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Research Article

Coral bleaching in the Caramuanas reef (Todos os Santos Bay, Brazil) during the 2010 El Niño event

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ABSTRACT. Episodes of coral bleaching related to El Niño events have been increasing in frequency and severity. This phenomenon is cited as a major cause of degradation of coral reefs. This study evaluates the effects of coral bleaching on the Caramuanas reef community, which occurred during the southern hemisphere summer of 2009/2010. Within this period the sea surface temperature of 31°C and thermal anomalies up to almost 1°C were recorded. During and after this El Niño event, frequency and severity of bleaching, live coral cover, number of colonies, class size, disease occurrence, and mortality rate were monitored on corals larger than 20 cm in diameter. The samples were taken at twelve fixed transects, in three reef stations. Statistical analysis showed that the severity of bleaching was different between the two periods, during and after the 2010 ENSO event. The Caramuanas reef showed sublethal bleaching effects indicating that this reef is tolerant to bleaching when the temperature anomalies do not exceed 0.75°C within one week.

Keywords: coral bleaching, sublethal effects, thermal anomaly, thermal tolerance, eastern coast of Brazil.

Blanqueamiento de corales en el arrecife de Caramuanas (Bahía de Todos los Santos, Brasil) durante el evento El Niño 2010

RESUMEN. Los episodios de blanqueamientos de corales relacionados con los eventos de El Niño han ido aumentando en frecuencia e intensidad durante los últimos años. Estos fenómenos se citan como una de las principales causas de la degradación de los arrecifes de coral. Este estudio evaluó los efectos del blanqueamiento del arrecife de coral en la comunidad de Caramuanas, que se produjeron durante el verano austral de 2009/2010. En este período se registró temperaturas de la superficie del mar de hasta 31°C y anomalías térmicas del orden de 1°C. Durante y después de este episodio El Niño, se analizó la frecuencia y severidad del blanqueamiento, cobertura de coral vivo, número de colonias, clases de tamaño, aparición de enfermedades y tasa de mortalidad en los corales mayores de 20 cm de diámetro. Las muestras fueron tomadas en doce transectas fijas, divididas en tres estaciones de arrecife. El análisis estadístico mostró que la severidad del blanqueamiento fue diferente entre los dos períodos, durante y después del evento. El arrecife de Caramuanas mostró efectos subletales de blanqueamiento que probó que este arrecife es tolerante a los fenómenos de blanqueamiento cuando las anomalías de temperatura no exceden 0,75°C durante una semana.

Palabras clave: blanqueamientos de corales, efectos subletales, anomalías térmicas, tolerancia térmica, costa oriental de Brasil.

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INTRODUCTION

Bleaching is a major cause of coral mortality and represents one of the major threats to corals world-wide (Hoegh-Guldberg, 1999). This phenomenon has become more frequent and is responsible for the loss of biodiversity and fishing resources in the reef ecosystems (Bellwood *et al*., 2004).

Coral bleaching occurs in response to environ-mental stress and disrupts the symbiotic relationship established between corals and the zooxanthellae (dinoflagellates). These microalgae live in the coral tissue and provide a considerable portion of the energy required by the coral to survive. Under stress the coral tissue becomes transparent upon the expulsion of the zooxanthellae and/or the loss of their photosynthetic pigments; once transparent, the coral appears to be white due to the color of its subjacent calcareous skeleton (Douglas, 2003; Weis, 2008).

Bleaching episodes of large intensity and scale (lethal or mass bleaching) have been attributed to abnormal increases in oceanic water temperature, and these phenomena occur frequently during El Niño Southern Oscillation (ENSO) periods (Glynn, 1988; Bruno *et al*., 2001). This suggests that mass bleaching is related to global climate changes (Oxenford *et al*., 2008; Wilkinson, 2008; Hoegh-Guldberg & Bruno, 2011). And this fact also explains the large number of studies conducted in the last decades that have recorded lethal effects of bleaching, for example, the mass mortality of some coral species (Wilkinson *et al*., 1999; Wilkinson & Souter, 2008; Oxenford *et al*., 2010; Eakin *et al*., 2011).

Sub-lethal bleaching effects have been observed, recently, but they have not been extensively studied (Suggett & Smith, 2011). They occur when corals do not experience mortality after bleaching, but rather undergo a temporary loss of zooxanthellae and/or of their photosynthetic pigments, with later recovery. This potential for recovery suggests that corals have an adaptive capacity or resistance to seasonal changes in environmental conditions (Buddemeier & Fautin, 1993; Hennige *et al*., 2010; Hughes *et al*., 2011).

Thermal anomalies on the Brazilian coast have been monitored by NOAA satellite imaging since 1998, and there have been many reports of bleaching events occurring in association with ocean warming events (Migotto, 1997; Castro & Pires, 1999; Dutra *et al*., 2000; Costa *et al*., 2001, 2004; Costa & Amaral, 2002; Kikuchi *et al*., 2003; Leão *et al*., 2003, 2008; Ferreira & Maida, 2006). None-theless, only Dutra *et al*. (2000), reported observations of the reefs after the occurrence of the bleaching phenomenon. To help bridge this gap in knowledge, this study was designed to evaluate the effect of bleaching in the corals from Caramuanas reef by comparing their communities during and immediately after the thermal anomalies related to ENSO 2010.

MATERIALS AND METHODS

Study area

The Caramuanas reef is located in the entrance of Todos os Santos Bay, on the State of Bahia, at the eastern coast of Brazil. In this region there are the largest and the richest coral reefs of the southwestern Atlantic ocean (Laborel, 1970; Leão *et al*., 2003). The Caramuanas reef comprise three main flat reef banks (13°07'S-38°43'W, 13°07'S-38°44'W and 13°08'S-38°44'W) (Fig. 1). These banks are distributed within an area of approximately 4 km in length and 50 m in width, at a depth of less than 6 m. The reef is exposed during low spring tides, and is exploited by several different types of fishing activities.

The thermal anomalies, along the coast of Bahia, were recorded from the National Environmental Satellite Data and Information Service (NESDIS) database, provided by National Oceanic Atmospheric Administration (NOAA), and the temperature of the ocean surface water was generated by processing satellite images collected from NASA and publically available online. It was used data from January to April 2010, which correspond to the end of summer and beginning of fall in the southern hemisphere. This also corresponds to the period of highest ocean surface water temperatures off the Brazilian coast (Leão *et al*., 2008). The data were acquired every three days using the hot spot maps for coral bleaching from http://www.osdpd.noaa.gov/ml/ocean/-cb/hotspots.html.

The water temperature data were generated by the MODIS sensor on the NASA AQUA satellite and obtained by processing remote images taken during and after the occurrence of the thermal anomalies using GIOVANNI software (http://disc.sci.gsfc.nasa.gov/giovanni).

Field data collection and statistical analysis

The field data in the Caramuanas reef were collected in three stations, located as follows: one on the northern part of the reef (north station), one on its center (central station), and one on the southern portion (south station) (Fig. 1). At each station, four fixed transects were marked with rebar. Each station was studied during the thermal anomaly period (March 2010), and after the anomaly period (October and/or November 2010), with a total of six visits to the reef.

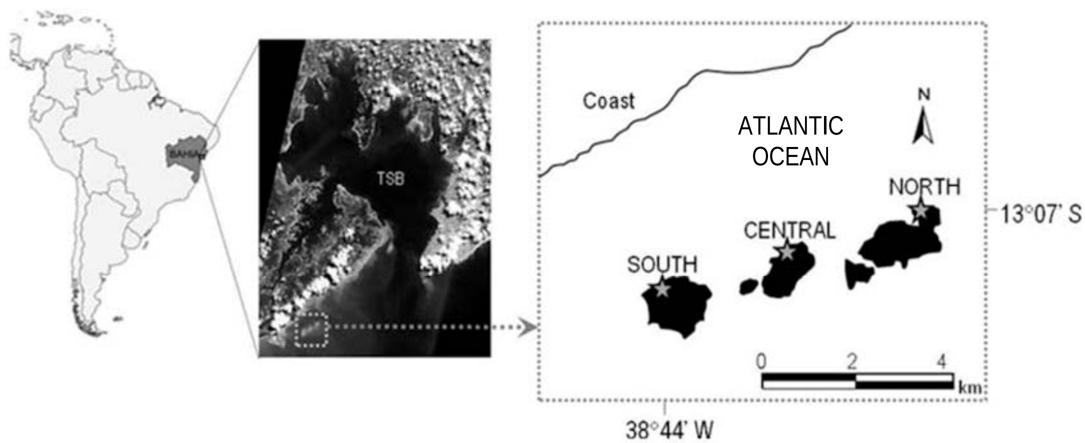

Figure 1. Location of studied reef stations. Caramuanas reef, Todos os Santos Bay, eastern Brazilian coast.

Following the BLAGRRA protocol (Bleaching Atlantic and Gulf Rapid Reef Assessment, Lang *et al.*, 2010), a visual census of corals along transects was performed during scuba diving. The original protocol was modified by increasing the length of transects. Instead of six transects 10 m long, in five reef stations, as it is in the original protocol, we used four transects 20 m long in three reef stations. A total of twelve replicates were made at each time point, *i.e.*, four replicates per station. Along these 12 fixed transects the percent live coral cover, determined as the extension of the live surface of each coral colony present under the transect line, was measured. For each colony larger than 20 cm in diameter present in a distance up to 50 cm on each side of the transect line (a band of 1 m in width), the following parameters were recorded: number and name of the coral species, length, width and height of the colony, percentage of the colony area bleached, bleaching intensity (how pale the coral was), presence of disease, extension (%) and time (recent, intermediate or old) of mortality of the colony surface area.

The bleaching intensity (weak or strong) was assigned accordingly to the tonality of the colony (pale or white), and recorded as a percentage of the colony affected area. The extension of mortality was the percentage of the dead colony area. The time of mortality (recent, intermediate or old) was assigned to the colony dead area. Recent mortality was characterized by a white skeleton that had recently been exposed due to death of living tissue covering it (*i.e.*, a complete, intact skeletal structure). Colonies were classified as having intermediate mortality when the skeleton was slightly eroded or covered by a fine layer of sediment, filamentous algae, diatoms or cyanobacteria, and the structure of the corallite could still be observed. Colonies were classified as having old mortality when the corallites were covered by organisms that were not easily removed, such as macroalgae and/or invertebrates. All types of mortality, as designated in the protocol, were recorded as the percentage of the affected area of the colony surface.

The Kruskal-Wallis (KW) test was used to evaluate differences between the investigated time periods of the following parameters: total bleaching, bleaching severity, bleaching pattern among species, live coral cover, number of colonies, and mortality, which did not have a normal distribution. In the overall, 13 statistical tests were performed, leading to the use of the Bonferroni for correcting the $\alpha = 0.05$ to $\alpha = 0.004$. Analysis of variance (ANOVA) was used to verify differences in the colony sizes among the most abundant coral species.

RESULTS

ENSO intensity and bleaching severity

Starting in February, the thermal anomalies that affected the TSB in 2010 lasted for eight weeks, reaching a maximum value of 0.75°C in March, completely dissipating in April (Fig. 2). During the thermal anomaly period, the water temperature reached 31°C, which is the highest value recorded in the last ten years for this region.

Total and weak bleaching showed significant differences during and after thermal anomalies within the study period (KW total bleaching: $P < 0.004$; weak bleaching: $P < 0.004$; strong bleaching: $P > 0.004$, Fig. 3). During the thermal anomalies, 133 coral colonies were measured and 57.1% were affected to

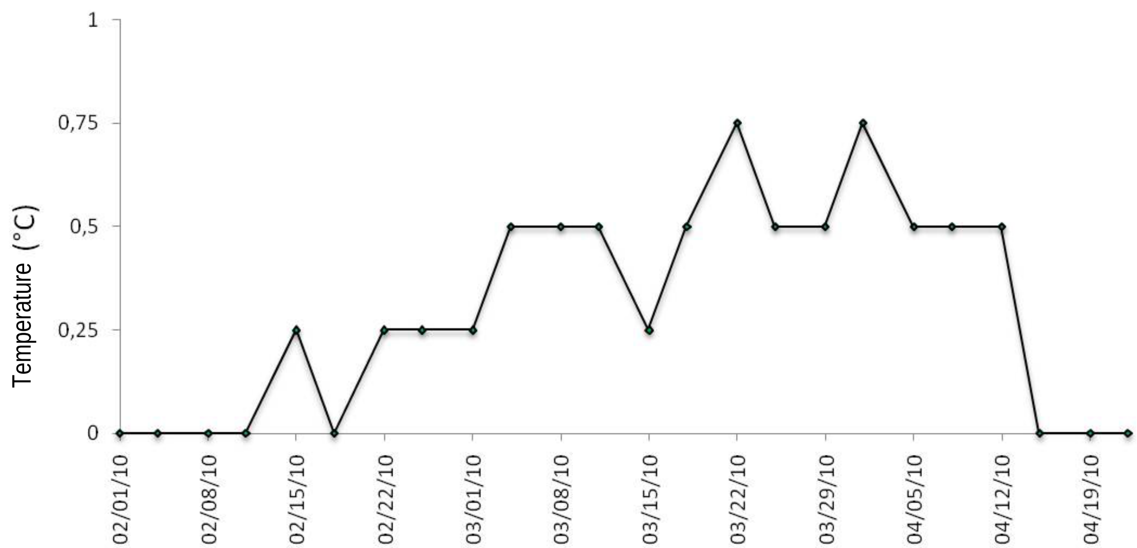

Figure 2. Thermal anomalies in Todos os Santos Bay in 2010.

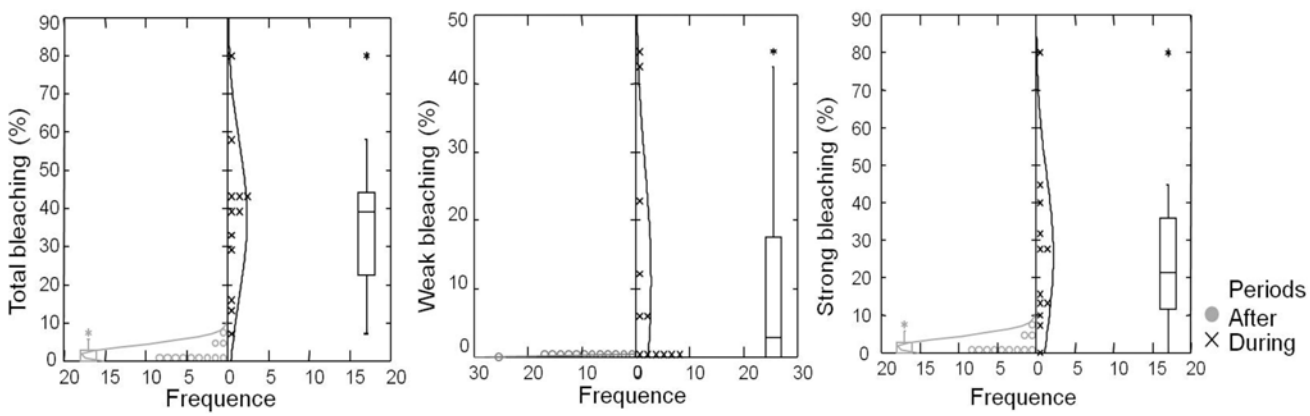

Figure 3. Graph depicting the total bleaching and the degree of bleaching intensity (weak, strong) in each evaluated period, during and after the thermal anomalies.

some degree of bleaching most of them with weak bleaching. After the occurrence of the thermal anomalies, when a total of 118 colonies were recorded, only 5.1% still had some signal of weak bleaching (Table 1). Fifteen coral colonies were not found during the second survey, although both assessments were performed along fixed transects.

Coral bleaching on the assessed coral community

Five scleractinian coral species and one hydrocoral were found on the studied reef sites. The most abundant species were *Siderastraea* spp., followed by *Montastraea cavernosa*, *Mussismilia hispida*, *Millepora alcicornis*, *Mussismilia braziliensis* and *Mussismilia harttii*. They presented different percentages of the area affected by bleaching, as well as different intensity of bleaching (weak and/or strong). Of the six species recorded only *Mussismilia harttii* did not suffer bleaching (Table 1).

Siderastraea spp., the most abundant coral during both surveys, had 60.3% of their colonies affected by bleaching, during the occurrence of the thermal anomalies. Of the 37% of the colony area affected, 34% was by weak bleaching and only 3% by strong bleaching. After the period of occurrence of the ENSO event, only 5.8% colonies still presented signal of bleaching, with less than 1% of the colony area affected by weak and/or strong bleaching.

Montastraea cavernosa was the coral specie the most affected during the occurrence of warming waters, with 81% of their colonies presenting some degree of bleaching (weak or strong). 58% of their

Table 1. Number of colonies recorded, number of bleached colonies and average (± SD) of the colony area affected by different intensity of bleaching (weak, strong) for the coral species and the calcareous hydroid *Millepora alcicornis* in the Caramuanas reef during and after the 2010 thermal anomalies. NC: number of colonies, NBC: number of bleached colonies, TB: total bleaching, WB: weak bleaching, SB: strong bleaching, SD: standard deviation.

Species	During thermal anomalies						After thermal anomalies					
	NC	NBC		TB	WB	SB	NC	NBC		TB	WB	SB
	(#)	(#)	(%)	(average ± SD)	(average ± SD)	(average ± SD)	(#)	(#)	(%)	(average ± SD)	(average ± SD)	(average ± SD)
Siderastraea spp.	73	44	60.3	36.98 ± 37.19	33.97 ± 36.31	3.01 ± 16.49	52	3	5.8	0.65 ± 4.17	0.63 ± 0.00	0.01 ± 0.00
Montastraea cavernosa	27	22	81.5	57.59 ± 38.26	19.70 ± 26.30	37.88 ± 37.74	18	2	11.1	7.77 ± 22.89	7.77 ± 22.89	0.00 ± 0.00
Mussismilia hispida	21	6	28.6	12.14 ± 26.48	3.80 ± 12.44	8.33 ± 24.76	22	0	0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Mussismilia braziliensis	2	0	0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	11	1	9.1	7.27 ± 24.12	7.27 ± 24.12	0.00 ± 0.00
Mussismilia harttii	3	0	0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	3	0	0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Millepora alcicornis	7	4	57.1	45.71 ± 44.66	8.57 ± 22.67	37.14 ± 47.15	12	0	0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Total	133	76	57.1				118	6	5.1			

surface area was bleached, being the highest value observed among all studied species, also, with the highest percentage affected by strong discoloration (38%). After the anomalies, only two colonies still presented some signal of weak bleaching.

Mussismilia hispida the third coral specie in abundance, in both surveys, had 28.6% of its colonies bleached during the occurrence of the 2010 ENSO event. Only 12.1% of the colonies area was affected by bleaching, being *circa* 8% by strong bleaching. After the thermal anomalies no colony was found bleached.

*Mussismilia braziliensi*s was the specie with the smallest number of colonies recorded during the first survey (two colonies) and none was affected by bleaching. After the anomalies, of the total of 11 recorded colonies, only one showed *circa* 7% of its surface area affected by weak bleaching.

The hydrocoral *Millepora alcicornis* had 57.1% of its colonies bleached during the occurrence of the 2010 ENSO event, mostly by strong bleaching (37% of the total affected surface area of 46%). After the thermal anomalies no colony of this specie was found bleached.

The results of the statistical analysis showed that differences among bleached colonies, during and after the thermal anomalies, were significant only between the species *Montastraea cavernosa* and *Mussismilia hispida* (KW test, $P < 0.004$; Fig. 4).

Coral parameters measured

Three measured parameters of the studied coral community are related with the vital condition of the reef: the percent of live coral cover, the number of live colonies and the rate of coral mortality. The records found for all three parameters, from both surveys (during and after the occurrence of the thermal anomalies), show that statistically there are no significant differences (KW test, $P > 0.004$) between the two evaluations. The percent of live coral cover varied from 2.9 ± 1.3% during the anomalies, to 3.6 ± 0.45% after the event of warming waters (Fig. 5). From a total of 133 live coral colonies that were recorded during the first survey (warmer time), only 15 live colonies were not found during the survey performed after the 2010 ENSO event (Fig. 6). The values of the mortality rates (recent, intermediate and old) were not significantly different between the thermal anomaly period and the subsequent period of thermal normalcy (Table 2, Fig. 7).

Table 3 shows, for the most abundant coral species, *Siderastraea* spp., *Montastraea cavernosa* and *Mussismilia hispida*, what were the most common

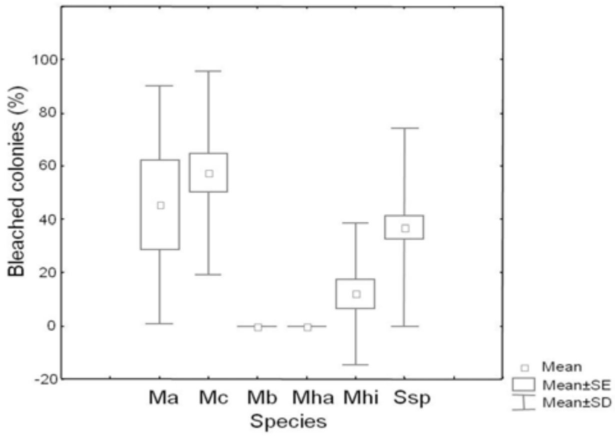

Figure 4. Total bleaching pattern among species, during thermal anomalies. Ma: *Millepora alcicornis*, Mc: *Montastraea cavernosa*, Mb: *Mussismilia braziliensis*, Mha: *M. harttii*, Mhi: *M. hispida*, Ssp: *Siderastraea* spp.

colony size classes in both surveys. In the three coral species, predominated the smallest colonies, the size class 20-30 cm diameter, either during or after the thermal anomalies. Statistically there was no change detected in the structure of this evaluated parameter (ANOVA, $P > 0.004$; Figs. 8a-8c).

About the occurrence of coral disease, only one colony was recorded affected, disabling any statistical test.

DISCUSSION

Of the 57% coral colonies that were affected by bleaching in the study area during the thermal anomalies of the 2010 ENSO, the great majority recovered, which indicate that the effects were sub-lethal for the Caramuanas corals. The 5% of the colonies that still exhibited signs of bleaching after the anomalies could represent normal episodes in shallow reefs exposed to daily thermal variations, as it is suggested by Leão *et al*. (2008) for the coastal reefs along the coast of the state of Bahia. After this bleaching event, neither the rate of mortality nor the number of colonies with disease increased; the size class structure of the most abundant species did not vary; and the number of live colonies and live coral cover also remained the same. Therefore, the reef showed certain resilience to the perturbations caused by the 2010 ENSO event.

Among the most common coral species analyzed, *Montastraea cavernosa* exhibited the highest suscep-tibility to bleaching, and its colonies had the highest relative bleaching values. However, this specie exhibited great capacity for recovery after the

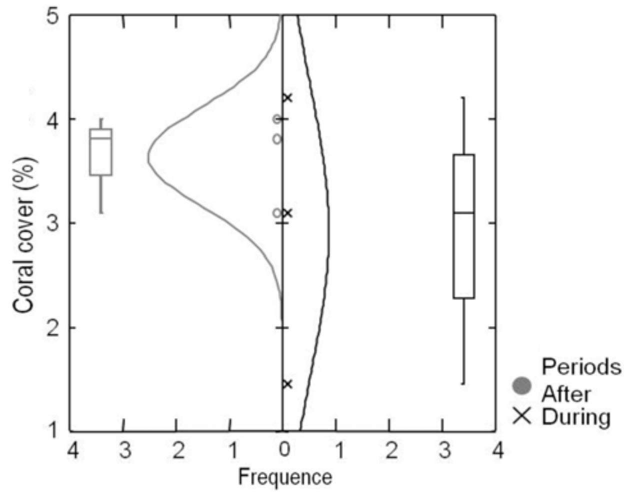

Figure 5. Mean (± SD) live coral cover during each evaluated period, during and after the thermal anomalies.

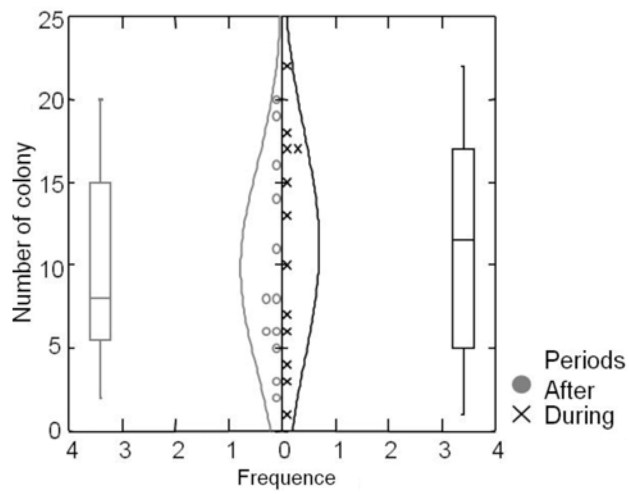

Figure 6. Number of live colonies in each evaluated period, during and after the thermal anomalies.

anomalies ended. Similarly, most *Siderastraea* spp. colonies were pale during the anomalies but later recovered completely. The three species of *Mussismilia*, *M. hispida, M. braziliensis* and *M. harttii*, were the least affected, exhibiting low bleaching rates and complete recovery. These findings are consistent with the literature, suggesting that variations in the susceptibility to bleaching are common and that bleaching affects different species in different ways (McClanahan *et al*., 2005). Suscep-tibility and response to bleaching are thought to be influenced by colony morphology, colony growth rate, metabolic rate and size, as well as the lineage of the symbiotic algae, and thickness of coral polyps (Brandt, 2009). The water depth and/or the zonation of the corals within the same reef may also affect the

Table 2. Number of colonies of the most abundant coral species registered in each size class analyzed during and after the period of thermal anomalies.

Mortality types	During (Average ± SD)	After (Average ± SD)
New	0.31 ± 00.00	0.00 ± 00.00
Intermediate	0.43 ± 00.58	0.47 ± 00.13
Old	13.30 ± 23.36	16.72 ± 24.35
Total	14.05 ± 23.33	17.19 ± 24.37

bleaching process (Marshall & Baird, 2000; Williams *et al*., 2010). The hydrocoral *Millepora alcicornis* showed a rather high susceptibility to bleaching, and besides of being the second species with the highest relative bleaching, it also had the highest percent of dead colonies after the occurrence of the bleaching event. The high sensitivity of this calcareous hydroid has been described in other bleaching events (Glynn & De Weerdt, 1991; Stafford-Smith *et al*., 1993). According to these authors, after the bleaching occurs, several colonies with dead areas become covered with crustose coralline algae, as was seen in the *Millepora alcicornis* colonies.

The sub-lethal effects of bleaching in Brazilian corals have been observed previously. In 1998, the northern littoral of Bahia experienced a bleaching event that affected up to 60% of the coral community, which after one year have completely recovered (Dutra *et al*., 2000). At this same period, the blea-

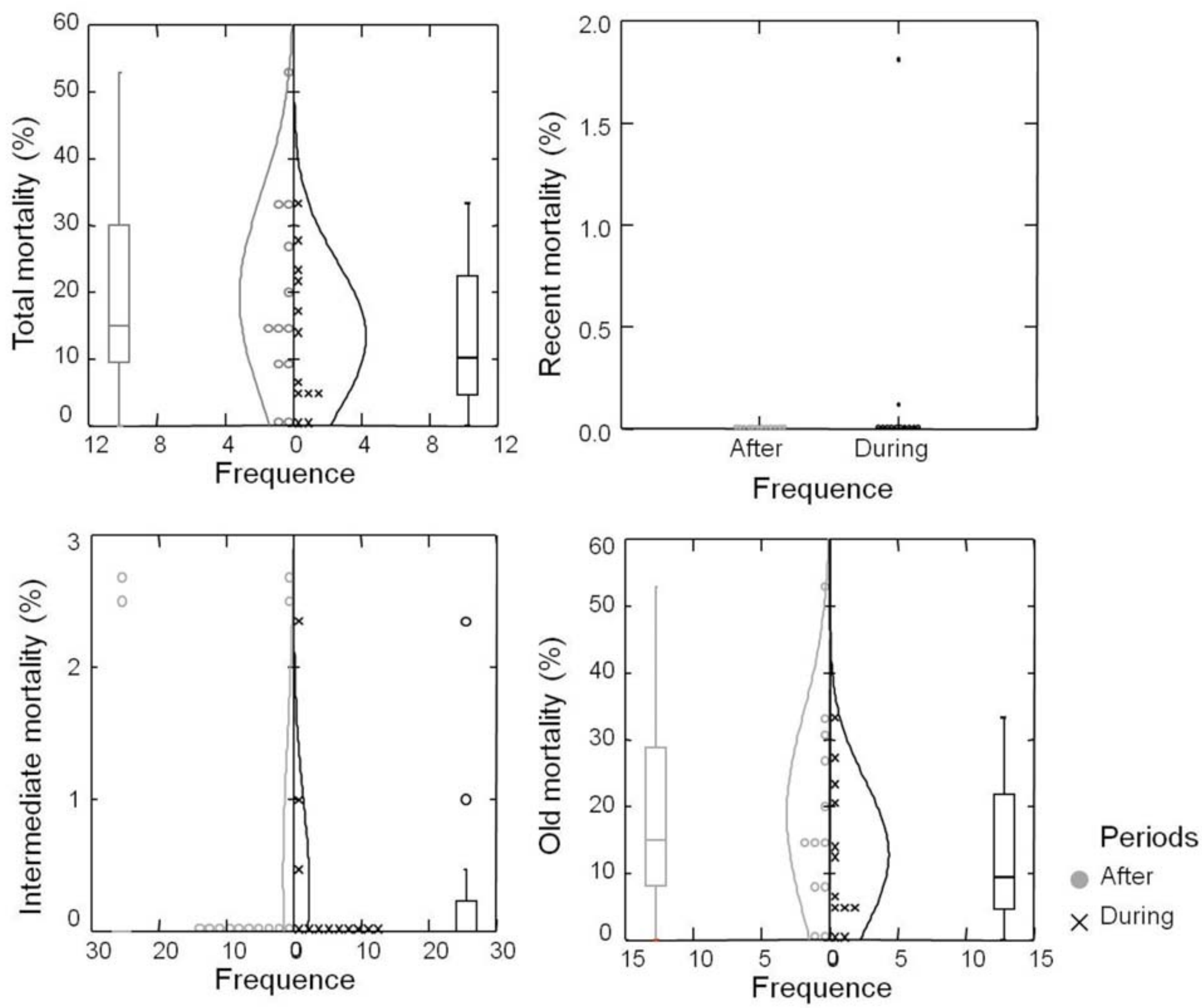

Figure 7. Average total mortality and mortality times (recent, intermediate and old) between the two evaluated periods, during and after the occurrence of thermal anomalies.

Table 3. Average (± SD) of total mortality and mortality time (recent, intermediate and old) during and after the 2010 thermal anomaly events.

Coral species	Period of thermal anomaly	Number of colonies							
Siderastraea spp.	During	60	7	3	3	0	0	0	0
	After	45	7	0	0	0	0	0	0
Montastraea cavernosa	During	15	4	1	2	0	3	0	2
	After	9	5	2	1	0	0	0	1
Mussismilia hispida	During	18	3	0	0	0	0	0	0
	After	22	0	0	0	0	0	0	0
Size classes (cm)		20-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100

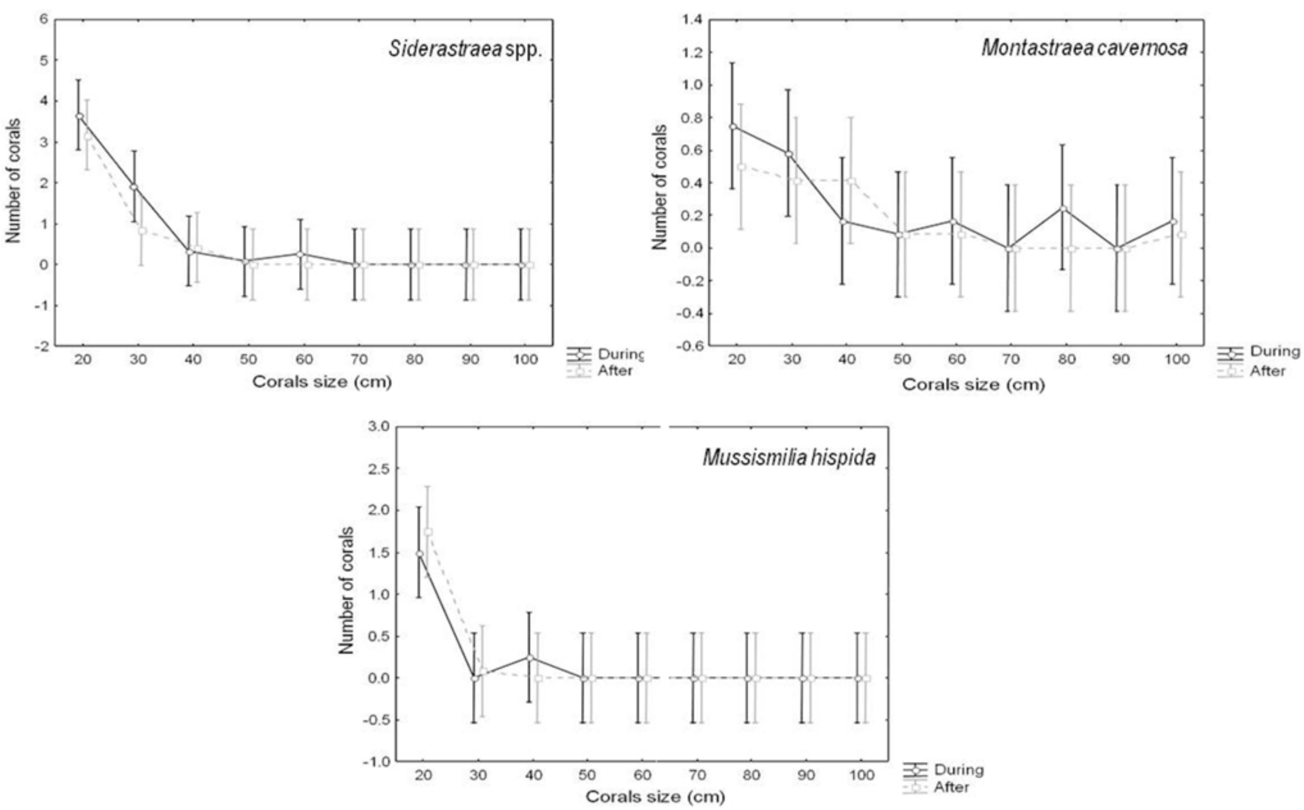

Figure 8. Colonies' averages by size class in 10 m^2 of the Caramuanas reef for: a) *Siderastraea* spp. (ANOVA, F = 0.37039, P = 0.93527); b) *Montastraea cavernosa* (ANOVA, F = 0.31256, P = 0.96069); c) *Mussismilia hispida* (ANOVA, F = 0.10918, P = 0.99888).

ching associated with ENSO caused the death of approximately 16% of reefs worldwide, particularly those from the Indian and Pacific oceans (Wilkinson & Souter, 2008). In all other occasions of bleaching events in Brazilian reefs, there were no mass deaths reported for the coral fauna associated with thermal perturbations due to ENSO events (Migotto, 1997; Castro & Pires, 1999; Leão *et al*., 2003, 2008; Dutra *et al*., 2000; Costa *et al*., 2001, 2004; Costa & Amaral, 2002; Kikuchi *et al*., 2003; Ferreira & Maida, 2006).

The Brazilian reefs seem to be resilient to bleaching and resistant to mortality, or they may be functionally adapted to the environmental stresses of the Brazilian waters, such as high turbidity and elevated rates of sedimentation (Leão & Ginsburg, 1997). The Brazilian zooxanthellate coral fauna is characterized by endemic species, with some reminiscent of a Tertiary coral fauna that may be adapted to these inhospitable environment conditions (Leão *et al*., 2003). Examples are the species of the genus *Mussismilia*, which showed the lowest percent of bleached colonies and those that bleached completely recovered during this investigation.

The results found in this work indicate that the coral fauna of the Caramuanas reef can become tolerant to the effects of bleaching when the thermal anomaly does not exceed 0.75°C over a period of one week. The high degree of endemism of the Brazilian coral fauna (Laborel, 1970) is one important reason for choosing them as targets for conservation. The fact that the Caramuanas reef was shown to be resilient for bleaching events from its first report, in 1998, is a further evidence of its importance. Eliminating or reducing anthropogenic effects on this reef may increase its resistance and resilience to bleaching, allowing its maintenance. The Caramuanas reef could than acts as a reserve of species and genes for this geographic region.

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REFERENCES

Bellwood, D.R., T.P. Hughes, C. Folke & M. Nystrom. 2004. Confronting the coral reef crisis. Nature, 429: 827-833.

Brandt, M.E. 2009. The effect of species and colony size on the bleaching response of reef-building corals in the Florida Keys during the 2005 mass bleaching event. Coral Reefs, 28(4): 911-924.

Bruno, J.F., C.E. Siddon, J.D. Witman, P.L. Colin & M.A. Toscano. 2001. El Niño related coral bleaching in Palau, western Caroline Islands. Coral Reefs, 20: 127-136.

Buddemeier, R.W. & D.G. Fautin. 1993. Coral bleaching as an adaptive mechanism. Bioscience, 43(5): 320-326.

Castro, C.C. & D.O. Pires. 1999. Brazilian coral reefs: what we already know and what is still missing. Bull. Mar. Sci., 69: 357-371.

Costa, C.F., F.M.D. Amaral & R. Sassi. 2001. Branqueamento em *Siderastraea stellata* (Cnidaria, Scleractinia) da praia de Gaibu, Pernambuco, Brasil. Rev. Nordestina Biol., 15(1): 15-22.

Costa, C.F. & F.M.D. Amaral. 2002. Density and size differences in zooxanthellae from five reef-building coral species from Brazil. Proceedings of International Coral Reef Symposium Indonesian Institute of Sciences, Bali, 1: 159-162.

Costa, C.F., C.S. Coutinho, R. Sassi & L.A.C. Brito. 2004. Microsymbionts of *Siderastraea stellata* (Cnidaria, Scleractinia) in coastal reefs of Cabo Branco, State of Paraíba, northeastern Brazil. Trop. Oceanogr., 32(2): 173-181.

Douglas, A.E. 2003. Coral bleaching-how and why? Mar. Pollut. Bull., 46: 385-392.

Dutra, L.X.C., R.K.P. Kikuchi & Z.M.A.N. Leão. 2000. Thirteen months monitoring coral bleaching on Bahia's north coast, Brazil. Proceedings of International Coral Reef Symposium Indonesian Institute of Sciences, Bali, pp. 373.

Eakin, C.M., J.A. Morgan, S.F. Heron, T.B. Smith, G. Liu, L. Alvarez-Smith, B. Baca, E. Bartels, C. Bastidas, C. Bouchon, M. Brandt, A.W. Bruckner, L. Bunkley-Williams, A. Cameron, B.D. Causey, M. Chiappone, T.R.L. Christensen, M.J.C. Crabbe, O. Day, E. de la Guardia, G. Diaz-Pulido, D. DiResta, D.L. Gil-Agudelo, D.S. Gilliam, R.N. Ginsgurg, S. Gore, H.M. Guzmán, J.C. Hendee, E.A. Hernandez-Delgado, E. Husain, C.F.G. Jeffrey, R.J. Jones, E. Jordan-Dahlgren, L.S. Kaufman, D.I. Kline, P.A. Kramer, J.C. Lang, D. Lirman, J. Mallela, C. Manfrino, J.P. Marechal, K. Marks, J. Mihaly, W.J. Miller, E.M. Mueller, E.M. Muller, C.A. O. Toro, H.A. Oxenford, D. Ponce-Taylor, N. Quinn, K.B. Ritchie, S. Rodriguez, A. Rodriguez-Ramirez, S. Romano, J.F. Samhouri, J.A. Sanchez, G.P. Schmahl, B.V. Shank, W.J. Skirving, S.C.C. Steiner, E. Villamizar, S.M. Walsh, C. Walter, E. Weil, E.H. Williams, K.W. Roberson & Y. Yusuf. 2011. Caribbean corals in crisis: record thermal stress, bleaching, and mortality in 2005. PLoS ONE, 5(11): e13969.

Ferreira, B.P. & M. Maida. 2006. Monitoramento dos recifes de coral do Brasil-situação atual e perspectivas. Ministério do Meio Ambiente, Secretaria de Biodiversidade e Florestas, Brasília, 116 pp.

Glynn, P.W. 1988. El Niño-southern Oscillation 1982-1983: nearshore population, community, and ecosystem responses. Ann. Rev. Ecol. Syst., 19: 309-345.

Glynn, P.W. & W.H. De Weerdt. 1991. Elimination of two reef building hydrocorals following the 1982-1983 El Niño warming event. Science, 253: 69-71.

Hennige, S.J., D.J. Smith, S. Walsh, M.P. Mcginley, M.E. Warner & D.J. Suggett. 2010. Acclimation and adaptation of scleractinian coral communities along environmental gradients within an Indonesian reef system. J. Exp. Mar. Biol. Ecol., 391: 143-152.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Mar. Freshw. Res., 50: 839-866.

Hoegh-Guldberg, O. & J.F. Bruno. 2011. The impact of climate change on the world's marine ecosystems. Science, 328: 1523-1528.

Hughes, T.P., A.H. Baird, M. Bellwood, S.R. Card, C. Connolly, R. Folke, O. Grosberg, J. Hoegh-Guldberg, B.C. Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nystrom, S.R. Palumbi, J.M. Pandolfi, B. Rosen & J. Roughgarden. 2011. Climate change, human impacts, and the resilience of coral reefs. Science, 301: 929-933.

Kikuchi, R.K.P., Z.M.A.N. Leão, V. Testa, L.X.C. Dutra & S. Spanó. 2003. Rapid assessment of Abrolhos reefs, eastern Brazil (Part 1: stony corals and algae). Atoll Res. Bull., 496: 172-188.

Laborel, J. 1970. Les peuplement de Madreporaires de côtes tropicales du Brésil. Annales de L'Université D'Abidjan, Serie E - II Fascicule 3, Abidjan, Costa do Marfim, 260 pp.

Lang, J., K. Marks & R. Ginsburg. 2010. BLAGRRA, bleaching Atlantic and gulf rapid reef assessment. [http://www.agrra.org/BLAGRRA]. Reviewed: 23 March 2010.

Leão, Z.M.A.N. & R.N. Ginsburg. 1997. Living reefs surrounded by siliciclastic sediments: the Abrolhos coastal reefs, Bahia, Brazil. Proceedings of International Coral Reef Symposium, Panamá 2: 1767-1772.

Leão, Z.M.A.N., R.K.P. Kikuchi & V. Testa. 2003. Corals and coral reefs of Brazil. In: J. Cortês (ed.). Latin America coral reefs. Elsevier Publisher, Amsterdam, pp. 9-52.

Leão, Z.M.N., R.P.K. Kikuchi & M.D.M. Oliveira. 2008. Branqueamento de corais nos recifes da Bahia e sua relação com eventos de anomalias térmicas nas águas superficiais do oceano. Biota Neotrop., 8(3): 69-82.

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Marshall, P.A. & A.H. Baird. 2000. Bleaching of corals on the Great Barrier Reef: differential susceptibilities among taxa. Coral Reefs, 19: 155-163.

McClanahan, T.R., J. Maina, R. Moothien-Pillay & A.C. Baker. 2005. Effects of geography, taxa, water flow, and temperature variation on coral bleaching intensity in Mauritius. Mar. Ecol. Prog. Ser., 298: 131-142.

Migotto, A.E. 1997. Anthozoan bleaching on the southeastern coast of Brazil in the summer of 1994. Proceedings of International Conference on Coelenterate Biology, 6, 1995. CCB, Leeuwenhorst, pp. 329-335.

Oxenford, H.A., R. Roach, A. Brathwaite, L. Nurse, R. Goodridge, F. Hinds, K. Baldwin & C. Finney. 2008. Quantitative observations of a major coral bleaching event in Barbados, southeastern Caribbean. Clim. Change, 87: 435-449.

Oxenford, H.A., R. Roach & A. Brathwaite. 2010. Large scale coral mortality in Barbados: a delayed response to the 2005 bleaching episode. Proceed. 11th Intern. Coral Reef Symp. Ft. Lauderdale, Florida, pp. 505-509.

Stafford-Smith, M.G., C.B. Cook, A. Logan, J. Ward, B. Luckhurst & C.J. Berg Jr. 1993. Sediment-rejection efficiency of 22 species of Australian Scleractinian corals. Mar. Biol., 115: 229-243.

Suggett, D.J. & D.J. Smith. 2011. Interpreting the sign of coral bleaching as friend *vs*. foe. Global Change Biol., 17: 45-55.

Weis, V.M. 2008. Cellular mechanisms of cnidarian bleaching: stress causes the collapse of symbiosis. J. Exp. Biol., 211: 3059-3066.

Wilkinson, C., O. Lauden, H. Cesar, G. Hodgson, J. Rubens & A. Strong. 1999. Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean. An ENSO impact and a warning of future change? Ambio, 28(4): 188-196.

Wilkinson, C. 2008. Status of coral reefs in the world: 2008. Global coral reef monitoring network and rainforest Research Centre, Townsville, 296 pp.

Wilkinson, C. & D. Souter. 2008. Status of Caribbean coral reefs after bleaching and hurricanes in 2005. Global coral reef monitoring network and rainforest Research Centre, Townsville, 152 pp.

Williams, G.J., I.S. Knapp, J.E. Maragos & S.K. Davy. 2010. Modeling patterns of coral bleaching at a remote Central Pacific atoll. Mar. Pollut. Bull., 60: 1467-1476.