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Temporal variability in macroalgae recruitment and succession on sandstone reefs at Piedade Beach – PE, Brazil

Variação temporal do recrutamento e sucessão ecológica de macroalgas em recifes areníticos da Praia de Piedade – PE, Brasil

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Abstract

Two sites, in which Rhodophyta and Chlorophyta were the dominant algae, were selected in the intertidal zone of a sandstone reef at Piedade Beach to evaluate macroalgal recruitment and succession from March 2007 through January 2008. At each site, 2 meter transects were sampled using 20 x 20 cm quadrats in the midlittoral zone of the reef flat. The initial position of the quadrats was randomly chosen. Green algae (filamentous and foliose) showed a bloom at the end of the rainy season (approximately 250 grams of dry weight/m^2 on October 2007), as indicated by the differences between the monthly average biomass values observed in the recruitment plots. The biomass measurements of control quadrats and in the succession treatments did not differ statistically during the rainy season for either Chlorophyta or Rhodophyta at Site 1 or during the dry season at Site 2. Green and red algae (filamentous and corticated) exhibited a pattern of alternating oscillations, as shown by the principal component analysis of recruitment, rainfall and air temperature. These results suggested a negative relationship between temperature and the recruitment of red algal biomass.

Key words: Macroalgal Biomass, Benthic Ecology, Sandstone Reefs, Ecological Succession, Algal Recruitment.

Resumo

Dois pontos foram selecionados ao longo do recife arenítico da praia de Piedade, no meso-litoral inferior, onde havia predominância de algas clorofíceas e rodofíceas, para avaliar o recrutamento e a sucessão de março de 2007 a janeiro de 2008. Nessas áreas foram amostrados transectos de 2 metros com quadrados de 20 cm X 20 cm, que foram dispostos aleatoriamente no platô recifal. No estudo de sucessão, finalizado na estação chuvosa, a biomassa de algas verdes e vermelhas não diferiu estatisticamente da biomassa média dos quadrados de controle na Estação 1, assim como durante o período seco na Estação 2. As algas verdes (foliáceas e filamentosas) mostraram um bloom no final da estação chuvosa (média próxima de 250 gramas por m^2 em outubro de 2007 no experimento de recrutamento). As algas verdes e vermelhas (filamentosas e corticadas) apresentaram um padrão de oscilação invertido evidenciado pela ordenação oposta na Análise de Componentes Principais, que correlacionou os dados de recrutamento, pluviometria e temperatura do ar, evidenciando uma relação negativa entre temperatura do ar e o recrutamento da biomassa de algas vermelhas.

Palavras-chave: Biomassa de Macroalgas, Ecologia Bêntica, Recifes de Arenito, Sucessão Ecológica, Recrutamento Algal.

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Introduction

The sandstone reefs located in the southern littoral area of Pernambuco State are generally parallel to the coast and are not always exposed at low tide. They furnish the main hard substrate for the attachment of benthic algae in the region (Sousa and Cocentino, 2004). These ecosystems exhibit a high faunal diversity and important biological interactions (Oliveira *et al*., 2003; Simões *et al*., 2009). The Piedade Beach littoral is influenced by the Jaboatão River, which receives pollution from industrial and urban sources (Passavante and Feitosa, 1995). Organic pollution, one of the most important threats affecting the development of benthic communities in coastal regions, leads to a decrease in species diversity and favors opportunistic species (Breves-Ramos *et al*., 2005).

Previous research conducted at Piedade Beach has demonstrated that a decrease in species richness occurred between the 1970s and 1990s, since some species characteristic of sites experiencing low human impact have disappeared. Simões *et al*. (2009) showed that the percentage cover of opportunistic algae, such as *Ulva* spp., which are characteristic of the impacted site on Piedade Reef (Sousa and Cocentino, 2004) can reach 80 % after a month of field measurements following artificial disturbance experiments. However, Mansilla and Pereira (2001) have observed reduced Rhodophyta biomass and algal diversity on a reef further south in Pernambuco's littoral during the rainy season, compared with samples collected during the summer. These authors found differences related to rainfall, temperature and salinity in the community structure of tidal pools. Perennial algae, such as the corticated algae belonging to the phylum Rhodophyta, genera *Gelidium*, *Solieria*, *Gracilaria* and *Hypnea,* in addition to the filamentous red algae *Centroceras* and *Ceramium*, were also observed at the study sites (Simões *et al*., 2009).

Patrício *et al*. (2006) found that filamentous and foliose Chlorophyta were the early colonizers in succession experiments on an intertidal rocky coast in Portugal. Similar findings have been made by Simões *et al*. (2009) on the reef at Piedade and by Breves-Ramos *et al*. (2005) at Guanabara Bay –RJ, Brazil. The bottom-up effect of nutrients on algal growth was indirectly evaluated at Piedade Beach because the area was known to be polluted. Cultural eutrophication, along with the removal of herbivorous fishes, can affect the community structure of coastal areas by promoting a shift from coral-dominated to algal-dominated communities (Lapointe, 1997; Sotka and Hay, 2009). However, reefs dominated by macroalgae have also been viewed as a stable state of coral reef communities. Such dominance is thought to be associated with reduced pressure from herbivores and low coral recruitment in addition to disturbance and patch dynamics (Mumby, 2009). Therefore, the seasonal variation of algal functional form groups at Piedade reef is likely to be affected by the interaction between herbivory, eutrophication and human trampling.

A study by Figueiredo *et al.* (2004) has suggested that competition between algae belonging to different morphological and functional groups supports the Steneck and Dethier (1994) model that predicts the dominance of more complex algae in environments that are less exposed to biological and physical disturbance. Grazing pressure on recruits can also favor species that are morphologically resistant (Lotze *et al*., 2001) and can control the recruitment of opportunistic species up to a threshold nutrient level (Lotze and Worm, 2002). Nevertheless, Bellgrove *et al*. (2004) have found that the propagules and recruits of ephemeral algae were frequent in field samples but that these algae were not abundant on the shore. In contrast, the propagules of the dominant perennial algae were rarely found in the samples.

The objective of the present work was to evaluate the temporal and spatial variability of algal biomass in control, succession and recruitment plots. This information was used to test the hypothesis that the outcome of the successional patterns of the green and red algae on Piedade reef shows seasonal differences related to the spatial and temporal variation in algal growth and recruitment. This approach suggests that algal succession is limited by desiccation and low nutrient concentrations during the summer at Piedade Reef communities.

Materials and Methods

Sampling Area

Piedade Beach is located in Jaboatão dos Guararapes district, in the southern littoral of Pernambuco state, between 08º 11´08.48´´ S and 34º 55´ 04.66´´ W - 08º 11´03.45´´ S and 34º 55´ 03.24´´ W. The area of the reef is approximately 234 km^2. The reef is oriented obliquely in relation to the littoral and is covered by water during high tides (Simões *et al*., 2009). A small lagoon is formed between the reef and the beach during low tides. The local climate is characteristic of the Tropical Atlantic, with an average air temperature of 26 ºC. The annual pattern of rainfall defines two seasons: the dry season (from October through February) and the rainy season (from March through September). Algal samples were collected from the midlittoral zone of two areas on the Piedade Reef located approximately 500 m apart. Site 1 was close to the reef's outer edge. Site 2 was in a *Brachidontes solisianus* bed located higher on the reef flat and was therefore affected to a greater degree by trampling and desiccation than Site 1.

Field Methods

Macroalgal biomass was measured at the study sites from March 2007 through January 2008. Samples were taken from the control plots, and artificial disturbance experiments were conducted at two sites located on the reef to follow algal recruitment and succession (by re-colonization and vegetative growth). Both sites were located in the midlittoral, where green and red algae were dominant. At these two sites, 2-meter transects were sampled using 20 x 20 cm quadrats. In March 2007, 3 quadrats were designated as control plots, 3 as recruitment treatments and 3 as succession treatments. The locations of the quadrats were randomly chosen in each transect. The recruitment quadrats were sampled every month by scraping the organisms from the rock. The succession treatments were sampled using the same collection method in March and August 2007 and in January 2008 to evaluate succession during the rainy and dry seasons.

The samples were placed in plastic bags, along with appropriate identification, and taken to the Marine Biology Lab at Universidade de Pernambuco. They were then frozen for later sorting and dry weight measurement. In addition, randomly chosen quadrats next to the original transects were sampled in August 2007 for comparison with the succession treatments. Likewise, the control plots were sampled in January 2008 and compared with the succession treatments.

Laboratory Methods

Each sample was placed in a plastic tray for sorting, where algae were separated from the animals. The green and red algae were separated using color and morphological traits because the filamentous forms were entangled with foliose and corticated algae. Species were not identified because the purpose of our study was to evaluate the overall biomass of the dominant phyla in each quadrat. After sorting, the algae were placed in preweighted aluminum baskets and dried at 60 ^{o}C for 24 hours. The samples were weighted on a precision balance (precision: two decimal places). The measured weight was subtracted from the weight of the basket to obtain the algal dry weight. Algae from the Phylum Ochrophyta were not considered in the study because they have a low average biomass at the study sites (1.6 g/m^2) and occur mainly as epiphytes and as drift algae (Simões *et al*., 2009).

Statistical Analyses

Repeated measures MANOVAs were used to evaluate the differences in recruited biomass. The *a posteriori* Tukey test was used to obtain p-values for the MANOVA models and to validate the differences in algal quantification between the monthly samples for Chlorophyta and Rhodophyta at each site. The JMP software from the SAS Institute was used for these analyses. In addition, a Kruskal-Wallis test was used to compare the biomass of the red and green algae sampled from the non-manipulated plots in March and August 2007 and January 2008. A log (x + 1) transformation was applied to the biomass data to satisfy the assumption of homoscedasticity.

The nonparametric Mann-Whitney test was used to compare the algal biomass in the control quadrats with the biomass in the succession treatments for August 2007 and January 2008. In addition, a principal component analysis was performed using the correlation between average algal recruitment (Sites 1 and 2) and environmental variables (average monthly air temperature and rainfall – ITEP, 2007) from April through December 2007.

Results

The green algal biomass in the control plots was statistically different in August 2007 at Site 2 (df = 2, $p < 0.05$) from the biomass sampled from these non -manipulated plots in March 2007 and January 2008 (Figure 1), whereas no such statistical differences were found for the biomass of the red algae collected from the control plots at Site 1. The biomass of Chlorophyta in the recruitment plots at Site 1 in October differed from that in April, May, June, July, November and December 2007 and January 2008. The Chlorophyta biomass in these plots also differed between August and April, May, June and January. September differed from April, May and June (df =11, F=12.024, $p<0.001$) (Figure 2).

At Site 2, the green algal biomass recruitment in September differed from that in April, May, June, July, November and December 2007 and January 2008. August differed from April, May, June, July, November and December 2007 and January 2008. October differed from April, May, November and December 2007 and January 2008 (df =11, F=12.124, $p<0.001$) (Figure 2). The average green algal biomass sampled in August was statistically similar only to that in September and October. This finding suggested that an algal bloom occurred at the end of the rainy season.

The red algal biomass in the recruitment treatments at Site 1 differed between August and April, May, June, September, October, November and December. July differed from April, May and November (df =11, F=12.222, $p<0.001$) (Figure 2). No statistical difference in the biomass recruitment of red algae was found for Site 2.

The principal component analysis of monthly average algal biomass, rainfall and air temperature produced two components that jointly explained 73 % of the variation in the data. The axis corresponding to the second component separated the green algae at site 1 from the red algae collected at the same area and was considered to represent biological interactions. Component 1 was related to seasonal variation because it separated algae from rainfall and temperature (Figure 3). No statistical differences between the biomass on the succession and the control quadrats were found for the red algae (U=2, Z=1.091, $p>0.05$) or for the green algae (U=1, Z=1.528,

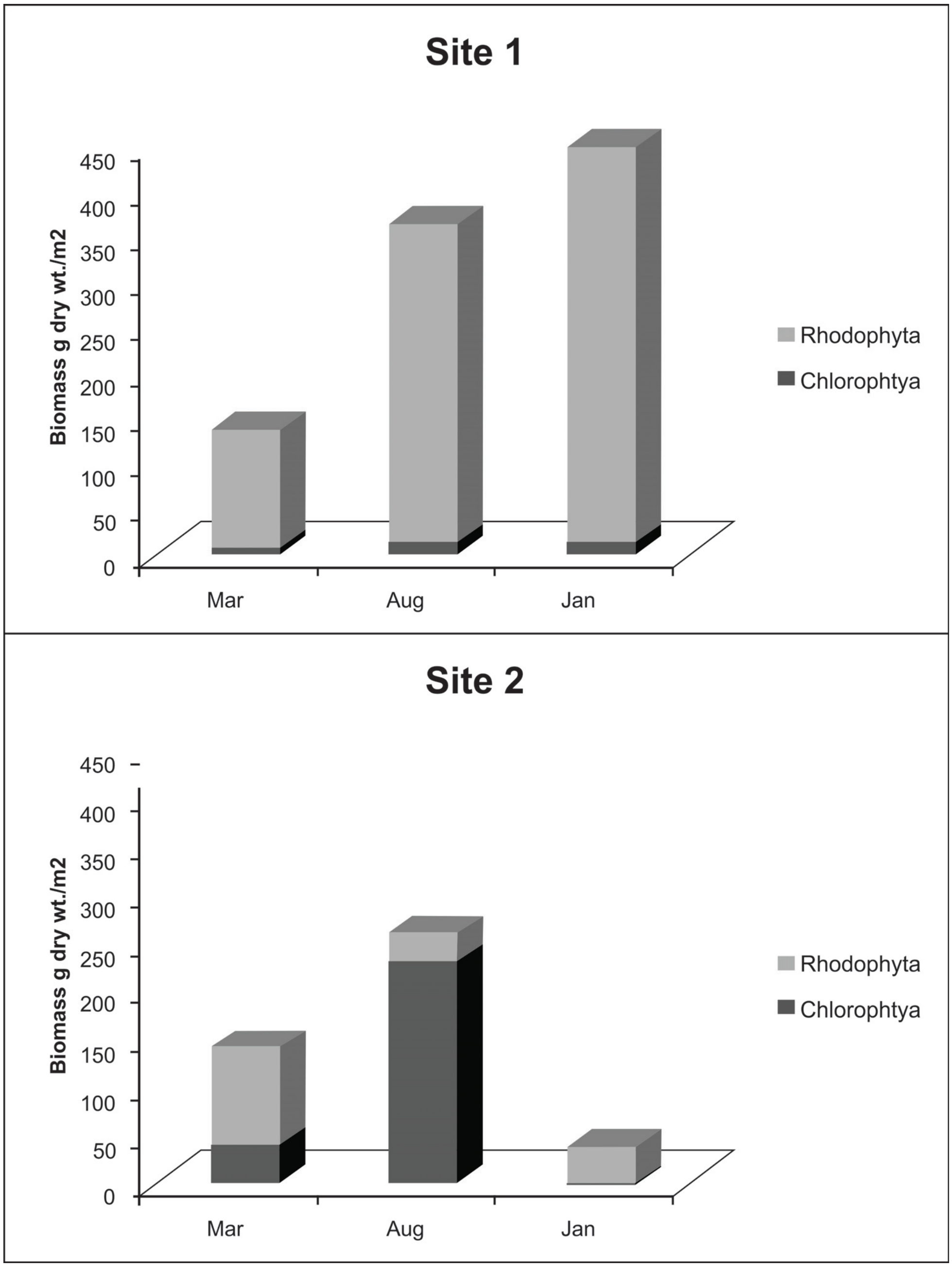

Figure 1 – Algal biomass (grams of dry weight/m^2) in non-manipulated plots sampled in March and August 2007 and January 2008.

p>0.05) (Figure 4) collected at the end of the succession experiments at Site 1 in August 2007. However, we found statistical differences between the succession and the control plots for green algae in August 2007 at Site 2 and for red algae in January 2008 at Site 1.

Discussion

Differences in the outcomes of competition in macroalgal communities have been related to recruitment patterns and resistance to herbivory. In turn, these differences are also related to different surface-to-volume ratios (Lotze and Schramm, 2000), and to the different light requirements and physiological responses of macroalgae functional form groups. Moreover, alternating high and low percent cover measures can suggest that competition between macroalgae is a factor controlling benthic intertidal communities (Guimaraens *et al*., 1996;

Guimaraens and Coutinho, 1998). Green and red algae showed alternating biomass values on the recruitment plots at Piedade reef. A peak of recruited red algal biomass close to 200 grams of dry weight/m^2 was recorded in August 2007, whereas the green algae showed an average biomass maximum close to 250 grams of dry weight/m^2 in October 2007 at Site 1.

Passavante and Feitosa (1995) found that sites closer to the shore at Piedade Beach were meso- to eutrophic, although phytoplankton production could be limited during the rainy season by sediment transport from the Jaboatão River estuary. Therefore, the increase in green algal biomass may be related to the high nutrient concentration during the end of the rainy season and to low rates of herbivory, considering that urchin-dominated reefs may show faster recovery rates for filamentous turf algae compared with the diversity of successional communities in sites affected by fish grazing (McClanahan, 1997).

The samples taken in August 2007 at Site 1 from the succession treatments did not differ statistically from the control plots. Likewise, the sam-

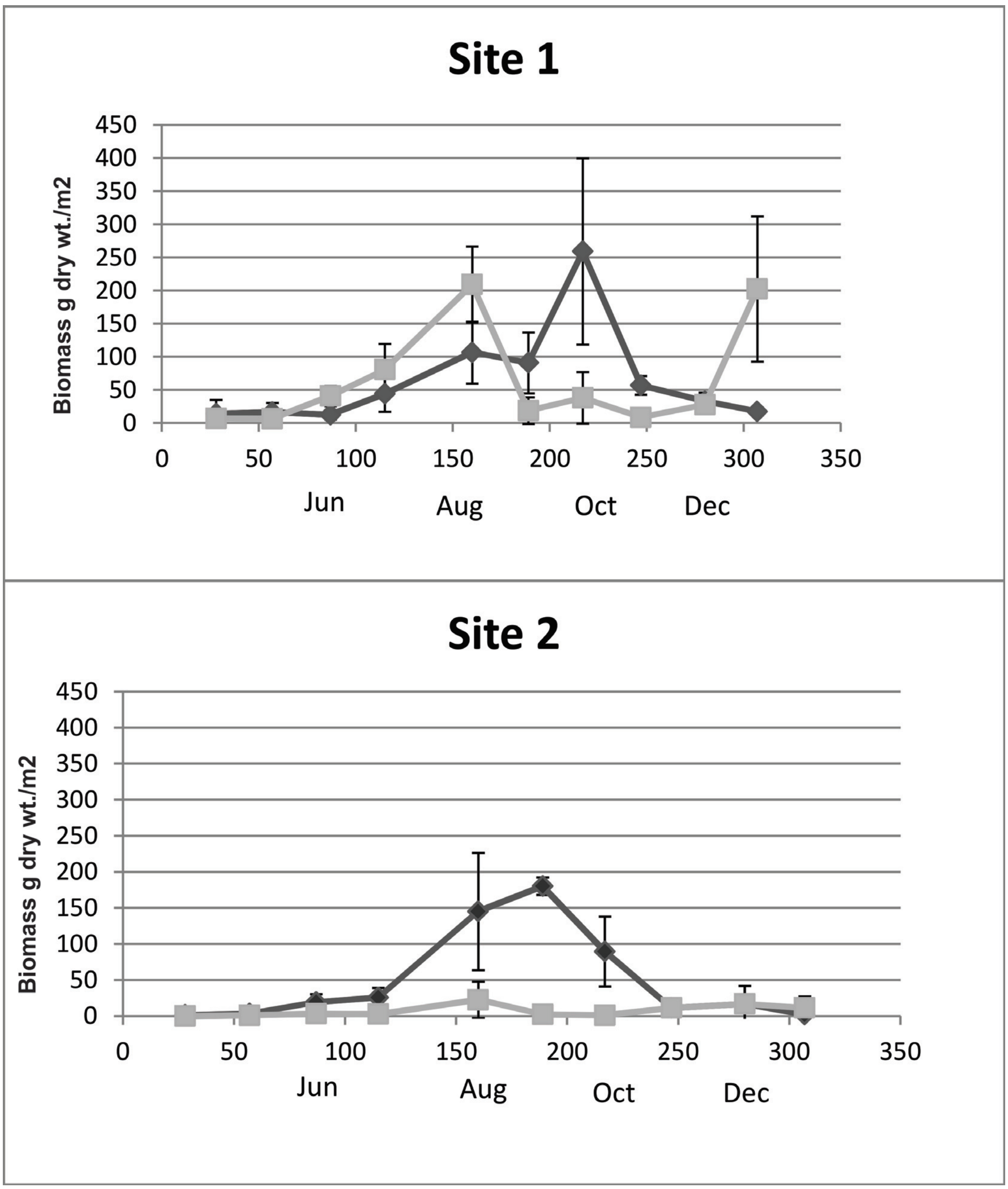

Figure 2 - Algal biomass (grams of dry weight/m^2) in recruitment plots. Chlorophyta (dark line), Rhodophyta (grey line).

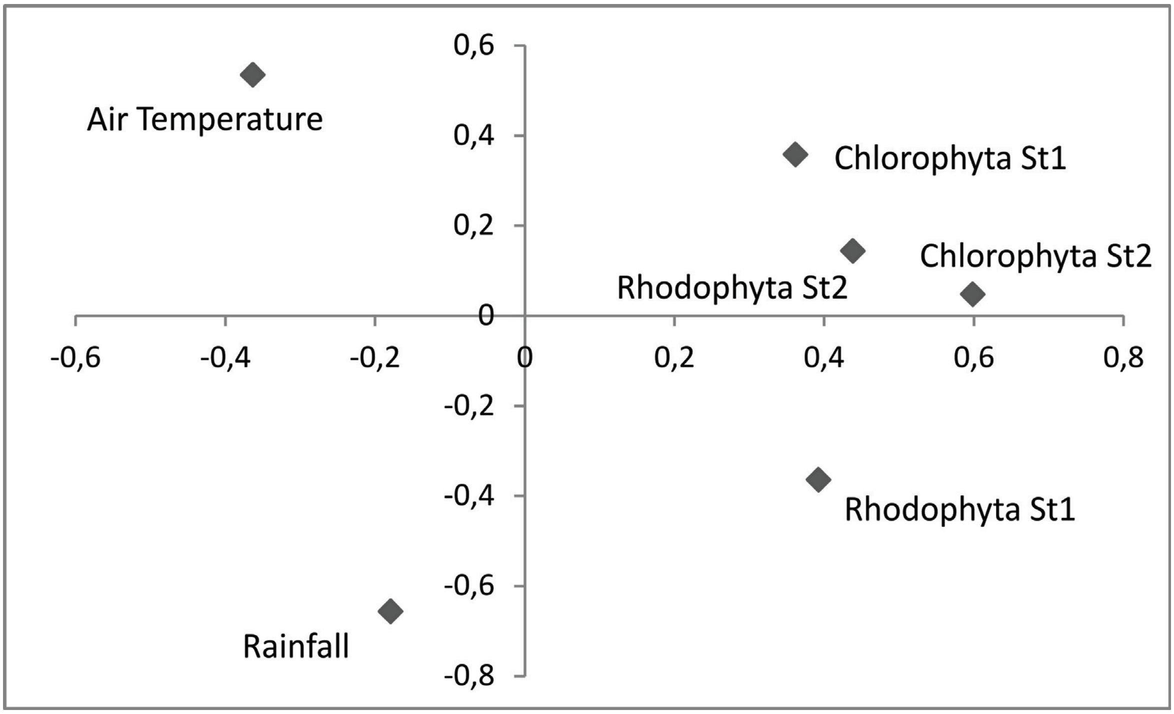

Figure 3 – Principal component analyses for monthly recruitment of average algal biomass, air temperature and rainfall.

ples taken at Site 2 in January 2008 for a similar experiment showed no differences between the succession treatments and the control (Figure 4). These results generally showed a pattern of recovery for the red algae. However, the red algae did not show statistically similar values between the control and succession treatments at the end of the dry season at Site 1. This finding suggests that the community recovered only partially and may be limited by desiccation during the dry season. Furthermore, this finding is also consistent with the data on the percent cover of algae recorded in an experiment on succession ecology conducted by Simões *et al*. (2009) at Piedade reef.

Breves-Ramos *et al*. (2005) have shown that the recovery of benthic communities at Guanabara Bay – RJ was observable after 4 months and that faster development occurred on a eutrophized site. The greater abundance of green algae on the control plots than on the succession plots at Site 2 in August 2007 may be related to the bloom at the end of the rainy season, whereas there seems to be a negative relationship between temperature and red algal biomass recruitment in the study area. On samples taken at both sites on March 2007 in the non-disturbed plots, the biomass of the red algae was greater than that of the green algae. The average biomass of the Rhodophyta was nearly 130 grams of dry weight/m^2 at Site 1 and nearly 100 grams of dry weight/m^2 at Site 2 (Figure 1).

During the study period, the growth of algal films and filamentous green and red algae in the experimental plots was observed. However, the dominant algae were the foliose green and corticated red forms. The other functional forms mentioned were sometimes noticed only during sorting in the laboratory. The coastal zones of northeast Brazil and their associated reefs are susceptible to environmental impacts, such as eutrophication. Figueiredo *et al*. (2008) have reported the occurrence of shifts on Brazilian reefs from animal to algal-dominated communities. These shifts are related to eutrophication and to low rates of herbivory. Although, the coralline algae of the genus *Amphiroa* were only observed in non-manipulated plots by Simões *et al*. (2009), opportunistic algae such as *Ulva flexuosa* were mainly observed colonizing plots after monthly disturbance experiments performed by the same authors. These results support the present study's findings regarding the recovery that occurred during the recruitment and succession experiments.

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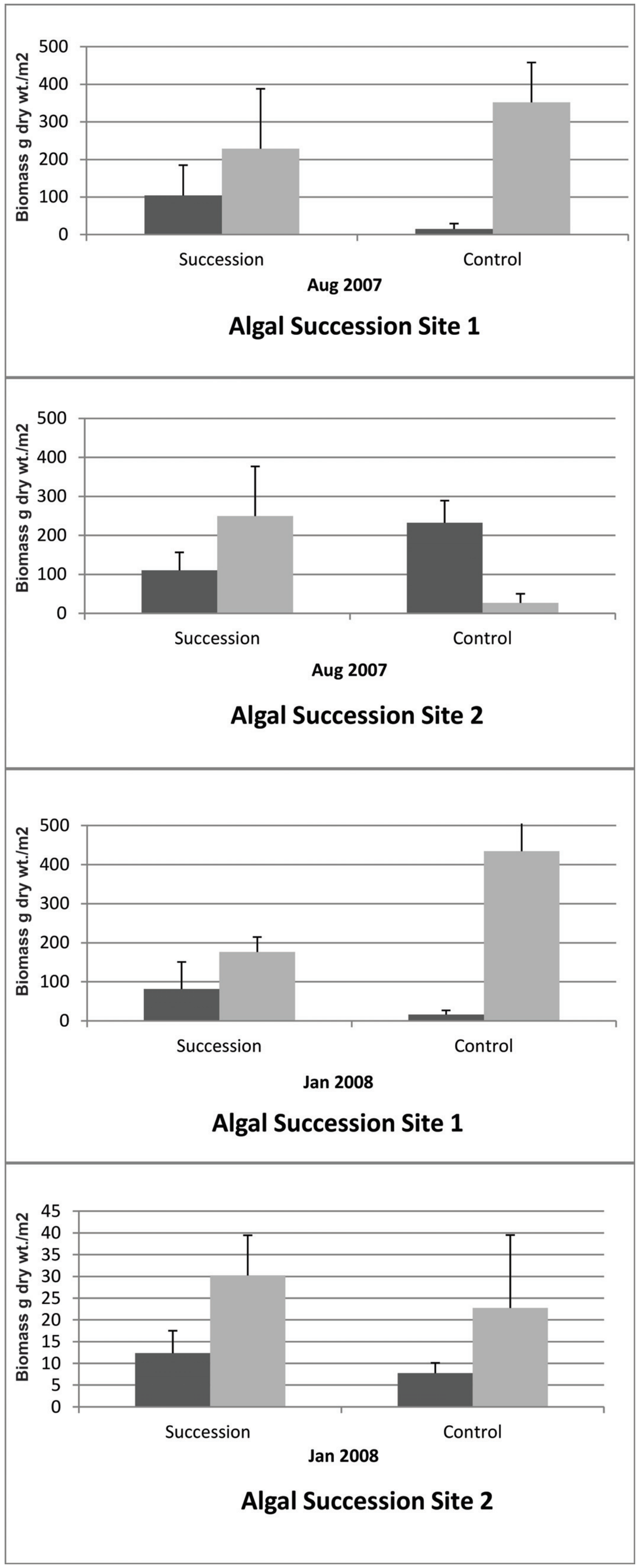

Figure 4 – Biomass (grams of dry weight/m2) on succession and control plots. Chlorophyta (dark bars), Rhodophyta (grey bars).

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