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Intratidal Variation and Net Transport of Dissolved Inorganic Nutrients, POC and Chlorophyll *a* in the Camboriú River Estuary, Brazil

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The aim of this study was to evaluate the intratidal variability of dissolved inorganic nutrients (NO_3^-, NO_2^-, NH_4^+, PO_4^{3-} and Si), Particulate Organic Carbon (POC) and chlorophyll *a* (chl *a*) in the estuary of the Camboriú River, and to quantify their transport into the adjoining coastal zone. During a 1-day spring tide sampling in March 1998, continuous records of direction and velocity of currents within the estuary channel over a period of 25 h were obtained, covering two complete tidal cycles. Vertical profiles of salinity and temperature were observed and samples of surface and bottom water were collected at hourly intervals. The transport of these substances through the estuary was calculated from the data on: (1) concentration of nutrients, POC and chl *a*; (2) velocity and direction of surface and bottom currents and (3) the area of the channel cross section. The values obtained for residual transport of nutrients to the bay were as follows: $2{\cdot}9 \times 10^4$ mol of DIN (401 kg N); $6{\cdot}6 \times 10^2$ mol of PO_4^{3-} (20·4 kg P- PO_4^{3-}); and $4{\cdot}5 \times 10^4$ mol of Si (1264 kg Si). The main form of DIN was NH_4^+, which may be related to the decomposition of organic material in the estuary, as well as to the entry of effluents from the Balneário Camboriú sewage treatment plant, located about 3 km upstream from the collection site. The N:P ratio between the nutrients was high (45), which may have contributed to the higher values for this ratio in the bay. The results also showed an export of 532 kg of POC and 5 kg of chl *a* into the bay. The maximum values of chl *a* always occurred right after the periods of tide inversion, at the beginning of the ebb tide or of the flood tide, invariably with salinities between 25 and 35. The highest of these peaks (23 $\mu g\, l^{-1}$) was recorded in the afternoon period, during the ebb tides. This pattern suggests the existence of a belt of productivity located close to the mouth of the estuary, whose precise location is related to the tide, sometimes entering the estuary (flooding) and sometimes exiting to the bay (ebbing). The high values for cla may be explained as being the result of the balance between the high supply of nutrients provided by the Camboriú River, and the increase of light penetration due to the higher transparency of salt water. The prevalence of coastal phytoplankton species during the peaks of cla confirms the idea that, when entering the estuary, they find ideal conditions of light and nutrients for their optimum development. The result of the export of cla in this case may have been due to the fact that the growth of organisms occurred within the estuary after the entry of a smaller innoculum of organisms during the high tide which, in this study, was registered early in the morning.

Keywords: nutrient transport; tide cycle; nutrients; nitrogen; phosphorus; silica; southern Brazilian coast

Introduction

Dissolved inorganic nutrients are the raw material for the marine trophic chain and estuaries are the main entry routes for nutrients coming from continental drainage to the marine environment. For this reason, high primary productivity and biological abundance are usually found in coastal regions. The nutrient supply is greater in estuaries that are near densely populated regions, due to the entry of domestic and industrial waste, urban drainage, and agricultural effluents. The increase of nutrient concentrations in estuarine and coastal waters causes several environmental modifications, such as increases in productivity (Nixon, 1992) and fishing yields (Cederwall & Elmgren, 1980; Nixon, 1982; Nixon *et al.*, 1986). However, anthropogenic inputs frequently cause excessive eutrophication in the environment, especially where the circulation is restricted, such as in bays, estuaries and coastal lagoons. Several alterations in chemical characteristics and water quality in such bodies of water occur as a result of changes in biogeochemical flows. Such alterations can lead to various ecological consequences, e.g. alteration of the species composition (Beukema, 1991), increase of phytoplankton blooms and decrease of oxygen concentrations (Parker & O'Reilly, 1991; Pennock *et al.*, 1994). Many studies have assessed the environmental changes caused by anthropogenic input of nutrients and organic material (Berounsky & Nixon, 1985; Innamorati & Giovanardi, 1990; Kimor, 1990; Carmouze & Vasconcelos, 1992), however, only a few

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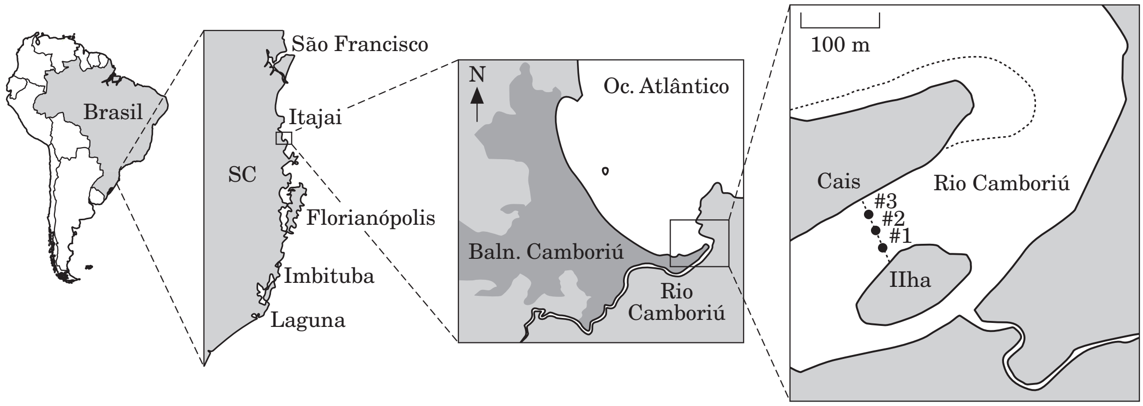

FIGURE 1. Location of the study area, with the position of the sampling station (no. 2).

studies have quantified these entries (Nixon, 1982; Nixon & Pilson, 1984; Smith & Veeh, 1989; Niencheski & Windom, 1994).

The city of Balneário Camboriú is located on the northern coast of the state of the Santa Catarina (Figure 1), and it is the most important tourist resort in southern Brazil. Its permanent population is about 60 000 inhabitants, although it receives a large inflow of tourists during the summer, which can raise its population to more than 600 000 inhabitants on peak days. The town has undergone rapid real estate growth to accommodate a large contingent of tourists, with the construction of many condominiums, most of them near the Camboriú beach. As a consequence of such growth, the bight has suffered an increase in the input of nutrient and organic materials, leading to eutrophication and decrease in the water quality, particularly during the summer (Kuroshima *et al.*, 1996). The main material inflow to the bight is through the Camboriú River estuary (Figure 1), although there are also other minor inputs along the beach and through a small stream at the northern end of the bight.

The objective of this paper is to evaluate the intra-tidal variability of dissolved inorganic nutrients (NO_3^-, NO_2^-, NH_4^+, PO_4^{3-} and Si), Particulate Organic Carbon (POC) and chl *a* in the estuary of the Camboriú River. We also assess the transport of these parameters into the Camboriú Bight.

Study area

The Camboriú River estuary is located in southern Brazil, in the state of Santa Catarina (27°S and 48.5°W, Figure 1). The Camboriú River has a drainage area of about 200 km^2, exhibiting an estimated mean discharge of about 3 m^3 s^{-1}. Spread over the drainage basin are several regions of intense agricultural activity, mainly rice cultivation. The Camboriú River estuary channel, near its mouth, is about 120 m wide and 2 m deep. Most of the surrounding mangrove area has been claimed for urban growth during the last decades, although a few remaining patches of mangrove forest remain along the estuarine borders and islands (*Avicennia* sp). Despite its modest dimensions, the Camboriú River system is important since it flows into the Camboriú Bight, one of the most important tourist resorts in Brazil.

The regional climate is subtropical and thus results in variable seasonal patterns. According to the classification of Thornthwaite (1948), the climate is mesothermic humid with no water deficit throughout the year. The mean annual temperature is 21 °C, the mean annual precipitation is 1·406 m, and the mean annual potential evapotranspiration is 0·958 m, giving a mean water surplus of 0·448 m per year (Gaplan, 1986).

There is little information about the hydrology of the Camboriú River. Silva and Schettini (1997), estimated its mean discharge to be about 3 m^3 s^{-1}, but the instantaneous discharge varies greatly over time as a response to meteorological events like cold fronts and extra tropical storms. There is more information about the hydrology of the Itajaí-açu River, which is just north of the Camboriú River. That river discharge is very low most of the time, with sporadic high discharge pulses. There is no clear seasonal pattern, and such pulses occur randomly throughout the year (Schettini, in press).

The local tide is mixed, but leans toward, being semi-diurnal, with a mean range of about 0·7 m. During neap tide periods the tidal range varies between 0·1 and 0·4 m and during spring tide periods, it varies between 0·9 and 1·2 m. The tidal form

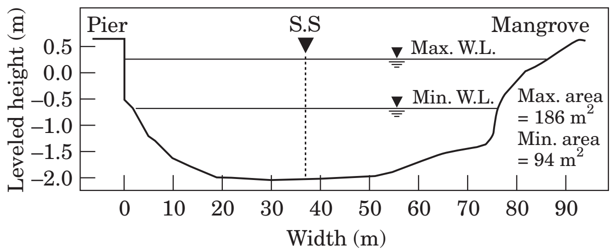

FIGURE 2. The sampling cross section, looking downstream. S.S.: sampling station. W.L.: water level.

number is 0·4 (Schettini, 1996) and was obtained by looking at the ratio of the sum of the main diurnal harmonic constituents to the sum of the main semi-diurnal constituents $[(K_1+O_1)/(M_2+S_2)]$ (Pugh, 1987). Meteorological tides associated with cold front passages can induce heights about 1 m above the astronomical level during critical conditions (Truccolo, 1998), and may occasionally be an important factor in estuarine flushing.

Schettini *et al.* (1996), Siegle *et al.* (1998*a*, *b*, 1999) and Siegle (1999) have assessed estuarine hydrological and sedimentological characteristics. The estuary often presents a partially mixed salt structure, and is classified as type 2b according to the stratification circulation diagram of Hansen and Rattray (1966). During neap tide, a continuous vertical stratification pattern is observed over all the tidal cycles; during spring tide, stronger stratification is observed only at high and low slack waters. The near-mouth bottom sediments in the estuarine basin are mainly sandy with variable content of mud and most of the suspended sediment in the water column is caused by resuspension during current peaks. The transport rate of suspended sediments during spring tide is 2·5 times greater than during neap tide, and the transport is seaward in both cases.

Material and methods

Sampling

The sampling station was approximately 500 m from the estuarine mouth (Figure 1). The sampling station was in the center of the channel, where there is a regular geometry and almost no depth variation across (Figure 2). The cross section area was calculated from echo sounding surveys done at a given water level. For the transport calculation, the area was corrected every hour according to the tidal level information. The water level was monitored every half-hour by the use of a tide rule placed at the margin.

The water samples were taken hourly at near-surface and near-bottom depths at the center of the channel during two complete tidal cycles. The campaign started at 10 a.m., 12 March and finished at 11 a.m., 13 March 1998, under spring tide conditions with 1·2 m of total range. Current speed and direction were recorded using three SensorData™ SD6000 current meters moored in such a way as to collect data at 0·5 m above the bottom, 1 m above the bottom and 0·5 m below surface. Salinity and temperature were recorded using a SensorData™ SD201 conductivity, temperature and depth probe. The hydrodynamic data processing and results were reported in Siegle (1999) and Siegle *et al.* (1999).

The water samples were filtered through pre-combusted GF/C Whatman filters immediately after they were taken. After sample filtration, the filter was washed with Na_2SO_4 solution to eliminate chlorides and then frozen for posterior lab analysis of POC and chl *a*. The filtered material was divided into sub-samples, then frozen for posterior lab analysis of dissolved inorganic nutrients. Aliquots of non-filtered samples were preserved with Lugol solution for microscopic estimation of the phytoplankton and protozooplankton composition. Some of these samples were selected and brought to sedimentation in Uthermöl chambers, and were later counted using an inverted microscope.

Laboratory analysis

The POC concentration was determined by acid digestion with potassium dichromate, and the surplus was titrated with ammoniacal ferrous sulfate (Grashoff *et al.*, 1983). The chl *a* was extracted using 90% acetone, by means of 30 s ultrasonic disintegration of the filter inside 2-ml Ependorff vials. The concentration was measured using the Reversed Phase Binary Gradient HPLC method (Mantoura *et al.*, 1997). The extracts were clarified before injection into the chromatograph by filtration through GF/C Whatman filters. Dissolved inorganic nutrients (NH_4^+, NO_2^-, NO_3^-, Si and PO_4^{3-}) were determined from the filtered material by colorimetric methods adapted from Strickland and Parsons (1972).

Net transport estimation

The cross section transport rate Q, in kg per hour, for every parameter was obtained by

$$Q = A_t \int_{t1}^{t2} \overline{cu}\, dt \qquad (1)$$

TABLE 1. Mean, standard deviation (s.d.), minimum and maximum values of dissolved inorganic nutrients, POC and chlorophyll *a*, and linear determination coefficient between the parameters and salinity. N: number of samples

	Sal.	Temp. (°C)	NH_4 (μm)	NO_2 (μm)	NO_3 (μm)	DIN (μm)	PO_4 (μm)	N:P	Si (μm)	Cla (μg l^{-1})	POC (μm)
Mean	25·0	25·1	29·7	1·0	2·8	33·9	0·71	50	80·4	10·4	137·9
s.d.	9·6	2·2	20·3	0·5	2·2	22·8	0·53	28	61·4	4·1	69·1
Min.	8·4	10·6	2·4	0·2	0·4	3·9	0·13	12	14·7	5·1	13·4
Max.	35·0	26·5	66·2	1·8	6·5	73·9	3·26	149	210·0	22·8	382·2
N	50	50	49	50	49	48	49	47	50	50	47
R^2			0·79	0·73	0·85	0·82	0·40	0·09	0·84	0·09	0·01

TABLE 2. Net transport rate and total transport over two tidal cycles of dissolved inorganic nutrients, POC and chl *a*. Minus sign stands for seaward transportation

Parameter	Transport rate mol h^{-1}	Transport rate kg h^{-1}	Transport rate mol ($\times 10^4$) per 2 tidal cycles	Total transport kg per 2 tidal cycles
$N\text{-}NH_4^+$	1064	− 14·9	2·6	− 372·8
$N\text{-}NO_2^-$	21·4	− 0·3	0·06	− 8·4
$N\text{-}NO_3^-$	57·1	− 0·8	0·14	− 20·1
DIN	1150	− 16·1	2·8	− 401·3
$P\text{-}PO_4^{3-}$	25·8	− 0·8	0·06	− 20·4
Si	1800	− 50·6	4·5	− 1263·8
POC	1775	− 21·3	4·4	− 532·5
Chlorophyll *a*		− 0·2		− 4·9

where A_t is the instantaneous cross section area (m^2), c is the parameter concentration (kg m^{-3}), and u is the current speed (m s^{-1}). The over bar denotes water column average. The net transport rate was calculated by time-averaging the hourly transport rate over two tidal cycles, and the total transport was obtained by integrating the net transport rate over the two tidal cycles. By convention, positive values mean transport into the estuary, and negative values, transport out of the estuary.

Results

Tables 1 and 2 summarize the results obtained during the sampling period. Temporal and vertical salinity and current distribution are presented in Figure 3. The detailed hydrodynamic description and discussion of these results are presented in Siegle (1999) and Siegle *et al.* (1998, 1999). Strong tide control over salinity variation was observed, with the highest values occurring during high tide (approximately 35 psu) and the lowest during low tide (approximately 7 psu). Higher stratification was observed during low tide, but most of the time the vertical structure was partially mixed or even vertically homogeneous, mainly during the periods of stronger currents.

Dissolved inorganic nutrients often showed an inverse relationship with salinity: the highest concentrations were recorded during the periods of lowest salinity. Silica concentrations (Si) were 80 μm on average, varying between 16 and 210 μm. Silica presented the greatest inverse relationship with

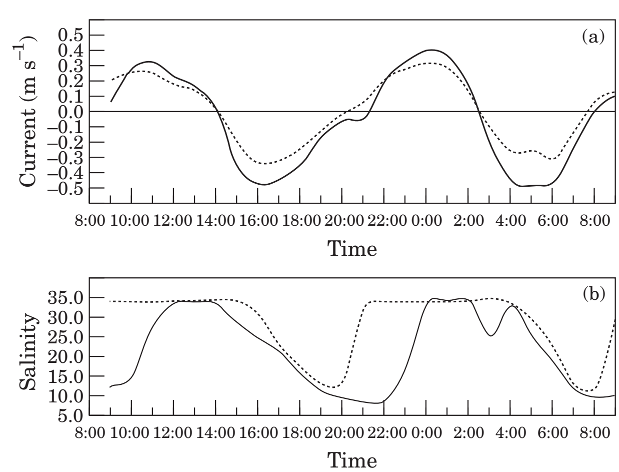

FIGURE 3. Distribution fields of hourly average values of stream velocity (a) and salinity (b). Negative values: estuary-ocean; positive values: ocean-estuary (according to Siegle, 1999). ——— Surface; - - - - - - bottom.

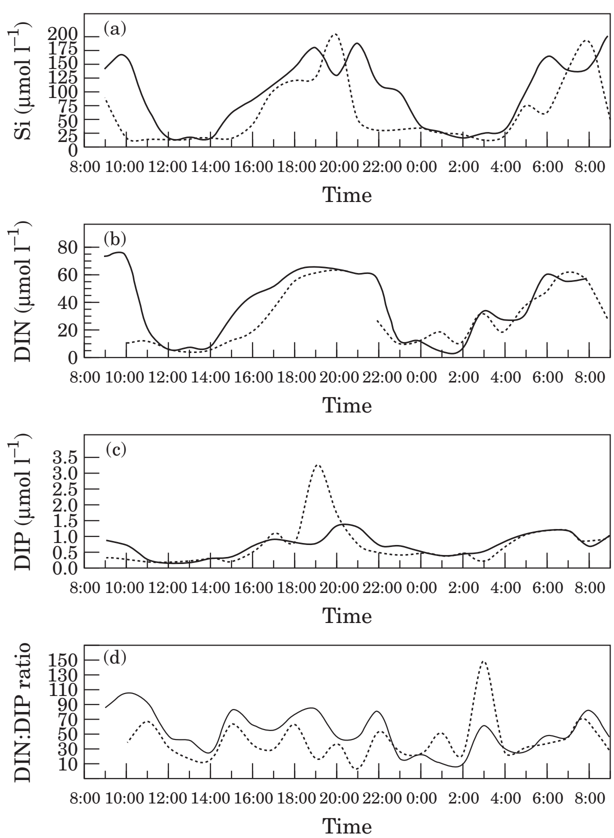

FIGURE 4. Distribution of dissolved inorganic nutrients and N:P ratio during the period of study: (a) Si, (b) DIN, (c) DIP, and (d) N:P ratio. ——— Surface; ------ bottom.

salinity. The concentration of dissolved inorganic nitrogen (DIN), varied between 4 and 74 μm (mean concentration of 33 μm). Ammonium (NH_4^+) represented 89% of the DIN, and its highest values were always associated with fresh water inflow. Phosphate (PO_4^{3-}) showed mean concentration of 0·7 μm, with a maximum value of 3 and a minimum of 0·1 μm. The N:P ratio, obtained from the DIN and PO_4^{3-}, showed high variability, averaging 42 and ranging from 5 to 149. The highest values were also associated with fresh water. The hourly variations of Si, DIN, PO_4^{3-} and the N/P ratio are shown in Figure 4.

The POC showed a mean concentration of 176 μm, ranging from 13 to 365 μm. The highest values were found near the bottom, which may be the result of resuspension of sediments by the tidal current action. The chl *a* mean concentration was 10·5 μg l^{-1}, actual values ranging from 5 to 23 μg l^{-1}.

Some surface samples from the main chl *a* peaks (14:00, 15:00, 16:00, 17:00, 00:00 and 06:00 h) were selected for quali-quantitative analysis of phytoplankton and protozooplankton. The results showed that the species were mainly of marine origin, and were dominated by diatoms. The highest density values of cells (cells ml^{-1}) were registered in the afternoon (14:00, 15:00, 16:00 and 17:00 h) and the lowest in the samples collected at night (00:00 and 06:00 h; Table 3). However, species smaller than 10 μm (coccoid, cyanobacteria, nanoflagellates) could not be quantified due to the high values of suspended matter in the samples, which could cause an underestimation of phytoplankton density.

Discussion

Inorganic nutrients

The highest concentrations of nutrients in the Camboriú River estuary were always associated with waters of continental origin and lower salinities. This caused a typical variation pattern in the analyzed nutrients. During flood tide and high tide, a nutrient concentration decrease was observed as the coastal salt water entered the estuary. On the other

TABLE 3. Phytoplankton composition (%) according to taxonomical classes and original environment (marine or freshwater) and total cell density (cells ml^{-1}) for each surface sample analysed. Cells smaller than 10 mm were not counted

	14:00	15:00	16:00	17:00	00:00	06:00
Cyanobacteria	0	0	0·5	0·5	0	1·3
Chlorophyceae	1	3	3	5·8	0	2
Baccilariophyceae	89	60	77	86	81	85
Dinophyceae	10	36	19	7	19	11
Ciliates	0	1	0·5	0·7	0	0·7
Marine	98·4	95·8	96·4	92·3	98·3	96·2
Freshwater	1·6	4·2	3·6	7·7	1·7	3·8
Total cells per ml	2114	1724	1461	1353	865	665

hand, during the ebb tide, an increase of fresh water contribution in the estuary was noted, resulting in an increase in all nutrient concentrations. Such behaviour, with nutrient concentration peaks at regular intervals of about 10–12 h, shows the strong influence of the tide on the estuarine flushing and nutrient concentration at a given location.

The tide-nutrient relationship was clear in the cases of Si and the nitrogenous nutrients (NO_3^-, NO_2^-, and NH_4^+), which showed high inverse relationships with salinity (Table 1). Among the inorganic nutrients, PO_4^{3-} had the lowest relationship with salinity. Such behaviour was caused by its relatively low variation of concentration in the water column. This behaviour may have been caused by the tendency of PO_4^{3-} to be adsorbed to sediment particles. When its concentration becomes high, part of the PO_4^{3-} tends to be adsorbed to particulate suspended material, mainly at the surface of oxides and hydroxides and organic material (Carmouze, 1994). Fresh water, which usually contains high concentrations of suspended material, has a high adsorption capacity. For this reason, part of the PO_4^{3-} is probably transferred from the dissolved compartment to the particulate one in the water column, and remains in the dissolved mode for only limited periods. This ' buffering ' mechanism for PO_4^{3-} has been recognized in studies on natural environments (Spencer, 1975).

The predominant form of DIN was NH_4^+, related mainly to fluvial inflow, with values as high as 65 μm. The NH_4^+ is directly related to the biological activity and decomposition of organic matter. In the case of the Camboriú River estuary, high concentrations can be related to sewage inflow from the Balneário Camboriú city sewage treatment plant: the effluent outlet enters the river approximately 3 km upstream from its mouth. Illegal discharge of sewage may also have contributed to the high concentrations. However, a similar increase in PO_4^{3-} was not observed as would be expected from domestic sewage contribution, keeping the N:P ratio high. This was true especially during periods of lower salinity, when values above 100 were found, much higher than would be expected for sewage (3–5; Bishop, 1983). The high N:P ratio in fresh water may contribute to a possible lack of P, when compared to N, in the Camboriú bight, since the estuary is the main inflow of freshwater and nutrients to the bight. Morelli (1997) found average values close to 37 for the N/P ratio for the whole bight. These ratios are considerably higher than those of Redfield (16), which are considered ideal for the growth of phytoplankton.

The adsorption tendency of P and suspended matter can explain the high N/P ratio for dissolved

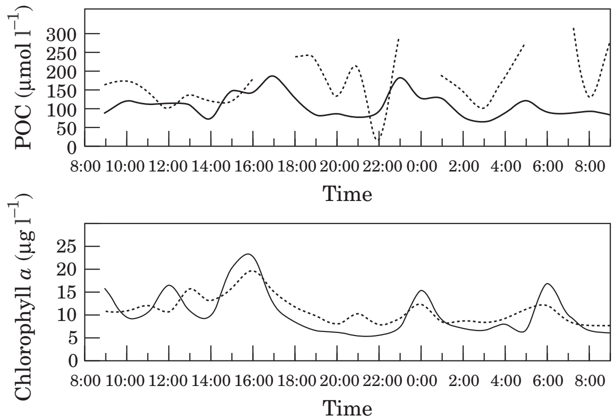

FIGURE 5. Distribution of POC and chl *a* at the collection site. ——— Surface; - - - - - - bottom.

inorganic nutrients. However, this mechanism is not sufficient to explain the values obtained by Morelli (1997) for the whole bight, because the availability of suspended matter is low in salt waters. Thus, the estuarine waters, enriched with nutrients, may show a very high N/P ratio. This high ratio could occur because of the Camboriú River drainage basin. The river provides water to various locations with substantial agricultural activity, particularly in the city of Camboriú, where rice fields are common. In this area, more than 3000 tons of rice per year are produced on approximately 600 hectares (IBGE, 1997). These rice cultures use several types and quantities of chemical fertilizers—particularly urea, ammonium sulfate, and mixed fertilizers (NPK). In the case of mixed fertilizers, the one that is most used in the region has an N:P ratio of approximately 1·3, which is, however, much less than the N:P ratio found in the river. Since consistent data on the real quantities of ammonium sulfate and urea used do not exist, it is impossible to confirm this hypothesis. Because the nitrogen-based fertilizers used are completely soluble in soil, a considerable portion may be leached (Comissão de Fertilidade do Solo-RS/SC, 1997).

Chlorophyll a

Chlorophyll *a* always showed high values in the estuary. The highest values occurred just after peaks of the flood or ebb tidal phases. For example, see the peak at the fourth hour of the sampling during the flood tide (Figure 5). After the high water during the ebbing, a new peak was noted (15:00 and 16:00 h). The same pattern was noted in the subsequent tidal cycle (Figure 5).

This pattern apparently shows that there is a maximum of chl *a* that is displaced by the water flow,

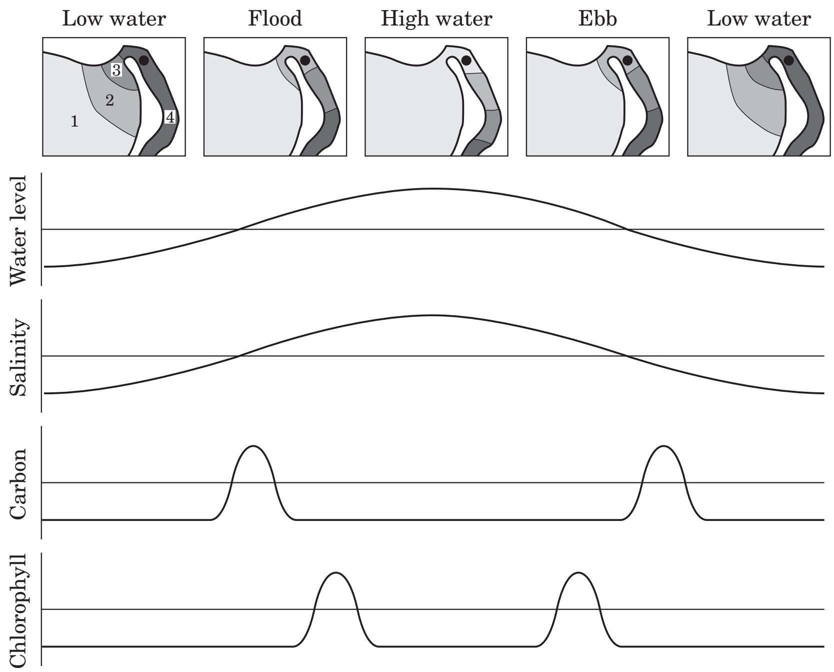

FIGURE 6. Conceptual model showing the belt of productivity close to the Camboriú River mouth and its position during the tide cycle (spring tide): (1) Coastal water, (2) Chlorophyll belt, (3) POC belt and (4) Riverine water. The upper diagram shows the position of the chlorophyll and POC belt and the sampling point. The graphics below show the variation of these and related parameters at the sampling site, in each situation.

sometimes entering and sometimes exiting the estuary following the tide. A plausible explanation is the existence of an area of maximum primary productivity close to the estuary mouth forming a productivity belt. Within this area, the phytoplankton may find favourable light conditions with a reduction in the turbidity of the estuarine waters, associated with high availability of nutrients from the estuary, thus characterizing an ideal area for primary production. This productivity belt is common around river plumes (Mann & Lazier, 1991; Robertson *et al.*, 1998). Also, the hydrodynamic conditions in the bight near the estuarine mouth are not favourable for the mixing and dispersal of the incoming material, and a fraction of the water that enters the estuary during the flood tide may have already entered it during previous tidal cycles, thereby further contributing to the consistently high level of chl *a*.

In the case of our Camboriú River study, the chl *a* belt was very close to the mouth of the estuary, which caused part of it to enter during the flood tide, passing the sampling site, going upstream and returning during the ebb tide. However, the chl *a* peaks were higher during the ebb tide than during the flood tide, resulting in a residual transport of chl *a* into the bight. This observation can be explained by the fact that the growth of organisms occurred inside the estuary after the entry of a smaller innoculum of organisms from the sea during the flood tide. This explanation is also based on the composition of phytoplankton in the samples from these chl *a* peaks. These samples were composed mainly of marine species which present high growth rates in nutrient-enriched waters (diatoms). The flood tide occurred early in the morning, thus providing an entire day for organisms growth within the estuary, utilizing available light and nutrients. This hypothesis is shown in Figure 6.

Another hypothesis relates to the presence of benthic algae associated with mangrove vegetation on the margins of the estuary. Some of these algae could have been flushed during the ebb tide and then been added to the organisms produced in the external region that entered the estuary during the flood tide, causing the peak to increase. However, microscopic analysis of the samples with chl *a* peaks revealed that coastal phytoplanktonic species were dominant.

Particulate Organic Carbon—POC

POC originates largely from phytoplankton in marine environments. However, high relationship between POC and chl *a* is not always observed in estuaries and coastal environments, because part of the POC is organic detritus originating from continental drainage. There was little correlation between POC and chlorophyll levels in the Camboriú River estuary (Figure 5), where the highest values of POC probably came from river detritic matter.

Despite a low correlation, POC and chl *a* showed an interesting variation pattern. The chl *a* variation reflected the tidal inversions and the existence of a productivity belt. The POC did not show the same behaviour as chl *a*, but showed a clear relationship with the inflow and outflow of water in the estuary, at least at the surface layer. The highest values of POC preceded or succeeded the chlorophyll peaks. During the flood tide, the POC peak preceded the chl *a* peak, which in turn preceded a smaller peak of POC. Inversely, the chl *a* peak during the ebb tide was preceded by the smaller POC peak, and succeeded by the higher POC peak. Thus, a belt of POC appears to enter and exit the estuary following the tidal cycle. These high values of POC may be caused by riverborn detritus accumulation, forming an estuarine front close to the mouth. The detritic matter settled in the estuary could be re-suspended during the maximum current periods, and would be added to this POC belt. Figure 6 presents a conceptual model for this situation.

Transport of material

The cross section area during the experiment ranged from 94 to 186 m^2, and the total transport calculation considering only measurements at the center of the channel did not give the true total transport values. However, Silva *et al.* (1998) showed that the cross section salinity distribution is almost homogeneous: the difference between the vertical- and time-averaged values was less than 2% at two stations. This behaviour was observed due to the macro turbulence stirring generated by the friction which was induced by channel shallowness and narrowness, and also because the cross section was situated in a rectilinear reach of the estuary.

Kjerfve *et al.* (1981) suggested that for a percentage of error in the cross section transport of less than 15%, the lateral sampling station density should be governed by an area of 2×10^6 m^2 $station^{-1}$. Such value is four orders of magnitude larger than the area used in the present assessment, of 2×10^2 m^2 $station^{-1}$ at high tide. Further, the sampled cross section bathymetry did not present channel differentiation, when lateral tidal current assimetry generated a side preference for ebb and flood currents (Kjerfve & Proehl, 1979). Thus, considering the salinity as a tracer for lateral mixing efficiency, we expect that the transport calculation results are close to the real values for the given sampling period, or at least in the same order of magnitude.

The tidal-averaged net transport rates were negative for all nutrients, POC and chl *a* (Table 2). Such results suggest that the Camboriú River estuary exported these substances to the bight during the sampling period. Nevertheless, it can also be considered, that the same thing happens when the environmental conditions are similar to those found during this sampling. Even if the results obtained in this study are not representative of the whole year, they indicate a great potential for eutrophication of the bight water as result of nutrient input from the Camboriú River estuary.

Results from Kuroshima *et al.* (1996) and Morelli (1997), corroborate the results of this study. They found higher levels of eutrophication in the southern part of the bight, where the inlet of the Camboriú River estuary is located. This region has high chl *a* concentrations and N:P ratios and also presents the worst water quality for recreational purposes of the entire beach, particularly during the summer.

Conclusions

This study showed that: (1) there is a belt of high productivity and another of detritic matter close to the estuary mouth, entering and exiting the estuary as a function of the tide; (2) there is a high N:P ratio which suggests that local phytoplankton productivity is limited by phosphorus and, (3) the estuary presents a high potential for eutrophication of the bight through the supply of high concentrations of inorganic material. The origin of these nutrients may be related to: (a) the sewage treatment plant in Balneário Camboriú which releases its treated effluent into the Camboriú River; (b) the entry of illegal sewage into the Camboriú River; (c) the entry of agricultural effluents, which could carry unknown amounts of chemical fertilizers used in fields along the river's drainage; and finally, (d) the natural nutrient concentration of the Camboriú River. Further assessments should provide a better understanding of the hydrodynamics and biogeochemical processes in the Camboriú Bight around the estuarine inlet–bodies of water which are a critical link to material transfer to the open sea.

References

Beukema, J. J. 1991 Changes in composition of bottom fauna of a tidal-flat area during a period of eutrophication. *Marine Biology* **111,** 293–301.

Berounsky, V. M. & Nixon, S. W. 1985 Eutrophication and the Rate of Net Nitrification in a Coastal Marine Ecosystem. *Estuarine, Coastal and Shelf Science* **20,** 773–781.

Bishop, P. L. 1983 *Marine pollution and its control*. McGraw-Hill, New York, 358 pp.

Carmouze, J.-P. 1994 *O metabolismo dos ecossistemas aquáticos*. Edgard Blucher, ed. 254 pp.

Carmouze, J.-P. & Vasconcelos, P. 1992 The Eutrophication of the Lagoon of Saquarema, Brazil. *Science of the Total Environment* (Suppl.), 851–859.

Cederwall, H. & Elmgren, R. 1980 Biomass increase of benthic macrofauna demonstrates eutrophication of the Baltic Sea. *Ophelia* (Suppl. 1), 287–304.

Comissão de Fertilidade do Solo-RS/SC. 1997 *Recomendaçues de adubação e de calagem para os estados do Rio Grande do Sul e de Santa Catarina*. 3a ed. 224 pp.

Gaplan—Gabinete de Planejamento de Santa Catarina 1986 *Atlas de Santa Catarina*. Aerofoto Cruzeiro, Rio de Janeiro, 173 pp.

Grasshoff, K., Ehrhardt, M. & Kremling, K. 1983 *Methods of seawater analysis*. Verlag Chemie, 419 pp.

Hansen, D. V. & Rattray, Jr. M. 1966 New dimensions on estuarine classification. *Limnology and Oceanography* **11,** 319–326.

IBGE 1997 Censo Agropecuário de Santa Catarina: 1995–96.

Innamorati, M. & Giovanardi, F. 1990 Interrelationships between Phytoplankton Biomass and Nutrients in the Eutrophicated Areas of the North-Western Adriatic Sea. In *Marine Coastal Eutrophication* (Vollenweider, R. A., Marchetti, R. & Viviani, R., eds). Proceedings. Elsevier, 235–250.

Kimor, B. 1990 The Impact of Eutrophication on Phytoplankton Composition in Coastal Marine Ecosystems. In *Marine Coastal Eutrophication* (Vollenweider, R. A., Marchetti, R. & Viviani, R., eds). Proceedings. Elsevier, 871–878.

Kjerfve, B., Stevenson, L. H., Proehl, J. A., Chrzanowski, T. H. & Kitchens, W. M. 1981 Estimation of material fluxes in an estuarine cross section: a critical analysis of spatial measurement densidty and errors. *Limnology and Oceanography* **26,** 325–335.

Kjerfve, B. & Proehl, J. A. 1979 Velocity variability in a cross-section of a well-mixed estuary. *Journal of Marine Research* **37,** 409–418.

Kuroshima, K., Bellotto, V., Barreiro, M. & Chevarria, G. 1996 Elaboração de um índice para monitoramento da qualidade de água na enseada de Camboriú-SC. In *III Simpósio sobre Oceanografia—IOUSP. Resumos*, p. 304.

Mann, K. H. & Lazier, J. R. N. 1991 *Dynamics of marine ecosystems*. Blackwell Scientific Publications, Boston, 466 pp.

Mantoura, R. F. C., Barlow, R. G. & Head, E. J. H. 1997 Simple Isocratic HPLC Methods for Chlorophylls and their Degradation Products. In *Phytoplankton Pigments in Oceanography* (Jeffrey, S. W., Mantoura, R. F. C. & Wright, S. W., eds). Unesco, pp. 307–226.

Morelli, F. 1997 Dinâmica de Nutrientes Inorgânicos na Enseada de Camboriú, Balneário Camboriú-SC. *Monografia de Conclusão do Curso de Oceanografia*. Univali, 82 pp.

Niencheski, L. F. & Windom, H. L. 1994 Nutrient flux and budget in Patos Lagoon Estuary. *The Science of Total Environment* **149,** 53–60.

Nixon, S. W. 1982 Nutrient Dynamics, Primary Production and Fisheries Yields of Lagoons. *Oceanologica Acta* (Suppl.), 357–371.

Nixon, S. W. 1992 Quantifying the relationship between nitrogen input and the productivity of marine ecosystems. *Proceedings of the advanced Marine Technical Conference* **5,** 57–83.

Nixon, S. W., Oviatt, C. A., Frithsen, J. & Sullivan, B. 1986 Nutrients and the producitivity of estuarine and coastal marine ecosystems. *Journal of Limnology Society of South Africa* **12,** 43–71.

Nixon, S. W. & Pilson, M. E. Q. 1984 Estuarine Total System Metabolism and Organic Exchange Calculated from Nutrient Ratios: An Example from Narragansett Bay. In *The Estuary As a Filter—Seventh Biennial International Estuarine Research Conference* (Kennedy, V. S., ed.). Academic Press, 261–290.

Parker, C. A. & O'Reilly, J. E. 1991 Oxygen depletion in Long Island Sound: a historical perspective. *Estuaries* **14,** 248–265.

Pennock, J. R., Sharp, J. H. & Schroeder, W. W. 1994 What controls the expression of estuarine eutrophication? Case studies of nutrient enrichment in the Delaware Bay and Mobile Bay Estuaries, USA. In *Changes in fluxes in estuaries: implications from science to management* (Dyer, K. R. & Orth, R. J., eds). Olsen & Olsen, Fredensborg, pp. 139–146.

Pugh, D. T. 1987 *Tides, surges and mean sea level*. John Wiley and Sons, New York, 472 pp.

Robertson, A. I., Dixon, P. & Alongi, D. M. 1998 The influence of fluvial discharge on pelagic production in The Gulf of Papua, northern Coral Sea. *Estuarine, Coastal and Shelf Science* **46,** 319–331.

Schettini, C. A. F., Carvalho, J. L. B. & Jabor, P. 1996 Comparative hydrology and suspended matter distribution of four estuaries in Santa Catarina Satate—Southern Brazil. Workshop on Comparative Studies of Temperate Coast Estuaries, Bah Blanca. *Proceedings*, IADO, pp. 29–32.

Schettini, C. A. F. (in press) *Caracterização hidrodinâmica e sedimentológica do estuário do Rio Itajaí-açu*. Notas Técnicas da Facimar.

Siegle, E. 1999 *Morfodinâmica da Desembocadura do Rio Camboriú, Balneário Camboriú, SC*. Dissertação de Mestrado. IG/UFRGS, Porto Alegre, RS, 124 pp.

Siegle, E., Schettini, C. A. F., Klein, A. H. F. & Toldo, Jr. E. E. 1998*a* Mecanismos de Transporte de Sedimentos em Suspensão no Estuário do Rio Camboriú, Balneário Camboriú, Santa Catarina. In *III Encontro de Engenharia de Sedimentos. Anais III Encontro de Engenharia de Sedimentos*. Associação Brasileira de Recursos Hídricos. Belo Horizonte, MG. pp. 25–32.

Siegle, E., Schettini, C. A. F., Klein, A. H. F. & Toldo, Jr. E. E. 1998*b* Estuário do Rio Camboriú: Hidrografia e sedimentos em Suspensão. In *Anais XI Semana Nacional de Oceanografia*. FURG. Rio Grande, RS, pp. 463–465.

Siegle, E., Schettini, C. A. F., Klein, A. H. F. & Toldo, Jr. E. E. 1999 Suspended Sediment Transport and Hydrodynamics at Camboriú River Inlet, Brazil. *Coastal Sediments '99* (ASCE) **1,** 675–687.

Silva, F. L., Schettini, C. A. F. 1997 Contribuição à hidrologia do estuário do Rio Camboriú: avaliação da contribuição fluvial. Semana nacional de oceanografia, 10, Itajaí, *Resumos Expandidos* . . . Facimar/Univali, pp. 496–498.

Silva, F. L., Schettini, C. A. F. & Siegle, E. 1998 Variabilidade lateral da salinidade no estuário do Rio Camboriú. In *Semana Nacional de Oceanografia*, 11, Rio Grande, *Resumos Expandidos. FURG*, pp. 419–421.

Smith, S. V. & Veeh, H. H. 1989 Mass balance of biogeochemically active materials (C,N,P) in a hypersaline gulf. *Estuarine, Coastal and Shelf Science* **29,** 195–215.

Spencer, C. P. 1975 The Micronutrients Elements. In *Chemical Oceanography*, Vol. 2 (Riley, J. P. & Skirrow, G., eds). Academic Press Inc, London, pp. 245–300.

Strickland, J. D. & Parsons, T. R. 1972 A pratical handbook of seawater analysis. *Fisheries Research Board of Canada Bulletin*, 2nd edition, 1–311.

Thornthwaite, C. W. 1948 An approach toward a rational classification of climate. *The Geographical Review* **38,** 55–94.

Truccolo, E. C. 1998 *Maré meteorológica e forçantes atmosféricas locais em São Francisco do Sul—SC*. UFSC, Florianópolis, Dissertação de mestrado, 100 pp.