Journal of Coastal Research | SI 39 | 1246 - 1250 | ICS 2004 (Proceedings) | Brazil | ISSN 0749-0208

Structure and Succession of the Surf-Zone Phytoplankton in Cassino Beach, Southern Brazil

L.R. Rörig†, T.C. M. de Almeida† and V.M.T. Garcia‡

†Centro de Ciências Tecnológicas, da Terra
e do Mar Universidade do Vale do Itajaí
(CTTMar UNIVALI); C.P. 360; CEP:
88302-202; Itajaí SC Brazil
rorig@cttmar.univali.br

‡ Lab. of Ecology of Phytoplankton and Marine
Microorganisms; Dept. of Oceanography, FURG; C.P.
474; CEP: 96.201-900;
Rio Grande RS Brazil
docvmtg@super.furg.br

ABSTRACT

RÖRIG, L.R.; ALMEIDA, T.C.M and GARCIA, V.M.T., 2006. Structure and Succession of the Surf-Zone Phytoplankton in Cassino Beach, Southern Brazil. *Journal of Coastal Research*, SI 39 (Proccendigs of the 8th International Coastal Symposium), 1246 - 1250. Itajaí, SC, Brazil, ISSN 0749-0208.

Cassino Beach, in Southern Brazil, is an exposed, intermediate to dissipative sandy beach, which presents conspicuous accumulations of the diatom *Asterionellopsis glacialis* in the surf-zone. Despite this phenomenon represents a very high input of organic matter to the beach trophic chains, it is only occasional and during most of the time, surf-zone phytoplankton is influenced by coastal and oceanic assemblages. The present work attempted to identify the phytoplankton assemblages structure ("community structure") and the environmental factors that control its succession. An one year weekly sampling was carried out at a fixed point in the surf-zone, for determination of phytoplankton (qualitative and quantitative analysis), physical-chemical variables of surf-zone water, beach morphodynamics features and local meteorological conditions. Multivariate analyses were conducted (correspondence analysis and canonic correspondence analysis) and the results discriminated four distinct groups of species: group (1) benthic species, group (2) benthic and epibenthic species associated with *A. glacialis* patches, group (3) neritic planktonic chain forming diatoms and group (4) neritic planktonic species. *A. glacialis* dominated in biomass, but was always accompanied by other benthic species. The *A. glacialis* accumulations have been identified as local interferences (at the surf-zone) in the succession patterns of regional neritic phytoplankton, increasing biomass while decreasing diversity and the relative importance of neritic species. The most important environmental variables controlling this complex succession were dissolved inorganic nitrogen, dissolved silicate, water temperature and surf-zone width.

ADDITIONAL INDEX WORDS: *Sandy beaches, chlorophyll-a, multivariate analysis.*

INTRODUCTION

Sandy beaches are harsh physical environments. The high hydrodynamics and the intensive interactions with adjacent ecosystems and sometimes with antropogenic stresses (*i.e.* pollution, buildings, landscape changes), select a closely adapted biota with complex patterns of spatial and temporal distribution.

The features of the beach system depend essentially on interactions between particle size parameters and wave action. These physical interactions result in beach types ranging from reflective to fully dissipative and these two extremes representing different ecosystems and ecosystem functioning (BROWN *et al.,* 2000). Exposed, intermediate to dissipative sandy beaches tend to exhibit high diatom biomass in the surf-zone (surf-zone diatoms), representing a high level of primary production. Reflective beaches do not have surf-zones and resident primary producers are importers of material from the sea (TALBOT *et al.,* 1990).

Much of the understanding on sandy beaches ecosystem functioning have been developed from studies carried out in South Africa (BROWN *et al.,* 2000), but recent efforts in Southern Brazilian beaches have reinforced most of it and added important new knowledge (ODEBRECHT *et al.,* 1995; RÖRIG *et al.,* 1996; RÖRIG and GARCIA, 2003; ABREU *et al.*, 2003).

Along the Southern Brazilian coast, extensive patches of *Asterionellopsis glacialis* are a normal feature of wide and exposed sandy beaches (specially in Cassino Beach, 32º S). These patches were firstly regarded as classical blooms (Aguiar and CÔRTE-REAL, 1973; ROSA and AGUIAR, 1973). Later, focused studies suggested a seasonal pattern in patch occurrences, which were associated with rainfall and onshore winds (GIANUCA, 1983; 1985; ODEBRECHT *et al.*,1995a). Now it is known that these patches accumulate in the inner surf-zone by ressuspension of benthic stocks in events of increased wave energy (RÖRIG & GARCIA, 2003). Once these stocks are in the water column, photosynthesis increases and the resulted biomass fuel very rich trophic chains in the beach ecosystem. North of Cassino Beach (around 26º S), co-occurrences of *Asterionellopsis glacialis* and *Anaulus australis* have been reported (REZENDE, 1995; RÖRIG *et al.*, 1996), showing a similar pattern to that found for South African beaches (DU PREEZ *et al.*, 1990; CAMPBELL, 1996). Chlorophyll *a* concentrations in these Southern Brazilian events are among the highest reported in the world marine ecosystems (RÖRIG *et al.*, 1997; RÖRIG *et al.*, 2003).

Despite of these several ecological studies on surf-zone diatoms in Southern Brazilian beaches, few discussions about the dynamics of the whole surf-zone phytoplankton, including not-blooming species, have been done. This paper attempts to identify the phytoplankton assemblages structure ("community structure") and the environmental factors that control its succession in Cassino Beach.

METHODS

Water samples were collected in the surf-zone of Cassino Beach (Southern Brazil, Lat. 32° S) at weekly intervals between June 18 1992 and August 12 1993. These water samples were used to determine temperature and salinity (termosalinometer), pH (pHmeter), inorganic dissolved nutrients (NH_4+NO_2+NO_3, PO_4 and Si, spectrophotometric determination according to PARSONS *et al.*, 1984), Chlorophyll *a* (fluorometric determination according to PARSONS *et al.*, 1984) and phytoplankton cell density (according to UTERMÖHL, 1958). Water transparency was determined at the sampling site by secchi disk. Daily rainfall (as the accumulated precipitation over the seven days before sampling day), mean air temperature and wind data were obtained at a local meteorological station. Wave height and surf-zone width, were visually determined *in situ*.

Table 1. *Environmental and ecological data at Cassino Beach during the sampling period showing the general average values and the average values to situations with and without patches of surf-zone diatoms (n= number of observations; CV= coeficient of variation).*

	General (n=56)				With patches (n=24)				Without patches (n=32)			
	Average	Min	Max	CV	Average	Min	Max	CV	Average	Min	Max	CV
Air temperature (°C)	16,5	5,0	26,3	35,8	14,4	5,0	25,5	36,3	18,1	5,2	26,3	32,9
Water temperature (ºC)	18,0	10,0	26,0	28,5	16,3	10,0	25,5	26,5	19,3	10,8	26,0	27,9
Salinity (%o)	28,2	17,0	35,0	14,5	27,2	17,0	34,0	13,3	28,9	20,0	35,0	15,0
Transparency (m)	0,3	0,1	1,6	87,3	0,2	0,1	0,4	47,9	0,4	0,1	1,6	75,2
Wave height (cm)	61,7	35,0	150,0	37,6	74,8	35,0	150,0	37,0	51,9	35,0	90,0	24,0
Surf-zone width (m)	239,1	50,0	750,0	67,0	298,8	50,0	750,0	63,9	194,4	60,0	550,0	60,1
Rainfall (mm)	21,9	0,0	109,1	121,0	32,7	0,0	109,1	96,0	13,7	0,0	79,8	136,2
PH	8,1	7,9	8,5	1,7	8,1	7,9	8,5	1,6	8,1	7,9	8,5	1,7
NID (μM)	3,4	0,4	10,2	69,2	3,1	0,4	9,0	64,3	3,7	0,8	10,2	71,4
PO4(μM)	1,0	0,1	3,6	56,7	0,9	0,3	1,7	38,9	1,1	0,1	3,6	63,4
Si (μM)	28,7	3,5	66,1	59,3	30,7	8,8	58,6	59,8	27,3	3,5	66,1	59,1
Chlorophyll a (μg/L)	50,2	1,0	352,2	170,1	103,1	4,2	352,2	107,4	0,6	1,0	37,7	85,1
Shannon Diversity Index	1,04	0,02	2,21	64,0	0,60	0,02	1,71	103,0	1,35	0,20	2,21	38,0

In order to summarize the relations among phytoplankton species and to describe the patterns of structure and succession of phytoplankton assemblages, correspondence analysis was applied considering species with frequency of occurrence greater than 30%. Additionally, canonical correspondence analysis was developed considering the more significative environmental variables.

RESULTS

Several differences can be observed when comparing days with and without patches of surf-zone diatoms (Table 1). In patch conditions air and water temperature and transparency values tended to be lower. Wave height, surf-zone width and rainfall values tended to be greater in these situations. However, dissolved nutrients did not show notable differences between these two situations. The differences observed on patch days are effects of the meteorological cold front passages, that generate strong southern winds, followed by wave energy increase, air and water temperature decrease and turbity increase as a result of ressuspension of sediments and surf-zone diatoms, as discussed previously by (RÖRIG and GARCIA, 2003).

Dissolved nutrients, in this case, do not cause the chlorophyll-a increase represented by the patches, but their relatively high concentration certainly allow the diatoms to grow vigorously once ressuspended, as demonstrated by CAMPBELL and BATE (1997).

Except for the diatom *Asterionellopsis glacialis* (the patch forming species), which was present in 100% of the samples, the species frequency of occurrence also shows notable differences between patch and no patch situations (Table 2).

Typical neritic planktonic species like *Chaetoceros* spp. *Skeletonema* spp., *Dictyocha* sp., *Ditylum brightwellii*, *Rhizosolenia* sp. were clearly associated with no patch condition, while benthic/epibenthic organisms (*i.e. Campilosira cymbeliformis*, *Cymatosira* sp., cysts of flagellates etc.) were associated with *A. glacialis* patch conditions. This result reinforces the idea that patches results from ressuspension conditions. The higher importance of neritic species in the absence of patches (calm periods) indicates that the surf-zone phytoplankton assemblages are normally similar to the coastal ones. In this sense, the patch formation can be

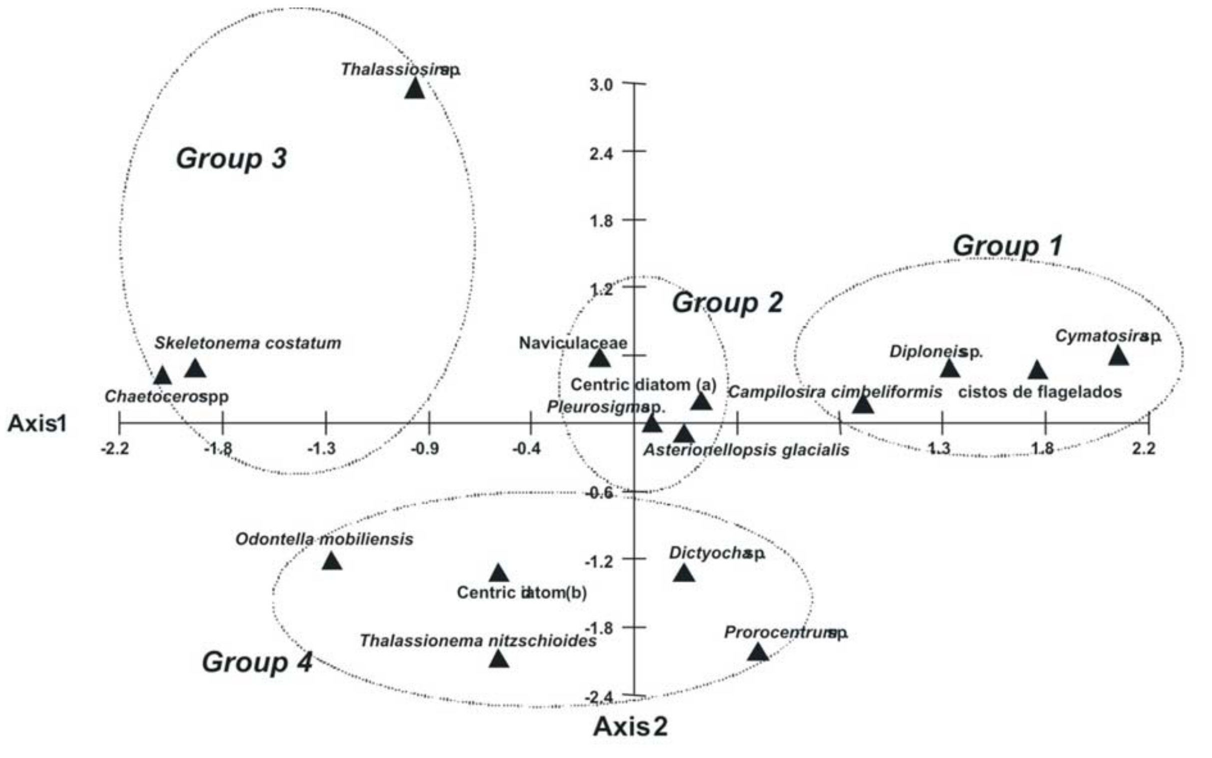

Figure 1. Plot of the first two axes of the Correspondence Analysis carried out with the phytoplankton species coordinates showing the four distinct groups of associated species.

Table 2. *Phytoplankton species found at Cassino Beach during the sampling period and its percentage of occurrence in general conditions, patch condition and no patch condition.*

Taxa	Class/Group	General (%)	With patches (%)	Without patches (%)
Asterionellopsis glacialis	Bacillariophyceae	100,0	100,0	100,0
Campilodiscus sp.	Bacillariophyceae	25,0	21,7	27,3
Campilosira cimbeliformis	Bacillariophyceae	75,0	82,6	69,7
Cerataulina daemon	Bacillariophyceae	3,6	4,3	3,0
Cerataulina sp.	Bacillariophyceae	3,6	0,0	6,1
Ceratium candelabrum	Dinophyceae	10,7	4,3	15,2
Ceratium furca	Dinophyceae	1,8	0,0	3,0
Chaetoceros debile	Bacillariophyceae	3,6	4,3	3,0
Chaetoceros sp.	Bacillariophyceae	39,3	8,7	60,6
Chaetoceros subtilis	Bacillariophyceae	8,9	0,0	15,2
Cysts of flagellates	Dinophyceae	30,4	34,8	27,3
Coscinodiscus sp. (1)	Bacillariophyceae	3,6	4,3	3,0
Coscinodiscus sp. (2)	Bacillariophyceae	12,5	8,7	15,2
Cymatosira sp.	Bacillariophyceae	32,1	39,1	27,3
Centric diatom (a)	Bacillariophyceae	78,6	82,6	75,8
Centric diatom (b)	Bacillariophyceae	53,6	43,5	60,6
Dictyocha sp.	Dictyochophyceae	35,7	26,1	42,4
Dinophysis sp.	Dinophyceae	8,9	8,7	9,1
Diploneis sp.	Bacillariophyceae	41,1	30,4	48,5
Ditylum brightwellii	Bacillariophyceae	23,2	8,7	33,3
Ebria sp.	Ebriidea	10,7	8,7	12,1
Eucampia sp.	Bacillariophyceae	1,8	0,0	3,0
Gymnodinium spp.	Dinophyceae	17,9	17,4	18,2
Gyrodinium spp.	Dinophyceae	8,9	0,0	15,2
Hemiaulus sp.	Bacillariophyceae	7,1	4,3	9,1
Leptocilyndrus danicus	Bacillariophyceae	23,2	8,7	33,3
Mesodinium rubrum	Ciliate	26,8	43,5	15,2
Navicula sp.	Bacillariophyceae	1,8	0,0	3,0
Noctilucca sp.	Dinophyceae	14,3	8,7	18,2
Odontella mobiliensis	Bacillariophyceae	30,4	21,7	36,4
Odontella sinensis	Bacillariophyceae	3,6	4,3	3,0
Naviculaceae	Bacillariophyceae	82,1	65,2	93,9
Pleurosigma sp.	Bacillariophyceae	39,3	30,4	45,5
Polykrikos schwarzii	Dinophyceae	1,8	0,0	3,0
Proboscia alata	Bacillariophyceae	19,6	4,3	30,3
Prorocentrum minimum	Dinophyceae	8,9	4,3	12,1
Prorocentrum sp.	Dinophyceae	33,9	34,8	33,3
Protoperidinium spp.	Dinophyceae	10,7	8,7	12,1
Pseudo-nitzschia sp. (1)	Bacillariophyceae	7,1	8,7	6,1
Pseudo-nitzschia sp. (2)	Bacillariophyceae	25,0	4,3	39,4
Pseudo-nitzschia sp. (3)	Bacillariophyceae	8,9	4,3	12,1
Rhizosolenia sp.	Bacillariophyceae	23,2	0,0	39,4
Scripsiella sp.	Dinophyceae	7,1	0,0	12,1
Skeletonema costatum	Bacillariophyceae	44,6	30,4	54,5
Skeletonema tropicum	Bacillariophyceae	23,2	13,0	30,3
Stephanopyxis sp.	Bacillariophyceae	5,4	0,0	9,1
Thalassionema nitzschioides	Bacillariophyceae	35,7	39,1	33,3
Thalassiosira sp.	Bacillariophyceae	30,4	21,7	36,4

interpreted as interference on the normal structure and succession of coastal phytoplankton at the surf-zone environment. The Shannon Diversity Index and chlorophyll-*a* values clearly show the differences between high biomass/low diversity situation, observed in patch conditions and the inverse situation observed in no patch condition (Table 1). It is important to note that in both conditions *A. glacialis* was the more abundant species.

The two first factorial axes of correspondence analysis explained 32% of the variance. By analyzing the distribution of species coordinates over these two first axes, four distinct groups of species were identified (Figure 1): benthic species (group 1), benthic and epibenthic species associated with *A. glacialis* patches (group 2), neritic planktonic chain forming diatoms (group 3) and neritic planktonic species (group 4). Groups 1, 2 and 3 were related to the first axis and group 4 to the second axis.

Even though they have the same ecological niche, each group can be associated with four different stages of sucession. Group 1 was related to the beginning of the ressuspension process, group 2 indicated the peak of the ressuspension process (patch formation) and group 3 and 4 were related to an after patch condition. Groups 3 and 4 can be distinguished by seasonal factors. Group 3 species are more typical from spring conditions while group 4 species can be better associated with autumn/winter conditions.

When environmental variables were analyzed together with species by a Canonical Correspondence Analysis, the two first axes were significant (axis 1: F= 2,43; P= 0,01 and axis 2: F= 1,42; P= 0,005) (Figure 2). By this analysis, the pattern presented above was partially confirmed. Water temperature (WT), dissolved inorganic nitrogen (DIN), silicate (SI), chlorophyll *a* (CLA) and surf-zone width (SZW) were significant (Table 3). The species from group 1 had a noisy

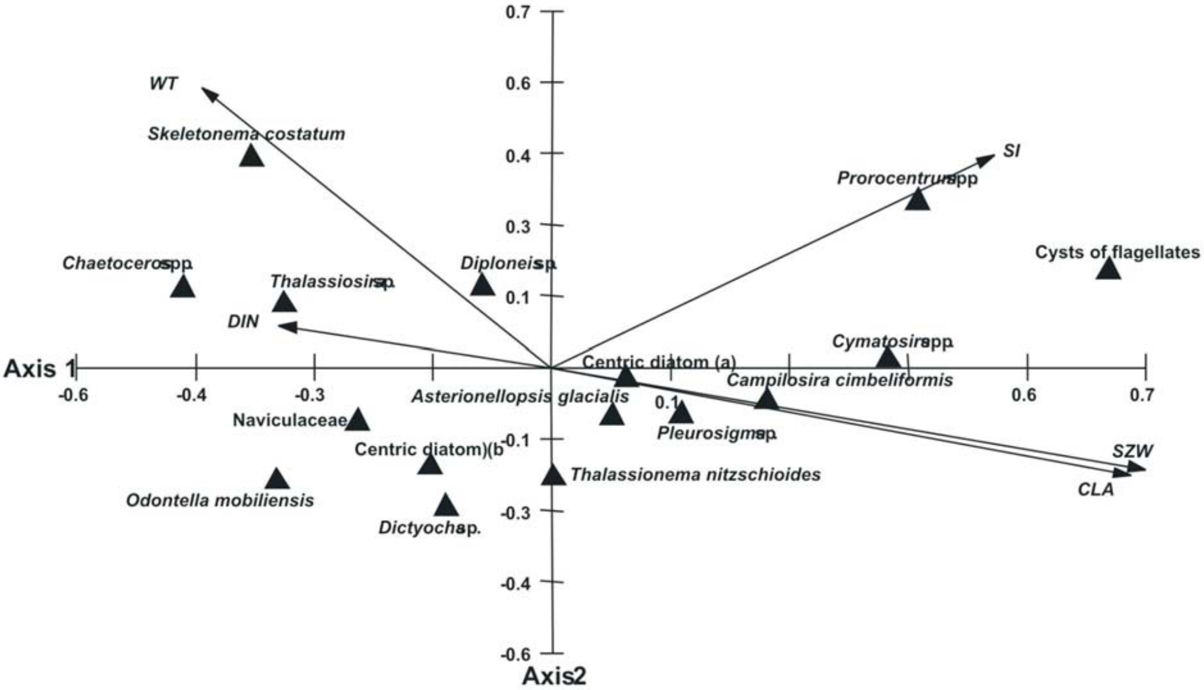

Figure 2. Plot of the first two axes of the Canonical Correspondence Analysis carried out with the phytoplankton species and significant environmental variables (WT= water temperature; DIN= dissolved inorganic nitrogen; SI= dissolved inorganic silicate; SZW= surf-zone width; CLA= Chlorophyll-*a* concentration).

distribution, but weakly associated with CLA e SZW, together with group 2 species. Species from group 3 were associated with WT and NID and those from group 4 had direct association with DIN and inverse association with CLA e SZW.

It can be concluded that despite of the great complexity of the Cassino beach surf-zone environment, some patterns of structure and succession of phytoplankton can be observed. Surf-zone diatom patches appear as a sudden local interference on the gradual succession of the coastal phytoplankton, being the *cold fronts passage* the temporal microscale factor of this interference.

Multivariate analysis were very useful to reduce complexity among biotic and abiotic data, as already pointed by classical bibliography (LEGENDRE and LEGENDRE, 1998; VALENTIM, 2000). However, species with low frequency and abundance usually introduce some noise in the results and must be removed. Also, other kinds of analyses in which biotic and abiotic variables can be considered simultaneously could be applied to corroborate de results (*e.g.* Discriminant Analysis). Finally, is important to emphasize that the results of multivariate analysis must have their significance tested.

AKNOWLEDGEMENTS

This study was funded by the Brazilian National Council of Research (CNPq) and University of Rio Grande (FURG). The authors thank Dr. Lauro J. Calliari and MSc. Antonio H.F. Klein for their incentive and collaboration in the study of sandy Beaches; Dr. André Barreto for English revision and also Dr. Charrid Resgalla Jr., Dr. Paulo R. Pezzuto, MSc. Luiz E. Bonilha, Dr. Agnaldo S. Martins, MSc. Humber A. de Andrade, Dra. Graziela Persich, Dra. Clarisse Odebrecht, MSc. Eduardo T. da Silva and MSc. Eliane Truccolo for the precious assistance in all phases of this research.

Table 3. *Significance test applied to abiotic variables over canonical axes.*

Variable	Significance (P)	F	No. of permutations
Water temperature	0.005	2.47	199
Dissolved inorganic nitrogen	0.010	1.91	199
Silicate	0.005	1.63	199
Chlorophyll-*a*	0.020	1.57	199
Surf-zone width	0.025	1.52	19

LITERATURE CITED

BROWN, A.C.; MCLACHLAN, A.; KERLEY, G. I. H. and LUBKE, R.A. 2000. Functional Ecosystems - Sandy Beaches and Dunes. *In*: DURHAM, B.D. and PAUW, J.C. (eds.), Marine Biodiversity Status Report, March 2000, Port Elizabeth.

TALBOT, M. M. B.; BATE, G. C. and CAMPBELL, E. E., 1990. A review of the ecology of surf-zone diatoms, with special reference to *Anaulus australis. Oceanography and Marine Biology Annual Review*, 28: 155-175.

ODEBRECHT, C.; SEGATTO, A.Z. and FREITAS, C.A., 1995a. Surf-zone Chlorophyll *a* variability at Cassino Beach, Southern Brazil. *Estuarine, Coastal and Shelf Science,* 41, 81-90.

RÖRIG, L.R.; RESGALLA JR., C.; PEZZUTO, P.R.; ALVES, E. DOS S. and MORELLI, F., 1997. Análise ecológica de um processo de acumulação da diatomácea *Anaulus* sp. na zona de arrebentação da praia de Navegantes (Santa Catarina, Brasil). *Oecologia Brasiliensis*, 3, 29-43.

LEGENDRE, P. and LEGENDRE, L., 1998. Numerical Ecology. 2nd English edition. Developments in Environmental Modelling, 20, Elsevier, New York, 853 pp.

VALENTIM, J. L., 2000. Ecologia numérica: uma introdução à análise multivariada de dados ecológicos. Rio de Janeiro: Interciência, 2000, 117 pp.

RÖRIG, L.R. and GARCIA, V.M.T., 2003. Accumulations of the surf-zone diatom *Asterionellopsis glacialis* (CASTRACANE) ROUND in Cassino Beach, Southern Brazil, and its relationship with environmental factors.

Journal of Coastal Research, SI35 (Proceedings of the Brazilian Symposium on Sandy Beaches: Morphodynamics, Ecology, Uses Hazards and

Management), 167-177. Itajaí, SC Brazil.

ABREU, P. C.; RÖRIG, L. R.; GARCIA, V. M. T.; ODEBRECHT, C. and BIDDANDA, B., 2003. Decoupling between bacteria and the surf-zone diatom *Asterionellopsis glacialis* at Cassino Beach, Brazil. *Aquatic Microbial Ecology,* 32: 219-228.

AGUIAR, L. W. and CÔRTE-REAL, M., 1973. Sobre uma uma floração de *Asterionella japonica* Cleve (1878) na costa do Rio Grande do Sul. *Iheringia* 17, 18-27.

BROWN, A. C. and MCLACHLAN, A., 1990. Ecology of Sandy Shores. Elsevier, Amsterdam, 328p.

CAMPBELL, E. E. and BATE, G. C., 1997. Coastal features associated with diatom discoloration of surf-zones. *Botanica Marina,* 40, 179-185.

CAMPBELL, E. E., 1996. The global distribution of surf diatom accumulations. *Revista Chilena de Historia Natural,* 69, 495-501.

DUPREEZ, D. R.; CAMPBELL, E. E. and BATE, G. C., 1990. Photoinhibition of photosynthesis in the surf-diatom *Anaulus australis* Drebes et Shulz. *Botanica Marina*, 33 (6): 539-543.

GIANUCA, N. M., 1983. A preliminary account of the ecology of sandy beaches in Southern Brazil. *In*: A. McLachlan and T. Erasmus (eds.), Sandy Beaches as Ecosystems. The Hague: W. Junk, pp. 413-419.

GIANUCA, N. M., 1985. The ecology of a sandy beach in Southern Brazil. PhD. Thesis, Universtiy of Southampton. 330p.

PARSONS, T. R.; MAITA, Y. and LALLI, C.M., 1984. A Manual of Chemical and Biological Methods for Seawater Analysis. Oxford: Pergamon Press, 173p.

REZENDE, K.R.V., 1995. Dinâmica Temporal do Fitoplâncton de Zona de Arrebentação da praia de Pontal do Sul (Paranaguá - PR). MSc. Thesis. Universidade de São Paulo. 130p.

RÖRIG, L.R.; RESGALLA JR., C.; PEZZUTO, P.R.; ALVES, E. DOS S. and MORELLI, F., 1997. Análise ecológica de um processo de acumulação da diatomácea *Anaulus* sp. na zona de arrebentação da praia de Navegantes (Santa Catarina, Brasil). *Oecologia Brasiliensis*, 3, 29-43.

ROSA, Z.M. and AGUIAR, L.W., 1973. Diatomáceas da costa do Rio Grande do Sul, Brasil: I- Praia do Cassino - Rio Grande. *Iheringia*, 21, 103-128.

UTERMÖHL, H., 1958. Zur Vervollkommnung der quantitativen Phytoplankton Methodik. *Mitteilung Internationale Vereinigung für theoretische angewandte Limnologie,* 9, 1-38.