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Temporal changes in the seaweed flora in Southern Brazil and its potential causes

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Abstract. The anthropogenic activities in recent centuries have led to atmospheric changes that directly influence the climate, resulting in global warming. Coastal ecosystems are subjected to global threats by their sensitivity to chemical and physical characteristics of seawater and seaweed communities are considered good indicators of environmental changes. This study aimed to evaluate changes in the seaweed flora at Ribanceira Beach (Santa Catarina state, Southern Brazil) by comparing recent to past data (30 years apart), motivated by the possible effects of climate change in this subtropical region, dominated by warm-temperate coastal waters. Significant differences between the past and the current flora were observed. The absence of 17 taxa, observed in the past, and the presence of 16 taxa not reported before in the area are discussed under the perspective of possible global warming effects.

Key words: coastal ecosystems, climate change, macroalgal flora, Southern Brazil

Resumo: Mudanças temporais na flora de macroalgas no Sul do Brasil e suas causas potenciais. A ação antrópica nos últimos séculos vem provocando alterações atmosféricas que influenciam diretamente o clima, resultando no aquecimento global. Os ecossistemas costeiros estão sujeitos a ameaças globais pela sua sensibilidade a alterações químicas e físicas da água marinha, e as macroalgas são consideradas boas indicadoras de mudanças ambientais. Este trabalho teve como objetivo detectar mudanças na flora macroalgal da Praia da Ribanceira (Santa Catarina, Sul do Brasil) através da comparação de resultados de um inventário recente com um estudo passado, motivados pelos possíveis efeitos das mudanças climáticas nesta região sub-tropical, dominada por águas costeiras temperada quente. Diferenças significativas entre a flora atual e de três décadas atrás foram observadas. A ausência de 17 táxons, observados no passado, e a presença de 16 táxons não reportados para área no levantamento anterior são discutidas sob a perspectiva de possíveis efeitos do aquecimento global.

Palavras-chave: ecossistemas costeiros, mudanças climáticas, flora macroalgal, Brasil, Região Sul

Introduction

The planet has been affected by accelerated processes of global changes in such a way that probably no area, worldwide, remains completely unaffected by human influence (Halpern *et al.* 2008). Coastal ecosystems are one of the most vulnerable natural environments. Although not well understood, but traditionally used for providing goods and services, coastal ecosystems have been broadly threatened by anthropogenic impacts and will very likely be severely affected by climate changes (Vitousek *et al.* 1997, Orfanidis *et al.* 2001).

Some evidences are showing that global warming are progressing at a faster rate than previously recorded by IPCC third assessment report (IPCC, 2007), be responsible by recent variation in the species composition and distribution in marine environments (e.g. Stachowicz *et al.* 2002, Dijkstra *et al.* 2010). On the other hand, despite of the temperature increase be one of the most debated global climate change effect, directly or indirectly related factors must be considered. Additionally, the synergistic action of other physical, chemical and biological factors should be evaluated (Russel *et al.* 2009). Anthropogenic drivers associated to global climate change are distributed widely and are another important component of global synergistic impact (Halpern *et al.* 2008). Macroalgae, being stationary organisms, can be useful bioindicators to detect environmental changes of various kinds. Therefore, monitoring macroalgae distribution in space and time may help to anticipate effects of global changes on the biota and guide policies towards environmental conservation and planning of mitigation initiatives.

Changes in distribution patterns of macroalgae attributed to pollution have been documented only in two restricted areas along the Brazilian coast (Oliveira & Berchez 1978, Oliveira & Qi 2003, Taouil & Yoneshigue-Valentin 2002). However, an important constraint to detect changes in distribution patterns along time is related to the non-existence of previous reliable floristic surveys of seaweed floras. The publications mentioned above dealt with temporal changes on polluted tropical bays on the South East Brazilian coast and cannot be attributed to climate changes alone. In 1978, the seaweed flora of Imbituba, (Santa Catarina State, South Brazil) was surveyed motivated by the establishment of a carbon-chemistry industrial complex, in order to document the pre-impact situation (Citadini-Zanette *et al.* 1979). However, the company was declared bankruptcy shortly after opening and the power plant was not established. Despite the increased urbanisation and population increment observed along most of the Brazilian coast, the referred area was kept with similar pattern of urban occupation observed 30 years before (IBGE 2005). Here we report the results of a recent survey in the same area, to look for eventual changes in the seaweed flora after 30 years. This new survey meets further justification since the macroalgal flora reported for Santa Catarina is considered warm-temperate and transitional to the more tropical northern flora (Horta *et al.* 2001) and, therefore, more prone to yield clues to spot floristic differences due to environmental changes, eventually related with global warming process and anthropogenic ecological footprint.

Material and Methods

Macroalgal specimens were collected at Ribanceira Beach, Imbituba (Santa Catarina, Brazil). Samplings were made on two rocky shores (28°14' S/ 48°40' W; 28°11' S /48°39' W), which were selected in order to cover the same area surveyed by Citadini-Zanette *et al.* (1979). Our floristic list was based on collections made in August (winter) and June (late autumn) of 2007, and March (late summer) and September (early spring) of 2008. On each site, one 10 cm broad transect was placed perpendicularly to the water line and algae was scraped from the rocky substrate from the supra to the sublittoral fringe.

Specimens were collected during periods of low water spring tides, sorted and preserved in formaline:seawater 4%. After identification, vouchers were deposited at the Herbário Raulino Reitz (CRI, UNESC). Abiotic parameters were measured at surface water at each sampling period. Salinity was measured with a portable refractometer (RTS-101 ATC, Meditec, Brazil), pH with a portable pH-meter (pH 1800, Instrutherm, Brazil) and water temperature with a digital thermometer (HT-210, Instrutherm, Brazil).

The floristic similarity between this study and the previous one (Citadini-Zanette *et al.* 1979) was evaluated through similarity index of Sorensen ($S = [2C/(A + B)]\times100$, in which C is the number of common species in both surveys , A is the total number of species and B is the total number of species in the work B, (Cullen *et al.* 2003). Comparison between both surveys consider that Citadini-Zanette *et al.* (1979) carried their survey out in the spring with similar methodology and general area. The Feldmann (1937) and Cheney (1977) indexes were utilized as an attempt to characterize the biogeographic affinities of the floras on the two sampling moments.

Results

Salinity varied from 35 to 39 ppt, pH from 7.20 to 7.37 and water temperature from 18.7 to 29.5 °C (Tab. I). The non expected low pH values may be due to the dynamics of oceanic CO_2 uptake on surface water determined by the rate of downward transport of CO_2 from the surface to bottom (Siegenthaler & Sarmiento1993) or to the runoff of residual waters from neighboring industries or urbanized areas. This hypothesis are reinforced by the works of Feely *et al.* (2010) that, working in estuary complex in the U.S. Pacific Northwest, estimate that part of the acidification observed results from remineralization of organic matter due to natural or anthropogenically stimulated respiration processes. Therefore, even considering that referred data are punctual and that pH is a very sensitive parameter, the observed values can be resulted from processes related to urbanization and pollution.

A total of 62 infrageneric taxa (Tab. II) was found, being nine Phaeophyceae (14.5%), 14 Chlorophyta (22.5%) and 39 Rhodophyta (63%). Among those, 43 species were found in the spring of 2008, 32 in the summer, 28 in the autumn and 50 in the winter (Tab. II, Fig. 1). Besides that, *Arthrocardia flabellata*, *A. gardneri*, *Crytopleura ramosa*,

Table I. Seasonal variation of the chemical and physical water parameters.

	Summer	Autumn	Winter	Spring
Water temp (°C)	25.8	29.5	18.7	24.7
Salinity (ppt)	39.0	35.0	36.0	35.0
pH	7.20	7.30	7.37	7.33

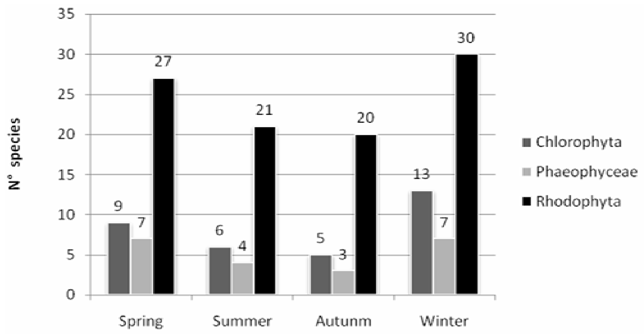

Figure 1. Seasonal distribution in number of species of Chlorophyta, Phaeophyceae and Rhodophyta, found at Ribanceira Beach, Imbituba, SC.

Gelidium floridanum, *Codium decorticatum*, *Ulva fasciata*, *U. lactuca*, *Cladophora prolifera*, *Chondracanthus teedi*, and *C. elegans* were the most frequent species in all seasons.

Among the Chlorophyta, the Cladophoraceae (six species) and the Ulvaceae (five species) were the more diversified, while among the Rhodophyta the families with higher diversity were Corallinaceae, with six species, followed by Gelidiaceae, Ceramiaceae and Rhodomelaceae with four species each. Within the Phaeophyceae, Scytosiphonaceae (three species), Acinetosporaceae (two species) and the other families with only one species each. Most of the species belonged to the filamentous morphological-functional group which are more likely to colonize physically disturbed environments, such as intertidal zones of rocky shores exposed to waves (Littler & Littler 1980).

The predominance in number of Rhodophyta species over Phaeophyceae and Chlorophyta is a common pattern for Santa Catarina region, as well as for other areas along Brazilian coast (Horta *et al.* 2001). However, looking at the physiognomy of the sampled area, the scenario was greenish since Chlorophyta, represented mainly by *Ulva* spp. and *Cladophora* spp., dominated over the red and brown seaweeds.

Species richness was higher in the coldest period, when water temperature was 18.7 °C, which is in agreement with Yoneshigue-Valentin & Valentin (1992) for an upwelling region in Rio de Janeiro state. However, one should consider that the highest species richness in winter may be due not to temperature, *per se*, but to other factors such as nutrient enrichment, what remains to be studied. The coastal upwelling around Cape of Santa Marta Grande occurs mainly in spring and summer, when northeast winds prevail, which facilitate the penetration of South Atlantic Central Water (ACAS) onto the local continental shelf (Pereira *et al.* 2008).The similarity followed by ANOSIM analyses shows a significant difference (ANOSIN p< 0,05) between our sample and the flora presented by Citadini-Zanette *et al.* (1979), indicating a change in species composition between the two surveys. Results from our analysis showed that the recent spring flora was more similar to summer, autumn and winter flora, surveyed in 2008 (similarities between 73,9 and 69,5), than to the old spring data (similarities between 64, and 51,2; Tab. III).

Yoneshigue-Valentin & Valentin (1992) documented a change in species richness along the year in areas subjected to upwelling north of Rio de Janeiro, which was attributed to temperature. However, in other instances, the distinction between the effects of temperature and other parameters, such as pollution, as causing factors of floristic changes is not clear. Stressful conditions due to the seasonal variation of different parameters seem to reduce species richness and favor the dominance of opportunist algae.

Comparing the total number of species found by Citadini-Zanette *et al.* (1979) in the spring and the present survey at the same season, a total of 27 taxa previously listed were not found in the study area. From these, 16 taxa were Rhodophyta, four Phaeophyceae and seven Chlorophyta. On the other hand, we observed the appearance of 15 taxa that were not present before: 11 Rhodophyta, one Phaeophyceae and three Chlorophyta. Feldmann and Cheney indices for 1978 show values typical of warm temperate environment (3.9 and 5.1, respectively). Higher values (5.0 and 6.14, respectively) were observed in spring of 2008, characterizing a tropical environment. The same results were found when considering general data of 2008 (4.5 and 6.125 respectively). Horta *et al.* (2001) evaluating the distribution pattern of the flora along the Brazilian coast, characterized the southern coast as belonging to a warm temperate province. Considering that temperature is traditionally considered the main controlling factor of seaweed distribution, the “tropicalization” of the values observed for Ribanceira beach, compared to the past, could be an indication of global warming. By analysing surface air and sea surface temperature trends in Southern Brazil, Marengo & Camargo (2007) highlighted that the frequency of warmer

Table II. Macroalgal species recorded at the Ribanceira Beach, Santa Catarina, during the periods 2007/2008 and Spring 1978 (Citadini-Zanette et al. 1979). Numbers I, II, III, IV refers to the sampling sites surveyed by Citadini-Zanette *et al.* (1979). 1 = presence and 0 = absence.

Species	**2007/2008 Present study**				**Spring 1978 (Citadini-Zanette *et al.* 1979)**			
	Sp	Su	Au	Wi	Site I	Site II	Site III	Site IV
Bryopsis pennata J. V. Lamour.	1	0	0	1	1	1	1	1
Bryopsis plumosa (Huds.) C. Agardh	0	0	0	1	0	0	1	0
Chaetomorpha antennina (Bory) Kütz.	0	0	0	1	1	1	1	1
Cladophora prolifera (Roth) Kütz.	1	1	1	1	1	0	1	0
Cladophora montagneana Kütz.	0	0	0	0	1	1	1	1
Cladophora sp.1	0	0	0	1	0	0	0	0
Cladophora sp.2	1	1	0	1	0	0	0	0
Cladophora vagabunda (L.) C. Hoek	0	1	0	1	1	1	1	1
Cladophoropsis membranacea (C. Agardh) Borgesen	1	0	1	1	0	0	0	0
Codium decorticatum (Woodw.) M. Howe	1	1	1	1	1	1	1	1
Codium intertextum Collins & Herv.	0	0	0	0	0	0	0	1
Codium taylorii P.C. Silva	1	0	0	1	0	0	0	0
Rhizoclonium riparium (Roth) Kütz. ex Harv.	0	0	0	0	1	1	0	0
Ulva compressa L.	1	0	0	0	0	0	0	0
Ulva fasciata Delile	1	1	1	1	1	1	1	1
Ulva lactuta L.	1	1	1	1	1	1	1	1
Ulva linza L.	0	0	0	1	1	1	1	1
Bachelotia antillarum (Grunow) Gerloff	0	0	0	0	1	0	0	0
Chnoospora minima (K. Hering) Papenf.	0	0	0	0	0	1	0	0
Colpomenia sinuosa (Roth) Derbès & Solier	1	0	0	1	1	1	1	1
Feldmannia irregularis (Kütz.) Hamel	0	1	0	1	1	0	0	0
Hincksia mitchelliae (Harv.) P.C. Silva	1	0	1	0	1	0	0	0
Levringia brasiliensis (Mont.) A.B. Joly	1	1	1	1	1	1	1	0
Padina gymnospora (Kütz.) Sond.	1	1	0	1	1	0	0	0
Petalonia fascia (O.F. Müll.) Kuntze	1	0	0	1	1	0	1	1
Rosenvingea sanctae-crucis Borgesen	1	0	0	1	0	0	0	0
Sargassum cymosum C. Agardh	1	1	1	1	1	1	1	1
Scytosiphon lomentaria (Lyngb.) Link nom.cons.	0	0	0	0	0	0	0	1
Rhodothamniella codicola Borgesen	0	0	0	1	0	1	0	0
Acrochaetium globosum Borgensen	0	0	0	0	1	0	0	0
Acrochaetium microscopium (Nägeli ex Kütz.) Nägeli	0	0	0	0	1	0	0	0
Aglaothamnion felliponei (M. Howe) N. Aponte, D. L.Ballant. & J. N. Norris	0	0	1	0	1	0	0	0
Aglaothamnion uruguayense (W.R. Taylor) N. Aponte, D. L.Ballant. & J. N. Norris	1	1	0	0	1	1	1	1
Arthrocardia flabellata (Kütz.) Manza	1	1	1	1	1	0	0	0
Arthrocardia gardneri Manza	1	1	1	1	1	1	1	1
Bangia fuscopurpurea (Dillw.) Lyngb.	0	0	0	0	1	1	1	0
Bostrychia tenella (J.V.Lamour.) J. Agardh	0	0	0	0	0	1	0	0
Bryocladia thyrsigera (J. Agardh) F. Schmitz in Falkenb	0	0	0	1	0	0	0	0

Callithamnion corymbosum (Sm.) Lyngb.	1	1	0	1	0	0	0	0
Centroceras clavulatum (C. Agardh in Kunth) Mont. in Durieu de Maisonneuve	1	1	0	1	1	1	1	1
Ceramium brevizonatum var. *caraibicum* H.E. Petersen	0	0	0	0	0	1	0	1
Ceramium dawsonii A.B. Joly	0	0	0	0	0	1	0	0
Ceramuim tenerrimum (G. Martens) Okamura	1	0	1	0	0	0	0	0
Champia parvula (C. Agardh) Harv.	1	0	1	1	0	0	0	0
Cheilosporum sagittatum (J. Ellis & Sol.) Aresch.	0	0	0	1	0	1	1	1
Chondracanthus acicularis (Roth) Fredericq	1	0	0	1	1	1	1	1
Chondracanthus elegans (Grev. in J. St.-Hil.) Guiry	1	1	1	1	0	1	1	1
Chondracanthus teedei (Mertens ex Roth) Kütz.	1	1	1	1	1	1	0	0
Corallina officinalis L.	1	0	0	1	0	0	0	1
Crytopleura ramosa (Hudson) Kylin ex L. Newton	1	1	1	1	1	1	1	1
Erythrotrichia carnea (Dillwyn) J. Agardh	0	1	0	1	0	0	0	0
Gelidium crinale (Turner) Gaillon	0	0	1	1	0	1	1	1
Gelidium floridanum W.R. Taylor	1	1	1	1	1	1	1	1
Gelidium pusilum (Stackh.) Le Jolis	1	0	0	0	0	1	1	1
Gracilaria cf. *tepocensis* (E.Y. Dawson) E.Y. Dawson	0	0	0	1	0	1	0	0
Grateloupia cuneifolia J. Agardh	1	1	1	1	1	0	0	0
Grateloupia filiformis Kützing	0	1	0	1	0	0	1	1
Gymnogongrus griffithsiae (Turner) Mart.	0	1	0	1	1	1	1	1
Herposiphonia secunda (C. Agardh) Ambronn	0	0	0	0	0	1	0	0
Hypnea musciformis (Wulfen in Jacquin) J.V. Lamour.	1	1	1	1	1	1	1	1
Hypnea spinella (C. Agardh) Kützing	1	1	0	1	0	0	0	0
Jania adhaerens J.V. Lamour.	1	0	0	0	1	0	0	0
Jania cappillacea Harv.	0	0	0	0	0	0	1	1
Jania crassa J.V. Lamour.	1	1	1	1	1	1	1	1
Laurencia sp.	0	0	0	0	1	1	0	0
Nemalion helminthoides (Velley in With.) Batters	1	0	1	0	1	1	1	0
Neosiphonia ferulacea (Suhr ex J. Agardh) S.M. Guim. & M.T. Fujii	0	0	1	0	0	0	0	0
Neosiphonia tepida (Hollenb.) S.M. Guim. & M.T. Fujii	1	0	1	1	0	1	0	0
Peyssonnelia capensis Mont.	0	0	0	0	1	1	0	0
Plocamium brasiliense (Grev. in J. St. -Hil.) M. Howe & W.R. Taylor	1	1	1	1	1	0	1	0
Polysiphonia decussata Hollenb.	0	0	0	0	0	0	0	1
Polysiphonia scopulorum Harv.	0	0	0	0	1	1	1	0
Polysiphonia subtilissima Mont.	0	0	0	1	0	0	0	0
Porphyra acanthophora E. C. Oliveira & Coll var. *acanthopora*	1	0	1	0	0	0	0	0
Porphyra pujalsiae Coll & E.C. Oliveira	0	0	0	1	0	0	0	0
Pterocladiella capillacea (S.G. Gmel.) Santel. & Hommers	1	1	0	1	1	0	1	1
Pterosiphonia parasitica var. *australis* A.B. Joly & Cord.-Mar	1	1	1	1	1	1	1	1
Pterosiphonia pennata (C. Agardh) Falkenb.	1	1	0	1	0	0	0	0
Sphacelaria tribuloides Menegh	1	1	1	0	0	0	0	0

Table III. Sorensen similarity matrix results, with comparison among the recent sampling periods and the four sites surveyed by Citadini-Zanette *et al.* (1979).

	Spring	Summer	Autumn	Winter	SiteI	SiteII	SiteIII	SiteIV
Spring								
Summer	71,23							
Autumn	69,56	62,07						
Winter	73,91	71,60	54,55					
SiteI	64,29	63,01	55,07	60,87				
SiteII	51,22	47,89	47,76	57,78	68,29			
SiteIII	59,74	60,61	51,61	65,88	72,73	74,67		
SiteIV	53,33	53,12	40	60,24	58,67	68,49	82,35	

days increased during both summer and winter, especially during the last two decades. Additionally, Wainer & Venegas (2002) described a possible displacement of the Brazilian/ Malvinas convergence to the south, resulting in a possible water warming in the referred region during next decades. Our results may represent some precocious signs of such reported warming. However, the variation of other parameters, such as eutrophization and pollution, or even their synergistic effect (Russel *et al.* 2009), besides species introduction, cannot be ruled out. Of course, on this kind of investigation, differences in presence-absence of species along time may be due to taxonomic problems, or details in sampling methodology.

However, in this case we were dealing mostly with conspicuous and easily identified taxa what makes our comparison more acceptable. The relative reduction in the number of Phaeophyceae species is an indication of impacts related to pollution. This is also supported by an increase of the Chlorophyta in comparison with other groups as documented by several authors (e.g. Reis & Yoneshigue-Valentin 1996; Oliveira & Qi 2003, Taouil & Yoneshigue-Valentin 2002, Lehmkuhl-Bouzon 2005). Conversely, the absence of *Scytosiphon lomentaria,* a species that need temperatures below 20 °C to induce macrothallus formation (Lüning 1980, Orfanidis *et al.* 1996) may also indicate a warming process.

The appearance of taxa not present before, such as *Rosenvingea sanctae-crucis*, *Champia parvula*, *Erythrotrichia carnea*, *Callithamnion corymbosum, Sphacelaria tribuloides* may be related to biogeographic issues (Oliveira *et al.* 2001). The presence of *C. parvula,* although not recorded by Citadini-Zanette *et al.* (1979), was reported earlier in the area by Cordeiro-Marino in 1966 (Cordeiro-Marino 1978). Considering that *R. sanctae-crucis* is considered a tropical species, recorded to the Brazilian northeastern coast (Oliveira *et al.* 1983), the extension of its distribution to higher latitudes may also be an indication of global warming what remains to be tested. One may hypothesize that the reported changes are responses to climatic change, considering that temperature alterations also alter the pattern of geographic distribution of species. However, among the species not recorded by Citadini-Zanette *et al.* (1979), stands out species of *Cladophora*, *Chaetomorpha* and *Ulva* (Tab. II), genera that includes typically opportunistic species, evidencing that we cannot discard the interaction of factors related to the eventual increases of the anthropogenic ecological footprint. The human activities can change the seawater quality due the effluent discharge favoring species opportunists (Orfanidis *et al.* 2001) or even be responsible by the arrival of newcomer species through their transport via ships hull fouling (Mineur *et al.* 2007).

A decrease of species richness and an elevation of the indices of Feldmann and Cheney was observed after the discharge of thermal effluent from a nuclear plant in the Bay of Ilha Grande, Rio de Janeiro state, resulting from the effects of temperature increase on the seaweed flora (Széchy & Nassar 2005). Schield *et al.* (2004) observed that a 3.5 ^{o}C rise in seawater temperature, induced also by the thermal outfall of a power-generating station, resulted in significant community changes in 150 species of algae and invertebrates relative to adjacent control areas. However, they did not evidence clear tendencies toward warmer-water species with southern geographic affinities replacing colder water species with northern affinities. These authors reinforce that responses of these benthic communities to ocean warming were strongly coupled to direct effects of temperature on some key taxa, as habitat-forming subtidal kelps, and indirect effects operating through ecological interactions between herbivores and primary producers.

In spite of the uncertainties about the causal factors that produced the differences in the algal community composition, the observed changes are real. The interaction of factors such as temperature increase, variation in salinity, nutrient availability and pollution, acting *per se*, and interacting in a complex fashion, will certainly have a broad impact on seaweed floras and biodiversity, and should be evaluated with an experimental approach. Further, if we consider ocean acidification and the increase in the intensity and frequency of storms, biodiversity losses can be very high in the coming years. This scenario reinforces the need for constant monitoring and decision making with regard to coastal management, to mitigate environmental impacts derived from human activities.

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