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A relic coral fauna threatened by global changes and human activities, Eastern Brazil

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Abstract

Coral species composition of drilled cores from emergent bank reefs, and coral cover of the surface of old and living reefs located along the coast of the state of Bahia, Eastern Brazil, revealed that there is a marked change in the occurrence of the major building coral species in different time intervals of the reef structure, as well as in the living surface of reefs located in two different geographical sites. Holocene core sections from two reef areas (12° 40′S–38° 00′W and 18° 00′S–39° 00′W) have as major reef builders, on its topmost core interval (3 to 4 ky old), the endemic coral *Mussismilia braziliensis* Verrill, 1868, which also dominate on the 2.5–3.5 ky old surfaces of truncated reef tops. At the base of the cores (the 2 m lower interval, older than 4 ky BP), another endemic coral *Mussismilia harttii* Verrill, 1868 is the dominant reef component. The relative abundance of *M. braziliensis* on the living surfaces of shallow reefs from both areas, shows that in the southern area, it is up to 98% on reefs located 60 km off the coast, in depths between 3 and 4 m, but do not exceed 1.3% on the surface of the northern reefs located 1–2 km off the coast in depths 4–5 m. The Holocene falling sea level that occurred along the coast of Brazil since 5.1 ky BP, causes an increasing runoff into the area of coastal reefs. This phenomenon may have affected the nearshore reef building fauna, replacing a more susceptive coral fauna with one better adapted to low light levels and higher sediment influx. The high turbidity associated with early Holocene shelf flooding, should also be responsible for the absence of *M. braziliensis* during the initial stages of reef buildup in Brazil. At the present time, the rapidly increasing human pressure, due to changes in land uses of the coastal zone (increasing sedimentation rate, nutrification of coastal waters, industrial pollution) and underwater practices, such as overfishing and an intense tourism, is aggravating the recovery capacity of this already naturally threatened coral community. If this situation coupled with increasing sea surface temperature persists, modern coral reef growth, in Brazil cannot be maintained and the major reef building coral species of the reefs in Bahia, a remnant endemic coral fauna will very soon appear in the list of endangered species.

Keywords: Brazilian coral fauna; Endemic species; *Mussismilia braziliensis*; Abrolhos reefs; Holocene sea level

1. Introduction

The coast of the state of Bahia has the most extensive and the richest area of coral reefs in the southwestern Atlantic Ocean. These reefs are characterized by their unusual growth forms of mushroom-shaped pinnacles that can fuse together on their tops forming larger reef structures, such as: (a) shallow small isolated reefs that occur adjacent to the shoreline and have often elongated form; (b) bank reefs off the coast, that have widely variable sizes (<10 to >20 km) and shapes; (c) fringing reefs bordering the coast of islands; (d) open sea coral pinnacles, named "chapeirões", usually in depths greater than 20 m, and (e) drowned reefs at the middle and outer continental shelves (Leão et al., 2003).

Studies carried out in two different areas of occurrence of these coral reefs, the northern (12° 40′S–38°

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00′W) and the southern (18° 00′S–39° 00′W) coasts of the state of Bahia, revealed the presence of reef structures constructed by a characteristic coral fauna, which is significantly different from the well known coral reefs, as (a) they present a very low coral diversity (18 species, Laborel, 1969, 1970; Castro, 1994), (b) the hermatypic corals have high endemism with the major reef builders represented by archaic forms, remnant of an ancient coral fauna dating back to the Tertiary time, and (c) they lack completely typically branching growth forms.

This study presents an analysis of previous data of the coral fauna composition from Holocene coral sections, and from the surface of living reefs, of two different sites along the coast of the state of Bahia, in Eastern Brazil, and discusses the major processes that may have been responsible for the observed spatial and temporal changes in the occurrence of the major reef builder coral species.

2. Physical setting

Two distinctive areas of occurrence of coral reefs were studied: the northernmost coast of the state (12° 30′S) (Fig. 1), where the average shelf width is about 15 km, and the Abrolhos region (18° 00′S) (Fig. 2) an enlargement of about 200 km of the eastern Brazilian continental shelf.

The coastal belt along the studied areas has a tropical humid climate, with rainfall ranging from 1300 mm/y at its northernmost part, to a maximum of 2000 mm/y at the Abrolhos region. The hinterland is rather dry (500–700 mm of rain per year). Average air temperature ranges from 23 °C in winter to 28 °C in summer (Nimer, 1987).

Around the studied nearshore reefs the shelf is very shallow and does not exceed 10 m. However on the Abrolhos offshore reefs, depths of surrounding waters can reach 30 m, and the shelf edge, in both areas, is about 70 m deep (DHN, 1993).

Dominant winds during summer (October–February) are from NE; winds from E are common from March to September, and strong SE winds can occur during winter storms (between May and August) (DHN, 1993).

The major current along the eastern coast of Brazil is the South Brazilian Current, which flows southward with an average speed of about 0.7 knots. Wind driven currents vary in direction and speed attaining maxima of 2 knots (DHN, 1993).

Available data on tidal range for the north coast is from the port of Salvador (about 60 km south of the reef area), where it varies from 2.6 m to 0.1 m. For the Abrolhos region, data from the reefs nearest area indicate an average range of 2.0 m during spring tides (DHN, 1997).

Temperature of surface waters varies in both areas from around 28 °C (in summer) to 24 °C (in winter). Average salinity values in the Abrolhos region is around 36, and in the north coast measured values from the

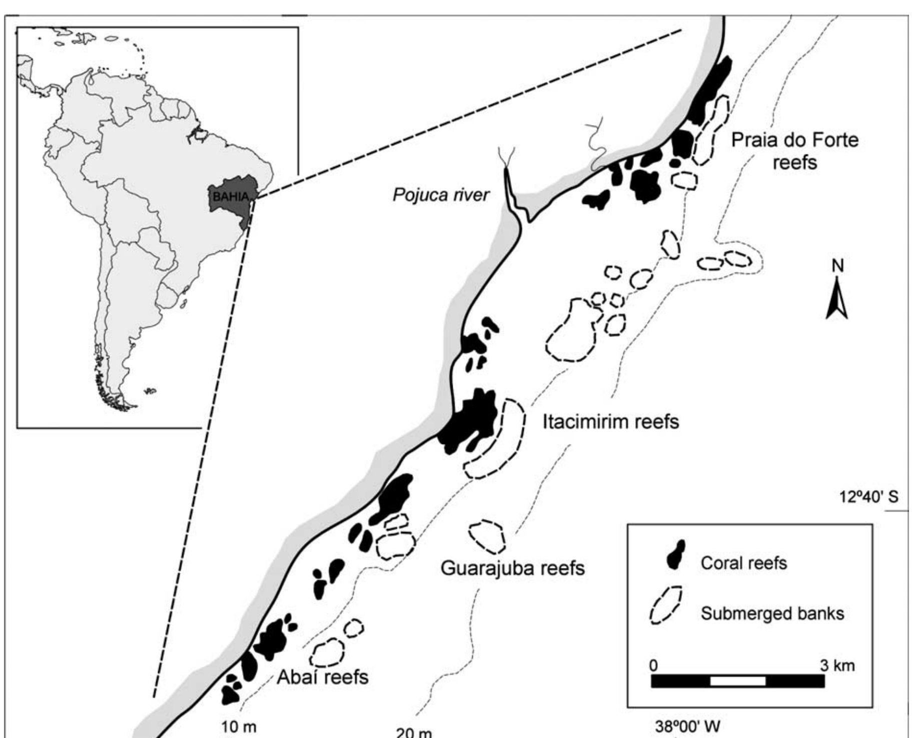

Fig. 1. Location of studied coral reefs of the north coast of the State of Bahia, Eastern Brazil (modified from Kikuchi, 2000).

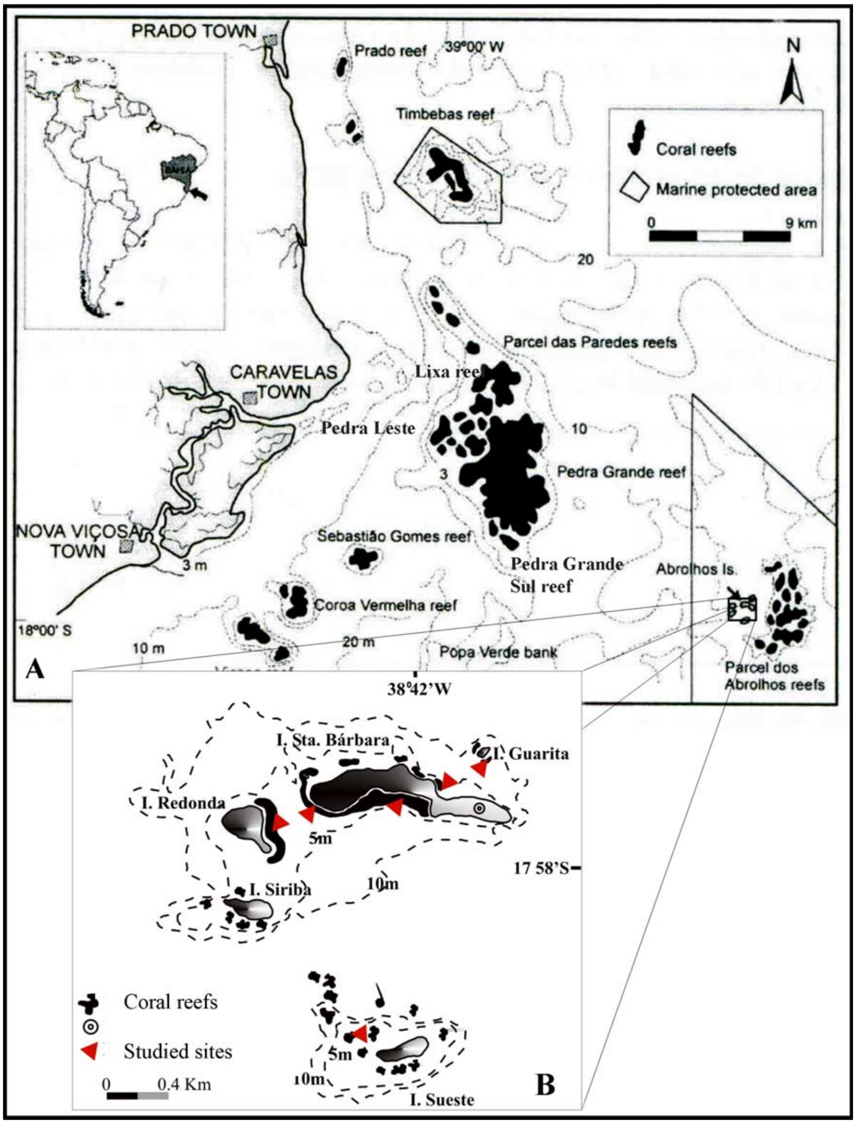

Fig. 2. A—Location of studied coral reefs of the south coast (Abrolhos region) of the State of Bahia, Eastern Brazil. B—Location of islands and fringing reefs of the Abrolhos Archipelago (modified from Leão et al., 2003; Spanó, 2004).

coastal reefs varied from 35 to 39 (Kikuchi and Leão, 1998).

3. Material and methods

3.1. Coral cover of living reefs

The percent coral cover of the living reefs was estimated using both the belt and the line transect methods. The belt transect was performed on the isolated shallow bank reefs from the north coast, where it consisted of three 10 m long by 01 m wide transects in each studied reef. These transects were all positioned paralleling the longer axis of reef structures. For the shallow fringing reefs of the Abrolhos area, Pitombo et al. (1988) applied the 20 m long line-transects method, where the transects were distributed following different water depths such as: in the Santa Barbara Island reef, three transects were run at 3, 3.2 and 4 m depths, and at the Siriba Island reef, four transects were run at depths of 0.7, 1.7, 1.9 and 2.9 m. In this same area Kikuchi et al. (2003) ran thirty (10 × 01 m) transects on four different reef sites, and fifty (10 × 01 m) transects on the offshore "chapeirões" according to the methodology proposed on the AGRRA (Atlantic and Gulf Rapid Reef Assessment) protocol (Ginsburg et al., 1998). On all surveyed sites only the living coral heads were considered, and all corals were identified to species level.

3.2. Coral cover of the old top of emergent bank reefs

The 3.0 ky old tops of the reefs from the north coast (Fig. 3) were surveyed using 1 square meter quadrats,

Fig. 3. The exposed top of Guarajuba reef, on the north coast of the state of Bahia, Eastern Brazil.

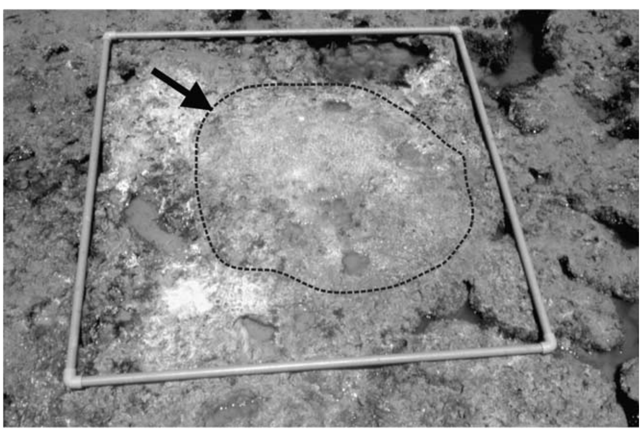

Fig. 4. An eroded colony of the endemic subfossil coral *Mussismilia braziliensis* (2.5–3.5 ky old) on the top of a nearshore reef at the north coast of the state of Bahia, Eastern Brazil. Quadrat is 1 m^2.

which were laid down, haphazardly, along two lines parallel to the coastline, coincident to the longer axis of the reefs. The truncated surface of the reef tops was brushed-cleaned and the coral heads recorded (Fig. 4). The colony size of all hermatypic coral species was measured in order to quantify its percent cover.

3.3. Core composition

Four reefs were cored using a Winkie Rotary Drill (JK Smith and Sons, International). In all of them the recovery was variable and dependent on the nature of the material (continuous coral units or fragmented reef structure) (see Fig. 5). The core samples (1–5/8″ in diameter) were cut in half along their axis. The frequency of the primary reef building organisms within each core interval was estimated with a 0.5 cm grid on overlays in large pictures taken from the surface of the core slabs. The description given in this paper is from the two longest cored Holocene sections: the Guarajuba reef at the north coast of the state (10.3 m, Nolasco, 1987), and the Abrolhos core (12.7 m, Leão, 1982) (Fig. 6). The number of the coral species present in each core interval was, also, determined.

4. Results

4.1. Spatial changes

There is a marked change in the coral fauna composition of the living reefs from the north and south coasts of the state of Bahia (Kikuchi, 2000; Kikuchi and Leão, 1998; Kikuchi et al., 2003; Leão et al., 1997; Pitombo et al., 1988). The relative abundance of the major building coral species of these reefs, the endemic form *Mussismilia braziliensis* Verrill 1868 varies significantly from one area to the other. In the south coast, the Abrolhos area, on the reefs located 60 km off the coast, the percentage of *M. braziliensis* reaches values up to 98%, while in the shallow nearshore reefs from the north coast the relative abundance of this coral species does not exceed 1.3% (Table 1). Also, a clear difference is found in the total coral cover from both surveyed areas. Whereas on the surface of the Abrolhos reefs the frequencies of living corals can reach values of up to 29%, on the north coast these numbers varies from 0.3 to 10.9% (see Table 1).

The number of coral species identified in the surveyed reefs differ between the two areas, from a maximum of seven in the reefs from the north coast to a maximum of 10 in the Abrolhos reefs (Table 1). On the north coast, the most common coral species in the shallower reefs (4–6 m depth) is *Siderastrea stellata* Verrill 1868 (0.4 to 7.5%) (Kikuchi, 2000). In the Abrolhos area *M. braziliensis* abound in all studied reefs with percentages varying from 19.5 to 71.7 (Pitombo et al., 1988) (Table 2).

4.2. Temporal changes

The occurrence of the major reef corals from the Holocene reef sequences change from bottom to top in the drilling core section (Fig. 6). Although there is a gap of at least 2 ky for reef initiation between the two cores, the endemic coral species *Mussismilia harttii* Verrill 1868 (Fig. 7), in both cores, is the major reef component in the 2 m thick lower core interval that is older than 4 ky BP. The species *M. braziliensis* (Fig. 8) appears in the uppermost core unit, which is, in the Abrolhos core, a massive layer of up to 1 m thick. The appearance of this second coral species occurs, in both cores, with an age interval greater than 1 ky after the *M. harttii* growth climax.

The core sequence, in both cores, show that reef growth started with *M. harttii* at depths equal or greater

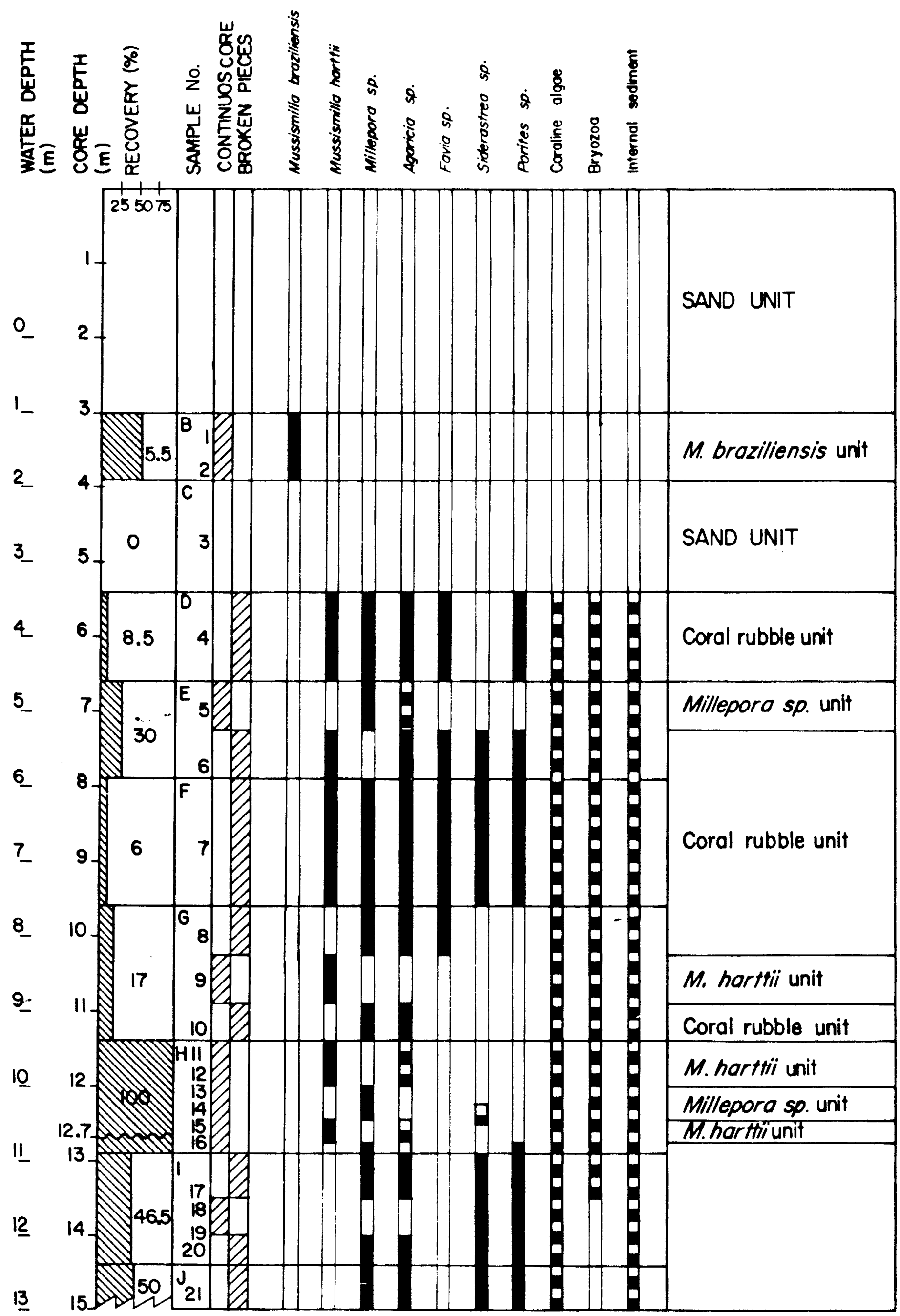

Fig. 5. A diagrammatic description of the composition of the Holocene core section of a reef of the Abrolhos region, south Bahia. The top sand unit is the sandy clay where the drill was located. The second sand unit is a probable internal cavity in the reef structure, filled with carbonate sand. The coral rubble units are sections with fragments of various coral species, more fragile and non-cemented, that were broken during the drill operation (data from Leão (1982)).

than 10 m (see Fig. 6 for the MSL estimated from the SL curve for the eastern coast of Brazil, Martin et al., 1985, Fig. 9), and that *M. braziliensis* appears at an estimated depth shallower than 5 m. *M. harttii* occurs also associated with other corals species in the middle section of the cores, where water depths are estimated to have varied between 10 and 8 m.

Another temporal change in the coral community is observed when comparing the relative abundance of coral species from the exhumed 2.5–3.3 ky old reef tops with the living surface of the reefs of the north coast (Table 3). The percentage coral cover of the old coral community of the exposed sub-fossil reef flat of near-shore reefs varies from 6.2% to 14.5%, whereas in the

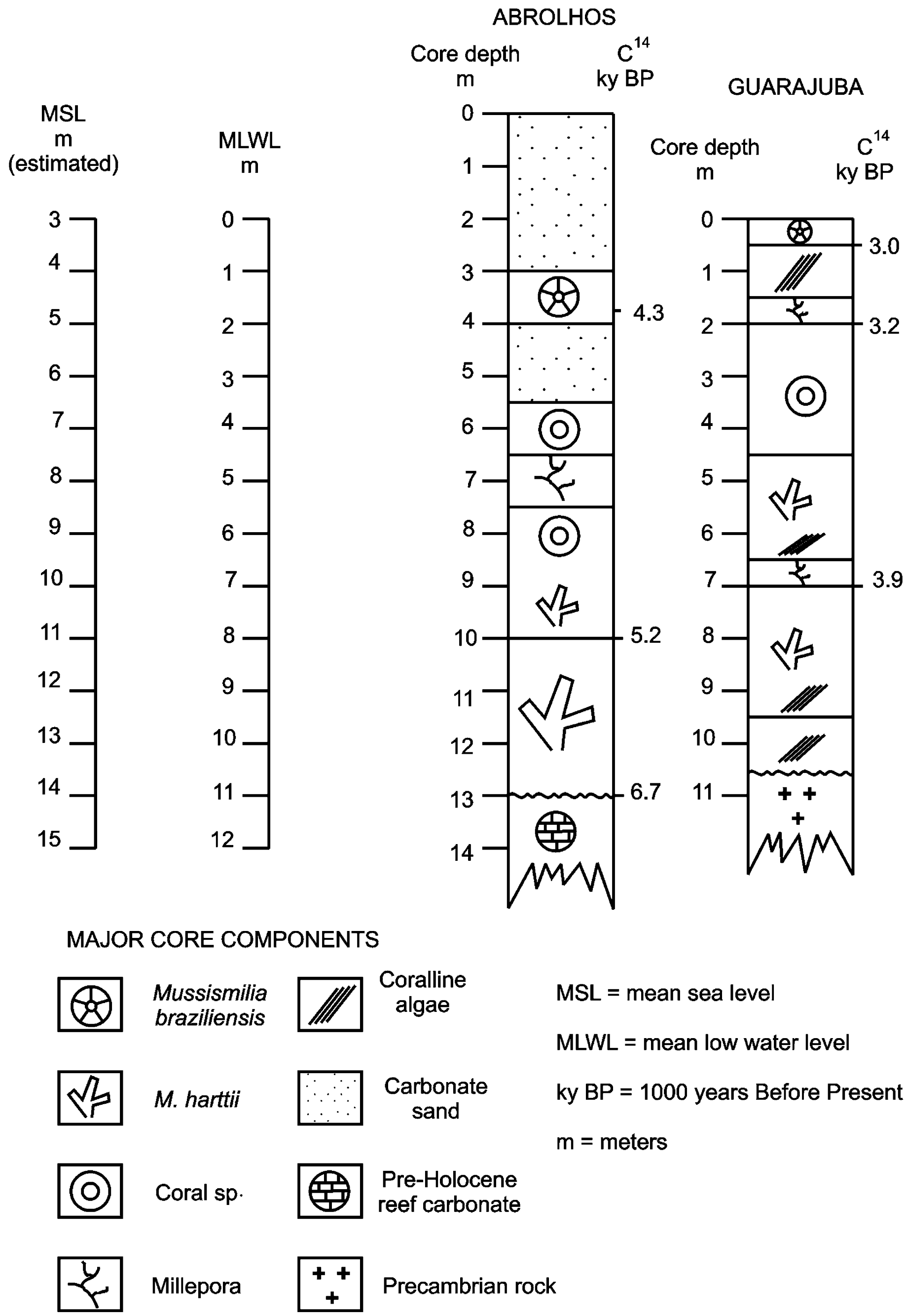

Fig. 6. General composition of two Holocene core sections: the Abrolhos reef of the south coast (Leão, 1982) and the Guarajuba reef of the north coast (Nolasco, 1987) of the State of Bahia, Eastern Brazil.

surface of living reefs the average cover of coral species is less than 3.5% (Kikuchi, 2000; Kikuchi and Leão, 1998; Leão et al., 1997). Another significant difference observed on the colonies of the coral species from the study sites, is the size reduction of the colony diameter of *M. braziliensis* (Table 3). In the 3.0 ky old reefs flat of the nearshore reefs, the measured sub-fossil colonies have diameters varying from 25 to 100 cm (see Fig. 4), while on the surface of the living reefs they are not greater than 20 cm (diameter) (Fig. 10). The colony size of the other coral species did not change very much among the old and the living communities.

5. Discussion

5.1. Natural threats

The late Quaternary sea-level curve for the coast of the State of Bahia, developed by Martin et al. (1985)

Table 1
Survey data of the coral fauna composition of living reefs from the north and the south coasts of the state of Bahia, Eastern Brazil

Reef sites	South coast						North coast		
	N St. Barbara Island	NE Siriba Island	N St. Barbara Island	S St. Barbara Island	W St. Barbara Island	Offshore reefs	Guarajuba	Itacimirim	Praia do Forte
Year of survey	1988	1988	2000	2000	2000	2000	1996–98	1996–98	1996–98
Water depth (m)	3.0–4.0	0.7–2.9	3.5–4.5	4.0–5.5	3.5–4.5	6.0–6.5	4.0–5.0	5.0	5.0
Coral cover (range %)	9.7–13.6	17.5–29.4	6.8–11.3	3.5–7.8	7.4–12.1	14.6–22.8	0.3–1.1	0.0–10.9	2.0–5.9
Coral species (N)	9	10	7	8	5	7	5	7	7
Mussismilia braziliensis (range %)	41.6–71.7	19.5–48.0	90.5–98.5	66.0–74.0	82.0–91.5	66.5–74.0	0.0–0.3	0.0–1.3	0.0–0.1
Diameter *M. braziliensis* (range cm)	8.8–20.0	21.6–23.4	36.5–45.5	45.0–50.5	37.5–47.0	37.5–47.0	15.0–20.0	15.0–20.0	3.5–7.0
Distance from shore (km)	60	60	60	60	60	80	1	2	1
Shelf width (km)	200	200	200	200	200	200	15	15	15
Number of transects	3 × 20 m	4 × 20 m	30 × 10 m	30 × 10 m	30 × 10 m	50 × 10 m	8 × 10 m	8 × 10 m	8 × 10 m
Data source	Pitombo et al. (1988)		Kikuchi et al. (2003)				Leão et al. (1997); Kikuchi (2000)		

is characterized by a transgressive phase that reached a maximum of 5 m above the present sea level at 5.10 ky BP, followed by a general regressive phase since that time, with two sudden drops at around 4.00 and 2.00 ky BP (see Fig. 9). These fluctuations of sea level exposed the reefs to marine erosion and the coral communities living on the flattened intertidal reef tops to an increased UV radiation and heavy sedimentation.

The survey of the 3.00 ky old reef flat of the nearshore reefs reveal that these were once flourishing reefs. They were established at about 6.00 ky BP and had a period of vigorous reef growth following sea level rise, when they attained sea surface, the climax of *M. braziliensis* growth, and their colonies reached diameters up to 100 cm (see Fig. 4). This situation is seen, at present time, on the offshore reefs of the Abrolhos area, where 25 m high coral columns (Brazilian "chapeirões"), mainly built by the endemic coral *M. braziliensis*, grow profusely in an environment free of terrigenous sediment influence (Fig. 11) (Leão, 1994, 1997; Leão et al., 2003).

The sea level drop that occurred after 5.00 ky BP caused progradation of the coastline, placing the beaches closer to the reefs and mobilized the western continent-derived terrigenous sediment toward the eastern reef system. This process exposed the nearshore reefs to a heavy sedimentation and must have contributed to increase coral mortality on the reefs of north Bahia.

Today only few coral species have a significant occurrence on the Brazilian reefs and most of them are endemic forms, a relic coral fauna dating back to the Tertiary. Now, only few small colonies (up to 20 cm diameter) of the *M. braziliensis* species, which once flourished on the reefs of north Bahia, thrive on this environment (see Fig. 10).

5.2. Anthropogenic disturbances

The fact that the Brazilian coastal reefs have been growing despite significant influx of terrigenous sediment for more than three thousand years, they seem to be, in recent time, clearly under a higher stress due to human activities. Recent studies developed on the reefs along the coast of the state of Bahia, show that several human activities are affecting the reefs and among them are: (a) the abnormal increase of eutrophic waters in the reef's surroundings, in highly populated areas of the north coast of the state, which is affecting the condition of the reef's biota (Costa Jr., 1988; Costa Jr. et al., 2000), (b) the rate of reef bioerosion influenced by a nutrient enrichment that is favoring the activity of planktivorous animals (Reis, 2001; Reis and Leão, 2003; Santa-Izabel, 2001; Santa-Izabel et al., 2000), (c) the effects of increasing sedimentation rate on the vital condition of the reef builder corals in the coastal reefs of Abrolhos (Dutra,

Table 2
Percent cover of major living reef building coral species (range)

	South coast		North coast		
Reef sites	N St. Barbara Island	N Siriba Island	Guarajuba	Itacimirim	Praia do Forte
Year of survey	1988	1988	1996–98	1996–98	1996–98
Mussismilia braziliensis	41.7–71.7	19.5–48.0	0.0–0.3	0.0–1.3	0.0–0.1
Mussismilia hispida	12.6	5.5–12.2	0.0–0.5	0.0–2.1	0.2–0.6
Mussismilia harttii	3.4–3.7	2.9–10.2	0.0	0.0–1.3	0.0
Siderastrea stellata	8.3–40.3	21.0–55.7	0.0–0.4	0.0–7.5	1.0–2.4
Montastrea cavernosa	2.5–20.0	7.3–11.0	0.0	0.0	0.0–0.3
Favia gravida	0.7–2.6	1.9–9.3	0.0–0.1	0.0–0.4	0.0–0.3
Favia leptophylla	3.9	2.3	0.0	0.0	0.0
Porites branneri	0.3–0.5	1.0–4.6	0.0	0.0	0.0
Porites astreoides	0.0	2.5–4.6	0.0	0.0	0.0
Porites sp	0.0	0.0	0.0	0.0–0.1	0.0–0.1
Agaricia sp	1.0–1.4	0.4–13.1	0.0–0.2	0.0–0.2	0.1–3.5
Data source	Pitombo et al. (1988)		Kikuchi (2000)		

Data obtained in reefs of the north and south coasts of Bahia State, Eastern Brazil.

2003; Dutra et al., 2005), and (d) the pressure of marine tourism in the reefs located within protected areas that are opened to recreational diving in the Abrolhos National Marine Park (Spanó, 2004).

5.2.1. Effects of high nutrients influx on the coral reefs from the north coast of the state of Bahia

Data from the studies developed by Costa Jr. (1988) and also published by Costa Jr. et al. (2000) show that

Fig. 7. The endemic coral *Mussismilia harttii* (6.7 ky old) on the lowest section of the core from the Abrolhos region. Scale on the right bottom is 1 cm (see Fig. 6 for location of the core section).

Fig. 8. The endemic coral *Mussismilia braziliensis* (4.3 ky old) on the topmost section of the core from the Abrolhos region. Scale on the right bottom is 1 cm (see Fig. 6 for location of the core section).

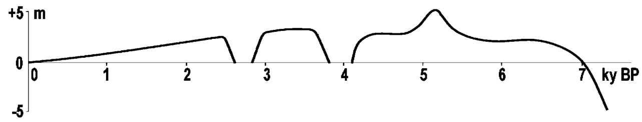

Fig. 9. The Holocene sea level curve of the coast of the State of Bahia during the last 7 ky years (after Martin et al., 1985).

the concentration of nitrate, nitrite, ammonia, phosphate and silicate in the groundwater from a highly urbanized area surrounding nearshore reefs is higher than in the groundwater from an area of low human occupation (Table 4). This fact suggests that the high levels of nutrients are affecting the community structure of the reefs of Guarajuba beach, where the increasing growth of turf and macro algae are causing a reduction in the living coral coverage (measured following the AGRRA protocol, Atlantic and Gulf Rapid Reef Assessment, Ginsburg et al., 1998) (see Table 4). According to the authors both the soil permeability and a prominent hydraulic head, which eventually leads to the percolation of nutrient-rich groundwater seaward to the reefs, facilitate the infiltration of nutrients in the reef's groundwater. The contamination of groundwater is a result of an accelerated unplanned urbanization of the area, e.g., the Guarajuba beach, with the uncontrolled use of septic tanks. The contaminated wastewater from the septic tanks can easily flow through the porous bedrock (beach sandstone) and reach the shallow groundwater (average depth 1.7 m). And this eutrophic condition appears to be clearly deleterious to the reef-building biota of the Guarajuba beach reefs, where macro and turf algae are taken the place of stony corals.

5.2.2. *The effects of macroborers activity on the north Bahia coral reefs*

The result of bioerosion on coral reefs, through the activity of micro and macroborers, can cause the dissolution and degradation of the reefs, as well as the destruction of coral colonies, which rapidly loose their

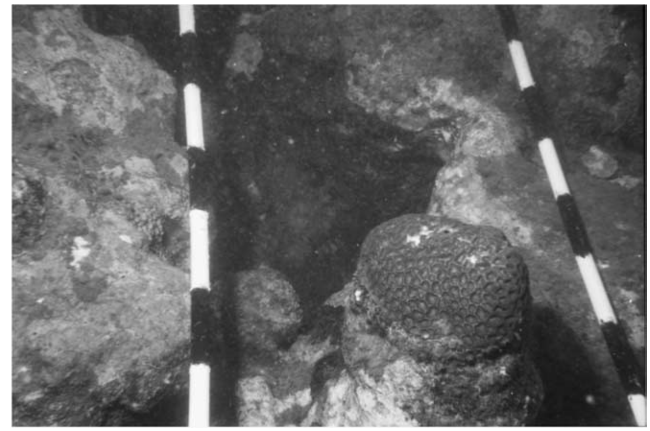

Fig. 10. The endemic coral *Mussismilia braziliensis* Verrill 1868 at the surface of a reef from the north coast of the state of Bahia, Eastern Brazil. Divisions of scale bars are 10 cm long.

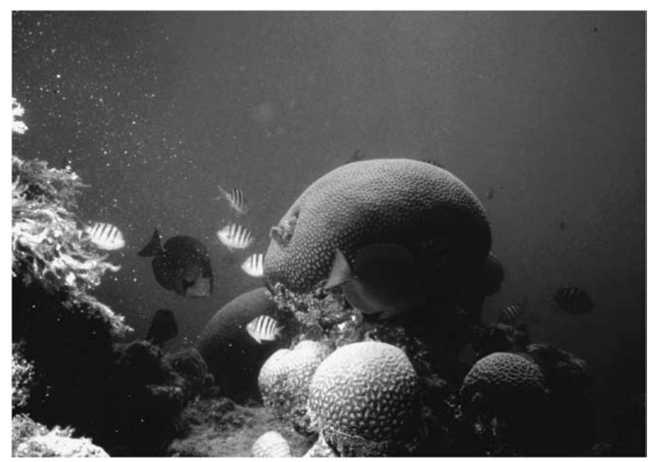

Fig. 11. The endemic coral species *Mussismilia braziliensis* Verrill 1868, at the reefs of Abrolhos, South Bahia (Photo courtesy of C. Secchin).

stability and become susceptible to the mechanical breakdown, causing removal of primary reef framework,

Table 3
Old and living reef's parameters

	Old reef tops (2.5 to 3.3 ky BP)			Living reefs surface		
Reef sites	Guarajuba	Itacimirim	Praia do Forte	Guarajuba	Itacimirim	Praia do Forte
Year of survey	1996–98	1996–98	1996–98	1996–98	1996–98	1996–98
Water depth (m)	<3 (estimated)	<3 (estimated)	<3 (estimated)	4.0–5.0	5.0	5.0
Coral cover (%)	6.2 ± 3.8	14.5 ± 10.5	11.1 ± 6.0	0.7 ± 0.4	2.6 ± 3.3	3.5 ± 1.5
Coral species (number)	7	4	3	5	7	7
Mussismilia braziliensis (%)	3.1 ± 3.2	4.8 ± 3.3	5.1 ± 8.3	0.1 ± 0.2	0.3 ± 0.5	0.0 ± 0.1
Diameter *M. braziliensis* (cm)	27.5 ± 3.8	33.9 ± 16.2	46.3 ± 20.7	17.5 ± 3.5	14.5 ± 6.7	3.5
Distance from shore (km)	2 (estimated)	2 (estimated)	2 (estimated)	1	2	1
Extension of survey	28 m^2	30 m^2	80 m^2	8 × 10 m	8 × 10 m	8 × 10 m
Data source	Leão et al. (1997); Kikuchi (2000)	Kikuchi and Leão (1998); Kikuchi (2000)	Kikuchi (2000)	Leão et al. (1997)	Kikuchi and Leão (1998)	Kikuchi (2000)

Data obtained in the north coast of Bahia State, Eastern Brazil.

Table 4
Nutrients values of groundwater and average percentages of algae and coral cover of two reef areas at the north coast of the state of Bahia, Eastern Brazil

Reef sites	Nitrite	Nitrate	Ammonia	Phosphate	Silicate	Macroalga	Turfalgae	Coral line algae	Coral	Others
Guarajuba reef (highly urbanized)	0.92 ± 0.26	11.63 ± 683	34.54 ± 3.94	4.88 ± 3.72	76.39 ± 46.16	33.0 ± 5.0	41.0 ± 5.0	3.0 ± 3.5	2.5 ± 2.5	20.5 ± 4.5
Papa Gente reef (low human occupation)	0.26 ± 0.13	4.49 ± 2.05	9.96 ± 3.56	1.74 ± 0.93	16.66 ± 9.87	15.0 ± 3.0	24.0 ± 3.5	2.5 ± 2.5	9.0 ± 5.0	44.5 ± 5.0

Others = sediment + dead coral + bare area + zooanthid + sponge. Data from Costa Jr. (1988); Costa Jr. et al. (2000).

Table 5
Average relative percentage of bioerosion by macroborers in the nearshore reefs of north Bahia

	Sponges	Bivalves	Worms
Siderastrea stellata	53.6 ± 25.3	28.9 ± 17.4	17.4 ± 14.7
Mussismilia hispida	–	71.8 ± 22.7	28.3 ± 35.0

Data of *Siderastrea stellata* from Reis (2001) and of *Mussismilia hispida* from Santa-Izabel (2001).

and this bioerosion activity is known to be favored by the increase of available nutrients (Hallock, 1988; Hallock et al., 1993).

Studies developed by Reis (2001) and Reis and Leão (2003) on X-rays of coral slabs of the reefs from north Bahia, considering the rates of bioerosion by sponges, bivalves and worms in living colonies of the endemic coral *Siderastrea stellata*, show that sponges and bivalves are the most active bioeroders in the studied corals, the sponges representing more than 50% of the macroborers infestation (Table 5).

Data from Santa-Izabel (2001) and Santa-Izabel et al. (2000), comparing the bioerosion activity of bivalves and worms (polyquetes and sipunculids), on X-rays of coral slabs from dead colonies of the endemic species *M. hispida* Verrill 1868, in the same reefs that Reis (2001) studied, found that bivalves are the bioeroders with the highest relative percentages in comparison with worms (see Table 5). These findings suggest that the influence of an enrichment of nutrient levels, due to the groundwater contamination by domestic sewage of the nearshore reefs of north Bahia (as seen above), is favoring the activity of the two macroborers, sponges and bivalves, which are planktivorous, and at levels that can be considered deleterious to the reefs.

5.2.3. The effects of increasing sedimentation rates on the coastal reefs of the Abrolhos region

Data from the works done by Dutra (2003) and Dutra et al. (2005) show that the sediment accumulation rates measured with sediment traps fixed in five reef sites in the Abrolhos region, in south Bahia, are negatively related with the biotic parameters of the reef biota, particularly the live coral cover, the diameter of hydrocorals and the number of coral recruits (measured according the AGRRA protocol, Atlantic and Gulf Rapid Reef Assessment, Ginsburg et al., 1998). The average rate of 15 $mg/cm^2/day$ seems to constitute a critical limit for coral survival, because within this limit there is a significant inverse relationship between the rate of sediment accumulation and the measured biotic parameters, as well as there is also a negative impact in relation to the terrigenous content of the sediment. The Pedra Leste and Lixa reefs, both distant less than 20 km from the coastline, have the highest values for sediment accumulation rates and the highest percentages of terrigenous

Table 6
Accumulation rate and terrigenous content of perireefal sediment versus biotic parameters of reefs of the Abrolhos region

Reef sites	Distance from shore km	Sed. Accum. rate mg/cm^2/day	Sed. terrigenous %	Coral cover %	Diameter Millepora cm	Recruits N
Pedra Leste	12	15.7 ± 6.2	50.4 ± 0.1	5.6 ± 2.8	42.1 ± 9.0	6.7 ± 4.2
Lixa	20	19.6 ± 10.9	36.1 ± 4.0	9.4 ± 4.0	42.9 ± 11.3	8.3 ± 3.3
Timbebas	18	7.3 ± 1.6	38.9 ± 2.4	12.2 ± 2.4	52.3 ± 8.8	10.5 ± 7.7
Pedra Grande Sul	32	6.0 ± 0.3	30.1 ± 2.8	10.7 ± 2.8	61.1 ± 24.7	13.7 ± 5.4
Parcel dos Abrolhos	60	8.9 ± 5.5	6.0 ± 0.1	14.4 ± 5.5	53.5 ± 17.1	10.2 ± 4.4

Data from Dutra (2003).

sediment, and they exhibit the lowest percentages of (a) live coral cover, (b) average diameter of the colonies of *Millepora alcicornis*, Linneus 1758, and (c) the average number of coral recruits. On the other hand, the opposite is seen with the reefs located far away from the coast (Parcel dos Abrolhos reefs) (Table 6). The proximity of the reefs from mainland constitutes, thus, the factor that exposes the reefs to the effects of the continent derived sediments. There is an exception, the Timbebas reef, which, despite being located in a similar distance of the coastline than the reefs Pedra Leste and Lixa, it shows lower sediment accumulation rate. Dutra et al. (2005) explain that the Pedra Leste and Lixa reefs are located on the lee side of a large group of bank reefs, which function as physical barrier to the free water flow, acting as sediment traps, whereas the Timbebas reef is formed by isolated coral pinnacles, which allows an opener water circulation that prevent sediment to accumulate in their surroundings. Dutra et al. (2005) also suggest that the reduction of the living coral cover can be due to the inhibition of coral recruitment, the reduction of coral skeleton growth or its death, and the diminution of coral recruitment is a result of the movement of sediment that removes and kills the juvenile corals before their fixation.

5.2.4. The tourism pressure on the reefs from the Abrolhos National Marine Park

The results of a period of three years (2000–2002) of monitoring the fringing reefs that borders the islands of the Abrolhos Archipelago (Fig. 12) applying the AGRRA protocol (Atlantic and Gulf Rapid Reef Assessment, Ginsburg et al., 1998), show that the fringing reefs located at the south coast of St. Barbara Island presented the lowest values for the stony corals vitality. Living coral cover, occurrence of the endemic coral *M. braziliensis* (the major reef-builder coral in Abrolhos) and number of coral recruits per square meter of that site are lower than the measured in the reefs located at its north and west shores and the reefs located in areas closed for diving (Table 7). The south St. Barbara shore is the preferred site for anchoring because it is, in the whole archipelago, the most protected area from the NE-E prevailing winds. As a consequence, diving is more

Fig. 12. The Abrolhos Archipelago. G = Guarita Island; SB = Santa Barbara Island; R = Redonda Island; Si = Siriba Island; Su = Sueste Island. Star illustrates the preferred site for anchoring at the south shore of Santa Bárbara Island. For location of the archipelago see Fig. 2 (Photo courtesy of M. Skaf).

Table 7
Major biotic parameters measured in the coral community of the fringing reefs of the Abrolhos Archipelago, according to the AGRRA protocol (Atlantic and Gulf Rapid Reef Assessment, Ginsburg et al., 1998), during the 2002 survey

Reef sites	Coral cover (%)	*Mussismilia braziliensis*/m^2	Coral recruits/m^2
S. St. Barbara Island	6.9 ± 2.8	1.8 ± 0.6	10.4 ± 1.8
N. St. Barbara Island	16.2 ± 6.9	4.4 ± 1.0	13.9 ± 2.1
W. St. Barbara Island	14.0 ± 4.6	3.5 ± 1.1	15.5 ± 2.4
Redonda Island	13.8 ± 6.9	3.4 ± 0.4	21.0 ± 2.6
Guarita Island	15.8 ± 6.8	3.2 ± 0.6	28.5 ± 3.4
Sueste Island	–	3.5 ± 1.6	–

frequent in this reef site. Visitors use the north shore of St. Barbara Island only when occasional SE winds occur during winter storms, and the W St. Barbara reef is not a good site for anchoring. The fringing reefs of Guarita and Sueste islands are closed for recreational use according to the Park Management Plan (Gonchorosky et al., 1989; IBAMA/FUNATURA, 1991).

Spanó (2004) found that the number of visitors that dive in the south shore of St. Barbara Island can reach over 10,000 persons per year, a number that it is considered high enough to be deleterious to the reef's vitality. Frequent impacts are boat grounding and anchor damage, but the divers direct interaction with corals, touching them with their hands, body, gear and fins, breaking the coral colonies can also promote reduction in reef vitality.

Although the Brazilian coral fauna have shown resistance to bleaching and mortality, and may be functionally adapted to the stressful condition of the Brazilian highly turbid coastal waters (Leão and Ginsburg, 1997), a synergism of these natural processes with anthropogenic disturbances can aggravate the recovery capacity of these already naturally disturbed coral community. Improvement of protective measures should then be enforced in the existing Brazilian Marine Reserves, identifying priorities for action, such as campaigns to change people's attitude towards reef conservation, strengthening monitoring programs and the value of reef assessment, specially in areas not yet even described. It must also be shown to decision-makers the need and effectiveness of management practices before the major reef building coral species of Brazil, the relic coral fauna, appears in the list of endangered species.

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