

TEMPORAL VARIATION IN VEGETATIVE DEVELOPMENT OF  
*Caulerpa scalpelliformis* (CHLOROPHYTA) FROM BALEIA  
BEACH, ILHA GRANDE BAY (RIO DE JANEIRO, BRAZIL)

Marcelo Augusto Vasconcelos<sup>1</sup>, Carolina Leite Queiroga Schubart<sup>2</sup> and  
Maria Teresa Menezes de Széchy<sup>1\*</sup>

<sup>1</sup>Universidade Federal do Rio de Janeiro – Instituto de Biologia  
Departamento de Botânica  
(Rua Professor Rodolpho P. Roço, 211, sala A-99, 21941-902 Ilha do Fundão, RJ, Brasil)

<sup>2</sup>Associação Nacional dos Fiscais Federais do Meio Ambiente  
(Ed. Porto do Lago, Lago Norte, Brasília, DF, Brasil)

\*Corresponding author: mtmszechy@gmail.com

ABSTRACT

*Caulerpa scalpelliformis* grows on rocky and sandy bottoms at different depths in Jacuacanga Cove, Ilha Grande Bay, where it can form dense patches. The invasive behavior of this and other species of *Caulerpa* is well documented in the literature. This study analyzed the variation of the vegetative development of *C. scalpelliformis* from Baleia Beach (23°01'63''S and 44°14'18''W) in Jacuacanga Cove, from June 2003 to September 2004, including plants from rocky and sandy substrates. Morphometric and dry weight data from the erect and prostrate portions were used. Plants were collected from 20 x 20 cm<sup>2</sup> plots (n=3), randomly positioned on the rocky boulders (≈1.5 m depth) and on contiguous sandy bottom (≈3.0 m depth). During the study period, *C. scalpelliformis* occurred on both substrates as a pseudo-perennial species, showing partial loss of the erect portions from winter to spring; the height and dry weight of the erect portions increased from summer to autumn on both substrates. The temporal variation of *C. scalpelliformis* vegetative development in Baleia Beach was similar to that described for the invasive *C. racemosa* and *C. taxifolia* from different geographical regions of the world.

RESUMO

*Caulerpa scalpelliformis* cresce sobre substrato rochoso e arenoso a diferentes profundidades na Enseada de Jacuacanga, Baía da Ilha Grande, onde pode formar bancos densos. O comportamento invasor desta e de outras espécies de *Caulerpa* é bem documentado na literatura. Este estudo analisou a variação do desenvolvimento vegetativo de *C. scalpelliformis* da Praia da Baleia (23°01'63''S e 44°14'18''W), Enseada de Jacuacanga, de junho de 2003 a setembro de 2004, considerando plantas do substrato rochoso e do fundo de areia. Dados morfológicos e de peso seco das porções prostrada e ereta foram usados. Plantas foram coletadas em quadrados de 20 cm de lado (n=3), posicionados aleatoriamente sobre o substrato rochoso (profundidade ≈ 1,5 m) e sobre o substrato arenoso (profundidade ≈ 3,0 m). Durante o período de estudo, *C. scalpelliformis* ocorreu nos dois substratos como espécie pseudo-perene, mostrando perda parcial das porções eretas do talo do inverno para a primavera; altura e massa seca das porções eretas mostraram tendência de aumento do verão para o outono nos dois substratos. A variação temporal do desenvolvimento vegetativo de *C. scalpelliformis* na Praia da Baleia foi similar à descrita para *C. racemosa* e *C. taxifolia*, espécies invasoras em diferentes regiões do mundo.

Descriptors: Brazil, Caulerpales, Chlorophyta, Invasive species, Rocky shores, Sandy bottom, Temporal variation, Vegetative development.

Descritores: Bioinvasão, Brasil, Caulerpales, Chlorophyta, Costões rochosos, Substrato arenoso, Variação temporal, Desenvolvimento vegetativo.

INTRODUCTION

*Caulerpa scalpelliformis* (R. Br. ex Turner) C. Agardh (Chlorophyta, Ulvophyceae) has been recorded since 1965 in the tropical regions of the Brazilian coast, where its distribution extends from the states of Piauí to Espírito Santo (JOLY et al., 1965;

MITCHELL et al., 1990; NUNES, 1998). Falcão and Széchy (2005) mentioned the occurrence of populations of *C. scalpelliformis* on Baleia Beach, Angra dos Reis, growing in dense patches on the rocky and sandy substrates. According to these authors, the abundance of *C. scalpelliformis* increased on Baleia Beach from 2001 to 2003, suggesting that

the species had become established in the area. Its invasive behavior was characterized by its ability to replace *Sargassum vulgare* C. Agardh, the dominant species on Ilha Grande Bay rocky shores. Figueiredo and Tâmega (2007), in a survey of the diversity of the macroalgae of Ilha Grande Bay carried out in the summer of 2003 and winter of 2004, also found *C. scalpelliformis* on Biscoia Beach, in Jacuacanga Cove, and on Macacos Island near Ilha Grande.

*Caulerpa scalpelliformis* is also recognized as an introduced and invasive species in the Mediterranean Sea (VERLAQUE, 1994; ERTAN et al., 1998) and in Australia (DAVIS et al., 1997). Other species of *Caulerpa* J. V. Lamour., such as *C. taxifolia* (H. West in Vahl) C. Agardh and *C. racemosa* (Forssk.) C. Agardh, are considered invasive species in the Mediterranean Sea (BOUDOUREQUE et al., 1995; BELLAN-SANTINI et al., 1996; PIAZZI et al., 2001; CECCHERELLI et al., 2002; BALATA et al., 2004; PIAZZI; BALATA, 2009), in Australia (MODENA et al., 2000) and along the Californian coast, USA (WILLIAMS; GROSHOLZ, 2002), because of their high rates of growth and dispersal. The invasive capability of seaweed species is related to their resistance to herbivores, growth rate, vegetative reproduction, and successful adhesion to different substrates, among other attributes (VALENTINE et al., 2007). Invasive *Caulerpa* species show high rates of vegetative development, which can be analyzed by measuring the growth of their erect and prostrate portions (MEINESZ et al., 1993; MEINESZ et al., 1995; PIAZZI et al., 2001; RUITTON et al., 2005; CEBRIAN, BALLESTEROS, 2009). They are able to cause disturbance to the communities they invade (MEINESZ; HESSE, 1991; VILLÈLE; VERLAQUE, 1995) because of their high biomass and density (PIAZZI et al., 2001; THIBAUT et al., 2004; KLEIN; VERLAQUE, 2008).

The marine habitats that are most susceptible to the introduction of exotic benthic species are those near ports and those subject to intense and constant commercial navigation. On the other hand, in areas that are not located near ports, the vectors for the introduction of exotic species are related to non-commercial shipping and to tourist activities such as fishing and aquatic recreation (HEWITT et al., 2007). In Ilha Grande Bay, in addition to the presence of two operating ports, a shipyard, mariculture structures, and many fishing villages, there is intense shipping activity related to tourism (CREED et al., 2007). Therefore, Ilha Grande Bay is considered to be a favorable environment for the introduction of exotic species (PAULA, CREED, 2004).

This study aimed to describe the temporal variation of the vegetative development of *C. scalpelliformis*, growing on the rocky and sandy substrates of Baleia Beach.

## MATERIAL AND METHODS

Baleia Beach is situated on Ponta Leste (23°01'63''S – 44°14'18''W), between Biscoia and Paraíso Beaches in Jacuacanga Cove, Ilha Grande Bay, Angra dos Reis municipality, Rio de Janeiro state. Jacuacanga Cove receives domestic sewage from Monsuaba village, a growing residential center (personal observation).

Access from the mainland to Baleia Beach is restricted due to the construction of private residences along the somewhat steep coastal strip; however, this beach is frequently visited by motorboats engaged in tourism and fishing, looking for sheltered waters. The narrow, sandy belt of Baleia Beach is bordered by an extensive strip of rocky boulders that extends from the supralittoral zone to the shallow sublittoral zone.

From June 2003 to September 2004, sampling was carried out along a 20 m horizontal length of the sublittoral zone on the left side of the sandy belt of the Baleia Beach, including the rocky boulders (rocky substrate) and the contiguous sandy bottom (sandy substrate). This location was chosen based on the previous record of *Caulerpa scalpelliformis* patches, both on the rocky substrate, where it was intermingled with *Sargassum vulgare*, and on the sandy bottom (FALCÃO; SZÉCHY, 2005).

On the rocky and sandy substrates, three randomly positioned plots of 20 x 20 cm<sup>2</sup> were sampled by snorkeling at two to three month intervals. The rocky substrate plots were positioned at a water depth of approximately 1.5 m, and the sandy substrate plots were approximately 3.0 m deep during high tides. The plots were scraped and the material collected was stored in individual plastic bags containing a 4% formaldehyde solution.

The vegetative development of *Caulerpa scalpelliformis* growing on both substrates was analyzed in the different seasons using both morphometric and dry weight data related to the erect and prostrate portions. The erect portions were constituted of the laminae and their stipes, and the prostrate portions were constituted of the stolons and their rhizoidal pillars (Fig. 1).

For each plot, *Caulerpa scalpelliformis* was separated from other organisms. Fifteen-centimeter-long fragments of *C. scalpelliformis* stolons were haphazardly chosen for the morphometric analysis (n=5). For each *C. scalpelliformis* fragment, the height of the erect portions (n=5) and the length of the rhizoidal pillars (n=5) were measured.

The dry weights of the erect and prostrate portions of *C. scalpelliformis* were obtained after drying at 80°C to constant weight.

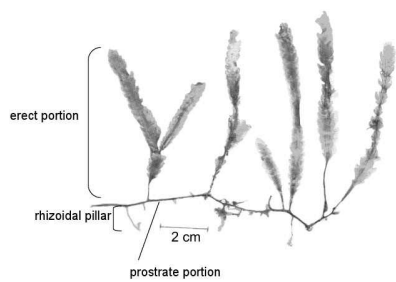


Fig. 1. *Caulerpa scalpelliformis* from Ilha Grande Bay: erect and prostrate portions of the thallus.

The temporal variation in the height and dry weight of the erect portions, the length of the rhizoidal pillars and the dry weight of the prostrate portions of *Caulerpa scalpelliformis* were described, in graph form, using mean and standard deviation values ( $n=75$ , 3 plots  $\times$  5 fragments  $\times$  5 measures for each fragment).

Two-way analysis of variance (ANOVA) was used for comparing the total dry weight of *Caulerpa scalpelliformis* (erect portions and prostrate portions considered together,  $n=3$ ), using the type of substrate and the seasons of the years as factors, with  $p<0.05$  as the level of significance. This variable showed equal variance (test of equal variance,  $p=0.53$ ) and normal distribution (test of normality,  $p=0.33$ ) (SIGMASTAT® 3.5, 2006).

## RESULTS

*Caulerpa scalpelliformis* occurred throughout the year on the rocky and sandy substrates at Baleia Beach, Ilha Grande Bay.

The height of the erect portions of *Caulerpa scalpelliformis* from the rocky substrate reached a maximum (12.5 cm) in winter 2003. This variable showed a gradual increase from autumn to winter in 2003, and from summer to autumn in 2004. A gradual decrease was observed from winter to spring in both years (Fig. 2A).

The dry weights of the erect portions of *Caulerpa scalpelliformis* from the rocky substrate varied, on average, from 2.07 g.400 cm<sup>-2</sup> in autumn 2003 to 13.40 g.400 cm<sup>-2</sup> in winter 2004, when the maximum value was reached (16.50 g.400 cm<sup>-2</sup>). This variable increased from autumn to winter in 2003 and 2004, and decreased from winter to spring in both years (Fig. 2B). The increase in the dry weights of the erect portions from autumn (mean= 2.99 g.400 cm<sup>-2</sup>) to winter 2004 (mean= 13.10 g.400 cm<sup>-2</sup>) did not coincide with the variation in the heights of the erect portions in the same period.

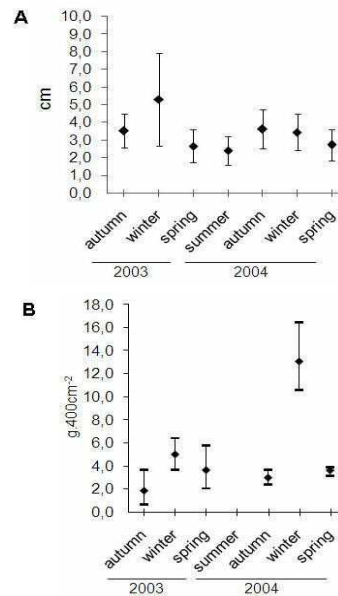


Fig. 2. Temporal variation of the erect portions of *Caulerpa scalpelliformis* growing on rocky substrate at Baleia Beach, Ilha Grande Bay, from autumn 2003 to spring 2004. 2A- Height of the erect portions ( $n=75$ , mean  $\pm$  standard deviation); 2B- Dry weights of the erect portions ( $n=3$ , minimum, median and maximum values).

The height of the erect portions of *Caulerpa scalpelliformis* from the sandy substrate reached a maximum (15.0 cm) in autumn 2003. This variable showed a gradual increase from spring 2003 (mean= 2.29 cm) to winter 2004 (mean= 6.62 cm). A decrease was observed from autumn (mean= 7.36 cm) to winter 2003 (mean= 2.95 cm) and from winter (mean= 6.62 cm) to spring 2004 (mean= 3.20 cm) (Fig. 3A).

The dry weights of the erect portions of *Caulerpa scalpelliformis* from the sandy substrate varied, on average, from 1.37 g.400 cm<sup>-2</sup> (autumn 2003) to 6.19 g.400 cm<sup>-2</sup> (winter 2003), when the maximum value was reached (7.45 g.400 cm<sup>-2</sup>). This variable increased from autumn to winter in both years, and decreased from winter to spring 2003 (Fig. 3B). The mean values of the dry weights of the erect portions of *C. scalpelliformis* in winter and spring 2004 were similar, and did not coincide with the decrease in the heights of the erect portions for this period. The maximum value for the dry weights of the erect portions was recorded in winter 2003, but did not coincide with the peak in the heights of the erect portions in autumn 2003. On the other hand, both variables behaved similarly in winter 2004, when the height of the erect portions (6.6 cm) and the dry weight of the erect portions (6.19 g.400 cm<sup>-2</sup>) reached their maximum values in that year.

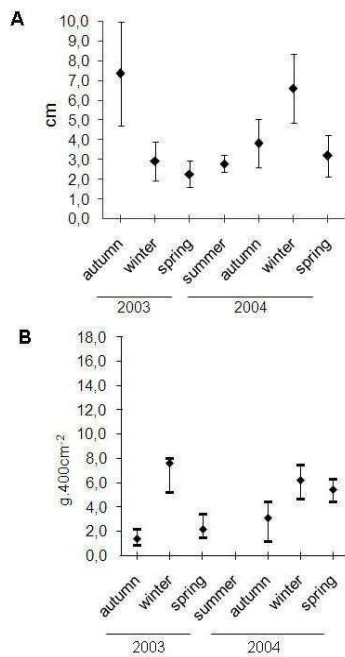


Fig. 3. Temporal variation of the erect portions of *Caulerpa scalpelliformis* growing on the sandy substrate at Baleia Beach, Ilha Grande Bay, from autumn 2003 to spring 2004. 3A- Height of the erect portions (n=75, mean  $\pm$  standard deviation); 3B - Dry weights of the erect portions (n=3, minimum, median and maximum values).

On both substrates, the maximum values of the dry weights of the erect portions occurred in the winters of both years. In contrast, the height of the

erect portions tended to increase from summer to autumn in 2004.

The total dry weights of *Caulerpa scalpelliformis* growing on both substrates in the different seasons were compared separately for 2003 and 2004. There was a significant interaction between substrate and season; but season was the most important factor for explaining the variation of the dry weight in each year (Table 1).

The length of the rhizoidal pillars of *Caulerpa scalpelliformis* from the rocky substrate varied, on average, from 1.05 cm (autumn 2004) to 1.70 cm (autumn 2003), but no temporal variation was detected (Fig. 4A).

An increase in the dry weights of the prostrate portions of *Caulerpa scalpelliformis* from the rocky substrate from autumn to spring in 2003, and a gradual increase from autumn to spring in 2004 were observed (Fig. 4B). The dry weights of the prostrate portions varied, on average, from 1.00 g.400 cm<sup>-2</sup> (autumn 2003) to 7.31 g.400 cm<sup>-2</sup> (spring 2003).

The length of the rhizoidal pillars of *Caulerpa scalpelliformis* from the sandy substrate varied, on average, from 1.10 cm (autumn 2004) to 1.92 cm (winter 2004). No clear temporal variation was observed (Fig. 5A).

The dry weights of the prostrate portions of *Caulerpa scalpelliformis* from the sandy substrate varied, on average, from 0.75 g.400 cm<sup>-2</sup> (autumn 2003) to 5.39 g.400 cm<sup>-2</sup> (spring 2004). There was an increase from autumn to winter 2003, and a gradual increase from autumn to spring 2004. From winter to spring 2003, a gradual decrease was apparent (Fig. 5B).

Table 1. Results of two-factor analysis of variance (ANOVA) of total dry weight of *Caulerpa scalpelliformis* from Ilha Grande Bay, studied in 2003 and 2004. Factors: Substrate (rock and sand) and season (n=3).

Source of Variation	Degrees of Freedom	Sum of Squares	Mean of Squares	F	p value
Year 2003					
Substrate	1	7.566	7.566	2.332	0.153
Season	2	184.740	92.370	28.475	<0.001
Substrate x Season	2	92.495	46.248	14.257	<0.001
Residual	12	38.927	3.244		
Total	17	323.727	19.043		
Year 2004					
Substrate	1	16.878	16.878	3.084	0.105
Season	2	230.351	115.176	21.045	<0.001
Substrate x Season	2	74.081	37.041	6.768	0.011
Residual	12	65.672	5.473		
Total	17	386.982	22.764		

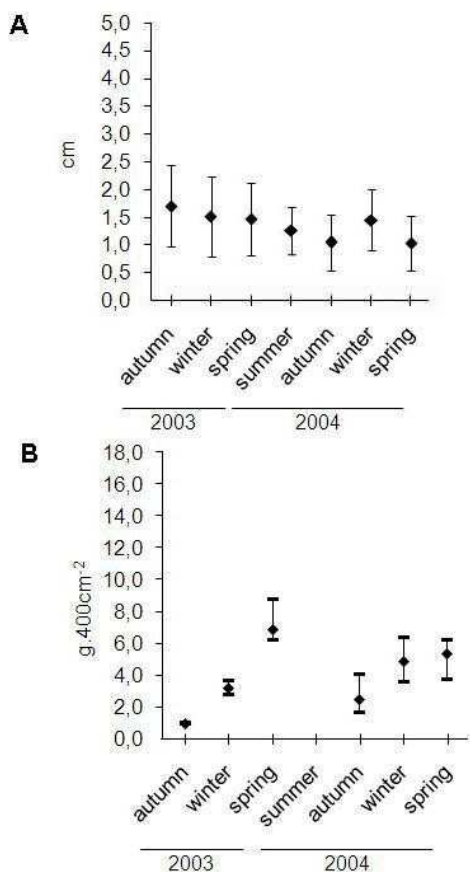


Fig. 4. Temporal variation of the prostrate portions of *Caulerpa scalpelliformis* growing on the rocky substrate at Baleia Beach, Ilha Grande Bay, from autumn 2003 to spring 2004. 4A- Length of the rhizoidal pillars (n=75, mean  $\pm$  standard deviation); 4B- Dry weight of the prostrate portions (n=3, minimum, median and maximum values).

## DISCUSSION

It was possible to define a temporal pattern of variation for the vegetative development of *Caulerpa scalpelliformis* on Baleia Beach. This pattern was evident in the development of the erect portions, and can be summarized as follows: a gradual increase in the population from summer to autumn, and a gradual decrease in the population from winter to spring. Similar temporal patterns have been described for other invasive *Caulerpa* species in other countries in different geographical regions (MODENA et al., 2000; CAPIOMONT et al., 2005). However, *C. scalpelliformis* populations did not show a clear temporal pattern in the development of the prostrate portions. Similarly to our results, no temporal pattern

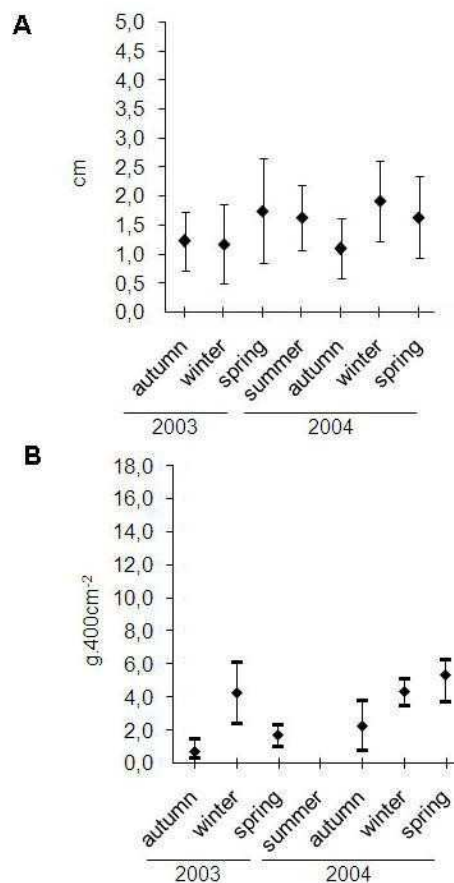


Fig. 5. Temporal variation of the prostrate portions of *Caulerpa scalpelliformis* growing on the sandy substrate at Baleia Beach, Ilha Grande Bay, from autumn 2003 to spring 2004. 5A- Length of the rhizoidal pillars (n=75, mean  $\pm$  standard deviation); 5B- Dry weight of the prostrate portions (n=3, minimum, median and maximum values).

was found in the development of the prostrate portions of *C. taxifolia* in the Mediterranean Sea (MEINESZ et al., 1995).

Taking into account both the height and the dry weight of the erect portions of the plants on sand and rock, the decreasing trend from winter to spring suggests the occurrence of senescence and the subsequent loss of the erect portions, mainly the tallest and oldest ones. The complete or partial loss of the erect portions of *C. scalpelliformis* may express intrinsic characteristics of the population, such as the age and the physiological state of the thalli, and may also result from extrinsic abiotic and biotic factors. Among the multiple abiotic factors, we may highlight the impact of storms, which are more severe and frequent in Ilha Grande Bay during the winter period

(PEREIRA, 1994). These storms may result in greater fragmentation of *C. scalpelliformis* thalli (SANTELICES, 1977). Although the occurrence of necrosis of *C. scalpelliformis* thalli has not been dealt with in this study, our results suggest that necrosis and senescence of the erect portions are expected to occur during winter, as in other species. Meinesz and Hesse (1991) and Meinesz et al. (1995) reported that necrosis in *C. taxifolia* thalli occurred throughout the year, mainly during winter. According to Klein and Verlaque (2008), in *Caulerpa racemosa* populations from different European regions, the number of erect portions decreases during winter, reinforcing the idea of a period of senescence. The study of necrosis and senescence in populations of *Caulerpa* species is, therefore, fundamental for the understanding of their temporal variation and competitive strategy in benthic communities, including the *C. scalpelliformis* populations in Ilha Grande Bay.

The loss of erect portions during winter seems to be quickly counterbalanced from spring to autumn, suggesting that *Caulerpa scalpelliformis* is able to regenerate and produce new erect portions continuously, during most of the year. This feature was more pronounced in the sandy-substrate population, where the height of the erect portions increased approximately 100% from spring 2003 to winter 2004. This behavior is similar to that observed for *C. taxifolia* and *C. racemosa* populations in the Mediterranean region (MEINESZ et al., 1995; MODENA et al., 2000; PIAZZI et al., 2001). The influence of abiotic factors such as temperature, light and salinity on the growth and physiology of *Caulerpa* species has been investigated in laboratory-controlled cultures (GACIA et al., 1996; GILLESPIE et al., 1997; FRIEDLANDER et al., 2006; WEST; WEST, 2007; BURFNEID; UDY, 2009). However, no physiological data on *C. scalpelliformis* have yet been published.

At Baleia Beach, *Caulerpa scalpelliformis* plants were observed throughout the 16-month study, in all the sampling periods, although there was a partial loss of the erect portions in the winter-spring period. This observation suggests that *C. scalpelliformis* is a pseudo-perennial species (MEINESZ et al., 1995). This seems to be a characteristic life form for the genus, because other species of this genus have also been described as pseudo-perennials, such as *C. prolifera* (Forssk.) J.V. Lamour. (CHAPMAN; CHAPMAN, 1976), *C. racemosa* (RUITTON et al., 2005) and *C. taxifolia* (MEINESZ et al., 1995; THIBAUT et al., 2004).

In the present study, in the light of the data for total biomass, no preference of *Caulerpa scalpelliformis* for rocky or sandy substrates was detected. The factors of substrate type and season showed a significant interaction in affecting the

biomass variation of *C. scalpelliformis*, but the season was the most important factor during the two years analyzed. To define the influence of substrate type and other factors on the vegetative development of the species in the study area, populations of other locations in Ilha Grande Bay should be monitored, and manipulative experiments should be undertaken. In agreement with a previous study in the area (FALCÃO; SZÉCHY, 2005), *C. scalpelliformis* is able to grow and form dense populations in the shallow sublittoral zone of rocky shores of Baleia Beach, and also on the adjacent sandy bottom. The adaptation to colonize different substrates is a characteristic feature of the genus. The ability to grow on different types of rocks and sand, as well as on benthic organisms, has been mentioned for *C. taxifolia* and *C. racemosa* (MEINESZ et al., 1993; MEINESZ et al., 1995; DAVIS et al., 1997; MODENA et al., 2000; THIBAUT et al., 2004).

The capability to colonize and grow on the sandy substrate is an important feature for the dispersal of *Caulerpa scalpelliformis*, especially as regards its dispersal by fragments. In Ilha Grande Bay, *C. scalpelliformis* fragments can be produced from dense populations by human recreational activities such as diving and fishing. Because of its calm warm waters and its beautiful landscape, Ilha Grande Bay is the scene of the intense movement of small boats, mainly during the summer (CREED et al., 2007), when *C. scalpelliformis* fragments can be transported by anchors and fishing gear from one place to another. Recreational activities near the seaweed beds can augment the fragmentation rate of their thalli and promote the secondary dispersal of invasive species (WEST et al., 2009). Therefore, it is reasonable to predict that Baleia Beach, where a dense population of *C. scalpelliformis* has been recorded on the sandy substrate since 2001 (FALCÃO, SZÉCHY, 2005), may act as a center of dispersal of this species to other localities in Ilha Grande Bay and also to other southeastern areas with similar environmental conditions, particularly those protected from direct wave action, such as the northern coast of São Paulo state. The vectors for the dispersal process may be anchors, fishing gear, and other equipments related to recreational activities in the waters of Baleia Beach. There is another possible vector for uncontrolled dispersal, i.e., the culture of this beautiful and luxuriant species in aquaria, by commercial traders or by marine aquarium hobbyists (OLIVEIRA et al., 2009). Following dispersal, *C. scalpelliformis* populations can be successfully established on different substrates, at different depths, occupying larger areas and competing with other benthic organisms. Changes in the benthic community structure are likely to occur sooner or later (FALCÃO; SZÉCHY, 2005). The importance of thallus

fragmentation as a possible means of vegetative reproduction and as a dispersal vector has been demonstrated for other *Caulerpa* species (CECCHERELLI; CINELLI, 1999; SMITH; WALTERS, 1999; KHOU et al., 2007).

Due to the disturbances occurring in marine ecosystems and to the economic issues related to bioinvasions, eradication programs developed especially for exotic *Caulerpa* species have been employed in some countries. Some of these eradication programs have been criticized because the techniques applied to kill or remove the invasive *Caulerpa* species, such as the alteration of the osmotic conditions through the addition of salts to the seawater, and the destruction of the species patches through sucking pumps, may also be harmful to other organisms (GLASBY et al., 2005; ANDERSON, 2007). However, some eradication programs, such as that used in California (ANDERSON, 2005), have been successful in controlling invasive *Caulerpa* species. This success of the California program is explained by the early discovery of the species in the new environments, at the beginning of its colonization process, and by the existing, adequate knowledge of the biological features of the species. One of the biological features that have to be understood to permit the effective monitoring of potentially invasive species is the temporal variability of the populations, including their growth and reproduction patterns.

The methodology applied in this study, concerning the sampling frequency and the number and size of the sampling units, was recently applied for studying the temporal and spatial variability in populations of *Caulerpa racemosa* var. *cylindracea* in the Mediterranean Sea, by Ruitton et al. (2005) and Cebrian and Ballesteros (2009). We considered that the sampling frequency and sample size adopted were sufficient for describing the temporal variations of the population studied on Baleia Beach. On the other hand, this sample size is open to re-evaluation, should methodological standardization be required for future studies in other localities. In this regard, financial support and substantial research effort are necessary to continue the study of the biological aspects of *C. scalpelliformis* on the Brazilian coast. Enhancing our basic knowledge of invasive species of *Caulerpa* and other seaweeds is the surest way to enable us to develop eradication or management programs which could also be applied in Ilha Grande Bay.

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