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Changes in shallow phytobenthic assemblages in southeastern Brazil, following the replacement of *Sargassum vulgare* (Phaeophyta) by *Caulerpa scalpelliformis* (Chlorophyta)

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Abstract

The structure of shallow sublittoral phytobenthic assemblages from Ilha Grande Bay, Rio de Janeiro, southeastern Brazil, was described to evaluate the effect of the presence of *Caulerpa scalpelliformis* on the dominant species, *Sargassum vulgare*. The canopy cover of macroscopic organisms was analyzed monthly or less frequently on rocky substrata from Baleia Beach (impact location, where *C. scalpelliformis* appeared) and from two reference locations (without *C. scalpelliformis*), during the periods September 1993 to May 1995 and October 2001 to September 2003, using the point sampling method (n=5 random quadrats). At the impact location, *S. vulgare* was dominant from September 1993 to September 2001, when *C. scalpelliformis* appeared on the rocky substratum beneath *S. vulgare*. In a few months, the cover of *S. vulgare* declined dramatically and *C. scalpelliformis* became dominant on the rocky and sandy substrata until the end of the study. Over the same period, *S. vulgare* was dominant at the reference locations. Multivariate community analysis revealed significant changes in the macroalgal community structure following the appearance of *C. scalpelliformis*. The replacement of *S. vulgare* by *C. scalpelliformis* suggests the competitive superiority of *C. scalpelliformis* under sheltered conditions. This is the first record of this pantropical macroalga in the warm temperate region of the Brazilian coast.

Keywords: abundance; benthic communities; Brazil; *Caulerpa*; invasive species; *Sargassum*.

Introduction

Along the southeastern Brazilian coast, phytobenthic assemblages of the shallow sublittoral zone from sheltered and unpolluted sites are dominated by *Sargassum* species (Phaeophyta, Sargassaceae), forming dense and extensive beds (Oliveira Filho and Paula 1979, Széchy and Paula 2000a, Amado Filho et al. 2003). *Sargassum vulgare* C. Agardh and *S. filipendula* C. Agardh are commonly encountered in the rocky phytobenthic communities of Ilha Grande Bay, on the southern coast of the state of Rio de Janeiro (Falcão et al. 1992, Széchy and Paula 2000b).

Sargassum species are strong competitors for space and light in rocky shore communities, as in the case of *S. muticum* (Yendo) Fensholt (Critchley et al. 1990). Paula and Eston (1987) suggested that some Brazilian species, such as *S. stenophyllum* Mart., possess the same invasive potential as *S. muticum*, when comparing their adaptive strategies. Later, the competitive superiority of *S. stenophyllum* in a shallow rocky sublittoral community from the state of São Paulo was demonstrated by Eston and Bussab (1990).

The state of Rio de Janeiro is situated on the southeastern coast of Brazil, which is defined as a warm temperate region (Horta et al. 2001). Compared to the tropical Brazilian northeastern coast, this region has a low number of species of *Caulerpa*, including *Caulerpa fastigiata* Montagne, *C. mexicana* Sonder *ex* Kützing, *C. racemosa* (Forsskål) J. Agardh, *C. sertularioides* (S.G. Gmelin) M. Howe and *C. verticillata* J. Agardh (Oliveira Filho 1977, Mitchell et al. 1979, Falcão et al. 1992, Pedrini et al. 1994, Guimaraens and Coutinho 1996, Széchy and Paula 2000b, Amado Filho et al. 2003). Among these species, *C. racemosa* is recognized as an invasive species in the Mediterranean Sea (Modena et al. 2000, Piazzi et al. 2001, Ceccherelli et al. 2002, Verlaque et al. 2003).

Sparse occurrence of *Caulerpa scalpelliformis* (R. Brown *ex* Turner) C. Agardh has been reported along the tropical region of the Brazilian coast (Joly et al. 1965, Pinheiro-Vieira and Ferreira 1968, Ferreira-Correia and Pinheiro-Vieira 1969, Nunes 1998), where this species does not show invasive behavior. Previous to the present study, the southern limit of distribution for this species on the Brazilian coast was established as the state of Espírito Santo (Mitchell et al. 1990) (Figure 1), a transition region between the Brazilian tropical and warm temperate regions (Horta et al. 2001).

This study aimed at chronicling the changes occurring in a phytobenthic assemblage of the shallow sublittoral zone of Ilha Grande Bay, dominated by the brown alga *Sargassum vulgare*, following the appearance of the green alga *Caulerpa scalpelliformis*. We contrast an invaded site at Baleia Beach with two nearby uninvaded reference locations.

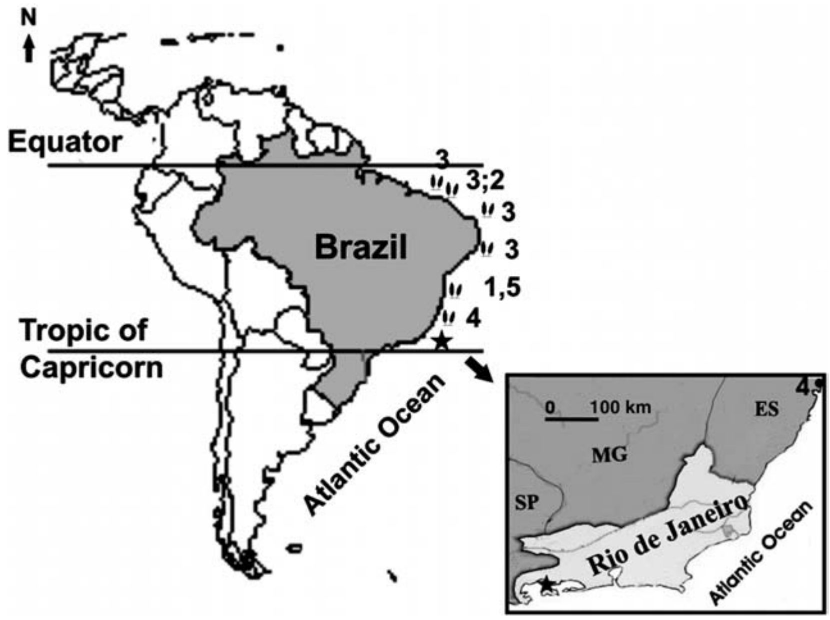

Figure 1 Distribution of *Caulerpa scalpelliformis* along the Brazilian coast, with the corresponding references. =previous records; ★=present record. 1=Joly et al. (1965); 2=Pinheiro-Vieira and Ferreira (1968); 3=Ferreira-Correia and Pinheiro-Vieira (1969); 4=Mitchell et al. (1990); 5=Nunes (1998). ES=Espirito Santo state; MG=Minas Gerais state; SP=São Paulo state.

Materials and methods

Two sites in Jacuacanga Cove, Ilha Grande Bay, were surveyed by diving: Baleia Beach and Gordas Beach (Figure 2). At Baleia Beach, two rocky shores were monitored: one, where *C. scalpelliformis* appeared (impacted location) and the other, where *C. scalpelliformis* did not occur (reference location 1). The rocky shore at Gordas Beach was taken as reference location 2.

Baleia Beach is relatively protected from exposure to wave action; there the impact location is more protected than reference location 1. Reference location 2 was moderately exposed to wave action. Baleia Beach is situated in the inner part of Jacuacanga Cove, near Verolme shipyard and Monsuaba village, where non-treated wastewater is discharged directly into the sea. In addition, there are many points along the coast of Jacuacanga Cove where the discharge of non-treated wastewater can be found (personal observations). At the three locations, boulders of different sizes covered the bottom from the fringe of the sublittoral zone to approximately 2 m depth. At the beginning of the study period, *Sargassum vulgare* formed a continuous and conspicuous bed on these rocky substrata.

At the impact location, temporal variation in the canopy cover of algae and sessile invertebrates on rocky substrata in the shallow sublittoral zone (1.0–1.5 m deep in relation to mean low water) was monitored from September 1993 to May 1995. Non-destructive samples were taken monthly. Only macroscopic organisms that could be readily identified in the field with the unaided eye were included. The percentage cover was estimated using the point quadrat sampling method (Foster et al. 1991). The quadrat was a 20×20 cm aluminium frame, divided by perpendicular nylon lines strung inside it; the intersections of these lines provided 81 points. For each sampling, five quadrats were analyzed, following the recommendation of other *Sargassum* studies (Critchley et al. 1990, Largo et al. 1994). The quadrats were randomly positioned along a horizontal extension of approximately 20 m of the rocky substratum, around the initial point where *Caulerpa scalpelliformis* was found later.

From October 2001 to September 2003, canopy cover at the impact location was quantified bimonthly or slightly less frequently, on rocky substrata (n=5), as well as on adjacent sandy substrata (n=5), approximately 2 m deep, using the same point quadrat sampling method.

To evaluate whether the temporal changes in the rocky assemblage of the impact location are related to the presence of *Caulerpa scalpelliformis*, the canopy cover of the organisms on rocky substrata of both reference locations was analyzed monthly, from June 2002 to February 2003, using the point quadrat sampling method, with 50×50 cm quadrats (n=5), randomly placed along a horizontal extension of 20 m.

Possible relationships between mean percentage cover of *Sargassum vulgare* and *Caulerpa scalpelliformis* were tested by the Spearman's rank correlation coefficient (Zar 1984).

The software package Primer 5 (Plymouth Routines in Multivariate Ecological Research, from Plymouth Marine Laboratory, UK) was used for multivariate statistical analyses to describe differences in the community structure at the different locations and times. Data were double square root transformed. Bray-Curtis similarity matrix was calculated and used to generate a two-dimensional plot with the non-metric multidimensional scaling (nMDS) technique (Clarke and Warwick 1994). One-way analysis of similarity (ANOSIM) was used to test whether the community structure at the impact location differed significantly from that at reference locations.

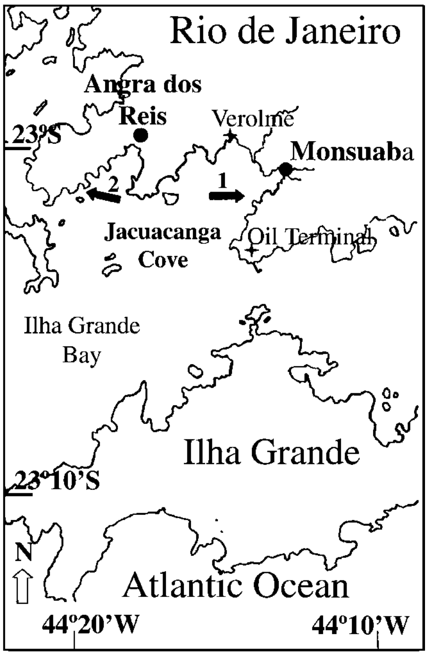

Figure 2 Study area at Jacuacanga Cove, Ilha Grande Bay, Rio de Janeiro state, showing the two sites studied: Baleia Beach (1) and Gordas Beach (2).
Note "Verolme" shipyard and oil terminal "Ilha Grande Bay".

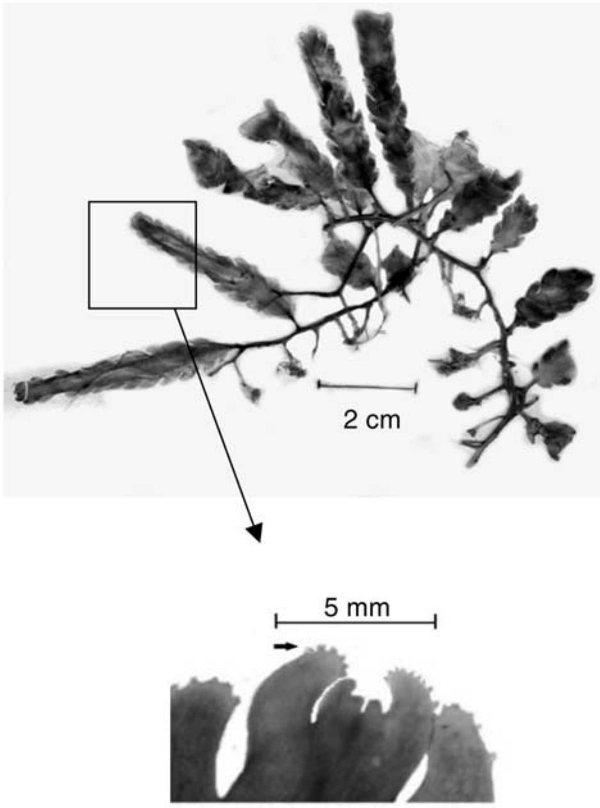

Figure 3 *Caulerpa scalpelliformis* from Jacuacanga Cove, Ilha Grande Bay, Rio de Janeiro state.
Note the characteristic broad teeth along the apical margins of the blades (→).

Material deposited in herbarium: *Caulerpa scalpelliformis* f. *denticulata* – Brazil, state of Rio de Janeiro, Angra dos Reis municipality, Ilha Grande Bay, Jacuacanga Cove, Baleia Beach, sublittoral zone of rocky coast, 10/12/2001, col. M.T.M. Széchy and C. Falcão (RFA 28258); 25/03/2002, col. C. Falcão and M.T.M. Széchy (RFA 28257).

Results

Caulerpa scalpelliformis was first noted on the rocky substrata at the impact location (Baleia Beach) in September 2001. At that time only a few thalli of this species occupied the shallow sublittoral zone (ca. 1 m deep), underneath thalli of *Sargassum vulgare*. In October 2001, this species covered an area of approximately 5.0×2.5 m^2, including both rocky substrata and the adjoining sandy bottom. This population persisted until the end of the study, expanding gradually on both rocky and sandy substrata and reaching greater depths (around 6 m deep).

The material from the state of Rio de Janeiro is similar to *Caulerpa scalpelliformis* (R. Br.) Weber van Bosse f. *denticulata* (Decaisne) Weber van Bosse from Itaparica Island, Salvador, state of Bahia, described by Joly et al. (1965), with the characteristic broad teeth along the apical margins of the blades (Figure 3).

In addition to *Sargassum vulgare* and *Caulerpa scalpelliformis*, 20 species of macroalgae were identified (Table 1). The remaining organisms were identified to the level of genus or complex of many taxa with similar morphology and color (e.g., filamentous Ectocarpaceae, calcareous crusts). Some macroalgae were found exclusively at the impact location, for example *Wrangelia argus, Ceramium* species and *Champia* species, as epiphytes, and *Acicularia schenckii* on the sandy substratum. Others, such as *Enteromorpha* species, *Ulva* species and Ectocarpaceae, were found only at the reference locations, where they generally showed great variability in the canopy cover (coefficients of variation higher than 100%).

From September 1993 to May 1995, *Sargassum vulgare* was dominant on the rocky substrata at the impact location (Figure 4). During this period, the highest cover values were reached during the summer months, especially in January 1994 (mean cover=87.4 ± 4.6%). A decline in the abundance of *S. vulgare* was observed from fall (March 1994) to winter, reaching its lowest cover in September 1994 (59.5 ± 9.7%), while the abundance of other organisms increased. These organisms were mainly jointed calcareous members of the Corallinaceae (Figure 5a). *Dictyota* species occurred epiphytically on *Sargassum*, mainly in the winter of 1994 ($\geq$10% mean cover) (Figure 5b). Other macroalgae also occurred on the rocky substrata during this period (Figure 5c), but they showed lower cover values ($<$10% mean cover), including *Dictyopteris delicatula, Padina gymnospora, Champia parvula* and *Champia vieillardii*.

From October 2001 to September 2003, following the discovery of *Caulerpa scalpelliformis* on the rocky substrata at the impact location, the abundance of *Sargassum vulgare* declined dramatically: mean cover $\pm$SD declined from 14.8 ± 25.6% (December 2001) to 1.7 ± 2.7% (April 2003), while the cover of *C. scalpellifor-*

Table 1 Canopy cover (%, mean±SD) of macroalgae and sessile macroinvertebrates of phytobenthic assemblages of rocky and sandy substrata from the shallow sublittoral zone of Ilha Grande Bay, SE Brazil, before and after the appearance of *Caulerpa scalpelliformis*.

Organisms	Impact location			Reference locations	
	Baleia Beach			(1) Baleia Beach	(2) Gordas Beach
	Rocky substrata		Sandy substrata	Rocky substrata	Rocky substrata
	Before (n=21)	After (n=10)	After (n=10)	After (n=8)	After (n=8)
Chlorophyta					
Acicularia schenckii (K. Möbius) Solms	0.00	0.00	0.12±0.39	0.00	0.00
Caulerpa racemosa (Forsskål) J. Agardh	0.00	2.24±4.43	0.00	0.00	0.25±0.50
Caulerpa scalpelliformis (R. Br. *ex* Turner) C. Agardh	0.00	79.90±13.23	68.61±24.72	0.00	0.00
Enteromorpha species	0.00	0.00	0.00	0.00	0.08±0.24
Ulva species	0.00	0.00	0.00	0.25±0.36	0.00
Phaeophyta					
Dictyopteris delicatula J.V. Lamour.	1.73±0.88	0.07±0.22	0.20±0.54	0.75±0.90	0.08±0.24
Dictyota cervicornis Kütz. and *Dictyota* species	6.56±2.80	1.14±2.08	3.49±6.02	3.33±4.29	4.22±3.71
Filamentous Ectocarpaceae	0.00	0.00	0.00	0.08±0.24	0.58±0.83
Padina gymnospora (Kütz.) Sond.	4.62±1.95	1.95±1.84	0.26±0.58	7.00±5.14	3.64±3.50
Sargassum vulgare C. Agardh	73.67±7.82	5.34±4.25	0.00	64.50±7.81	57.58±7.35
Rhodophyta					
Acanthophora spicifera (Vahl) Børgesen	0.00	0.04±0.11	0.07±0.23	0.00	0.58±1.40
Asparagopsis taxiformis (Delile) Trevis.	1.13±0.98	0.00	0.00	1.42±1.57	5.21±3.68
Ceramium species	0.00	0.02±0.08	0.00	0.00	0.00
Champia parvula (C. Agardh) Harvey and *Champia vieillardii* Kütz.	0.98±0.88	0.36±0.48	1.30±2.88	0.00	0.00
Chondracanthus species	0.00	0.00	0.00	0.00	0.61±0.96
Corallinaceae – jointed calcareous: *Amphiroa brasiliana* Decaisne, *Amphiroa fragilissima* (L.) J.V. Lamour. and *Jania adhaerens* J.V. Lamour.	9.23±4.08	1.89±2.38	11.47±10.37	15.83±7.64	17.64±8.91
Corallinaceae – calcareous crusts	0.00	0.26±0.78	0.00	3.33±3.40	2.56±2.28
Dasya species	0.00	0.12±0.26	0.64±1.52	0.00	0.00
Galaxaura marginata (J. Ellis *et* Sol.) J.V. Lamour.	0.00	0.00	0.00	0.00	0.50±1.41
Gelidiales	0.00	0.00	0.00	0.00	0.31±0.57
Gelidiopsis planicaulis (W.R. Taylor) W.R. Taylor and *Gelidiopsis variabilis* (Greville *ex* J. Agardh) F. Schmitz	0.00	0.09±0.16	0.05±0.16	0.42±0.71	1.28±0.79
Gracilaria domingensis (Kütz.) Sond. *ex* Dickie	0.00	0.00	0.00	0.00	0.33±0.36
Hypnea musciformis (Wulfen *in* Jacqu.) J.V. Lamour. and *Hypnea spinella* (C. Agardh) Kütz.	0.00	0.02±0.08	1.00±2.57	0.00	0.08±0.24
Laurencia species	0.00	0.00	0.00	0.83±0.93	1.14±1.11
Solieria filiformis (Kütz.) P.W. Gabrielson	0.00	0.19±0.39	1.78±3.72	0.00	0.00
Wrangelia argus (Mont.) Mont.	2.08±2.10	2.67±3.69	0.49±1.32	0.00	0.00
Other filamentous Ceramiaceae	0.00	3.00±9.50	0.16±0.52	0.75±1.26	1.00±2.31
Ascidians	0.00	0.10±0.31	0.00	0.00	0.08±0.24
Sponges	0.00	0.47±0.45	0.84±1.95	0.83±1.11	0.61±0.46

Impact location: Baleia Beach (where *C. scalpelliformis* was found); reference locations (1) and (2): Baleia Beach and Gordas Beach (without this species). n=number of monthly samples.

mis increased, reaching 96.1±7.5% in October 2002 (Figure 4). Concomitantly with the appearance of *C. scalpelliformis* on the rocks, a substantial decline in the cover of other organisms was observed (Figure 5). The cover of the jointed calcareous macroalgae on the rocky substrata declined from 7.4±14.6% (May 2002) to zero (October 2002, April, July and September 2003) (Figure 5a); similarly, the cover of *Dictyota* species declined from 6.6±10.2% (March 2002) to zero (May, August and October 2002, July and September 2003) (Figure 5b). In this period, the cover for all other less abundant organisms was higher in December 2001, January 2003 and April

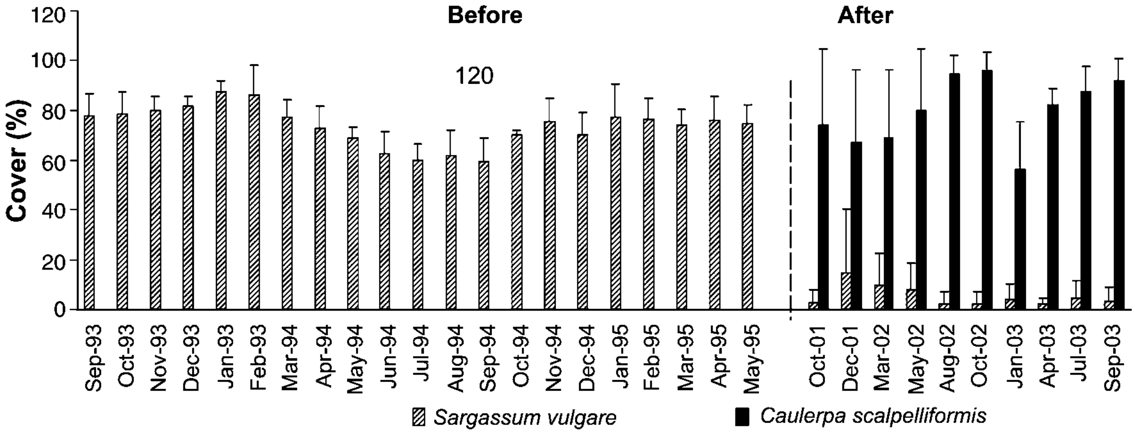

Figure 4 Canopy cover of *Sargassum vulgare* and *Caulerpa scalpelliformis* on the rocky substrata at the impact location (Baleia Beach, Jacuacanga Cove, Ilha Grande Bay) during the periods September 1993 to May 1995 (before) and October 2001 to September 2003 (after).
Arithmetic means and standard deviations.

2003 (Figure 5c) due to the major contributions of *Caulerpa racemosa* (12.96±21.69%), filamentous Ceramiaceae (30.4±23.63%) and *Wrangelia argus* (10.86±5.95%), respectively. Among others, *Padina gymnospora*, calcareous crusts, *Dasya* species, *Gelidiopsis* species, *Hypnea* species, *Solieria filiformis*, ascidians and sponges also occurred on the rocky substrata during this period, but they showed lower cover values (mean cover <10%).

On the sandy substrata at the impact location, a small number of isolated thalli of *Caulerpa scalpelliformis* was observed in October 2001 (6.4±4.0% cover ±SD). At this site, *C. scalpelliformis* turned into a dense population within a few months. Cover of this species on the sand reached 95.8±4.0% in September 2003 (Figure 6). Some common species of the rocky substrata appeared on the sand and started to grow, intermingled with the *Caulerpa* rhizome system, as observed for the jointed calcareous macroalgae (Figure 7a), especially *Jania adhaerens, Dictyota* species (Figure 7b) and other less abundant species (Figure 7c), such as *Dictyopteris delicatula, Padina gymnospora, Acanthophora spicifera, Champia* species, *Dasya* species, *Hypnea* species, *Solieria filiformis, Wrangelia argus*, other filamentous Ceramiaceae and sponges. *Acicularia schenckii* was noted growing directly on the sandy bottom in April 2003 (1.34±2.14% cover).

At the reference locations, *Sargassum vulgare* was dominant on the rocky substrata (mean cover >50%) from June 2002 to February 2003 (Figure 8a,b). During this period, other macroalgae occurred in the assemblages of the reference locations, growing on the rocks, such as the jointed calcareous macroalgae, the calcareous crusts and *Padina gymnospora*, or on the *Sargassum* thalli, such as *Dictyota cervicornis* and *Asparagopsis taxiformis*. Although mean cover values for *S. vulgare* showed no clear seasonal variation during the study period, they were more variable during the winter months (coefficients of variation ≈40–43%). In July 2002, the jointed calcareous macroalgae, which were frequently observed as understorey members of the *Sargassum* assemblage, showed the highest canopy cover values in the communities of Baleia Beach and Gordas Beach (24.00±17.86% and 34.00±15.35%, respectively; means ±SD). Similarly, the calcareous crusts showed the highest canopy cover values in July 2002 at reference location 1 (9.33±12.34%) and in June 2002 at reference location 2 (7.79±8.39%).

Based on the mean values for the macroalgal cover, the similarities among the sublittoral assemblages studied are shown by the nMDS plot (Figure 9). Two groups were formed at 55% level of similarity, irrespective of substratum, site and time of the year: 1) assemblages without *Caulerpa scalpelliformis* (reference locations 1 and 2: rocky substrata; impact location: rocky substrata, before the appearance of *C. scalpelliformis*); and 2) assemblages with *C. scalpelliformis* (impact location: rocky and sandy substrata, after the appearance of *C. scalpelliformis*). The sandy assemblage of the impact location, just after the appearance of *C. scalpelliformis* (October 2001), was placed separated from group 2, as the cover of this species was not as high as in group 2. The changes in the community structure after the appearance of *C. scalpelliformis* were confirmed by ANOSIM, that showed that groups 1 and 2 differed significantly ($r=0.977$, $p<0.001$).

Possible negative influence of *Caulerpa scalpelliformis* on *Sargassum vulgare* abundance was strengthened by the significant negative correlation obtained for mean cover values of these species (Spearman's rank coefficient=-0.71, $p<0.05$, $n=47$).

Discussion

The replacement of *Sargassum* by *Caulerpa* in benthic shallow assemblages of the southeastern Brazilian coast was described for the first time. The dominance of *Sargassum* species in phytobenthic communities of the southeastern region of the Brazilian coast is well documented (Oliveira Filho and Mayal 1976, Paula and Oliveira Filho 1982, Széchy and Paula 2000a, Amado Filho et al. 2003). However, this dominance is not observed in communities experiencing different kinds of disturbance, such as high exposure to water movement, pollution, or

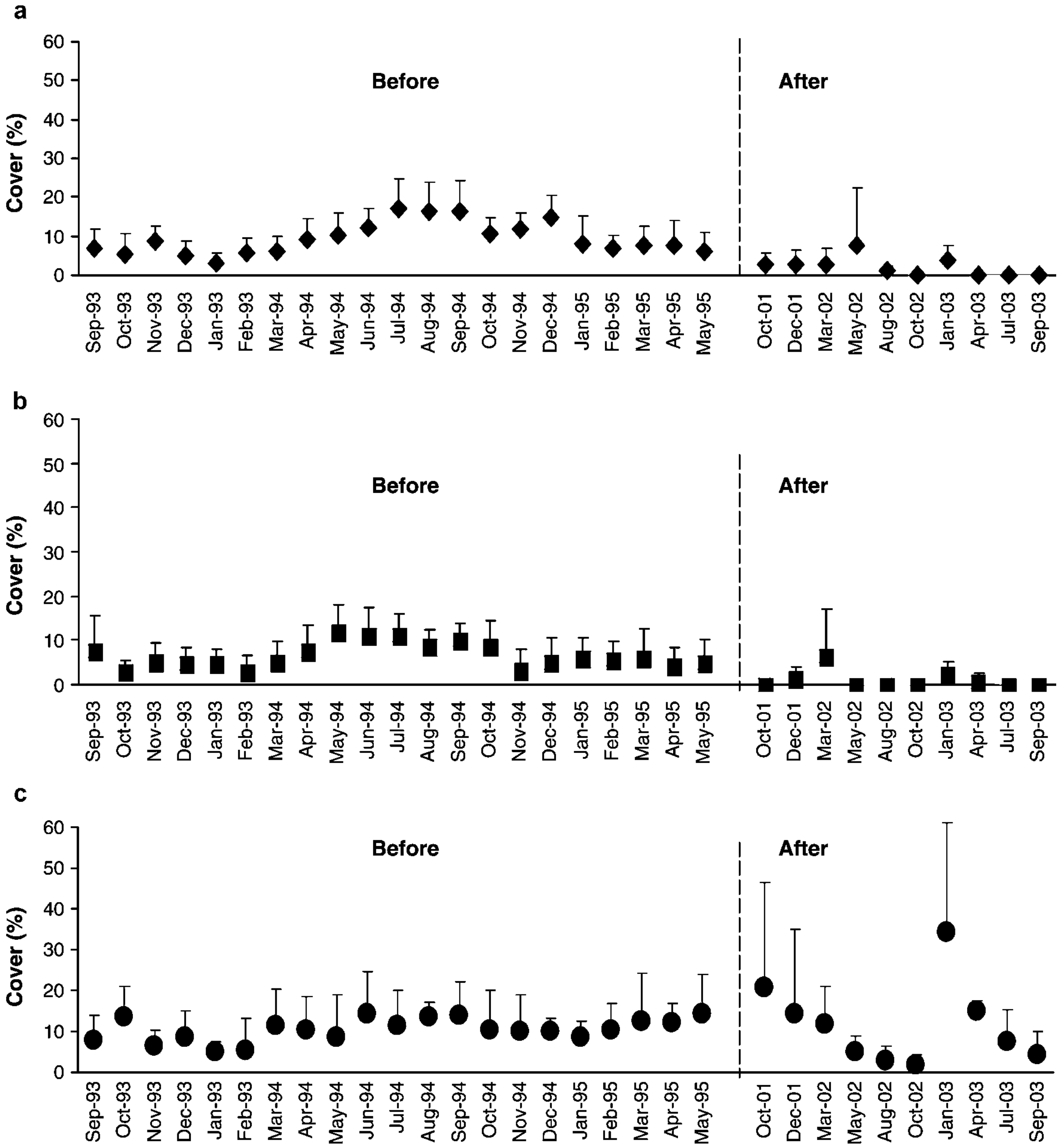

Figure 5 Canopy cover of macroscopic organisms on the rocky substrata at the impact location (Baleia Beach, Jacuacanga Cove, Ilha Grande Bay), before (September 1993 to May 1995) and after (October 2001 to September 2003) the appearance of *Caulerpa scalpelliformis*.
(a) Corallinaceae – jointed calcareous macroalgae. (b) *Dictyota* species. (c) Other less abundant organisms. Arithmetic means and standard deviations.

high abundance of herbivores, especially sea urchins. While describing the temporal changes in the marine benthic flora from Santos Bay, state of São Paulo, Oliveira Filho and Berchez (1978) associate the disappearance of the characteristic *Sargassum* communities with organic pollution. Széchy and Paula (2000a), studying the structure of communities of the rocky sublittoral zone of the states of Rio de Janeiro and São Paulo, mention the replacement of *Sargassum* species, including *S. vulgare*, by Corallinaceae as dominant members, whenever these communities are subjected to a high degree of wave action and emersion, and the replacement by macroalgae of more simple functional-form groups, such as *Padina* species and *Dictyopteris delicatula*, under intermediate degrees of disturbances.

The appearance and the increase in abundance of *Caulerpa scalpelliformis* at the impact location suggest the ecophysiological and reproductive adaptability of this green alga to the environmental conditions of the study area. This adaptability occurs in other species of the genus (Meinesz et al. 1995, Gillespie et al. 1997, Piazzi et al. 2001). Nutrient enrichment in the seawater due to the discharge of non-treated wastewater in the inner part of Jacuacanga Cove is one of the factors that could have contributed to the increase of this species of *Caulerpa* in Baleia Beach. This important factor is also responsible for the increase of green macroalgal species globally, particularly those of the coenocytic group (Chisholm et al. 1997, Chisholm and Jaubert 1997, Lapointe 1997). The increase in abundance of some *Caulerpa* species in

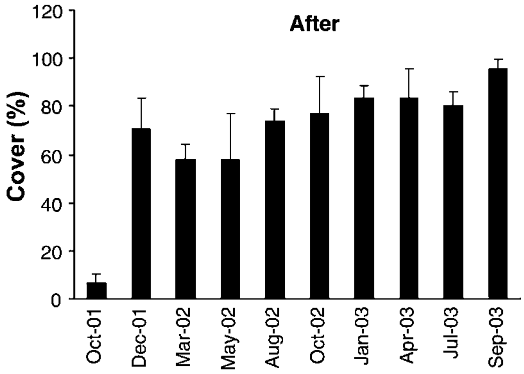

Figure 6 Canopy cover of *Caulerpa scalpelliformis* on the sandy substrata at the impact location (Baleia Beach, Jacuacanga Cove, Ilha Grande Bay) during the period October 2001 to September 2003.
Arithmetic means and standard deviations.

temperate regions has also been related to the increase of seawater temperature (Scrosati 2001); unfortunately, nutrients concentration and seawater temperature data are not available for the study area during the study period.

Not only did the abundance of *Caulerpa scalpelliformis* increase from 2001 to 2003, but also the cover of several indigenous species, mainly *Sargassum vulgare*, decreased at the same location during the same period, indicating competitive displacement through competition for space. This competition was also suggested by the high inverse correlation between *Caulerpa* and *Sargassum* cover.

It is not plausible to suppose that the dramatic decrease in the canopy cover of *Sargassum vulgare* in the impact location at Baleia Beach was due to major changes in the climatic and oceanographic conditions of Ilha Grande Bay, since the populations of the reference locations, especially from Baleia Beach, did not show such decline. In addition, the decline in *S. vulgare* abundance at the impact location seems not to have been caused by morpho-physiological changes, such as those related to different development phases of other species (Paula and Oliveira Filho 1980, Ang Jr. 1985).

Sargassum vulgare was abundant throughout the study at both reference locations, although its canopy cover was more variable in the winter months. During this period, the abundance of other macroalgae usually found in the understorey, such as the calcareous group, was greater. The highest coefficients of variation found for the winter months reflect the physiognomic aspect of the *Sargassum* beds during the winter, when *Sargassum* did not form a continuous canopy. The decline in *Sargassum* abundance during winter months has been described for populations of other species from warm temperate regions (McCourt 1984, Gillespie and Critchley 1999).

The changes observed at the impact location are probably due to the effect of the arrival of *Caulerpa scalpelliformis* rather than natural seasonal changes in the community. Similar changes in the structure of marine benthic communities have been documented for deep-reef habitats of Botany Bay, New South Wales (Davis et al. 1997), with the rapid replacement of sessile marine invertebrates, predominantly sponges, colonial ascidians and bryozoans, by *C. scalpelliformis*. In these habitats, this species displayed the capability of long-distance dispersal and establishment on non-continuous substrata. Changes to algal assemblages following the appearance of *Caulerpa taxifolia* (M.Vahl) C. Ag. were also described for the northern and western Mediterranean coast; there, the abundance of *C. taxifolia* increased, while the abundance of the remaining macroalgal species decreased (Meinesz et al. 1993, Verlaque and Fritayre 1994). Manipulative experiments are recommended, such as the transplant of thalli of *C. scalpelliformis* to other assemblages, and also exclusion experiments that allow study-

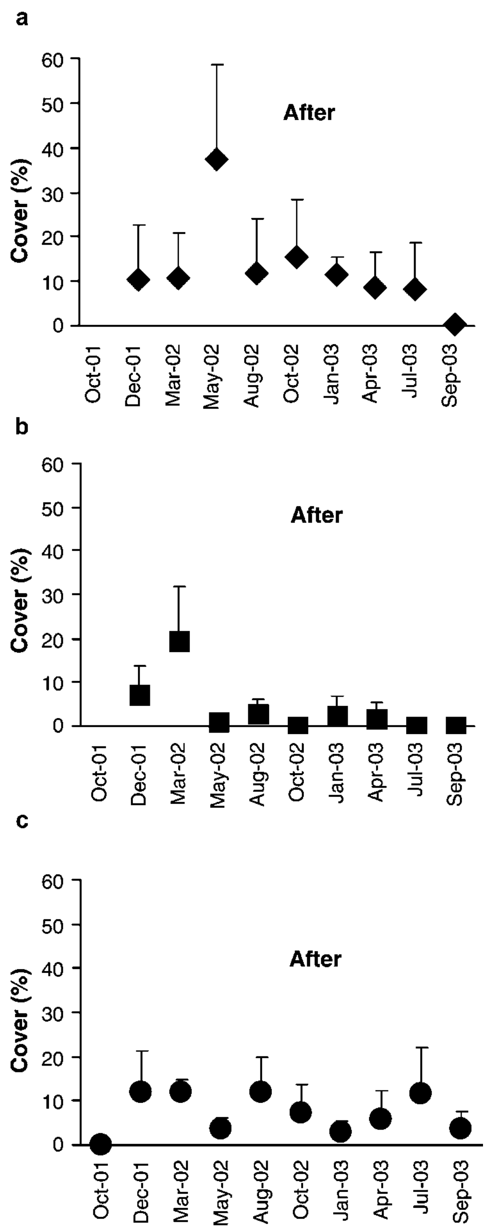

Figure 7 Canopy cover of macroscopic organisms on the sandy substrata at the impact location (Baleia Beach, Jacuacanga Cove, Ilha Grande Bay) during the period October 2001 to September 2003.
(a) Corallinaceae – jointed calcareous macroalgae. (b) *Dictyota* species. (c) Other less abundant organisms. Arithmetic means and standard deviations.

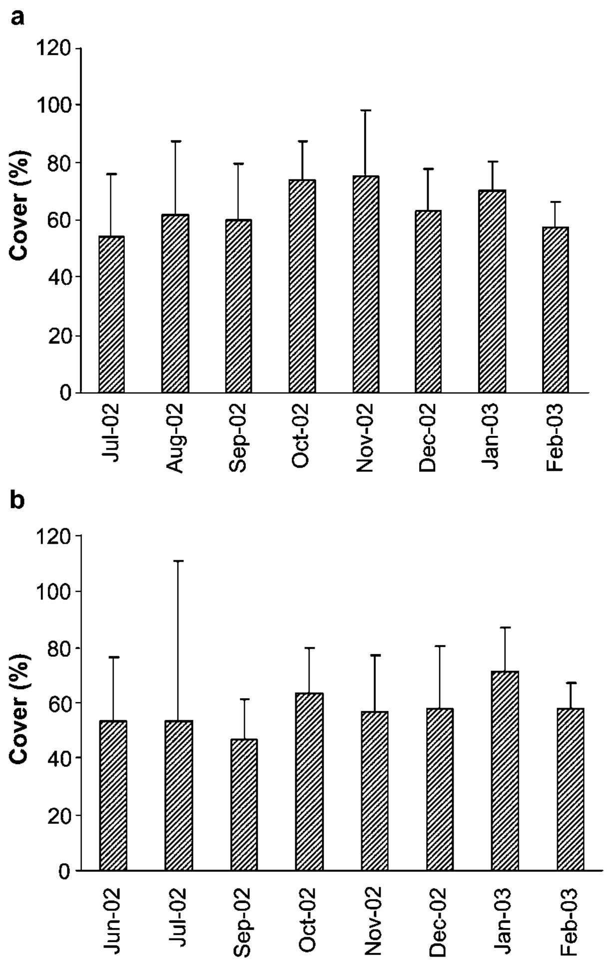

Figure 8 Canopy cover of *Sargassum vulgare* on the rocky substrata at the reference locations (Jacuacanga Cove, Ilha Grande Bay) during the period June 2002 to February 2003.
(a) Reference location 1 (Baleia Beach). (b) Reference location 2 (Gordas Beach). Arithmetic means and standard deviations.

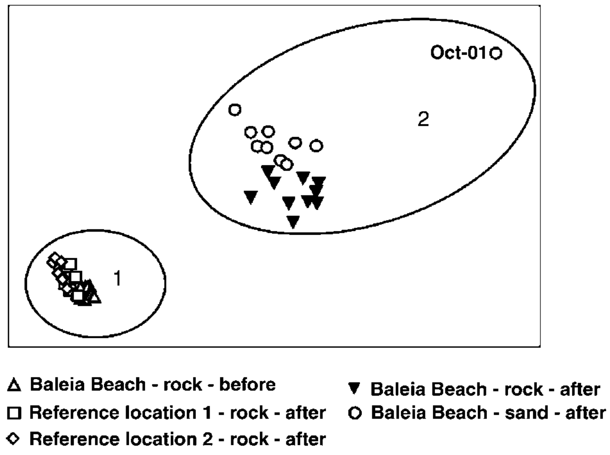

Figure 9 Two-dimensional non-metric multidimensional scaling plot (nMDS), indicating differences in the community structure of two sites, considering the canopy cover of macroalgae on different substrata and at different times.
1=assemblages without *C. scalpelliformis*; 2=assemblages with *C. scalpelliformis*; Δ=rocky substrata at the impact location, before the appearance of *Caulerpa scalpelliformis*; ▼=rocky substrata at the impact location, after the appearance of *Caulerpa scalpelliformis*; ○=sandy substrata at the impact location, after the appearance of *Caulerpa scalpelliformis*; □=rocky substrata at reference location 1; ◇=rocky substrata at reference location 2 (stress=0.05).

ing the succession in assemblages with and without *Caulerpa*.

Caulerpa scalpelliformis is most widespread in warm waters of different oceans (Oliveira Filho 1977, Lawson and John 1982) as are other Brazilian species of *Caulerpa*, which are pantropical (Lüning 1990). The temporary occurrence of *C. scalpelliformis* in the Antalya harbour, Turkey, a non-tropical region, was related to the higher seawater temperature noted during the summer of 1995 (Ertan et al. 1998) and should not be interpreted as an expansion of the distribution area of this species in the Mediterranean Sea. Taking into account the pantropical distribution pattern of *C. scalpelliformis*, its occurrence in Ilha Grande Bay, which is included in the warm temperate region of the Brazilian coast (Horta et al. 2001), can be interpreted as a recent introduction in the study area, regardless of the distance of its origin (Bellorín and Oliveira 2001). According to Carlton (2001), introduced species are “those that have been transported by human activities, intentionally or unintentionally, into a region in which they did not occur in historical time and are now reproducing in the wild”. Some potential sources of introduction of marine species (Carlton 2001) can be recognized in the Ilha Grande Bay, mainly the oil terminal “Ilha Grande Bay”, the “Verolme” shipyard and sparse aquaculture farms. Moreover, this species is currently being offered to Brazilian aquarists by Internet sites without any environmental control!

The occurrence of *Caulerpa scalpelliformis* in a region in which it did not occur could be also explained as the extension of its distribution range, due to climatic changes. However, it is important to emphasize that the presence of other species of macroalgae originated from the tropical region of the Brazilian coast has not been reported for the Ilha Grande Bay. To explain the origin of *C. scalpelliformis* in the study area is a very difficult task, as it is quite difficult to prove the source of new species in any region of the world. Undoubtedly, interdisciplinary approaches are needed, especially those involving genetic techniques (Olsen et al. 1998, Benzie et al. 2000, Schaffelke et al. 2002).

Caulerpa scalpelliformis from Ilha Grande Bay showed a dramatic increase in abundance since its discovery in this region. The flexible habitat requirements exhibited by this species in colonizing different substrata at different depths typifies other invasive *Caulerpa* species (Meinesz et al. 1993, Verlaque 1994, Ceccherelli and Cinelli 1999, Piazzi et al. 2001, Boudouresque and Verlaque 2002). One likely consequence of the colonization by *C. scalpelliformis* in the Ilha Grande Bay sublittoral zone is the alteration of habitat complexity (Crooks 2002), by changing the abundance of the native species, especially *Sargassum* species, on the rocky substrata.

Considering the persistence, rapid growth and likelihood of dissemination of *Caulerpa scalpelliformis* in the study area, we can conclude that this species has a high invasive potential for the Ilha Grande Bay ecosystems. This threat calls for the immediate implementation of monitoring and control procedures.

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