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Temporal Dynamic of the Dissolved Nutrients and the Eutrophization Processes in a Southern Brazilian Coastal Lagoon, Conceição Lagoon

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ABSTRACT

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The "Conceição Lagoon", 27°34'S e 48°27'W, located in "Santa Catarina" state, southern Brazil, has been suffering over the last decade from the release of domestic sewerage, and the generalized impacts of rapid demographic growth. Because the canal that connects it to the ocean is narrow, this ecossytem is sensitive to eutrophization because water exchange is poor and the residence time of water high. In this study conducted from April 2001 to March 2002, the temperature, transparency, pH, salinity, phytoplankton biomass and concentrations of dissolved oxygen and of dissolved nutrients were measured to characterize the pelagic system of the lagoon's three regions (South, Central and North). From each of these regions, two shallow areas (< 2 m depth) and two deeper areas (> 2 m depth) were sampled, for a total of 12 station areas. The water samples from these stations were taken from the sub-surface and the bottom with 5 L "Van Dorn" horizontal bottles. The characteristics of the periods were represented by Principal Components Analysis. In the Autumn-Winter, the pelagic system is characterized by low temperature and pH, and by high salinity, dissolved oxygen content and dissolved inorganic and organic nutrients. In the spring-summer, the average temperature increases as well as the pH and the phytoplankton pigments. In these seasons, the salinity, dissolved oxygen concentration and the dissolved inorganic and organic nutrient concentration decreased. The temporal dynamic of the pelagic system was primarily related to meteorological conditions. The eutrophication process is also discussed.

ADDITIONAL INDEX WORDS: *Coastal lagoon, eutrophication.*

INTRODUCTION

Coastal lagoons represent nearly 13% of the world's coastal areas (NOWICKI and NIXON, 1985). In South America this ecosystem occupies 12% of the coastal zone. Coastal lagoons are characterized by their semiclosed, shallow waters, and by permanent or ephermal contact with the open ocean (KJERFVE, 1994).

Coastal lagoons exercise an important role in the transport, modification and accumulation of material in the continental-ocean interface (KJERFVE and MAGILL, 1989). In contrast with the open ocean, the allochthonous material introduced into coastal lagoons by the atmosphere, rivers, subterranean waters, ocean and marginal vegetation is efficiently retained and recycled as a consequence of the longer residence time of the water, the minimization of energy sources such as tides, waves and currents, and the accentuated degree of coupling between the pelagic and benthic behavior (MARTENS, 1993). The high degree of primary production, frequently observed in these systems is associated directly to the high supply of dissolved inorganic nutrients, both of natural and anthropic origin, characteristic of these regions (ABREU *et al.,* 1995; HERRERA-SILVEIRA *et al*., 2002).

The region around the Conceição Lagoon, like other coastal environments, has been suffering a continuous urban population increase since the 1980s. The lack of suitable treatment for domestic effluents is altering the hydrochemical characteristics of this system, causing eutrophication (ODEBRECHT and CARUSO JR., 1987; FONSECA *et al*., 2002). In the past decade, there has been a lack of studies with seasonsal focuses in the Conceição Lagoon that would allow certifying chemical alterations in the environment. The purpose of this paper is to present seasonal and spatial information about nutrient concentrations during 2001-2002 and to compare it with previous studies about the Conceição Lagoon.

MATERIAL AND METHODS

Study Area

The Conceição Lagoon is located in the central-eastern portion of Santa Catarina Island, (27°34'S, 48°27'W), in southern Brazil (Figure 1). The lagoon is a semiclosed system that is connected to the ocean by a narrow channel with an area of approximately 40 m^2 and a depth of 2 m. The Conceição hydrographic basin has an area of 80.23 km^2, including the lagoon which has 20.09 km^2. The lagoon itself is 13.5 km long from north to south and varies in width from 0.2 to 2.5 km, with a volume of approximately 49 x 10^6 m^3 and an average depth of 1.7 m. The lagoon is bordered by Atlantic Forest, pasture and agricultural zones, reforested areas, and urbanized regions, beach vegetation, sand dunes and *restingas*. (KNOPPERS *et al*., 1984). The Lagoon has three regions that have distinct physical and chemical characteristics. The southern region is the most isolated from the others and the most urban. There is a 3m wide bridge at the point where the southern portion connects to the central region. The bridge chokes a natural channel. There is no saline stratification and a predominance of oligo to mesohaline waters (an average of 17.5 5.2). Of the three regions, the southern has the highest level of turbidity and the water column has oxic conditions. In recent decades, the concentration of phytoplankton chlorophyll *a* has fallen and there has been a formation of extensive banks of opportunistic macroalgae. The central region includes the canal that gives access to the open ocean. The water column has saline stratification, with meso to polihaline characteristics (an average of 23.7 4.3); the turbidity values are between those of the other regions; the highest concentrations of cholorphyll *a* and seston are found in the deep waters and the deepest areas are anoxia because of their stagnation. The northern region suffers the greatest fluvial influence of the three, from the input of the basin's largest tributary (João Gualberto River); it has a water column without saline stratification, with meso to polihaline characteristics (average of 18.9 6.2); both the values of turbidity as well as those of cholorphyll *a* and seston are the lowest registered (on average) in the lagoon; there is sporadic stratification in the values of dissolved oxygen, and no anoxia.

Sampling

The southern, central and northern regions of the Conceição

Figure 1. Location of the Conceição Lagoon, SC, Brazil. Bathymetry (2m, pointed contour; 5m, dashed) and regions South, Central and North.

Lagoon were sampled on April 10 and 26 and July 10 and 13, 2001 to characterize the autumn-winter period. The sampling in the spring-summer period occurred on November 15, and December 4 and 6, 2001 and March 1, 2002. In each region was selected a shallow areas, with depths not greater than 2m, and a deep area, deeper than 2m. Two sampling levels were established in each one of the areas (Figure 1), sub-surface and close to the bottom. The collections were conducted with the use of a "Van Dorn" Bottle type collector, with horizontal closing and an opening with a turbulence reducer.

Temperature and pH were measured in the field with a portable Hach pHmeter (mod. 50205, precision 0.01) with heat sensor. The transparency was calculated from data obtained with a Secchi disk. The sample for analysis of dissolved oxygen was collected and processed according to the Winkler method (GRASSHOFF *et al*., 1983). The sample for analysis of ammonium was fixed in the field according to methods described by TRÉGUER and LE CORRE (1976) and GRASSHOFF *et al*. (1983). The rest of the water samples were collected in acid-washed bottles and stored on ice (5 °C), in the dark until they reached the laboratory. Once they arrived in the laboratory, the salinity was measured by conductivity methods (TDS Hach mod. 44600). The water samples were filtered to calculate total suspended material SESTON (pre-rinsed, pre-ashed Schleicher & Schuell GF-52C glass fiber filters) and phytoplankton pigments (Schleicher & Schuell GF-52C fiber glass filters). The filtered solution was used to analyze the dissolved inorganic nutrients, and was stored in a pre-cleaned polyethylene flask chilled to 20 ºC until the moment of analysis. Phosphates and silicates were determined by the spectrophotometric method according to GRASSHOLFF *et al.* (1983). The absorbances of the samples to quantify ammonia, phosphate and silicate were measured in a spectrophotometer Bauch & Lomb (model Genesis 2), using a 5 cm cuvette for the ammonia and the phosphate, and a 1 cm cuvette for the silicate analysis. The nitrite and nitrate were analyzed by the automatized method according to the recommendations of TRÉGUER and LE CORRE (1976), using an *AutoAnalyzer II* - Bran-Luebbe system, with a 5 cm cuvette. Phosphorus and dissolved organic nitrogen were determined according to ARMSTRONG *et al.* (1966), adapted by SARAIVA (2003). Dissolved inorganic nitrogen was calculated by the sum of the concentrations of nitrate, nitrite and ammonia. The concentrations of chlorophyll *a* and of pheophytin *a* were determined fluorimetrically, with a TURNER 10-AU device, following the recommendations described in STRICKLAND and PARSONS (1972).

Multivariate statistical analysis was applied to the data set. The Principal Component Analysis, with standardized and untransformed data, was used. The differences between periods were tested by analysis of similarity, one-way ANOSIM, using Euclidean distance matrix of the standardized and untransformed data.

The rainfall, evaporation and wind intensity and direction were cordially provided by CLIMERH (Centro Integrado de Meteorologia e Recursos Hídricos de Santa Catarina), which has a meteorological station close to the study area.

RESULTS

In autumn-winter, the winds from the south were the most frequent and of greatest intensity, with maximums of 11 $m.s^{-1}$. The monthly rainfall was 151 ± 109 mm and evaporation was 73 ± 6 mm. In the warm months, the winds from the north were more frequent, while those from the south were stronger, with maximums of 5 $m.s^{-1}$. The monthly rainfall was 158 ± 58 mm and evaporation was 99 ± 23 mm.

The analysis of the principal components of the physical-chemical and biological variables studied here indicate the seasonal difference of the hydric characteristics of the Conceição Lagoon (Figure 2). For the first principal component, 50 %, separated the samples from the autumn-winter period from the samples of the spring-summer period. According to the ANOSIM one-way similarity analysis, these periods were significantly different (R global 0,35 and p 0,000).

In autumn-winter, the average temperature of the lagoon waters was 23 ± 3 ºC, with homogeneity throughout the water column. The only exception was the deep area of the central region were there were thermohaline stratifications in nearly all of the samples. In general the salinity (26.6 ± 4.6) and the degree of dissolved oxygen (5.78 ± 1.56 $ml.L^{-1}$) were the highest of the system in this study, as well as the average concentrations of silicate (16.56 ± 10.68 µM) and of dissolved inorganic phosphorus (0.28 ± 0.20 µM) and organic phosphorus (10.70 ± 10.37 µM).

The dissolved nitrogen compounds, ammonia (2.74 ± 3.51 µM), nitrite (0.16 ± 0.12 µM), nitrate (1.10 ± 1.66 µM) and dissolved organic nitrogen (40,83 ± 24,03 µM) were higher than in the spring-summer period. On the other hand, the pH (7.79 ± 0.31), the seston (0.77 ± 0.61 $mg.L^{-1}$) and the phytoplanktonic pigments, chlorophyll *a* (2,54 ± 1,40 $\mu g.L^{-1}$) and pheophytin *a* (2,36 ± 4,35 $\mu g.L^{-1}$), were lowest in this study.

The spring-summer samples were overlapping in the analysis of the principal components, indicating the homogenization of the physical, chemical and biological variables throughout the lagoon. The exception is in the shallow areas of the southern and northern regions, which had high concentrations of dissolved inorganic nitrogen. In this period, the lagoon waters had an average temperature of 26.4 ± 1.6 ºC, with thermohaline stratification only in the deep areas of the central region. The salinity and concentration of dissolved oxygen averaged 21.8 ± 4.0 and 5.24 ± 1.05 $ml.L^{-1}$, respectively. There was an average concentration of silicate of 9.86 ± 11.15 µM. The average concentrations of dissolved inorganic and organic phosphorus were of 0.14 ± 0.15 µM and 5.49 ± 0.50 µM, respectively. The dissolved nitrogen compounds had the lowest concentrations in the study, ammonia (1.35 ± 2.37 µM), nitrite (0.11 ± 0.08 µM), nitrate (0,41 ± 0,90 µM) and organic nitrogen (19,19 ± 10,55 µM). During this period there was an increase in the pH (8.05 ± 0.22), the seston (0.90 ± 0.85 $mg.L^{-1}$) and in the concentrations of chlorophyll *a* (3.21 ± 3.51 $\mu g.L^{-1}$) and of pheophytin *a* (5,70 ± 23,31 $\mu g.L^{-1}$).

The N:P ratio varied considerably among the sampling points in the lagoon. The average in the autumn-winter period was of 18 ± 19 and in the spring-summer 24 ± 35. The highest

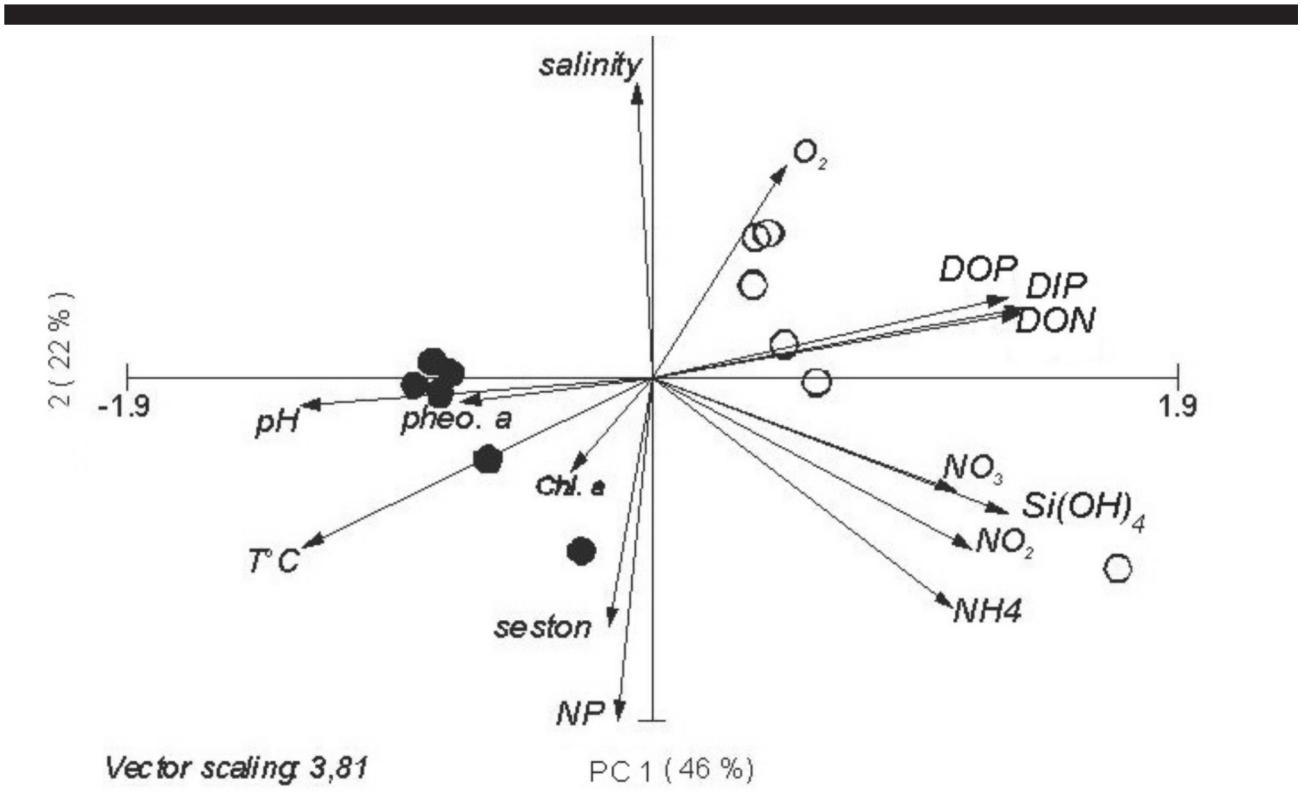

Figure 2. PCA graph of the physical, chemical and biological variables (arrows) and the samples (autumn-winter 2001 ; spring-summer 2001-02) at Conceição Lagoon, Southern BRazil. DOP, dissolved organic phosphorus; DON, dissolved organic nitrogen; DIP, dissolved inorganic phosphorus. NH4, ammonia; NO_2, nitrite; NO_3, nitrate; $Si(OH)_4$, silicate; O_2, dissolved oxygen.

N:P ratios, as well as the highest concentrations of dissolved nutrients, were in the shallow areas close to the sewerage outlets in the southern region, in the deep waters of the Central region and in the shallow area close to the João Gualberto River in the northern region.

DISCUSSION

Hydrographic conditions in coastal lagoons are influenced by the force of the tides, the wind and by the rates of evaporation and precipitation (KJERVE, 1994). The strength of the tide in the Conceição Lagoon is reduced 90% by the shallow meandering canal that links the lagoon to the ocean (SIERRA de LEDO and SORIANO-SIERRA, 1994). The winds from the south that occur with the greatest intensity and frequency in the autumn-winter in this region, favor the entrance of marine water in the lagoon (ODEBRESCHT and CARUSO-JUNIOR, 1987). The rains, typical of the spring-summer period (CRUZ, 1998), favor continental drainage and the entrance of nutrients to the Conceição Lagoon, registering high values of nutrients and phytoplanktonic biomass (SOUZA-SIERRA *et al*., 1987; PERSICH, 1990).

In this study, the autumn-winter and spring-summer periods presented similar average rains, while the monthly rate of evaporation was much greater in the hotter period than in autumn-winter. The relation between the precipitation of the two periods studied here is not typical, because in general, the rains in the spring-summer in the Conceição Lagoon are higher than in the autumn-winter (CRUZ, 1998). According to CLIMERH (www. climerh.rct-sc.br) between the spring of 2001 and summer of 2002 there was a strong drought in Santa Catarina state, with a below average volume of rain. Given this situation, this study did not find high values of nutrients in the hottest period, as verified by other authors, (SOUZA-SIERRA *et al*., *op. cit*.; PERSICH, *op. cit*.), confirming the importance of continental drainage for the increase in nutrients in the lagoon in this period of the year.

The highest concentrations of dissolved organic and inorganic nutrients in the Conceição Lagoon were observed in autumn-winter 2001. Considering that the precipitation in this period was within the average for the region (CRUZ, 1998) and that the values found here are similar to those of earlier studies conducted in this lagoon (KNOPPERS *et al*., 1984, PERSICH, 1990), it can be considered that this period is characterized by a regeneration process, that reestablishes the pool of inorganic forms. The demand for nutrients by primary producers is greater in the spring-summer, because of the increased luminosity and temperature (ODEBRECHT and CARUSO JR., 1987). The increase of phytoplankton demand in the period studied, verified by the amounts of chlorophyll *a*, on the reservoir of dissolved inorganic nutrients caused their low concentrations throughout the lagoon. This suggests that the phytoplankton are capable of removing more nutrients from the system than the remineralization of organic matter can insert. It should be emphasized that the highest values of chlorophyll *a* in the spring-summer, above 15 $g.L^{-1}$, occur in areas close to the sewerage outlets in the southern and northern regions and in the deep water in the central region. The maximum amounts of chlorophyll are related to the anthropic source of nutrients and to the remineralization of the sediment material in the deep areas of the central region.

Eutrophication in coastal environments can be observed by the proliferation of opportunist macroalgaes of the genre *Enteromorpha* and *Ulva*, depletion of oxygen accompanied by the liberation of hydrosulphuric gas (H_2S) and high concentrations of dissolved inorganic nutrients (DE JONGE *et al*., 2002). FONSECA *et al*. (2002), in a sampling at the beginning of spring 2000, found the Conceição Lagoon to be eutrophic to hypertrophic based on the evolution of the concentration of inorganic dissolved nutrients in the past two decades and on the proliferation of opportunist macroalgaes in the southern region. During this study, the biomass of the macroalgaes in the southern region, although it was not quantified, was visibly higher in the summer, and accompanied by the fetid odor from the anaerobic decomposition at the locale. The deep waters of the central region are characterized as hipoxic to anoxic, principally in the autumn-winter, a period of intense

Table 1. *Comparative table of the inhabitant number, concentrations of the dissolved nutrients µM (nitrate* ***N-NO$_3$****, nitrite* ***N-NO$_2$****, ammonia* ***N-NH$_4$*** *and phosphate* ***P-PO$_4$****) and NP rate between 1980 and 2000 at Conceição Lagoon, Southern Brazil.*

Year	N° Inhab.	author	Sampled year	Regions	N-NO_3	N-NO_2	N-NH_4	P-PO_4	NP
1980	14784	Knoopers *et al*. 1984	Jul. 82	South	2,0	0,06	0,1	0,39	7
				Central	2,3	0,03	2,0	0,52	8
				North	13,2	0,06	0,1	0,47	29
		Souza-Sierra *et al*. 1987	Nov. 83 - Nov. 84	South	0,7	0,07	-	0,09	-
				Central	0,8	0,10	-	0,07	-
				North	1,2	0,09	-	-	-
1991	27432	Persisch 1990	Dec. 87 - Dec. 88	South	0,6	0,22	-	0,28	-
				Central	0,4	0,20	-	0,31	-
				North	0,4	0,33	-	0,38	-
2000	7897	Fonseca *et al*. 2002	Sept. 2000	South	4,7	0,3	2,7	0,19	44
				Central	3,4	0,2	6,0	0,21	69
				North	4,4	0,3	8,3	0,14	139
		Fonseca & Braga autumn-winter	This study	South	1,3	0,22	5,1	0,28	24
				Central	0,6	0,15	2,0	0,32	16
				North	1,4	0,12	1,1	0,24	14
		Fonseca & Braga spring-summer	This study	South	0,6	0,12	1,9	0,16	23
				Central	0,2	0,11	1,0	0,15	16
				North	0,5	0,10	1,2	0,13	32

remineralization of organic material. In a sample of this period, anoxia was also found in the deep water of the deep area of the southern portion. Considering the concentrations of dissolved nutrients in this study, both in autumn-winter as well here are low, using as a reference the data presented in the previous studies of this lagoon (Table I). KNOPPERS *et al*. (1984) and FONSECA *et al*. (2002) studied the physical-chemical characteristics of the pelagic system of the Conceição lagoon in one sample in winter 1982 and in the beginning of spring 2000, respectively. These authors found the highest average concentrations of nutrients of all the studies conducted in this lagoon. Nevertheless, this data represents the period of regeneration of the nutrients without an elevated microalgae demand, as detected in this study, which justifies the high concentrations found. On the other hand, the seasonal studies undertaken by SOUZA-SIERRA *et al*. (1987) and PERSICH (1990) show average concentrations of nutrients lower than the data presented by the authors cited above and similar to the data presented in this study. This indicates that the Conceição Lagoon has a high seasonal dynamic of nutrients and that a monitoring of the physical-chemical characteristics of the pelagic system along a greater time scale, and of its exchanges with benthic behavior and the ocean can elucidate how the lagoon has been responding to the anthropic impact from domestic effluents. KNOPPERS *et al*. (1984) found that nitrate represented an average of 68 ± 14 % of the dissolved inorganic nitrogen in the lagoon and that through the N:P ratio, the nitrogen forms were limiting primary phytoplankton production. FONSECA *et al*. (2002) and this study found that ammonia represents the greatest portion of dissolved inorganic nitrogen, 56 ± 14 % and 66 ± 26%, respectively, and that the PID is the limiting nutrient in this ecosystem. This alteration in the composition of the inorganic forms of nitrogen are related to the increase of organic material in the lagoon in recent decades and its processes of remineralization. This study revealed that the Conceição Lagoon is in a process of eutrofication. Nevertheless, this environment, in certain conditions, has low values of dissolved nutrients, indicating that the biogeochemical cycles of the lagoon are compensating some of the environmental alterations.

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