BENTHIC MARINE ALGAE OF THE CORAL REEFS OF BRAZIL: A LITERATURE REVIEW

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ABSTRACT

In Brazil, algae in coral reef environments can be found from Maranhão to Bahia State and there are today around 700 taxa, of which 78% are found on reef formations. The Rhodophyta are among the most common taxa found. Corallinales are the least studied group, in spite of their role in the formation and maintenance of Brazilian coral reefs. The species richness of algae on coral reefs is low in comparison with other coastal habitats, but there is an abundance of turf and fleshy macroalgae on certain parts of the coastal reefs. *Halimeda* spp., *Dictyota* spp., *Dictyopteris* spp., *Hypnea* spp., *Gracilaria* spp., *Gelidium* spp. and *Sargassum* spp. are some of the most conspicuous algae, while *Caulerpa* and *Udotea* and seagrasses are frequently found on unconsolidated sandy bottoms. Benthic marine algae are important components of shallow coral-reef communities in the Atlantic and they can be regarded as major competitors to corals. Over the last two decades, numerous cases of phase shifts from coral to algal predominance over coral reefs were reported worldwide. These reports coincide with the increasing concern with reef degradation, mainly attributed to anthropogenic nutrient enrichment and overfishing. In Brazil the effects of nutrification over coral reef dynamics are only recently being assessed, and crucial basic information is still lacking. The exploitation of marine algae, mainly of *Gracilaria*, is also recent in Brazil. Macroalgae growth in some disturbed Brazilian reefs were associated with grazing reduction caused by overfishing or nutrification. Rapid assessments of coral reef flora are needed in order to generate reliable information for environmental monitoring and to reinforce the legislation protecting Brazilian reefs.

Keywords: Algae, coral reefs, diversity, ecology, conservation.

RESUMO

ALGAS MARINHAS BENTÔNICAS EM RECIFES DE CORAL BRASILEIROS: UMA REVISÃO BIBLIOGRÁFICA. No Brasil, algas em recifes coralíneos ocorrem do Maranhão ao estado da Bahia e apresentam cerca de 700 taxons, dos quais 78% são encontrados ao longo de formações descontínuas. Táxons de rodofíceas estão entre os mais comuns. Corallinales é o grupo menos conhecido, apesar de desempenhar um papel importante na formação e manutenção dos recifes brasileiros. Nos recifes, a riqueza de espécies é baixa em comparação a outros habitats costeiros. *Halimeda* spp., *Dictyota* spp., *Dictyopteris* spp., *Hypnea* spp., *Gracilaria* spp., *Gelidium* spp. e *Sargassum* spp. são alguns dos táxons de algas mais conspícuos, enquanto que espécies de *Caulerpa*, *Udotea* e faneróganas marinhas ocorrem frequentemente nos fundos de areia não consolidados. Algas bentônicas marinhas são componentes importantes nas comunidades de recifes coralíneos rasos do Atlântico e potencialmente os maiores competidores de corais. Nas últimas duas décadas foram relatados numerosos casos de mudanças de fisionomia nos recifes no mundo, passando de recifes dominados por corais para recifes dominados por algas. Estes eventos coincidem com uma preocupação crescente em relação à degradação de recifes, atribuídos principalmente à eutroficação antropogênica e sobre-pesca. No Brasil, o efeito da eutroficação na dinâmica das comunidades recifais começou a ser verificado, porém ainda faltam informações sobre o enriquecimento de nutrientes nas águas dos recifes de corais. A exploração de algas marinhas, principalmente *Gracilaria*, também começou no Brasil. A proliferação de macroalgas em alguns recifes brasileiros tem sido associada à redução na herbivoria, causada pela sobre-pesca, ou à eutroficação. Levantamentos rápidos da flora recifal são necessários para estabelecer uma base de dados com informações para o monitoramento e reforço da legislação de proteção aos recifes no Brasil.

Palavras-chave: Algas, recifes de coral, diversidade, ecologia, conservação.

INTRODUCTION

Coral reef biomes have the greatest specific and phyletic biodiversity on the planet. This environment, at first characterized as an animal ecosystem, possesses algal components that may exceed the animal components in diversity and biomass, which are mostly composed of diminutive species (Adey 1998). In some Atlantic reefs, the abundance of macroalgae may exceed the coral coverage; for instance with non-geniculate corallines forming an extensive incrusting layer over the reef borders or turfs and fleshy algae forming a vertical canopy over the corals and other organisms. Because of the great relative contribution of macroalgae to the structure of Brazilian living reef communities, this work aimed to present a major bibliographical revision of their diversity, distribution, and ecological aspects, thus emphasizing the need to continue and intensify the phycological studies of these biomes, which are so sensitive to the environmental degradation caused by human interference.

REEF ALGAL DIVERSITY

The Brazilian marine benthic macroalgal flora includes around 700 infrageneric taxa (Horta 2000; Nunes 2005), of which nearly 80% are found in the tropics. Coral reef formations are discontinuously distributed and mainly concentrated in the coast range from the State of Maranhão to northern Espírito Santo (0°40'S to 19°30'S). Rhodophyta is the richest algae division found, and it includes the order Ceramiales, which contains most of the Brazilian species (Figure 1). Chlorophyta mainly comprises Bryopsidales and Cladophorales, while Phaeophyta is chiefly represented by Dictyotales and Ectocarpales (*e.g.* Villaça *et al.* 2006).

Numerous species compose the algal turf – considered itself a taxonomic operational unity (TOU) – which are basically filamentous algae and other delicate specimens. Turfs may be dominated by the geniculated corallines *Jania*, *Amphiroa* and *Haliptilon* or contain only filamentous non-coralline algae. Red and brown algae, such as *Anthithamnion*, *Ceramium, Digenea*, *Griffithsia, Gelidium* and *Sphacelaria*, are common components of algal turfs. Some green algae can also be present, mainly *Enteromorpha*, *Cladophora* and *Bryopsis* (Figueiredo 1997, Villaça & Pitombo 1997, Costa *et al.* 2002). The composition of turfs is similar to what is found in reefs of the Caribbean and Great Barrier, according with Steneck (1988), Adey (1998), and McCook *et al.* (2001). However, this type of TOU is frequently not taxonomically assessed and its specific richness is usually underestimated. In fact, Ceramiaceae together with some delicate

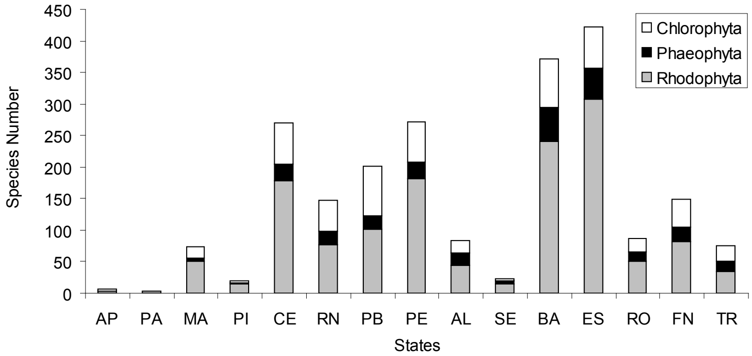

Figure 1. Infrageneric algal diversity of the tropical Brazilian coast according with taxonomic group and location (state or oceanic island). Adapted from Horta *et al.* (2001). Abbreviations of locations: (AP) Amapá, (PA) Pará, (MA) Maranhão, (PI) Piauí, (CE) Ceará, (RN) Rio Grande do Norte, (PB) Paraíba, (PE) Pernambuco, (AL) Alagoas, (SE) Sergipe, (BA) Bahia, (ES) Espírito Santo, (RO) Atol das Rocas, (FN) Fernando de Noronha archipelago, and (TR) Trindade island.

Delesseriaceae and non geniculated Corallinales, are the least studied and least known algae of the Brazilian coral reefs (but see Torres *et al.* 2004, Figueiredo & Steneck 2002). Among the fleshy red algae, the richest and most abundant genus is *Gracilaria* (19 species) of the Brazilian tropical region (Silva *et al*. 1987, Horta 2000, Nunes 2005). From comparing the flora of the Brazilian western Atlantic and of the Caribbean, it can be observed that the Chlorophyta represent a relatively small part to the South Atlantic reef flora (Figure 2).

In subtidal coral reefs even the most conspicuous components of the flora are little known. Although scuba-diving is efficient to investigate heterogeneous and hard substrata, it was rarely used in detailed reef surveys. Considering that constantly submerged areas represent most of the available hard substratum for phytobentic communities, it follows that algal diversity has been sub-estimated. A comparative analysis reveals that many macrophytic species are probably unknown from the Caribbean and adjacent waters, and that the region contains almost twice the number of species of the Southern Atlantic (Norton *et al*. 1996). Littler and Littler (2000) observed that some investigations of certain subtidal reef Chlorophyta of the Caribbean and Western Atlantic yielded more than twice the number of the presently described taxa (*e.g.* Littler & Littler 1990, 1991, 1992). In this group, genera such as *Anadyomene, Avrainvillea* and *Udotea* are probably not yet sufficiently known taxonomically and will eventually reveal a greater richness than the presently recorded.

Despite being conspicuous and quite often dominant in the Brazilian coast (Figueiredo 1997, 2000) the non geniculate coralline red algae are poorly known. Figueiredo and Steneck (2002) identified 11 species of corallines in a floristic survey of the reefs of Abrolhos Marine National Park. In a revision of the corallines of Brazil, Horta (2002) listed all described species and presented an artificial key for the identification of the genera of non-geniculated Corallinales. In earlier studies, Harvey (1847), Dickie (1874, 1875a, b), Piccone (1886), Moebius (1889, 1890), Foslie (1900, 1901), Lemoine (1917) and Taylor (1931, 1960) mentioned genera of non-geniculate Corallinales, but those studies used obsolete techniques and nomenclature.

Little is known about the associations of macroalgae with Brazilian coral reefs in terms of biogeographical patterns. Oliveira Filho (1977) appointed four biogeographical zones in the Brazilian coast. In contrast, Horta *et al*. (2001) presented two main biological zones: a tropical province and warm temperate province, with a transition zone over Espírito Santo state. In later work, Horta (2002) hypothesized that the Brazilian marine flora originated from the Indian Ocean, independently of the processes that brought about the Caribbean flora. These considerations raised issues against about the original hypothesis that the Brazilian flora originated from the Caribbean (Taylor 1955, Oliveira Filho 1977).

Few works employed Feldmann and Cheney indexes to analyze the marine flora of the Brazilian coast. Upon dividing the number of Rhodophyta species of a given region, or the number of Rhodophyta plus Chlorophyta, by the number of Phaeophyta species, it follows that the resulting values are usually lower for regions of higher latitude (Feldmann 1937, Cheney 1977). These indexes should be applied in a large spatial scale (but see Bolton 1986 for South Africa and Garbary 1987 for the North American west coast) and used with caution in small scale studies. Nevertheless, we have determined the Feldmann and Cheney indexes of the states of the Brazilian northern and northeastern coast (Figure 3). The values for the states Maranhão (MA), Ceará (CE), Paraíba (PB), Pernambuco (PE) and

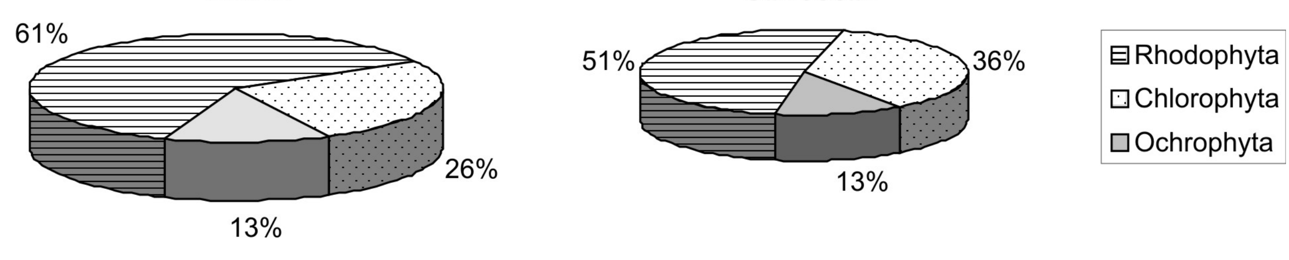

Figure 2. Comparison between the percent composition of algal groups on reefs in the Caribbean and Brazil (according with Littler & Littler 2000 and Horta *et al.* 2001).

Bahia (BA) resulted above four, which is expected for tropical regions (Pinheiro-Joventino *et al*. 1998). The Feldamnn index of Rio Grande do Norte (RN) resulted lower than expected, suggesting that the Rhodophyta groups of that region might not be very well studied. Similarly, the Cheney index of Espírito Santo (ES) and Rio Grande do Norte suggest that further studies of Chlorophyta are necessary in those regions. The states of Amapa (AP), Pará (PA), Alagoas (AL) and Sergipe (SE) were found to present low values of Feldmann and Cheney indexes, probably due to the strong influence of fresh water and elevated turbidity resulting of riverine outflows and mangrove areas. In fact, the sediment supply from rivers is known to limit the formation of coral reef along most of the northern coast of Brazil (Leão & Dominguez 2000). Upon working the total number of Brazilian taxons recorded, these indexes resulted similar to those of the tropical Caribbean region (based on data from Littler & Littler, 2000 and Horta *et al*. 2001) (Figure 4).

A biogeographical analysis, therefore, can only be made after a more complete inventory of the algae of Brazilian reef systems is built. Studies about macroalgal dispersion are also necessary in order to understand biogeographical patterns (Norton 1992), especially of widely distributed and invasive species (Deysher & Norton 1982). For example, 'natural' dispersal over large distances can be due to the ability of some algae, such as *Sargassum* spp., to float. The *Sargassum* transports a significant variety of algae along the Brazilian current (Oliveira *et al*. 1979). Nevertheless, nowadays, humans are the world's greatest evolutionary force (Palumbi 2001), potentializing dispersal over long distances through ballast water discharges and fouling (Hoek 1987, Carlton & Geller 1993) or by introducing species for mariculture (Russell 1982, 1987). Other kinds of human impacts on the biosphere can also disturb the dispersal capability of algal spores, as well as affect dispersal of coral planula (Norton 1992, Sammarco 1996). These factors, taken together with global warming, can change selective pressures, altering the actual biogeographical pattern and may cause economical impacts to humans (Beardall *et al.* 1998). Considering these flaws, knowledge about the benthic macroalgal diversity becomes necessary for Brazilian coral reef conservation and their sustainable exploitation is unfeasible and insufficient for supporting effective management programs.

ECOLOGY OF REEF ALGAE COMMUNITIES

Macroalgae are known to be among the most common organisms on many Brazilian living reefs (Figueiredo 2000). In northern regions, the reefs are mainly composed of crustose coralline algae, vermetids, and corals (Kempf 1968, Castro & Pires 2001). Fleshy and articulated calcareous macroalgae may also cover extensive areas and form high standing crops on the reefs. On the coastal windward reefs of Itamaracá island of Pernambuco state, the alga *Gracilaria* spp.,

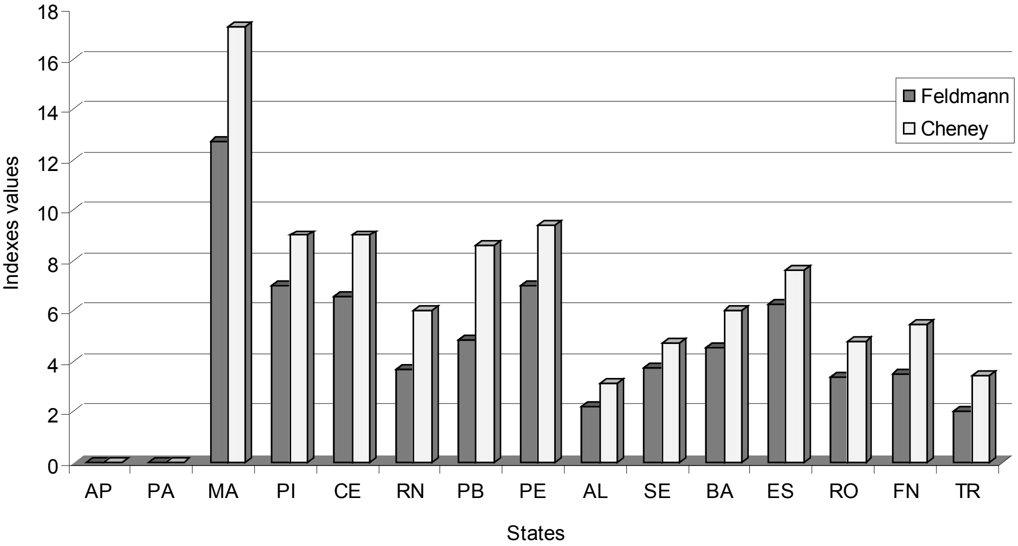

Figure 3. Feldmann and Cheney indexes of the northern to northeastern states of Brazil and oceanic islands. Abbreviations: (AP) Amapá, (PA) Pará, (MA) Maranhão, (PI) Piauí, (CE) Ceará, (RN) Rio Grande do Norte, (PB) Paraíba, (PE) Pernambuco, (AL) Alagoas, (SE) Sergipe, (BA) Bahia, (ES) Espirito Santo, (RO) Atol das Rocas, (FN) Fernando de Noronha archipelago and (TR) Trindade island.

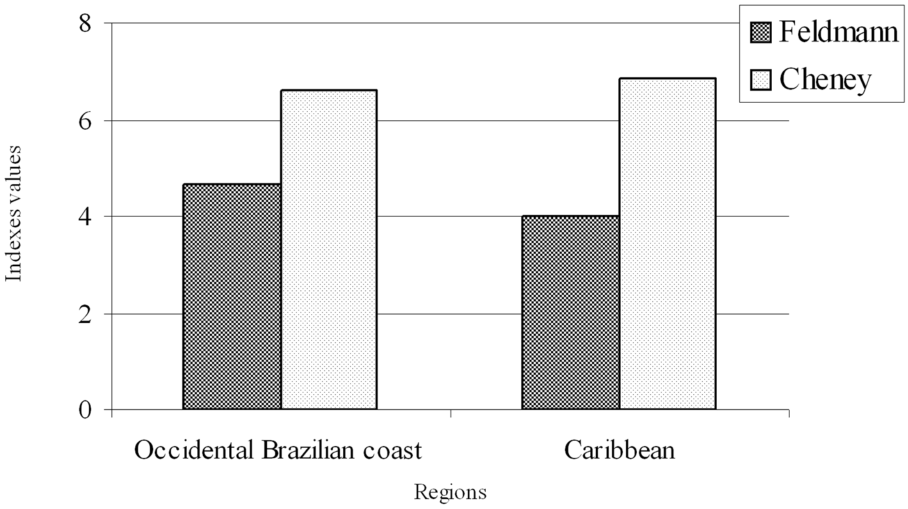

Figure 4. Feldmann and Cheney indexes of reef flora in Brazil and the Caribbean (based on Littler & Littler 2000 and Horta *et al.* 2001).

together with the red macroalgae *Hypnea musciformis*, *H. cervicornis*, and *Solieria filiformis*, and the green algae *Caulerpa* spp. locally achieve elevated biomass of up to 1,020g of fresh weight/ m^{-2} in the summer (Silva *et al*. 1987). At the Fernando de Noronha Archipelago, located at 345km from Natal in Rio Grande do Norte state, the brown alga *Dictyota mertensii* and the red alga *Laurencia papillosa* are dominant over shallow fringing reefs, along with the calcareous green alga *Halimeda tuna* and the red alga *Amphiroa fragilissima* (Pereira *et al.* 1996). In deeper areas, some brown algae species, mainly *Sargassum*, *Dictyota*, *Dictyopteris* and *Stypopodium*, become predominant (Eston *et al*. 1986). Over the southern reefs of Porto Seguro in Bahia state, algal turfs are always predominant, covering from 20 to 40% of the reef habitats. Green and brown fleshy algae and articulated calcareous red algae are also found (10 to 25%) on the reef flats coastal and offshore sites in Bahia along with *Caulerpa*, *Dictyosphaeria*, *Dictyota*, *Padina*, *Sargassum*, *Gelidiella,* and *Amphiroa* as the most abundant taxa (Costa *et al*. 2002). Small turf-forming algae are also abundant in the Abrolhos Marine National Park, covering from 25 to 80% of hard substratum of coastal and offshore reefs. Over most of the remaining coastal reefs of the Abrolhos Bank, large fleshy macroalgae are predominant (between 50 and 90% of coverage), mainly the brown algae *Dictyota*, *Dictyopteris*, *Lobophora*, *Padina*, *Spatoglossum*, *Stypopodium,* and *Sargassum* (Amado Filho *et al*. 1997, Figueiredo 1997, Villaça & Pitombo 1997, Figueiredo 2006).

A large number of macroalgae species of Caulerpaceae, Udoteaceae and Bryopsidaceae coexist with the seagrasses *Halodule wrightii* and *Halophila decipiens* on the biodetritic soft bottoms around or over the reefs of northern (Silva *et al*. 1987, Testa 1997, Pereira & Accioly 1998) and southern Brazil (Creed & Amado 1999, Figueiredo 2006). Creeping rhizomes allow those episamic macrophytes to thrive amongst the reefs and their leaves serve as hosts to many epiphytes. The seagrass *Udotea flabellum* was found to be the most available hard substratum in the reefs of Abrolhos (Paula *et al*. 2003), though relatively less important than is *Halimeda opuntia* in the reefs of northern Serrambi (Pereira & Accioly 1998). On the soft bottoms near to reefs, free living coralline algae also known as rhodoliths and maerls, like *Sporolithon*, *Mesophyllum* and *Lithothamnion*, are also found in association with seagrass meadows or forming extensive deposits (Testa 1997, Figueiredo & Steneck 2002, Paula *et al*. 2003, Figueiredo *et al.* 2006). Although carbonate sediment deposits are commonly found along both the northern and north-eastern continental shelf of Brazil (Kempf 1980), their origin and how they are transported across the reef areas are poorly known (but see Testa 1997, Leão & Dominguez 2000, Leão *et al.* 2003).

Crustose coralline algae, especially *Lithophyllum*, are commonly found in association with vermetids on the inner shelf of the reefs of northern Brazil (Testa 1997). This contrasts with the coralline-algal frameworks of Atol das Rocas, which are dominated by *Porolithon* alone (Gherardi & Bosence 2001, Villas Bôas *et al*. 2005). In the Abrolhos Archipelago, *Porolithon pachydermum* (Foslie) Foslie and *Lithophyllum congestum* (Foslie) Foslie are the coralline crusts of the shallow zones, where they cover as much as 80% of the fringing reefs and 50% of the columnar reefs. Sometimes they are barely visible, for growing under a thin sediment layer. Over the remaining areas of the Abrolhos Bank coralline crusts are less common, usually presenting < 30% coverage of coastal reefs (Figueiredo 1997, 2000, 2006, Figueiredo & Steneck 2002). The species found in Abrolhos, together with *Neogoniolithon strictum* (Foslie) Setchell & Manson, are the primary reef builders in the Caribbean, dominating the high energy algal ridges (Adey 1975, Adey & Vassar 1975, Steneck *et al*. 1997). Coralline crusts living in cryptic and deeper reef zones require more careful investigation because the species composition may change from thick to thin crusts in low light environments (Steneck 1986, Dethier *et al*. 1991) and we do not have much information on these crusts.

The distribution and abundance of benthic algae on most reefs of Brazil is poorly known because community level studies are scarce. In reef areas of the northern coast, most surveys were done on shallow and emergent reefs, so we know little about how communities change with depth. About the reefs of the offshore zone of the northern coast, it is known that coralline crusts are the main component of windward reefs at Atol das Rocas, increasing in abundance from 45% on the reef flats to 70% on the reef walls (Gherardi & Bosence 2001). Crustose corallines are occasionally present in the intertidal zone and tend to occupy more space in deep zones (up to 50-70%) under a dense macroalgae canopy over vermetid reef platforms in the Fernando de Noronha Archipelago (Eston *et al*. 1986). The pattern in the southern reefs of Porto Seguro is of coralline crusts and fleshy macroalgae covering 50-60% of the reef flats and decreasing to 30% over the reef walls of coastal and offshore areas (Costa *et al*. 2002). On the Abrolhos Bank, the fleshy macroalgae mainly grow over reef walls forming dense stands, but coralline crusts have a more variable habitat distribution, ranging 5-40% on the reef flats, 30-80% on the reef crests and 10-50% on the reef walls. The spatial variability of these patterns depends on the abundance of turf algae and herbivory pressure (Figueiredo 1997, 2000, Figueiredo & Steneck 2002).

Alternating dominance between corals and algae in the reef communities has been associated with either reduced grazing or nutrient enrichment, or a combination of both factors (Lapointe *et al*. 1997). In many Caribbean reefs, a substantial increase on the abundance of macroalgae was observed following urchin mass mortality (Williams & Polunin 2001) and hurricanes (Rogers *et al*. 1997). In the Abrolhos reefs, sea urchins form low density populations with little impact over the algal community, in contrast with the more abundant herbivorous scarid and acanthurid fishes, which can achieve elevated numbers in areas where fishing is not allowed (Villaça & Pitombo 1997, Figueiredo 1997, 2006, Figueiredo & Steneck 2002, Ferreira & Gonçalves 1999). Filamentous algal turfs grow fast and thus compensate for thallus loss by grazing and have advantage over the large macroalgae of grazed reefs (Steneck 1988, Steneck & Dethier 1994). Crustose corallines are also common on shallow productive reefs (Villas Boas *et al*. 2005, Tâmega & Figueiredo 2007). In reefs in which fishing is not allowed, herbivore fishes help remove the algal fouling from the surface of coralline algae. However, the high grazing pressure of scarid fish can limit the abundance of coralline algae and their growth rates (Figueiredo 1997). In contrast, on the Abrolhos Bank fleshy macroalgae and articulated calcareous algae are dominant on coastal reefs. There is no consensus as to whether this is a result of nutrient enrichment due to terrestrial runoff (Coutinho *et al*. 1993, Leão *et al*. 1994, Costa *et al.* 2002) or lowered fish herbivory because of overfishing (Ferreira & Gonçalves 1999). In other reefs, calcareous algae have been found to benefit from nutrient-enriched waters if the grazers consumed the more palatable fleshy algae (Thacker *et al*. 2001, Smith *et al.* 2001).

In highly depositional environments near the shore, the competition between different algal groups was suggested to explain the negative relationship found between the abundance of coralline crusts and algal turfs (Figueiredo & Steneck 2002). Sediments trapped within the turfs may affect the recruitment of crusts by preempting and reduce photosynthesis by shading as well as restricting the gas exchange (Kendrick 1991, Steneck 1997, Fabricious & De'ath 2001). In contrast, the competition between macroalgae and corals is less intense, since corals are not very abundant on the reefs of Brazil (Pitombo *et al.* 1988, Villaça & Pitombo 1997, Castro & Pires 1999). Algae are able to quickly occupy the newly available substrate when corals die due to environmental stress and diseases (McClanahan *et al*. 2001, Lirman 2001). However, it is difficult to assess whether algae are actively competing with corals or simply occupying the space left by their death (Miller & Hay 1996, McCook 2001, McCook *et al.* 2001). In addition, there is a lack of background data and reports on when bleaching events started in Brazil (Castro & Pires 1999, Creed, Figueiredo, Castro & Pires unpublished data). Therefore, studying the relationships between algal symbionts (zooxanthellae) and the mortality and survival of corals after bleaching events (Spencer-Davies 1992) will help understand the competition with macroalgae.

Despite their importance in structuring reef communities, the plant and animal interactions between crustose corallines, macroalgae and invertebrates have not been investigated in Brazilian reefs. Because of their extensive living coverage on reefs, the coralline crusts may be one of the major community structuring reef organisms. Their cell walls are heavily impregnated with calcium carbonate in the form of calcite (Cabioch & Giraud 1986), and provide structural resistance to erosion offering refuge and nursery sites for small invertebrates (Pitlik & Paul 1997). Some of these red algae also produce chemical cues known to induce settlement and metamorphosis of larvae of tubeworms, abalone, chitons, asteroids, urchins and soft and scleratinian corals (Morse 1992). However, fouling organisms can be deterred by some corallines which are able to shed their superficial layers, mainly in low light environments, such as cryptic habitats, deep reefs and under algal canopies (Steneck 1997, Littler & Littler 1999). Only a detailed knowledge of the taxonomy of coralline crusts would permit the recognition of coralline-coralline and coralline-other plant or animal interactions (Figueiredo *et al*. 1996, Morcom & Woelkerling 2000).

REEF ALGAE CONSERVATION

Regarding conservation, the macroalgae are not a major concern but are considered a major nuisance on reefs elsewhere from the tropics. Nowadays, shifts from coral to macroalgae domination in the communities are usually associated with reef degradation (McCook *et al*. 1997). Although macroalgae are not threatened and endemic species are unknown, there are common species known to the majority of protected reefs (Table I) within the Brazilian National Conservation System (Pedrini 1990). There are numerous conservation units in Bahia State, where coral reef formations are commonly found, including a national park, an environmental protected area and a fishing reserve. The most extensive protected area of reef systems is found in the coasts of Pernambuco and Alagoas States, although the local marine flora is only known from isolated studies of a few localities. The floras of the Marine National Parks of Abrolhos and Fernando de Noronha present the highest species richness, but most probably as a result of greater sampling efforts.

Coral reef systems all over the world experienced an increase in disturbances related to coastal erosion, hurricanes, nutrient enrichment, pollution, diseases, overfishing and changes in the water temperature. These factors taken together or separately change the structure of communities in association with reefs (McClanahan 2000). Eutrophication of inshore reefs near urbanized areas has resulted in macroalgae proliferation and a decrease in species diversity (Littler *et al*. 1992). Macroalgae dominated communities may be favored by nutrient enrichment, but also by overfishing (McClanahan *et al*. 1999, Tussenbroek & Vides 2000, Williams & Polunin 2001, Littler *et al.* 2006). One probable consequence of overfished reefs is that macroalgae protected by their calcified thalli or deterrent secondary metabolities (Hay 1997, Pitlick & Paul 1997) may eventually be substituted by more palatable fleshy algae. Such macroalgal beds are not the preferred habitat of these scraping and excavating herbivorous fishes and so a return to the former state would be difficult (McClanahan *et al.* 1999). Conversely, phase shifts from coralline/coral to turf-algal domination have been reported on intensively grazed reefs after broad scale epidemic diseases, such as the coralline lethal orange disease (Littler & Littler 1997). In fact, macroalgae are not necessarily more successful competitors than corals in euthrophic environments (McCook 2001) and not always kill corals by overgrowing them (Lirman 2001), but are opportunistic organisms that quickly take over spaces opened by the processes that cause reef degradation (McCook *et al.* 1997, McClanahan *et al*. 1999).

Preservation of species diversity and exploitation of macroalgae beds are regulated by Brazilian legislation in order to provide sustainable use (Constitution, Environmental Crimes Law and Environmental Agency Regulations). Among Brazilian reef communities, species that present potential use for colloid production are *Gracilaria* and *Hypnea* spp. (Silva *et al*. 1987). The exploitation process involves the local community who monthly remove around 80 tons of dry material (Oliveira & Miranda 1998), an activity that threats diversity and maintenance of macroalgal beds of coastal reefs. Rhodolith and maerl beds formed by free living non-geniculate corallines are another widely distributed resource often associated with Brazilian reefs. These calcareous algae have potential uses as fertilizers and lime to correct soil pH, though their extraction may cause severe impacts on other living resources (Foster 2001).

Table I. Richness of reef algae species in the Brazilian National Conservation System

Conservation Units (State)	Number of species	References
Fernando de Noronha National Park (PE)	122	1, 2, 3
Abrolhos Marine National Park (BA)	138	4, 5, 6, 7, 8, 9, 10
Rocas Marine Reserve (RN)	93	11
Corais Environmental Protected Area (PE, AL)	58	12, 13, 14
Baleia Environmental Protected Area (BA)	81	10
Recife de Fora Environmental Protected Area (BA)	51	15
Rio Mamanguape Environmental Protected Area (AL)	58	16
Corumbau Fishing Reserve (BA)	93	10

(1) Eston *et al*. 1986, (2) Pereira *et al*. 1996, (3) Pedrini *et al*. 1992, (4) Joly *et al*. 1969, (5) Amado *et al*. 1997, (6) Creed & Amado 1997, (7) Figueiredo 1997, (8) Villaça & Pitombo 1997, (9) Figueiredo & Steneck 2002, (10) Figueiredo 2006, (11) Pedrini 1990, (12) Pereira & Accioly 1998, (13) Muñoz & Pereira 1997, (14) Muñoz & Pereira 1998, (15) Costa *et al*. 2002, (16) Kanagawa, *pers. comm*.

The conservation of biodiversity is a major goal of the Brazilian government, which has implemented the National Biodiversity Program (Pronabio) to survey the national biodiversity, including coastal and marine environments, in order to indicate priority areas for conservation. Because of their potential economical uses macroalgae have been indicated as one of the main living resources that should be preserved. Therefore, we need to better understand their role in maintaining diversity and functions of other living organisms in order to protect and support the sustainable use of reef systems. However, the contribution of calcified macroalgae to the reef framework, which enhances biodiversity (Hay 1997, Paul 1997, Pitlik & Paul 1997) and propels biogeochemical cycles, is unknown in Brazil. Although structurally strong, their growth and calcification are negatively affected by high concentrations of certain nutrients, especially phosphate (Maudsley 1990). Heavy metal is another threat, mainly to brown algal species along coastal reef areas in the south of Bahia State (Amado Filho *et al*. 1997). Considering the importance of coralline algae as reef builders, the particularly harmful pollution of coastal waters should be monitored to sustain healthy reefs.

CONCLUSIONS

Coral reef habitats are characterized by an elevated spatial heterogeneity produced by extensive calcium carbonate structures with a superabundance of surfaces and internal or cryptic spaces (Adey 1998). Therefore, species diversity and density are expected to be the highest over all of any set of ecosystems. However, the diversity of the Brazilian reef flora is relatively low, indicating that either our reefs are under-studied or exposed to exceedingly intense disturbances, such as fish herbivory (Norton *et al.* 1996). Since taxonomic surveys may be not sufficient to detect disturbances, a functional group approach may be a good alternative to quickly assess seasonal changes or shifts among macroalgae groups reflecting selective adaptation to disturbance (Steneck & Dethier 1994). The importance of a more modern approach to better understanding of the diversity of macroalgae is justified by the important ecological role of some groups, such as calcareous algae (Steneck & Testa 1997), to this environment. Some Brazilian reefs are chiefly composed by crustose coralline algae, which, along with the stony corals, form relatively large geological structures (Kikuchi & Leão 1997), but calcareous green algae can also be one of the major components of the sediments around reefs (Leão 1982, Leão & Dominguez 2000, Testa 1997, Leão & Kikuchi 2001, Leão *et al.* 2003).

Habitat fragmentation and loss of functional diversity in consequence of human activities are altering the resilience, or the capacity of coral reefs to confront future disturbances (Nyström *et al*. 2000). In summary, rapid biodiversity assessments are needed to identify regional priorities and provide baseline information to long-term reef monitoring programs in order to successfully conserve the reef communities of Brazil.

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