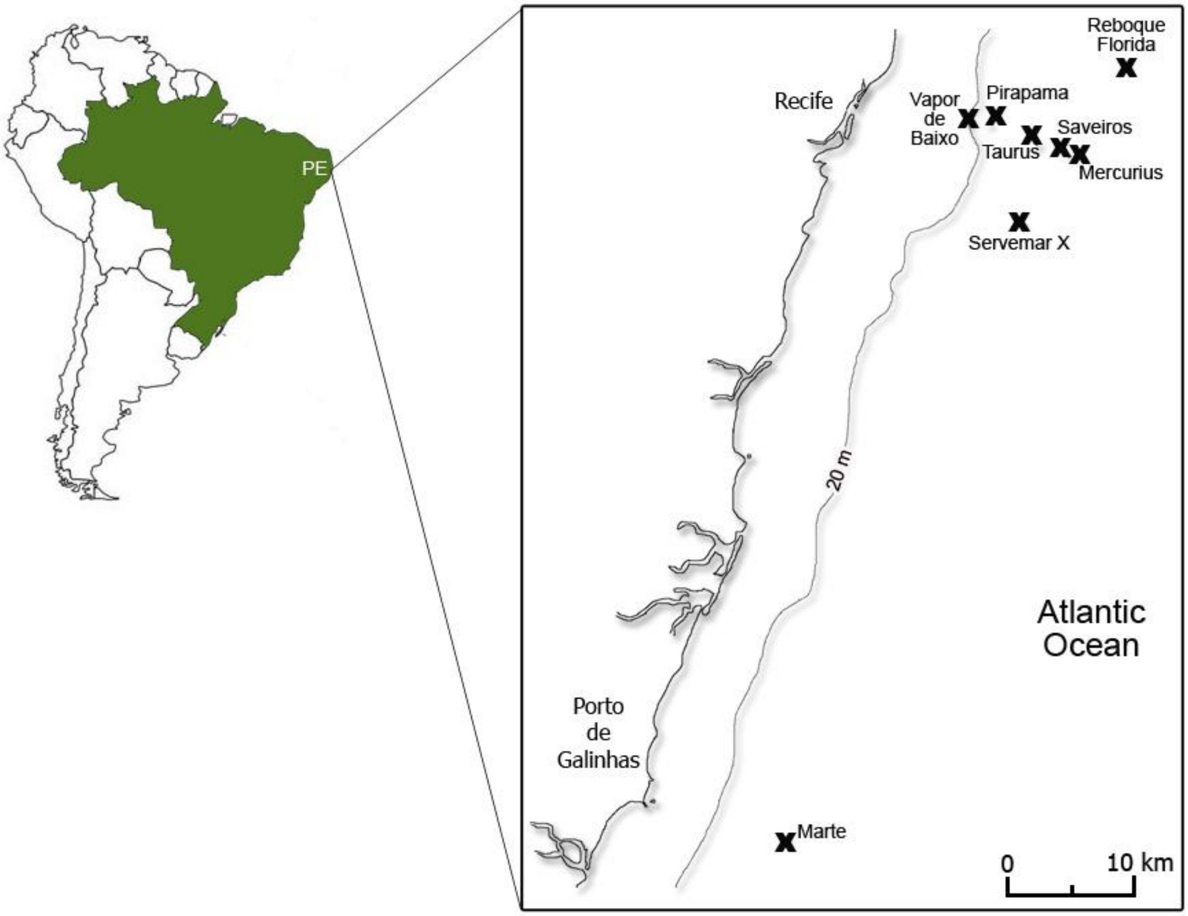

Figure 3-2 – Location of the eight vessel reefs, in the Coast of Pernambuco, compared in this study.

Table 3-2– Location and deployment date of the vessel reefs used in this study.

Vessel reef	Latitude (S)	Longitude (W)	Deployment date
Pirapama	08°03.383'	034°46.967'	Around 1889
Vapor de Baixo	08°03.283'	034°47.650'	Around 1850
Servemar X	08°07.317'	034°45.767'	10.01.2002
Marte	08°35.517'	034°54.717'	13.04.1998
Reboque Florida	08°01.017'	034°41.783'	28.06.1917
Taurus	08°04.193'	034°45.196'	03.05.2006
Saveiros	08°04.517'	034°44.327'	03.05.2006
Mercurius	08°04.725'	034°44.022'	03.05.2006

Analyses

To assess the ecological similarity of fish assemblages among different reefs (shallow, intermediate, deep and artificial, natural reefs) lists of species with presence/ absence data were used for a hierarchical cluster analysis. The Bray-Curtis similarity and group average routine were used for the cluster analysis and a two-way ANOSIM (Analysis of Similarity) was conducted to assess possible differences due to the type and depth of the studied reefs. To evaluate if there was a difference in the species composition between the sites in terms of the typical reef families, a separate analysis was run, using only species belonging to the Acanthuridae, Chaetodontidae, Labridae, Pomacanthidae, Pomacentridae and Scaridae families. Two-way ANOSIM and a SIMPER (Similarity Percentage Analysis) routines were used to identify differences regarding type and depth of reefs and species that most contributed for the differences, respectively. All these multivariate analyses were conducted using the PRIMER 6β ® software (Clarke & Warwick, 2001).

To spatially evaluate the differences between reefs, and corresponding groups of species that might influence their distribution, a correspondence analysis (CA) was used on the available data with the Multivariate Statistical Package, MVSP 3.13®. No data transformation or species weighting were used due to the data being only presence/ absence.

As the values obtained for the species that mostly contributed for the separation of the reefs was rather uneven, with points obtained from the correspondence analysis representing from one to more than ten species, a spatial density graph was plotted in Surfer 8® software. For this plot, the spatial coordinates and associated number of species resulting from the CA were used, and squares of 0.1x0.1 were stipulated where the number of species was added as to represent the total of species per square. The Kriging gridding method was used to create the grid from which the plot was build, using as minimum and maximum values for X and Y the limits of the CA graphic already obtained in MVSP 3.13® (Appendix 5).

RESULTS

From the cluster analysis, using all 196 species, it was possible to separate the different reefs types, with all the reefs, except the deeper ones (Fig. 3-3, I), showing a similarity of more than 50%. The shallower reefs had a resemblance of more than 60% (Fig. 3-3, II). The intermediary reefs, both artificial and natural, were all in the same cluster with similarities ranging from 60 to 85% (Fig. 3-3, III).

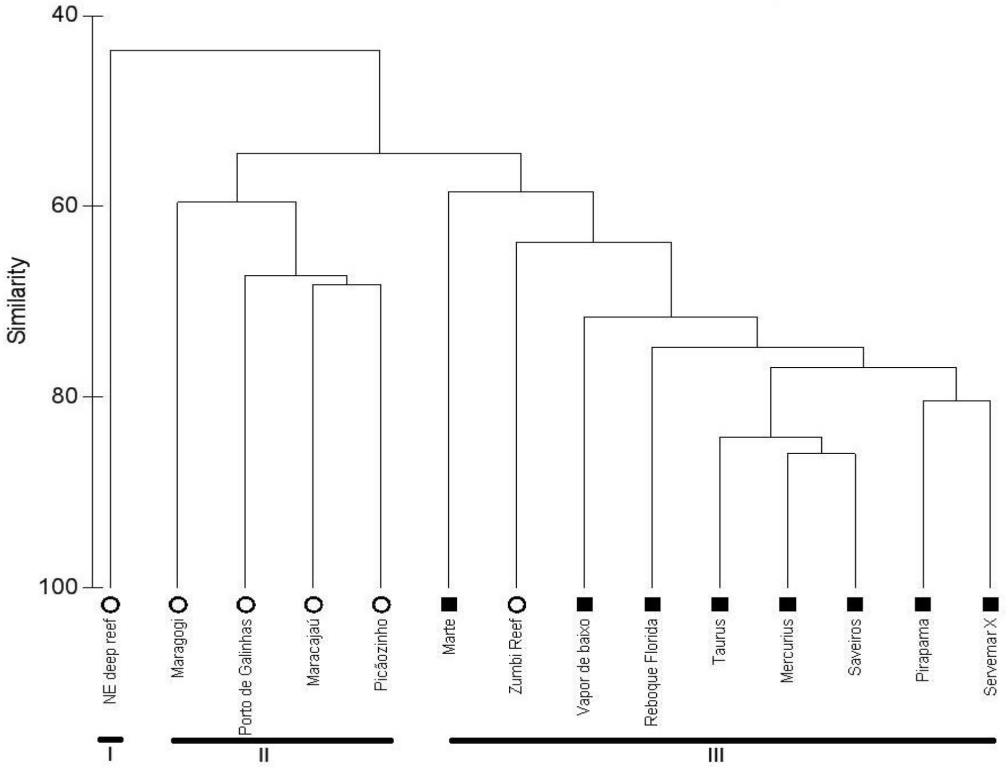

Figure 3-3 – Cluster analysis for the 14 compared reef environments, with both artificial (■) and natural (○) reefs, using all families: I – deep reef; II – shallow/coastal reefs; III – intermediary reefs.

In the cluster analysis, using only the typical reef families, four groups were formed with the deep reefs and Marte (Fig. 3-4, I and II) having a similarity of 58 and 63%, respectively, and the natural and/or shallow reefs as a third group (Fig. 3-4, III) with similarities ranging from 75 to 92%. The other seven artificial reefs formed the fourth group (Fig. 3-4, IV), showing a strong similarity of more than 85% between elements of the set.

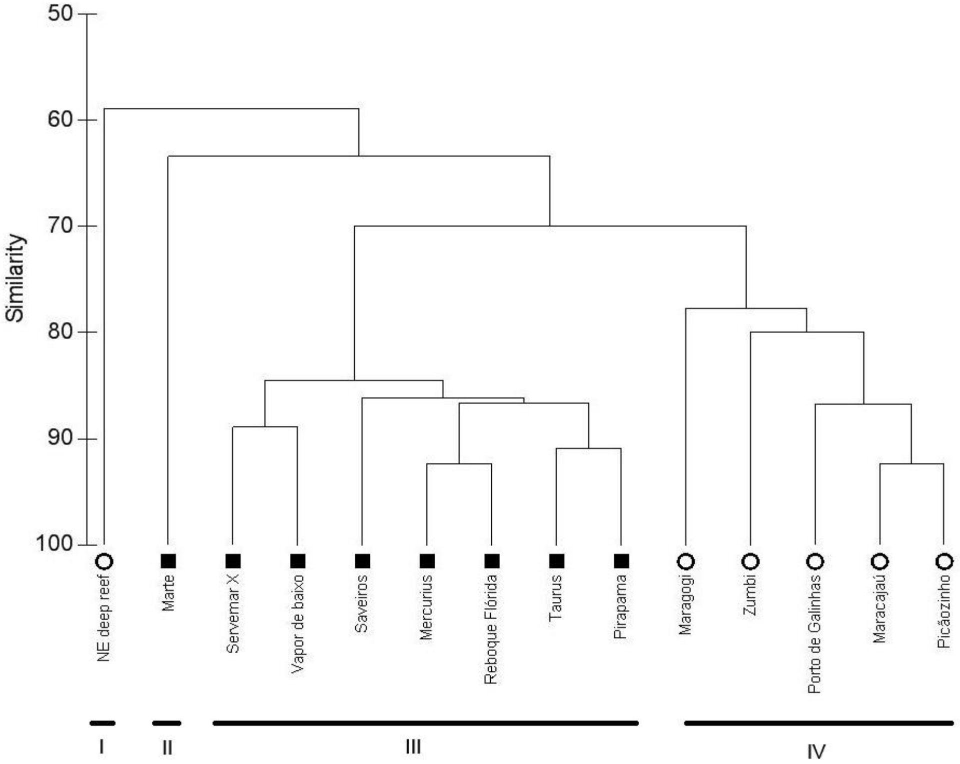

Figure 3-4 – Cluster analysis for the 14 compared reef environments, with both artificial (■) and natural (○) reefs, using only the typical reef families (Acanthuridae, Chaetodontidae, Labridae, Pomacanthidae, Pomacentridae and Scaridae): I – deep reef; II and III – intermediary artificial reefs; IV – coastal and intermediary natural reefs.

The two-way ANOSIM results, for all families and using only typical reef families, showed that although both reef type and depth accounted for some of the variations, there were no significant differences for either parameter (Table 3-3), with depth showing, nevertheless, a greater influence than the type of reef.

Table 3-3 – Two-way ANOSIM results for the type and depth of the studied reefs, using all families and only typical reef families.

	Parameter	Global R	p value
All families	**Between type**	0.54	0.22
	Between depth	0.93	0.07
Reef families	**Between type**	0.46	0.22
	Between depth	0.74	0.13

Due to the larger number of artificial intermediate depth reefs than natural intermediate depth reefs, eight versus one, some important reef associated species, only present in the natural reef, obtained a low result in the SIMPER analysis (Appendix 6). The four species that contributed most were *Centropyge aurantonotus*, *Chaetodon ocellatus*, *Microspathodon chrysurus* and *Stegastes variabilis*, all present only in the natural intermediate reef. The three species that were not present in the natural reefs but were present in the artificial ones were *Chromis jubauna*, *Halichoeres bivittatus* and *Scarus trispinosus*. *Stegastes fuscus* and *Sparisoma amplum*, despite being present in both natural and artificial reefs, showed a preference for the former, as they were present in only three and one vessel reef, respectively.

The results of the correspondence analysis (Fig. 3-5) showed a spatial pattern of the reefs with the configuration of three groupings that corresponded to: the shallow and/or coast sites, intermediary reefs, and the deeper reefs. The shallow reef group presented a wider distribution than the intermediary reefs, with these last ones being plotted more tightly in the negative part of axis 2. The deep natural reef showed the largest difference in species composition, both from the shallow and intermediary reefs.

When plotting the reef sites and species together in the correspondence analysis (Fig- 3-6), it was possible to see a distribution pattern for several species which supported the division of groups containing characteristic species (Table 3-4).

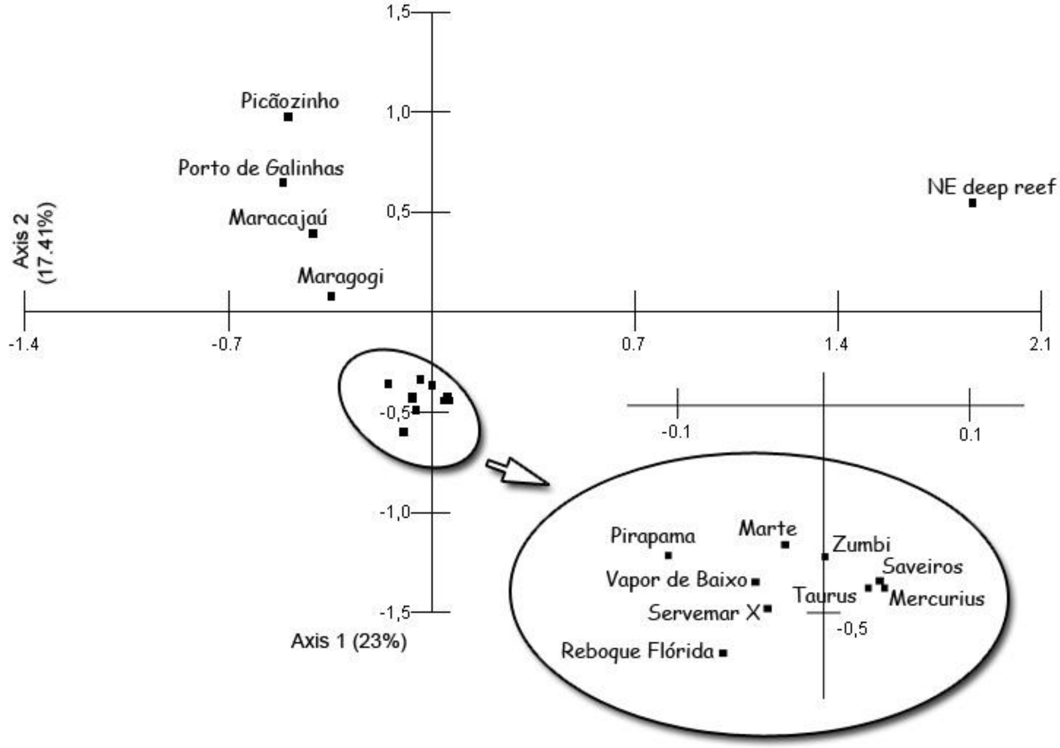

Figure 3-5. Correspondence Analysis for the 14 compared reef environments.

By the spatial points obtained in the correspondence analysis, it was possible to observe that the greatest density of species was positioned in the shallow reef area (Fig. 3-7, a) and also in zones that aggregated species belonging to shallow and intermediary reefs and species belonging to all sites (shallow, intermediate and deep reefs) (Fig. 3-7, b and c).

Species that were found only in shallow and intermediary reefs include *Anisotremus virginicus* and *Haemulon squamipinna* (Haemulidae), *Halichoeres brasiliensis* and *H. penrosei* (Labridae), *Sparisoma frondosum* and *Scarus zelindae* (Scaridae), *Diodon holacanthus* and *D. hystrix* (Diodontidae) and the serranids *Epinephelus adscensionis* and *Rypticus saponaceus*. In this group are also included cryptic species such as *Pempheris schomburgkii* and *Odontoscion dentex*, the omnivorous *Abudefduf saxatilis* and *Canthigaster figueiredoi*, the carnivorous *Gymnothorax funebris* and the piscivorous *Synodus intermedius*. *Acanthurus bahianus* unlike the other two species belonging to the genus, was only found in the shallower reefs. In this group, 23 of the 41 species were found, at least, in three of the shallow reefs and five of the intermediate ones (Fig. 3-7, b).

Thirty species were present in all reefs, from shallow to deep, with Lutjanidae as the most species-rich family, with five species, followed by Haemulidae and Labridae, with three species each. Several families had most, or all, of its species in this group, such as Acanthuridae, Gobiidae and Pomacanthidae with two of its three species present, and Holocentridae and Mullidae with both their species represented in all reef environments. From these 30 species, 22 had a similar distribution patterns, resulting in the large spatial density of points in the center of the correspondence analysis (Fig. 3-6 and Fig. 3-7, c).

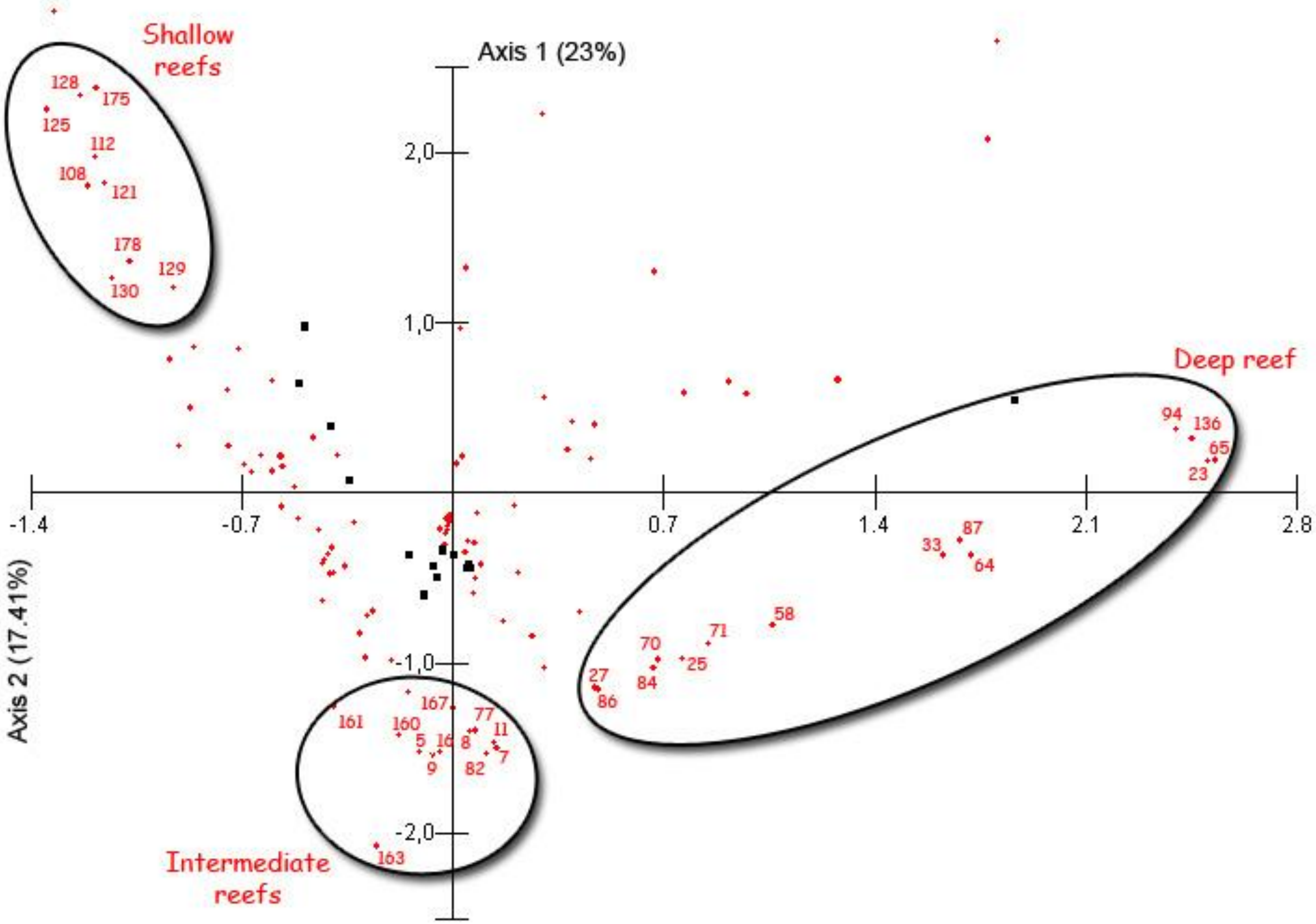

Figure 3-6 – Correspondence Analysis for all fish species for the 14 compared reef environments, described in Fig. 3-3. Key to species numbers as in Table 3-4. All the red dots represent species.

Table 3-4 – List of species corresponding to the groups in the Correspondence Analysis (Fig. 3-6).

Shallow reefs	N	Intermediary reefs	N	Intermediary to deep reefs	N
Amphichthys cryptocentrus	125	*Acanthostracion polygonius*	160	*Balistes vetula*	64
Anisotremus moricandi	112	*Acanthostracion quadricornis*	167	*Centropyge aurantonotus*	136
Archosargus probatocephalus	125	*Aetobatus narinari*	5	*Chromis jubauna*	23
Archosargus rhomboidalis	178	*Aluteros monoceros*	7	*Clepticus brasiliensis*	25
Aulostomus maculatus	108	*Aluterus scriptus*	8	*Dasyatis americana*	27
Aulostomus strigosus	125	*Amblycirrhitus pinos*	9	*Elagatis bipinnulata*	33
Canthigasther aff. Rostrata	178	*Antennarius multiocellatus*	11	*Malacanthus plumieri*	58
Decapterus sp.	125	*Cantherhines macrocerus*	167	*Opistognathus aurifrons*	64
Enchelycore nigricans	125	*Cantherhines pullus*	16	*Opistothonema oglinum*	65
Epinephelus guttatus	125	*Carangoides ruber*	167	*Ptereleotris randalli*	70
Eucinostomus gula	178	*Gymnachirus nudus*	161	*Rachycentron canadum*	71
Eucinostomus lefroyi	108	*Mycteroperca interstitialis*	167	*Seriola rivoliana*	94
Eucinostomus melanopterus	121	*Opsanus sp.*	163	*Stegastes pictus*	84
Gerres cinereus	125	*Serranus baldwini*	77	*Thalassoma noronhanum*	86
Gobionellus saepepalens	175	*Sphyraena guachancho*	163	*Xyrichthys splendens*	87
Haemulon steindachneri	112	*Sphyraena picudilla*	82		
Harengula sp.	128			**Total number of species**	**15**
Hemiramphus sp.	128	**Total number of species**	**16**		
Histrio histrio	125				
Labrisomus nuchipinnis	121				
Lactophrys trigonus	178				
Micrognatus crinitus	125				
Microspathodon chrysurus	129				
Mugil sp.	128				
Myrichthys ocellatus	121				
Narcine brasiliensis	125				
Priacanthus arenatus	125				
Pseudocaranx dentex	125				
Scartella sp.	178				
Serranus flaviventris	175				
Sphoeroides testudineus	128				
Stegastes variabilis	129				
Strongylura sp.	178				
Syacium micrurum	178				
Synodus foetens	130				
Total number of species	**35**				

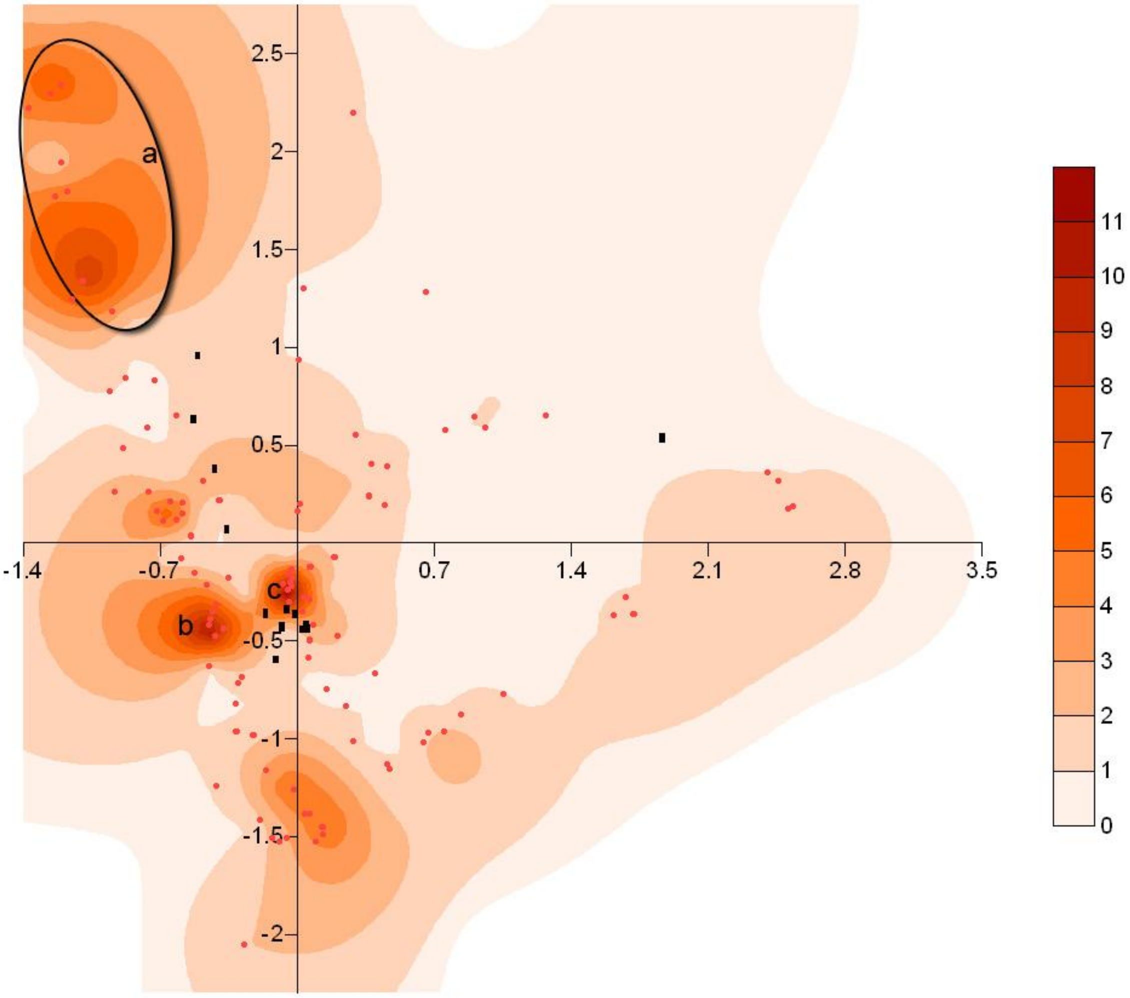

Figure 3-7 – Spatial species density and Correspondence Analysis for all fish species and the 14 reef environments. Species in the group a listed in Table 3-4 "shallow reefs"; species in group b and c in Appendix 7.

DISCUSSION

When using the species found in all reefs, the cluster and correspondence analysis resulted in the separation of three reef groups: the coastal/shallow reefs, the intermediary reefs and the deeper reefs. The results suggest that the separation of these groups is more related with depth than the type of reef involved. As has been previously reported, parameters such as depth, currents and even nearby sea grass or algae beds can play an important role in determining the fish community structure through their trophic significance (Gladfelter *et al.*, 1980).

However, in the cluster analysis using only families with complete association with coral reef environments – Acanthuridae, Chaetodontidae, Labridae, Pomacanthidae, Pomacentridae and Scaridae - it was possible to observe the integration of the intermediate natural reef (Zumbi) in the natural reefs group. This may reflect the need of some species for intrinsic characteristics of natural reefs (e.g., specific food resources). Nevertheless, one of the main constraints of this study was the impossibility of comparing natural and artificial reefs in shallow and deep (i.e. > 40m) areas, for the only artificial reefs intentionally deployed in the coast of Pernambuco are old vessels, with these being sited at intermediate depths. This technical difficulty does not allow a complete differentiation between the influences of depth and reef type.

The associated reef species that most contributed to the differences among intermediate depth reefs and that were only found in the natural reefs were two chaetodontoid species (*Chaetodon ocellatus* and *Centropyge aurantonotus*) and two labroid ones (*Microspathodon chrysurus* and *Stegastes variabilis*). The absence of these species in the vessel reefs is probably related to the non availability of proper habitat, for *C. aurantonotus* and *S. variabilis* are species known to be associated with great topographical complexity (Feitoza, 2001) and *M. chrysurus* as coral dependent (Carpenter, 2002a). *Chaetodon ocellatus* represents an interesting case as, in other studies on vessel reefs (Arena *et al.*, 2007; REEF, 2007), the species is present in recent deployed reefs. However, in those two studies, a great proximity between natural and vessel reefs sites was observed which can explain the species presence in those new vessel reefs and their absence in old vessel reefs off Recife, with more than 100 years, such as Pirapama and Vapor de Baixo. The detection of these four species might also been affected by the low dive/ sampling effort in the intermediate depth artificial reefs in the coast of Recife (880 minutes in 44 dives) versus the time spent at Zumbi intermediate depth natural reef (a total of 1832 minutes) or the number of surveys on the vessel reefs such as the study by REEF (2007) with 76 dives in a single artificial reef. Another important factor to consider is the fact that even in the former natural reefs (Feitoza, 2001), the number of individuals of the four above mentioned species was very low, varying from one specimen of *C. aurantonotus* and *S. variabilis* to 13 specimens of *M. chrysurus*, in a total of 50 visual census.

Three species, belonging to the considered typical reef families, *Halichoeres bivittatus*, *Scarus trispinosus* and *Chromis jubauna*, were found in the vessel reefs but not in the intermediate natural reef. The occurrence of *C. jubauna* in the northeastern coast of Brazil has been previously reported by Feitoza (1999, 2001) for depths from 20 meters on, and one specimen was seen in Taurus in a total of 44 dives of this project. This single occurrence reflects the low abundance of this species in the intermediate warmer waters of the northeastern coast as opposed to greater abundances in deeper cooler water (>60 m) in the same geographic area (Feitoza *et al.*, 2005) or in shallower cooler waters of the southeastern coast of Brazil (Moura, 1995; Luiz Jr. *et al.*, 2008). *Halichoeres bivittatus,* present in six of the eight artificial reefs, shows a clear preference for vessel reefs, especially as it is a species known to be present in coastal, intermediary and deep reefs in the northeastern coast (Feitoza, 1999, 2001; Engmann, 2006;). However, it is important to remark that only one natural reef was used in this comparison and further analysis prove necessary for the correct understanding of this species preferences.

This difference between intermediate reefs is probably related to the inherent differences between natural and artificial reefs, such as design and age of the reef, with more resident or reef species being found in natural reefs than in artificial reefs (e.g., Thanner *et al.*, 2006), as shown in this study. As pointed out by Moffit *et al*. (1989), structural material and design are important factors in the attraction of resident reef species, and it has been suggested that natural reefs have certain advantages that might not be present in artificial reef sites (Burchmore *et al*., 1985). However, one important factor to bear in mind is that the compared intermediate reef sites were located in two distant areas, separated by nearly 200 nautical miles, and although the northeastern coast is influenced by the North Brazil Current (Knoppers *et al*., 1999), different local wind and current regimes may result in different water circulation patterns. This difference in oceanographic conditions can have a larger influence in the distribution of small and reef resident species (e.g., the six reef families studied), than on a wider spectrum of transient and pelagic species, partially explaining the observed discrepancy in the resulting clusters using some or all species. However, as mentioned before, the results using all species indicate the distinction of three reef groups.

The first group, corresponding to the shallow and/ or coastal reefs, was characterized by the presence of species that are associated with brackish estuaries, like the mugilids (Cervignon, 1993), species that prefer shallow coastal marine waters such as *Anisotremus moricandi*, *Archosargus rhomboidalis*, *Eucinostomus spp*. and *Myrichthys ocellatus* (Acero & Gárzon, 1982; Carpenter, 2002a; Humann & DeLoach, 2002), and resident species of the intertidal environment such as *Labrisomus nuchipinnis* (Rosa *et al*., 1997; Barreiros *et al*., 2004). The greatest number and density of representative species of these reefs is probably related to the importance of shallow reefs as nurseries (Jenkins & Wheatley, 1998; Nagelkerken *et al*., 2000b; Lecchini, 2003) and protective sites with lower abundance of predators (Shulman, 1985; Parrish, 1989; Layman, 2000).

The second group, containing both natural and artificial reefs, clustered species with distinct habits, residence and trophic levels. The four species that were unique to intermediary reefs (and present in more than 50% of them) varied from a pelagic, transient and mobile invertebrate feeder, *Aetobatus narinari*, to a benthic and resident carnivore, *Amblycirrhitus pinos*, and two benthic transient omnivores, *Acanthostracion polygonius* and *Cantherhines pullus*. The distribution of *A. narinari* is related to its behavior. Since it is an active swimmer that can travel long distances (Carpenter, 2002b) it is understandable that its occurrence in the reefs is considered rare to uncommon. As a pelagic species, it is expected to prefer areas of clear water, not being registered in any coastal and/ or shallow reefs. The presence of *A. pinos*, with a known distribution from 5 to 25 m (Debelius, 1997), as restricted to intermediate reefs probably reflects the preference of this species for these environments due to the absence of possible competitors that are present in the shallower reefs. The large abundance of the carnivorous *Labrisomus nuchipinnis* in shallow reefs of the northeastern coast of Brazil (Rosa *et al*., 1997; Engmann, 2006; Pacheco, 2008) might be limiting the settlement of *A. pinos* in those reefs. As observed by Pacheco (2008) in a study on territorial species in the reefs of Tamandaré, south coast of Pernambuco, some territorial species appear to only allow the presence, or at least did not display an aggressive behavior towards individuals, of another species when there is no overlap of diets. This can help to explain the absence of *A. pinos* in shallow reefs and the low abundance, or even total absence, of *L. nuchipinnis* in intermediate reefs (e.g., Rosa *et al*.,1997; Feitoza, 2001), as these two species might compete for the same resources. Furthermore, predation by *L. nuchipinnis* on several other species as well as agonistic interactions has been observed (Mendes, 2006).

The deeper reef, although having pelagic species typically associated with the clear open water environment, such as *Acanthocybium solandri*, *Coryphaena hippurus* and *Thunnus atlanticus in* Feitoza (1999) (Carpenter, 2002a; Lessa *et al*., *in press*), was also characterized by several species that were present both in the intermediate and deep reefs. Among these were pelagic species that can be found over reefs, like *Rachycentron canadum* and *Elagatis bipinnulata* (Debelius, 1997; Carpenter, 2002a), as well as species of deep water environments, such as *Clepticus brasiliensis* and *Stegastes pictus* (Ferreira *et al*., 1998; Heiser *et al*., 2000; Halpern & Floeter, 2008). This group was always distinct from the other clusters, either using all species or just typical reef families, probably as a result of its distinct species composition and also its distance from the coast. This deep water environment presents carbonate sand and rubble plains, large blocks, and also some vertical walls with small crevices at their base. The presence of calcareous algae and some sponges is also frequent (Feitoza, 1999). However, the large resemblance between the deep and the natural reefs, in the analysis of reef associated species, might prove that even being distant and in an environment with different characteristics, the deeper reefs can also function as shallow reefs, posing both as shelter and nursery areas for some deep reef species (e.g., Boland & Parrish, 2005; Brokovich *et al*., 2007).

Regarding the number of species that distinguish different reefs, the largest densities were found in the shallow reefs (mentioned earlier), for species that characterize shallow and intermediary reefs and also for species present in all reefs.

The waters in the northeastern coast of Brazil show a relatively stable temperature throughout the year with values ranging from 26ºC in the winter, to 30ºC in the summertime (Medeiros & Araújo Filho, *in press*). This might explain the large distribution of species in the reefs over the continental shelf as a consequence of the low temperature gap, as temperature is known to be the major factor influencing marine life (Lowe-McConnell, 1999). Environmental stability has also been used to explain the rise of diversity, both taxonomic and morphological, on reef fishes from shallow tropical seas (Choat & Bellwood, 1991; Bellwood & Wainwright, 2002; Floeter *et al*., 2004).

Although several studies have highlighted the importance of reef structure on structuring the fish community (Luckhurst & Luckhurst, 1978; Gladfelter *et al*., 1980;), this study suggests that depth is a key factor in this process. Although no natural intermediate reefs were sampled off Recife's coast, it can be inferred that the main fish source were not the shallow reefs but other natural/ artificial reefs in the area, for the composition of the fish fauna on the intermediate depth reefs was somewhat distinct of the natural coastal reefs and very similar among the several vessel reefs.

FINAL REMARKS

The present work was part of a project which was the first to inventory the reef fish species present in three intentionally deployed vessel reefs, in the state of Pernambuco, and to study their community structure, diversity as well as the trophic and spatial distribution of the species present, including the changes in species composition for approximately one year.

Community diversity

By the comparison of the ichthyofaunal communities present in the three vessels, it was possible to conclude that these reefs had a fish community typical of reefs in the northeastern coast of Brazil, with most of the reef fish families that occur in them being also present in the vessel reefs (Chapter 1 and 3). The diversity indices used in the present work showed rich and diverse fish communities in all three vessels, with more dynamic species regulation processes in the shallower and smaller vessel, probably resulting from resources pressure (i.e. limited shelter and/ or food) and even anthropological impact, since this last vessel had a higher diving intensity than the others (Chapter 1).

Trophic guilds

The trophic guilds were very similar for the three vessels, with the main differences being found between the smaller/ shallower vessel and the two larger/ deeper ones. As previously reported, the main differences were found for a) the planktivores, with a greater abundance on the deeper vessel, which is in agreement with other studies in the area and on vessel reefs in general; b) mobile invertebrate feeders, which, in spite of being more abundant in the shallower vessel, were the second most abundant trophic group in the other two deeper reefs; c) omnivores, whose greater abundance in the deeper and diver free vessel is an observable effect of the presence of medium sized schools (<200 individuals); and d) territorial herbivores which showed a larger abundance in the shallower reef, although with much smaller values than the ones usually found in natural reefs (Chapter 1).

The continuous analysis of the trophic patterns throughout the colonization process allowed the identification of important changes in the number of species in each trophic guild. The main changes were related to species that were heavily present from the beginning of the dives, such as roving herbivores and mobile invertebrate feeders, and to those whose numbers increased through time, like the omnivores and planktivores (Chapter 2). These results show that some species have a higher dependence on the resources offered by the reefs (e.g. territorial herbivores) and that, as time passes by, the community fulfills all trophic guilds creating an intertwined web of relationships among different species with different needs. Thus, it could be inferred that the pioneer species for fish colonization on an artificial reef are those that can forage and move large distances from the reef to feed, returning to the reef for shelter.

Spatial distribution of species

The use of spatial categories to group the species in the present work had two main purposes: to allow comparisons with the distribution patterns and similarities found in different fish communities, and to evaluate the visual census methodology as a tool to identify the species in the colonization process of an artificial reef.

The cluster analysis applied to the data on spatial distribution, in the two deeper vessels, showed a clear separation between the first dives and the remaining ones, using all species and type B species (i.e. species that maintain visual contact with the reef and swim around it). This pattern is expected as these species are conspicuous by their color and shape and are considered to be “neutral species”. However, this pattern was not observed for the pelagic, type C, and reef/ substrate attached species, types A and D, which are species known to flee or hide at divers’ approximation. While most pelagic species are considered occasional species, type A and D species are usually species that exhibit camouflage characteristics, being sometimes very hard to spot (Chapter 2). Despite the inadequate temporal scale offered by these three last spatial distributions, as the dives in the cluster analysis were mixed, these species could show different patterns, in the vessel reef opened for recreational diving and the one closed, providing valuable information for posterior studies regarding species presence in artificial reefs.

Sampling limitations

Many of the analyses in this study were made using species presence/ absence data, especially the ones comparing different reefs and sites (Chapter 2 and 3). Such an approach was adopted because the main objective of this work was to study the evolution of the colonization process and to compare it with other reefs, in relation to the number of species in each trophic and spatial category. Although the communities studied were still experiencing some species regulating processes (Chapter 1), the work concluded that the species composition already resembled the ones found in natural reefs (Chapter 3). Another purpose of this study was to evaluate the ecological pattern of the colonization process of two recently deployed vessels and to understand the available resources the reef offered, based on the differential niche use (Chapter 2).

One of the main limitations of this study was the presence of large abundances of some reef-attached species, like *Haemulon aurolineatum* and *H. squamipinna*. The massive abundance of Haemulids has already been described for other artificial reefs (Randall, 1963; Smith *et al.*, 1979; Wolf *et al.*, 1983, Thanner *et al.*, 2006), so a way to better estimate their abundance (e.g. video transects), in the vessel reefs, is clearly needed. Another intrinsic limitation of the present work was the existence of only one natural reef at intermediate depth, versus eight vessel reefs, and no artificial reef in shallow and deeper areas (Chapter 3), which greatly hindered the comparison between different types and depths of reefs. Although the pattern found resembles the results from other studies on artificial reefs, it was difficult to ascertain which factor, i.e. depth or type of reef, had the main influence on the fish assemblages.

Can Artificial Reefs function as natural reefs?

The use of artificial reefs to create productive ecosystems in damaged or unproductive areas is a commonly used reason for the deployment of several types of reefs. As a consequence, much emphasis has been given to the attraction/ production of artificial reefs, with many of these efforts being put into work to evaluate the fishing potential of these types of structures (Solonski, 1985; Powers *et al.*, 2003; Santos & Monteiro, 2007; Whitmarsh *et al.*, 2008). However, in this study, the main purpose was not to evaluate the fishing or productive potential but to observe the possible changes in the community composition of the three vessel reefs along the first year, after deployment. As such, from the ecological data gathered in relation to trophic and spatial groups, the vessel reefs showed typical communities and behavioral patterns found in other studies in the northeastern coast of Brazil (e.g. Feitoza, 2001; Engmann, 2006; Souza *et al*., 2007). Even when compared to natural reefs, the artificial vessel reefs showed a greater similarity with reefs located in different geographical areas but at similar depths, than with reefs located in the same area but at different depths. This shows that the regulation processes acting on species composition are similar in both natural and artificial reefs.

Coral-reef fishes strongly associate with features of habitat structure (e.g., Jones & Syms, 1998), and two opposed views exist regarding the critical aspects of coral reef habitats. Some authors defend the importance of coral cover on fish distribution and abundance (e.g., Munday, 2002; Garpe & Öhman, 2003; Jones *et al*., 2004), while others relate abundance and diversity of coral-reef fishes to spatial and temporal variation in topographic complexity (e.g., Luckhurst & Luckhurst, 1978; Gratwicke & Speight, 2005), arguing that fish communities are more influenced by the existence of multidimensional topographical complexity than by the presence of corals in the area (Toller, 2002).

Even though artificial, coral and rocky reefs provide increased surface area for the attachment of primary and secondary producers, it is well known that no artificial reef surface can provide even an infinitesimal part of overall surface area available in the natural surrounding environment (Bortone *et al*., 2000). However, that structural complexity can be enlarged by sessile invertebrates that attract and support other organisms that depend on them, both for food or shelter (Jones *et al*., 1997).

Coral reef communities are extremely diverse and variable, and we should not expect that the relationships between reef organisms or the dynamics of the system to be simple to understand (Szmant-Froelich, 1983). However, knowledge of the nutrient cycle can be indicative of the productivity of a reef.

While dissolved nutrients and some particulates are taken up by organisms such as algae and zooxanthellae, other particulates are mostly trapped by the reef's filter feeding organisms. Planktivorous fish also concentrate particulates and excrete large amounts of organic material in their nocturnal shelters (Szmant-Froelich, 1983). Similarly, mobile invertebrate feeders, which account for a large proportion of reef fish biomass, forage diurnally and nocturnally over large areas (Wolf *et al*. 1983; Moura & Francini-Filho, 2005) and release nutrients onto the reef, which can also enhance coral growth (Meyer & Schultz 1985). Mobile invertebrate feeders, herbivores, and even other carnivorous and piscivorous species, are all important elements in the nutrient cycle of the reef, redistributing nutrients from adjacent habitats, for mobile invertebrate feeders and roving herbivores, as well as producing energy and nutrient-rich feces that enrich the reef environment and other reef-dependent organism (Choat & Bellwood, 1991).

As previously mentioned, in the three vessels reefs it was possible to see all types of species, from the ones that migrate to forage in other areas, like roving herbivores and mobile invertebrate feeders, to the ones that eat other fishes, such as carnivores and piscivores, and even species that take advantage of resources in the surrounding environment, such as planktivores. In addition to that, the presence of species belonging to all different spatial categories, from pelagic to site-attached species, also shows the amount of different resources available in the reefs.

An artificial reef undergoes a life cycle, which begins with the installation process, progresses to a period of maximum colonization effect and then it gradually moves into a phase of structural aging, after which the artificial reef reaches a level of complexity close to a natural reef (Sato, 1985). Arena *et al*. (2007), comparing several vessel reefs with different ages, concluded that, as time passes by, the fish community present in each vessel becomes closer to the ones observed in natural reefs. In the present study, however, high similarities were observed between all vessel reefs in the same area, regardless of age, which indicates that the colonization process in the northeastern coast of Brazil is a rapid event. Even though is has been previously argued that this sudden process may show a “relevant attraction effect to fishes” (Bohnsack & Sutherland, 1985), there is no question that the vessel reefs off Recife have self-regulating and complex communities resembling natural reefs, independently of the initial attraction/ aggregation and migration of fishes from nearby reefs.

All these results confirm the hypothesis that artificial reefs do support new fish assemblages, being able to offer food and shelter, within a structural complexity comparable to those found in natural reefs (Bohnsack, 1989; Solonsky, 1985). And no matter how attractive an area may be in terms of food supply, it will only be able to support large number of fishes if it can offer shelter (Randall, 1963; Ehrlich, 1975) as well many other biological requirements, emanating from the biological relationships amongst species.

As a final note, the economic benefits arising from ecotourism and SCUBA diving in these vessel reefs can show that, as pointed out by Brock (1994), this may be the most economically, as well as ecologically, viable use of an artificial reef. However, taking into account the actual exhaustion of natural marine resources worldwide, with no exception to the northeastern Brazil, I hope this study may serve as a comparative base for, in a future context, studies focused on the productivity of artificial reefs in this region.

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APPENDICES

Appendices

Appendix 1. List of observed species for Mercurius, Saveiros and Taurus. Trophic Guilds: Territorial Herbivores (TH), Sessile Invertebrate feeders (SI), Roving Herbivores (RH), Planktivores (PL), Piscivores (P), Omnivores (O), Mobile Invertebrate feeders (MI) and Carnivores (C).

Family	Species	Trophic Guild	Mercurius	Saveiros	Taurus
Ginglymostomatidae	*Ginglymostoma cirratum*	C	X	X	X
	(Bonnaterre, 1788)				
Dasyatidae	*Dasyatis americana*	C	X	X	X
	Hildebrand & Schroeder, 1928				
Myliobatidae	*Aetobatus narinari*	MI	X	X	
	(Euphrasen, 1790)				
Muraenidae	*Gymnothorax funebris*	C	X	X	X
	Ranzani, 1839				
	Gymnothorax vicinus	C		X	
	(Castelnau, 1855)				
Clupeidae	*Opisthonema oglinum*	PL	X		
	(Lesueur, 1818)				
Synodontidae	*Synodus intermedius*	P	X	X	X
	(Spix, 1829)				
Holocentridae	*Holocentrus adscensionis*	MI	X	X	X
	(Osbeck, 1765)				
	Myripristis jacobus	PL		X	X
	Cuvier, 1829				
Scorpaenidae	*Scorpaena plumieri*	C		X	
	Bloch, 1789				
Epinephelidae	*Alphestes afer*	C	X	X	X
	(Bloch, 1793)				
	Cephalopholis fulva	C	X	X	X
	(Linnaeus, 1758)				
	Epinephelus adscensionis	C	X	X	X
	(Osbeck, 1765)				
	Epinephelus itajara	C	X		
	(Lichtenstein, 1822)				
	Rypticus saponaceus	C	X	X	
	(Bloch & Schneider, 1801)				
Serranidae	*Serranus baldwini*	MI	X		
	(Evermann & Marsh, 1899)				
Grammatidae	*Gramma brasiliensis*	PL			X
	Sazima, Gasparini & Moura, 1998				
Opistognathidae	*Opistognathus aurifrons*	PL		X	X
	(Jordan & Thompson, 1905)				
Apogonidae	*Apogon americanus*	PL		X	X
	Castelnau, 1855				
Malacanthidae	*Malacanthus plumieri*	C	X	X	X
	(Bloch, 1786)				
Echeneidae	*Echeneis naucrates*	C	X		
	(Linnaeus, 1758)				
Rachycentridae	*Rachycentron canadum*	P	X		
	(Linnaeus, 1766)				
Carangidae	*Carangoides bartholomaei*	P	X	X	X
	(Cuvier, 1833)				
	Caranx crysos	P	X	X	X
	(Mitchill, 1815)				

Appendix 1. Cont.

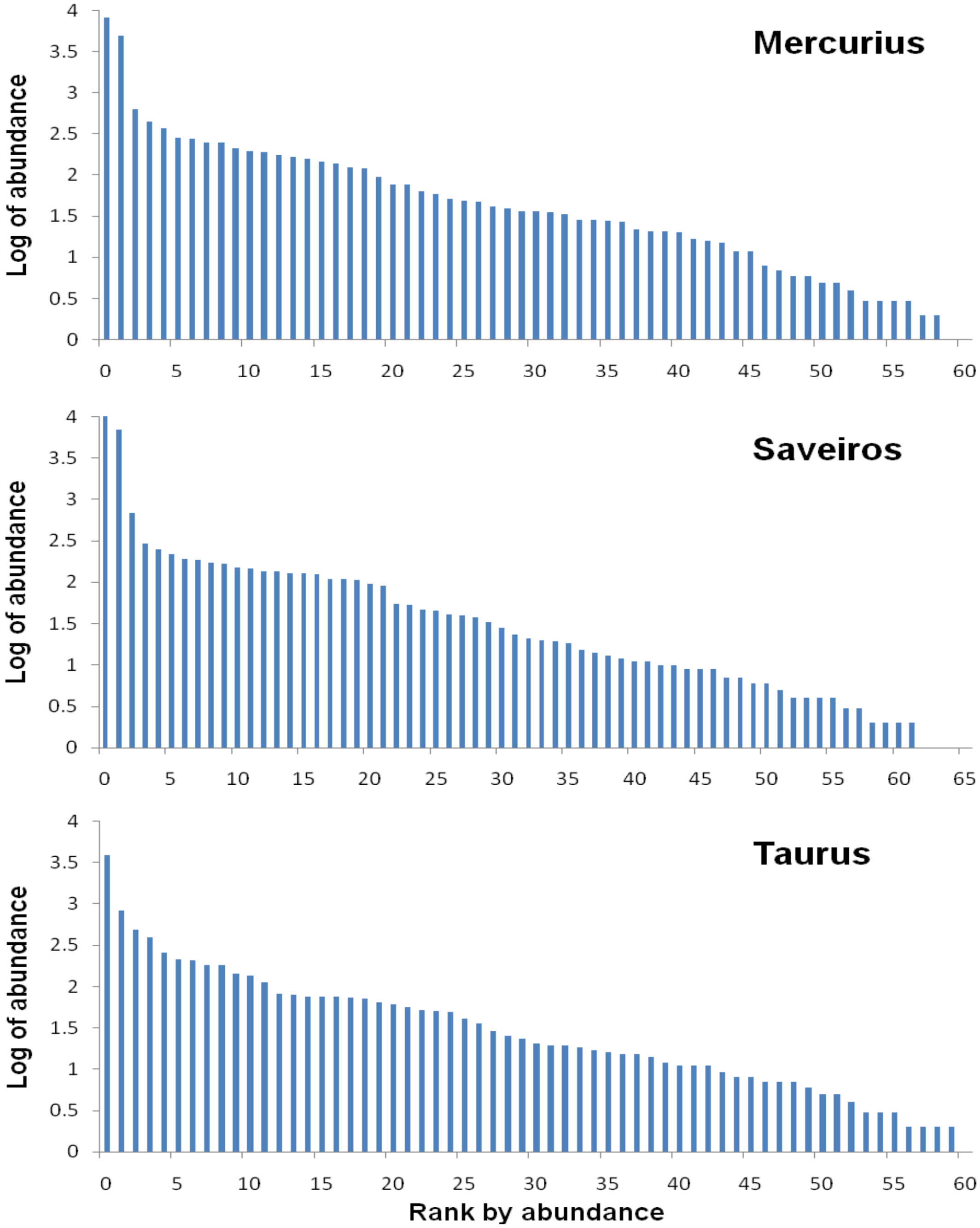
Family	Species	Trophic Guild	Mercurius	Saveiros	Taurus
Carangidae	*Decapterus macarellus* (Cuvier, 1833)	PL	X	X	X
	Elagatis bipinnulata (Quoy & Gaimard, 1825)	C	X		
Lutjanidae	*Lutjanus alexandrei* Moura & Lindeman, 2007	C	X	X	X
	Lutjanus analis (Cuvier, 1828)	C	X	X	X
	Lutjanus jocu (Bloch & Schneider, 1801)	C	X		X
	Lutjanus synagris (Linnaeus, 1758)	C	X	X	X
	Ocyurus chrysurus (Bloch, 1791)	C	X	X	X
Haemulidae	*Anisotremus virginicus* (Linnaeus, 1758)	MI	X	X	X
	Haemulon aurolineatum Cuvier, 1830	MI	X	X	X
	Haemulon parra (Desmarest, 1823)	MI	X	X	X
	Haemulon plumieri (Lacepède, 1801)	MI	X	X	X
	Haemulon squamipinna Rocha & Rosa, 1999	MI	X	X	X
Sparidae	*Calamus pennatula* Guichenot, 1868	C	X	X	
Sciaenidae	*Odontoscion dentex* (Cuvier, 1830)	C	X	X	X
	Pareques acuminatus (Bloch & Schneider, 1801)	MI	X	X	X
Mullidae	*Mulloidichthys martinicus* (Cuvier, 1829)	MI	X	X	X
	Pseudupeneus maculatus (Bloch, 1793)	MI	X	X	X
Pempheridae	*Pempheris schomburgkii* Müller & Troschel, 1848	PL	X	X	X
Chaetodontidae	*Chaetodon striatus* Linnaeus, 1758	SI	X	X	X
Pomacanthidae	*Holacanthus ciliaris* (Linnaeus, 1758)	SI	X	X	X
	Holacanthus tricolor (Bloch, 1795)	SI	X	X	X
	Pomacanthus paru (Bloch, 1787)	SI	X	X	X
Kyphosidae	*Kyphosus sectatrix* (Linnaeus, 1758)	RH	X	X	X
Cirrhitidae	*Amblycirrhitus pinos* (Mowbray, 1927)	C	X	X	X
Pomacentridae	*Abudefduf saxatilis* (Linnaeus, 1758)	O	X	X	X
	Chromis jubauna Moura, 1995	PL			X

Appendix 1. Cont.

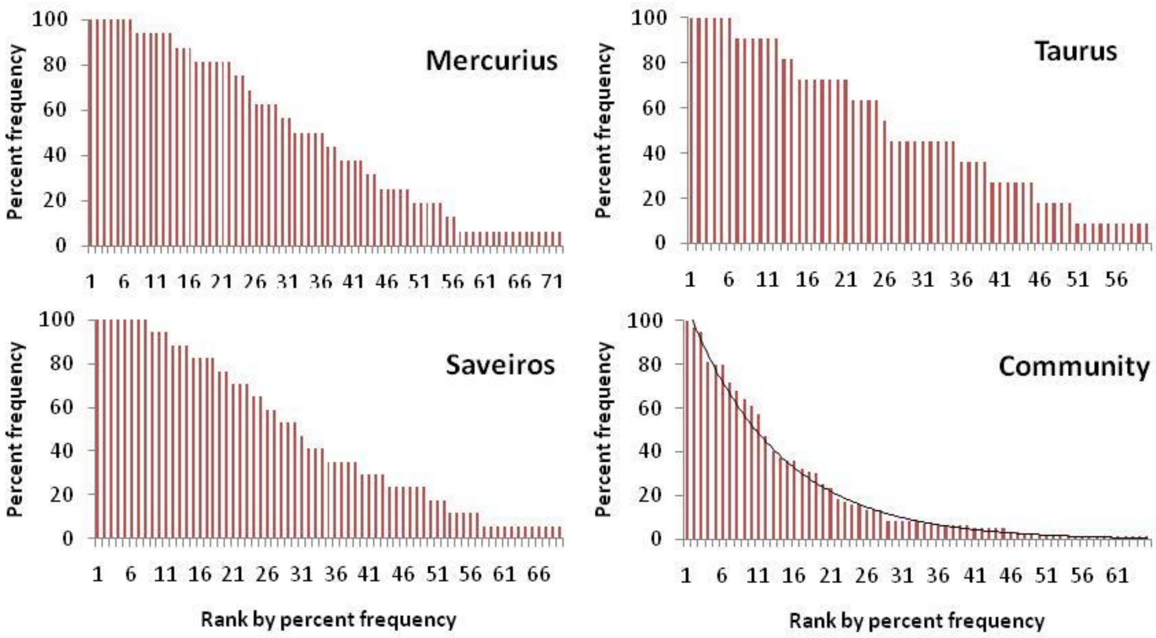
Family	Species	Trophic Guild	Mercurius	Saveiros	Taurus
Pomacentridae	*Chromis multilineata* (Guichenot, 1853)	PL	X	X	X
	Stegastes fuscus (Cuvier, 1830)	TH			X
	Stegastes pictus (Castelnau, 1855)	TH	X	X	X
Labridae	*Bodianus rufus* (Linnaeus, 1758)	MI	X	X	X
	Clepticus brasiliensis Heiser, Moura & Robertson, 2000	PL	X		
	Halichoeres bivittatus (Bloch, 1791)	MI	X	X	X
	Halichoeres brasiliensis (Bloch, 1791)	MI	X	X	X
	Halichoeres dimidiatus (Agassiz, 1831)	MI	X	X	X
	Halichoeres penrosei Starks, 1931	MI	X	X	X
	Halichoeres poeyi (Steindachner, 1867)	MI	X	X	X
	Thalassoma noronhanum (Boulenger, 1890)	PL	X	X	X
	Xyrichthys splendens Castenal, 1855	MI		X	
Scaridae	*Scarus trispinosus* Valenciennes, 1840	RH			X
	Scarus zelindae Moura, Figueiredo & Sazima, 2001	RH	X		X
	Sparisoma axillare (Steindachner, 1878)	RH	X	X	X
	Sparisoma frondosum (Agassiz, 1831)	RH	X	X	X
	Sparisoma radians (Valenciennes, 1840)	RH		X	
Bleniidae	*Ophioblennius trinitatis* Miranda-Ribeiro, 1919	TH	X		
Gobiidae	*Coryphopterus glaucofraenum* Gill, 1863	O	X	X	X
	Elacatinus figaro Sazima, Moura & Rosa, 1997	O	X	X	X
	Gnatholepis thompsoni Jordan, 1902	O	X	X	
Microdesmidae	*Ptereleotris randalli* Gasparini, Rocha & Floeter, 2001	PL	X	X	X
Ephippidae	*Chaetodipterus faber* (Broussonet, 1782)	O	X	X	X
Acanthuridae	*Acanthurus bahianus* Castelnau, 1855	RH	X	X	X
	Acanthurus chirurgus (Bloch, 1787)	RH	X	X	X
	Acanthurus coeruleus Bloch & Schneider, 1801	RH	X	X	X

Appendix 1. Cont.

Family	Species	Trophic Guild	Mercurius	Saveiros	Taurus
Sphyraenidae	*Sphyraena barracuda*	P	X		X
	(Edwards, 1771)				
	Sphyraena picudilla	P			X
	Poey, 1860				
Scombridae	*Scomberomorus regalis*	P	X	X	X
	(Bloch, 1793)				
Balistidae	*Balistes vetula*	MI			X
	Linnaeus, 1758				
Monacanthidae	*Aluterus monoceros*	O	X	X	
	(Ranzani, 1842)				
	Aluterus scriptus	O			X
	(Osbeck, 1765)				
	Cantherhines pullus	O	X	X	X
	(Linnaeus, 1758)				
Tetraodontidae	*Canthigaster figueiredoi*	O	X	X	X
	Moura & Castro, 2002				
Diodontidae	*Diodon holocanthus*	MI	X	X	X
	Linnaeus, 1758				
	Diodon hystrix	MI	X	X	
	Linnaeus, 1758				
Antennaridae	*Antennarius multiocellatus*	P		X	
	(Valenciennes, 1837)				
Total number of species	**87**		**72**	**69**	**68**



Appendix 2 – Pattern of total abundance for species observed in Mercurius, Saveiros and Taurus.



Appendix 3 – Pattern of percent frequency for species observed in Mercurius, Saveiros and Taurus and in a hypothetical diverse and stable Community. The Community curve was plotted using data from a study on the ichthyofauna of the natural reefs of Porto de Galinhas (Engmann, 2006) and used here for visual comparison on the stability of the fish communities of the recently deployed artificial reefs.

Appendix 4. List of observed species for Mercurius and Saveiros by month of first occurrence. Trophic Guilds (TG): Territorial Herbivores (TH), Sessile Invertebrate feeders (SI), Roving Herbivores (RH), Planktivores (PL), Piscivores (P), Omnivores (O), Mobile Invertebrate feeders (MI) and Carnivores (C). Spatial Categories (SC): A – species that prefer physical contact with the reef; B – species that are associated to the reef by vision and sound; C – species that remain in the water column; and D – species that use the area/surroundings of the reef (adapted from Nakamura, 1985).

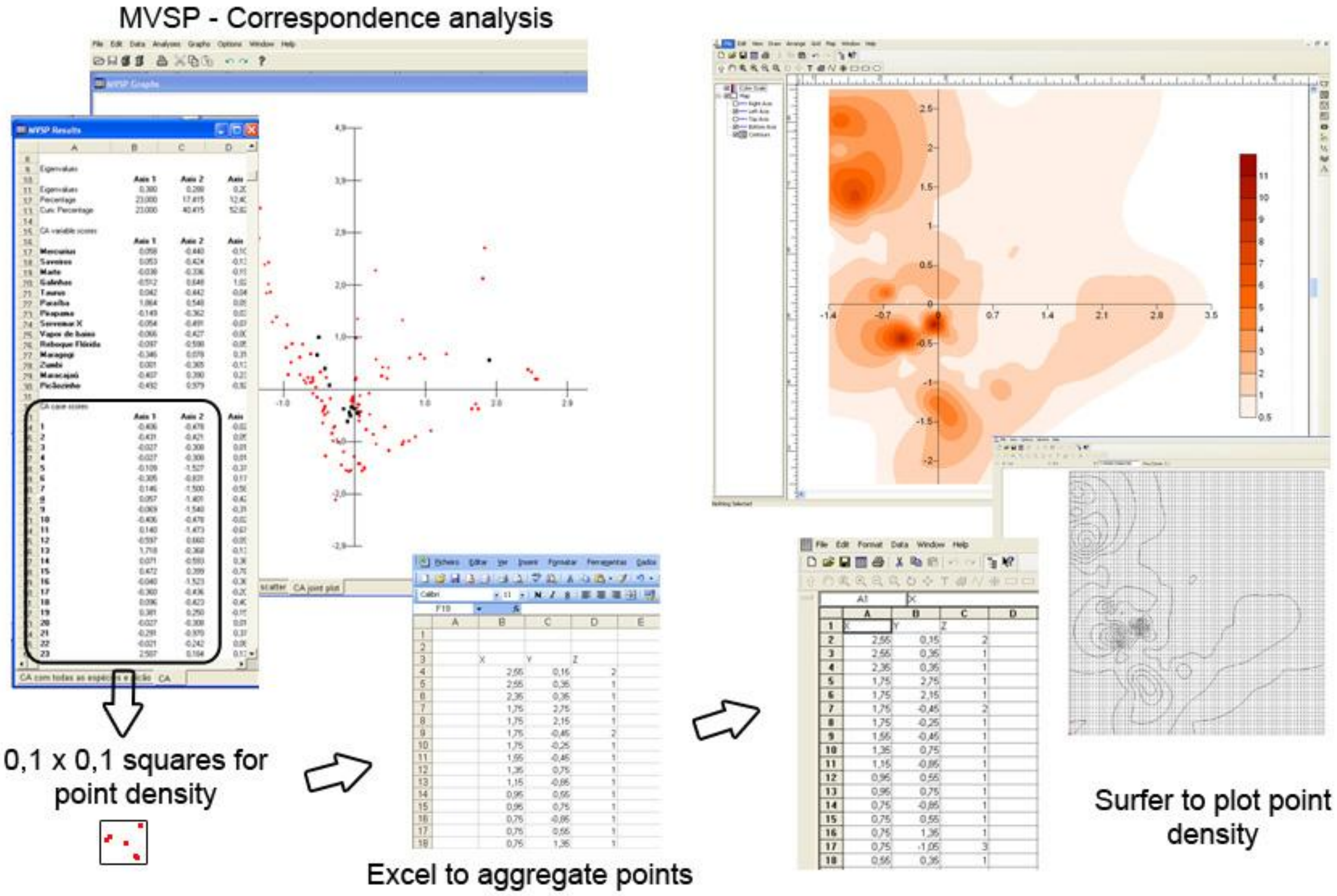
Family	Species	TG	SC	Mercurius	1st Occurrence	Saveiros	1st Occurrence
Ginglymostomatidae	*Ginglymostoma cirratum*	C	A	X	9	X	12
Dasyatidae	*Dasyatis americana*	C	D	X	3	X	4
Myliobatidae	*Aetobatus narinari*	MI	C	X	8	X	10
Muraenidae	*Gymnothorax funebris*	C	A	X	4	X	4
	Gymnothorax vicinus	C	A			X	4
Clupeidae	*Opisthonema oglinum*	PL	C	X	11		
Synodontidae	*Synodus intermedius*	P	D	X	7	X	4
Holocentridae	*Holocentrus adscensionis*	MI	A	X	3	X	3
	Myripristis jacobus	PL	A			X	5
Scorpaenidae	*Scorpaena plumieri*	C	D			X	7
Epinephelidae	*Alphestes afer*	C	A	X	3	X	3
	Cephalopholis fulva	C	B	X	3	X	3
	Epinephelus adscensionis	C	A	X	15	X	4
	Epinephelus itajara	C	A	X	13		
	Rypticus saponaceus	C	A	X	6	X	7
Serranidae	*Serranus baldwini*	MI	D	X	4		
Opistognathidae	*Opistognathus aurifrons*	PL	D			X	7
Apogonidae	*Apogon americanus*	PL	A			X	6
Malacanthidae	*Malacanthus plumieri*	C	D	X	8	X	10
Echeneidae	*Echeneis naucrates*	C	C	X	13		
Rachycentridae	*Rachycentron canadum*	P	C	X	4		
Carangidae	*Carangoides bartholomaei*	P	C	X	3	X	4
	Carangoides crysos	P	C	X	3	X	5
	Decapterus macarellus	PL	C	X	3	X	3
	Elagatis bipinnulata	C	C	X	4		
Lutjanidae	*Lutjanus alexandrei*	C	B	X	3	X	8
	Lutjanus analis	C	B	X	3	X	4
	Lutjanus jocu	C	B	X	4		
	Lutjanus synagris	C	B	X	6	X	3
	Ocyurus chrysurus	C	B	X	3	X	3
Haemulidae	*Anisotremus virginicus*	MI	B	X	3	X	3
	Haemulon aurolineatum	MI	B	X	3	X	3
	Haemulon parra	MI	B	X	3	X	3
	Haemulon plumieri	MI	B	X	3	X	3
	Haemulon squamipinna	MI	B	X	3	X	3
Sparidae	*Calamus pennatula*	C	B	X	7	X	5

Appendix 4. Cont.

Family	Species	TG	SC	Mercurius	1st Occurrence	Saveiros	1st Occurrence
Sciaenidae	*Odontoscion dentex*	C	A	X	9	X	4
	Pareques acuminatus	MI	A	X	3	X	3
Mullidae	*Mulloidichthys martinicus*	MI	B	X	4	X	10
	Pseudupeneus maculatus	MI	D	X	3	X	3
Pempheridae	*Pempheris schomburgkii*	PL	A	X	3	X	3
Chaetodontidae	*Chaetodon striatus*	SI	B	X	4	X	3
Pomacanthidae	*Holacanthus ciliaris*	SI	B	X	4	X	5
	Holacanthus tricolor	SI	B	X	7	X	6
	Pomacanthus paru	SI	B	X	5	X	4
Kyphosidae	*Kyphosus sectatrix*	RH	C	X	7	X	6
Cirrhitidae	*Amblycirrhitus pinos*	C	A	X	9	X	6
Pomacentridae	*Abudefduf saxatilis*	O	B	X	3	X	3
	Chromis multilineata	PL	B	X	6	X	6
	Stegastes pictus	TH	A	X	9	X	7
Labridae	*Bodianus rufus*	MI	B	X	4	X	7
	Clepticus brasiliensis	PL	B	X	11		
	Halichoeres bivittatus	MI	B	X	8	X	8
	Halichoeres brasiliensis	MI	B	X	3	X	4
	Halichoeres dimidiatus	MI	B	X	8	X	3
	Halichoeres penrosei	MI	B	X	6	X	6
	Halichoeres poeyi	MI	B	X	3	X	3
	Thalassoma noronhanum	PL	B	X	4	X	4
	Xyrichthys splendens	MI	B			X	8
Scaridae	*Scarus zelindae*	RH	B	X	10		
	Sparisoma axillare	RH	B	X	3	X	4
	Sparisoma frondosum	RH	B	X	3	X	4
	Sparisoma radians	RH	B			X	8
Bleniidae	*Ophioblennius trinitatis*	TH	A	X	11		
Gobiidae	*Coryphopterus glaucofraenum*	O	D	X	4	X	4
	Elacatinus figaro	O	A	X	8	X	6
	Gnatholepis thompsoni	O	D	X	15	X	8
Ptereleotridae	*Ptereleotris randalli*	PL	D	X	4	X	7
Ephippidae	*Chaetodipterus faber*	O	C	X	4	X	5
Acanthuridae	*Acanthurus bahianus*	RH	B	X	3	X	3
	Acanthurus chirurgus	RH	B	X	3	X	3
	Acanthurus coeruleus	RH	B	X	3	X	3
Sphyraenidae	*Sphyraena barracuda*	P	C	X	11		
Scombridae	*Scomberomorus regalis*	P	C	X	3	X	3
Monacanthidae	*Aluterus monoceros*	O	B	X	6	X	5
	Cantherhines pullus	O	B	X	8	X	3

Appendix 4. Cont.

Family	Species	TG	SC	Mercurius	1st Occurrence	Saveiros	1st Occurrence
Tetraodontidae	*Canthigaster figueiredoi*	O	B	X	8	X	7
Diodontidae	*Diodon holocanthus*	MI	B	X	4	X	3
	Diodon hystrix	MI	B	X	4	X	5
Antennaridae	*Antennarius multiocellatus*	P	D			X	8
Total number of species		**80**		**72**		**69**	



	A	B	C	D	E
1					
2					
3		X	Y	Z	
4		2,55	0,15	2	
5		2,55	0,35	1	
6		2,35	0,35	1	
7		1,75	2,75	1	
8		1,75	2,15	1	
9		1,75	-0,45	2	
10		1,75	-0,25	1	
11		1,55	-0,45	1	
12		1,35	0,75	1	
13		1,15	-0,85	1	
14		0,95	0,55	1	
15		0,95	0,75	1	
16		0,75	-0,85	1	
17		0,75	0,55	1	
18		0,75	1,35	1	

	A	B	C	D
1	X	Y	Z	
2	2,55	0,15	2	
3	2,55	0,35	1	
4	2,35	0,35	1	
5	1,75	2,75	1	
6	1,75	2,15	1	
7	1,75	-0,45	2	
8	1,75	-0,25	1	
9	1,55	-0,45	1	
10	1,35	0,75	1	
11	1,15	-0,85	1	
12	0,95	0,55	1	
13	0,95	0,75	1	
14	0,75	-0,85	1	
15	0,75	0,55	1	
16	0,75	1,35	1	
17	0,75	-1,05	3	
18	0,55	0,35	1	

Appendix 5 – Explanatory schematic for the plotting of species density resulting from the Correspondence Analysis.

Appendix 6. SIMPER for the species that most contributed to the differences between intermediate artificial and natural reefs, using only typical reef families. Value for the presence/absence of species in the artificial and natural groups, average dissimilarity – Av. Diss; contribution in percentage of each species for the overall difference – Contrib%; and cumulative percentage. Species in color are discussed in the chapter 3.

	Family	Species	Group Artificial	Group Natural	Av.Diss	Contrib%	Cum%
Intermediary reefs (Artificial & Natural) Average dissimiratiy: 24.59%	Chaetodontidae	*Chaetodon ocellatus*	0	1	2.13	8.67	8.67
	Pomacanthidae	*Centropyge aurantonotus*	0	1	2.13	8.67	17.33
	Pomacentridae	*Microspathodon chrysurus*	0	1	2.13	8.67	26
	Pomacentridae	*Stegastes variabilis*	0	1	2.13	8.67	34.67
	Scaridae	*Sparisoma radians*	0.13	1	1.88	7.63	42.3
	Scaridae	*Xyrichthys splendens*	0.13	1	1.88	7.63	49.92
	Labridae	*Sparisoma amplum*	0.13	1	1.88	7.63	57.55
	Labridae	*Halichoeres bivittatus*	0.75	0	1.57	6.39	63.94
	Pomacentridae	*Stegastes fuscus*	0.38	1	1.36	5.55	69.49
	Labridae	*Halichoeres poeyi*	0.5	1	1.12	4.56	74.05
	Labridae	*Clepticus brasiliensis*	0.5	1	1.02	4.15	78.2
	Pomacentridae	*Stegastes pictus*	0.63	1	0.85	3.45	81.65
	Scaridae	*Scarus trispinosus*	0.38	0	0.82	3.32	84.97
	Scaridae	*Scarus zelindae*	0.63	1	0.8	3.25	88.22
	Labridae	*Halichoeres penrosei*	0.75	1	0.58	2.37	90.59
	Pomacanthidae	*Holacanthus ciliaris*	0.75	1	0.58	2.35	92.94
	Scaridae	*Sparisoma frondosum*	0.75	1	0.58	2.35	95.28
	Acanthuridae	*Acanthurus bahianus*	0.88	1	0.3	1.24	96.52
	Chaetodontidae	*Chaetodon striatus*	0.88	1	0.3	1.24	97.76
	Labridae	*Thalassoma noronhanum*	0.88	1	0.3	1.24	99
	Pomacentridae	*Chromis jubauna*	0.13	0	0.25	1	100

Appendix 7. Species that most contributed for the observed densities in group B and C of Fig. 3-7

Group B (shallow and intermediate reefs)	Group C (in all type of reefs)
Abudefduf saxatilis	*Acanthurus chirurgus*
Acanthurus bahianus	*Acanthurus coeruleus*
Alphestes afer	*Bodianus rufus*
Anisotremus virginicus	*Carangoides bartholomaei*
Canthigaster figueiredoi	*Cephalopholis fulva*
Chaetodipterus faber	*Chaetodon striatus*
Decapterus macarellus	*Elacatinus figaro*
Diodon holocanthus	*Haemulon aurolineatum*
Epinephelus adscensionis	*Haemulon parra*
Ginglymostoma cirratum	*Haemulon plumieri*
Gymnothorax funebris	*Holacanthus ciliaris*
Gymonothorax miliaris	*Holocentrus adscensionis*
Haemulon squamipinna	*Lutjanus alexandrei*
Halichoeres brasiliensis	*Lutjanus analis*
Halichoeres penrosei	*Lutjanus jocu*
Kyphosus sectatrix	*Mulloidichthys martinicus*
Odontoscion dentex	*Myripristis jacobus*
Pempheris schomburgkii	*Ocyurus chrysurus*
Rypticus saponaceus	*Pareques acuminatus*
Scarus zelindae	*Pomacanthus paru*
Scomberomorus regalis	*Pseudupeneus maculatus*
Sparisoma frondosum	*Sparisoma axillare*
Synodus intermedius	