ENVIRONMENTAL IMPACTS OF ANTHROPOGENIC ACTIVITIES ON THE RIO JACUIPE ESTUARY, CAMAÇARI, BAHIA, BRAZIL[1].

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ABSTRACT

The rio Jacuipe and its estuary has been suffering in the last 15 years from human interventions along its course, causing a number of negative environmental impacts. These activities involve the input of human and industrial sewage and molasses, as well as major river flow changes. The climatic conditions govern the definition of stratified water column. During the rainy season a salt-wedge exists due to the increase in freshwater flow, while in the dry season the amount of running freshwater diminishes and is not sufficient to deter the tidal force. Although no systematic survey has been conducted either in the river or in the estuary, some patterns can be detected through assessment of the available data. The decrease in dissolved oxygen concentrations over the years indicates that the input of organic load has already surpassed the depurative capacity of the estuary. The decision to transfer the effluents to another receiving water body with greater dilution capacity will certainly lead to positive changes that

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should be evaluated together with more detailed oceanographical studies.

RESUMO

Nos últimos 15 anos o rio Jacuípe e seu estuário tiveram uma série de intervenções humanas que conduziram a impactos ambientais negativos. Estas intervenções envolveram a entrada de efluentes domésticos e industriais, inclusive vinhoto e grandes mudanças na vazão do rio. As condições climáticas são responsáveis pela definição ou não de uma estratificação: na estação chuvosa existe a formação de uma cunha salina, devido ao aumento do volume de água doce; por outro lado, na estação seca a quantidade de água doce diminui e não é suficiente para evitar a mistura da coluna d'água causada pela força das marés. Apesar de não ter-se realizado amostragens sistemáticas no rio ou mesmo no estuário, alguns padrões podem ser estabelecidos analisando-se as informações coletadas por diversos trabalhos. O decréscimo das concentrações de oxigênio dissolvido através dos anos indica que a carga orgânica lançada no ecossistema é maior do que a capacidade de depuração do mesmo. A decisão de se transferir os efluentes industriais para outro corpo receptor de maior poder de diluição, certamente, levará a mudanças positivas no ambiente, às quais deverão ser objeto de estudos, bem como estudos oceanográficos de caráter mais profundo.

INTRODUCTION

Estuaries offer a buffering interface between terrestrial and aquatic ecosystems but are, conversely, very fragile in their capacity to assimilate impacts. Although biodiversity is not one of their major characteristics, they shelter numerous species of great ecological and regional economic importance. Due to this dynamic and strategic role, estuaries deserve considerable attention in ecological research.

The Jacuipe estuary, object of this review, comprises the last 7.5 km of the 141 km long rio Jacuipe. It can be defined as a bar-built estuary following the classification of FAIRBRIDGE (1980), and is located 47 km north-east of Salvador the capital of the state of

Bahia (FIG. 1). The river drains an area of 1213 km^2, and its source is near Conceição do Jacuípe. Its course crosses five other small towns before reaching the Atlantic Ocean. The river has an average flow of 15 m^3/s, receiving water from several small tributaries; in its estuarine region it receives contributions from two streams, Capivara Pequeno and Capivara Grande. The tides are semi-diurnal and the spring tide range is 2.8 m.

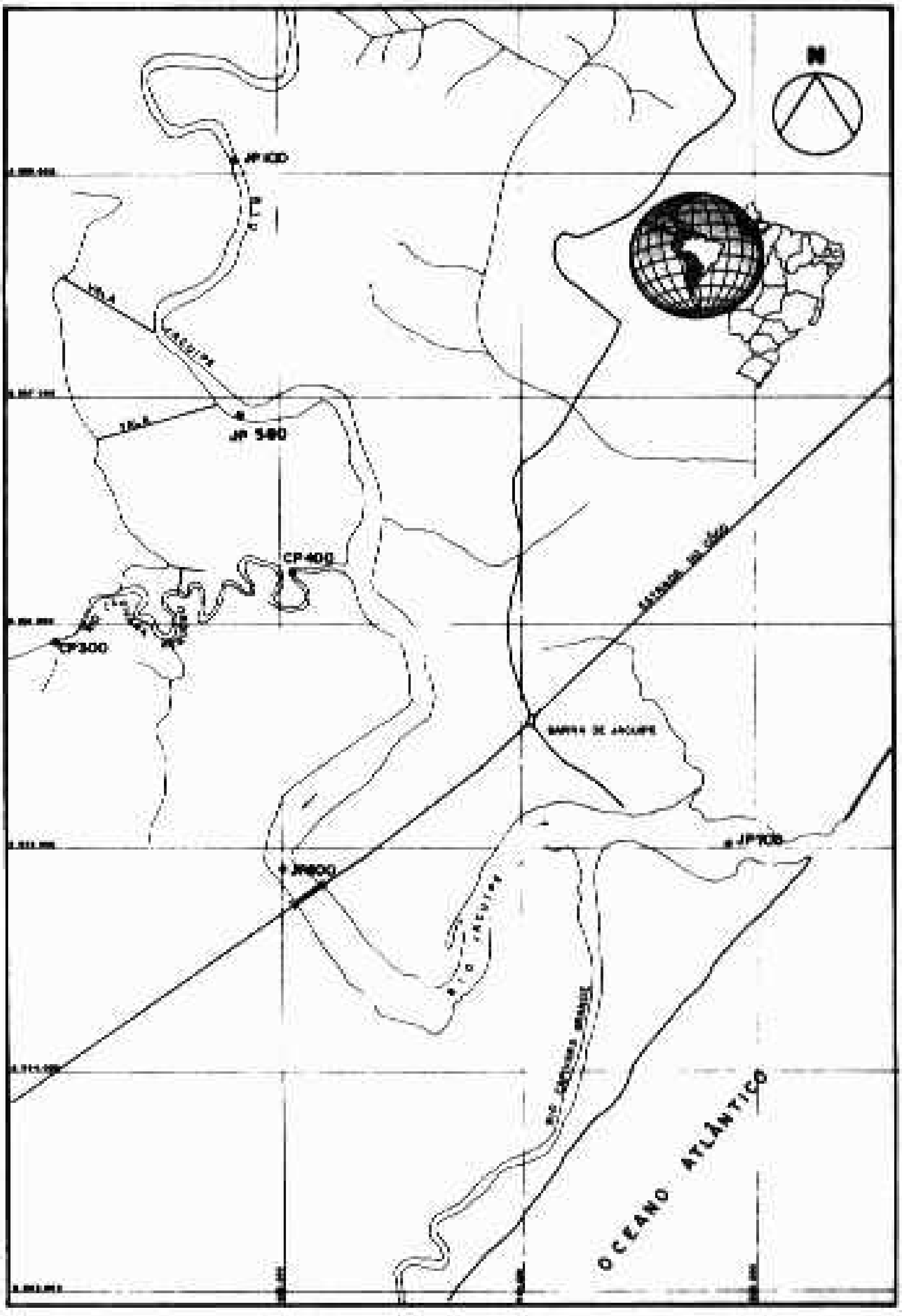

Fig. 1. The Jacuípe Estuary and the location of sampling.

The Jacuipe river estuary is relatively narrow, 105 m at the Station JP–600, with an average depth < 2.8 m during the lowest tide (m.l.s.w.). During the rainy season (March to September) it is common to notice a definite stratification due to a saline water wedge caused by the concomitant increase in surface freshwater flows. The degree of stratification depends directly on the amount of freshwater coming from its source.

During the last 15 years the river and its estuary have suffered from a series of negative environmental impacts: (1) a continuous load of untreated sewage effluent from the populations of the five towns; (2) molasses from a sugar-cane processing factory; (3) input of secondarily treated effluents from the Petrochemical District since 1979; (4) construction of the Santa Helena Dam in 1981; (5) increase in the production of the Petrochemical District without the respective improvement in the treatment in 1983; (6) rupture of the Santa Helena Dam in 1985; and (7) the recently planned transfer of the petrochemical industrial effluents to the ocean through the construction of a pipeline. This paper aims to describe the previous and present environmental status of the estuary and to recommend strategies for future studies based on the collected data.

HUMAN INTERVENTIONS

The Petrochemical District of Camaçari is 45 km to the north of Salvador, where approximately 150 different products are produced, including intermediary and transformed petrochemical products, electrolytic copper, and cellulose, as well as beer.

This generates approximately 100,000 m^3 of inorganic and 60,000 m^3 of organic effluents per day. TABLE 1 shows the characteristics of the specific organic effluents for each type of industry.

The wastewater generated at the Petrochemical District is separated into two streams. The first collects cooling-water and the effluent streams from inorganic processes. The second collects organic wastewater, rain water and domestic sewage. A treatment plant controls the two streams through two completely independent systems and,

TABLE 1 – Types of industries at the Petrochemical Complex of Camaçari and the principal characteristics of their organic effluents (mean annual values).

Type of Industry	Production (Ton/YR)	Waste Characterization Flow m^3/d	Bod ton/d	SS* ton/d
Petrochemical and Basic Chemicals	2,957,800	17,500	9.0	1.8
Petrochemical and Intermediary Chemicals	602,335	6,185	27.5	3.1
Polymers	807,540	7,273	3.3	0.9
Fine Chemicals	245,820	6,913	4.4	1.3
Cellulose	23,435	12,387	3.1	6.1
Brewery	2.4×10^5	5,75	3.8	2.5
Total		56,016	51.1	15.7

* Suspended solids

using activated sludge, treats the organic effluents. Both treated and untreated effluents flow into the Capivara Pequeno a 6 km long tributary, that then flows into the Jacuipe river estuary.

Following the closure of the Santa Helena Dam in 1981, there was an expected increase in the salinity of the estuarine waters (BRAZIL, CRA, 1983), caused by the drop in the current water speed values for the river, from 2400 to 973 m/h.

HISTORICAL MONITORING

The ecological surveillance of the rio Jacuipe has never been conducted regularly. The first studies were in the late 1970s (NOGUEIRA et al., 1976; PAREDES & FREITAS, 1977). During the first half of the eighties some sampling was carried out by the State Environmental Authority (BRAZIL, CRA, 1983, 1985, 1986). In 1987, a regular monitoring programme of the Lower Jacuipe Basin was launched. The sampling strategy has been frequently revised, however, to maximize the value of the data from the survey. Several stations were established along the rio Jacuipe by the CRA, along with five in the estuary and another two in the Capivara Pequeno, which have monitored the physico-chemistry, sediments and biology of the area.

During the dry season the flow of fresh water decreases and the current speed of the incoming tide, allied with the wind, is capable of destabilizing the water column, through turbulence, thus breaking the pycnocline. This complete mixing during the dry season is a very important factor in the management of the estuary as the waters with a high load of organic pollutants are immediately diluted. The effect of these effluents in the water colunm would otherwise be even higher.

The first survey in the Jacuipe estuary conducted by NOGUEIRA et al., (1976) sampled seven stations along the estuary. Their results show that pH varied between 5.6 and 7.8 for Station JP-580 located just above the confluence between the Capivara Pequeno stream and the rio Jacuipe demonstrating that during low tide the pH values decrease. This was also observed for the Stations JP-590 and JP-600 where minimum pH values were 5.4 and 5.6, respectively. PAREDES & FREITAS (1977) showed that oxygen saturation in the estuary waters varied from 42 to 77%, and salinity from 0.24 to 12.55‰ during the ebb tide in June and August. This was at a time when neither the Petrochemical District nor the Santa Helena Dam were in operation. Oxygen concentrations were lower than those found by NOGUEIRA et al. (1976), although the time of sampling was not given. Values during the rainy season are expected to be lower, because of the stirring up of the basin soil. It is possible that the results of NOGUEIRA et al. (1976) were based on samples taken in the dry season while PAREDES & FREITAS (1977) sampled during the rainy season.

Data available from BRAZIL, CRA (1983) also indicated that there were major changes in O_2 in the estuary following the construction of the Petrochemical District (FIG. 2, 3).

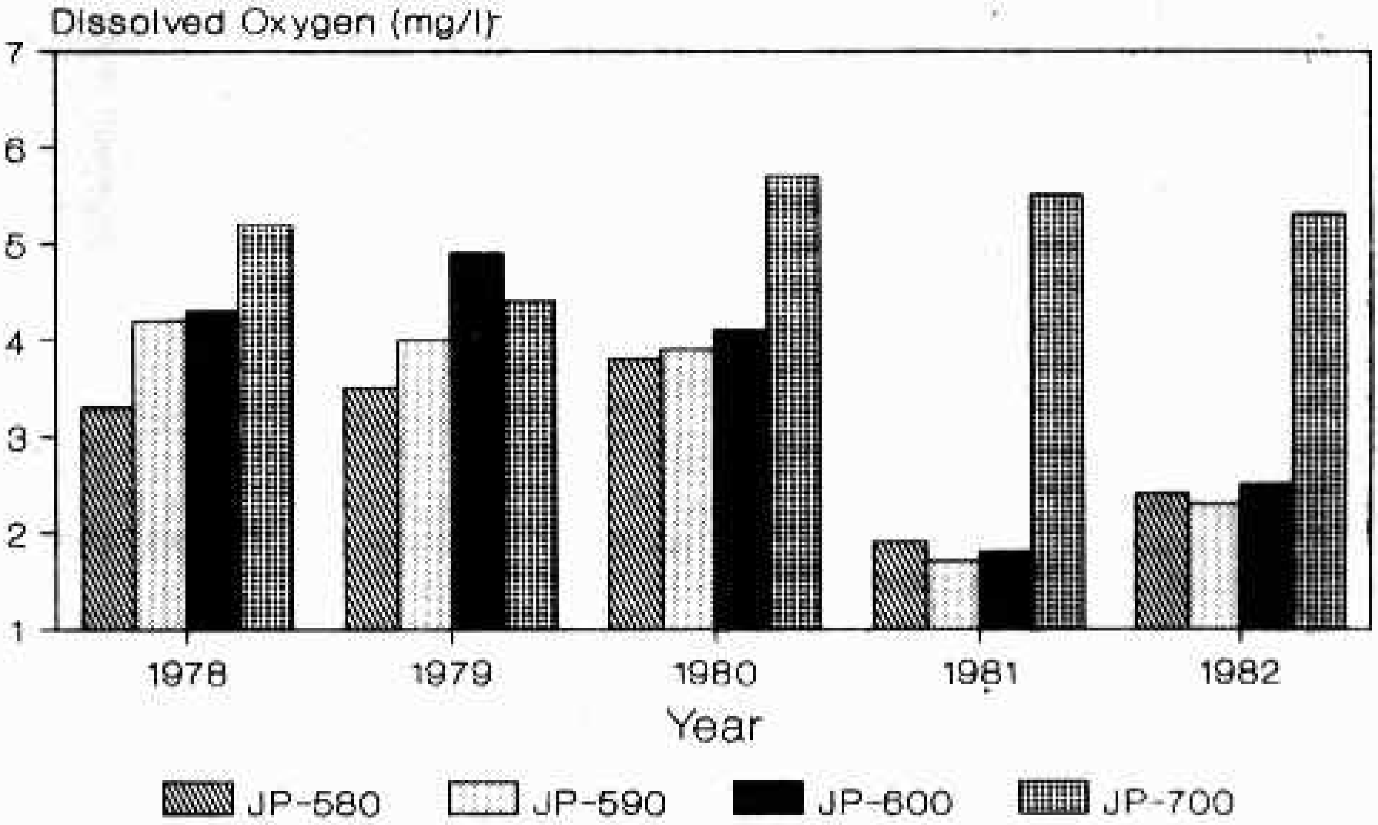

FIG. 2 — Dissolved oxygen concentrations for the Jacuipe estuary from 1978 to 1982, during the low tide (Data from PAREDES & FREITAS, 1978; BRAZIL, CRA, 1983).

In spite of the few data points, it can be seen that during low tides the oxygen concentrations for all stations decreased considerably. This picture is even clearer in the stations located nearer to the mouth of the Capivara stream (JP-580 and JP-590). The mouth of the Jacuipe estuary, on the other hand (station JP-700) seemed to be less affected

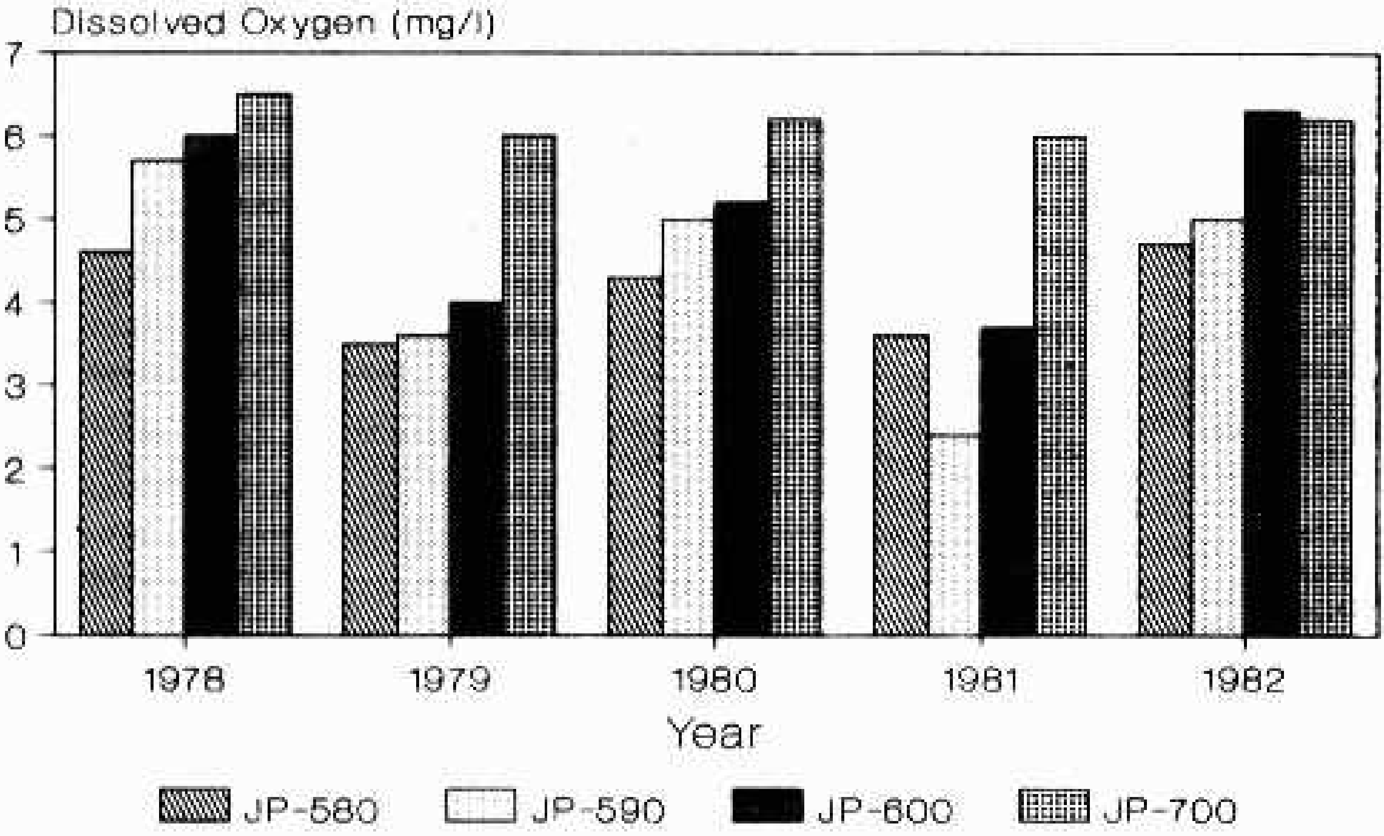

FIG. 3 – Dissolved oxygen concentrations for the Jacuipe estuary from 1978 to 1982, during the high tide (Data from PAREDES & FREITAS, 1978; BRAZIL, CRA, 1983).

by the organic load from the Petrochemical District industries and the decreased water flow due to the Santa Helena Dam. Indeed, the concentrations of dissolved oxygen during high tide did not seem to be much affected by the flow reduction and organic load. VERONESE (1983), who worked along the estuary, demonstrated that dilution due to the rising tide caused and increase in oxygen and decrease in ammonium concentrations. (FIGS. 4, 5).

The State Environmental Office has produced two reports, concerning the rio Jacuipe (BRAZIL, CRA, 1985, 1986), and their results for dissolved oxygen deserve some comment. In 1985, during the period January to April, the station JP-2060, located just below the sugar-cane processing plant, showed oxygen values around 0.0 mg/l. After the sugar-cane processing season ended O_2 values began to increase and reached 6.9 mg/l in September (FIG. 6). In 1985 the plant worked for only the first four months of the year, while in 1986, the low concentration of oxygen occurred from February to April, with a

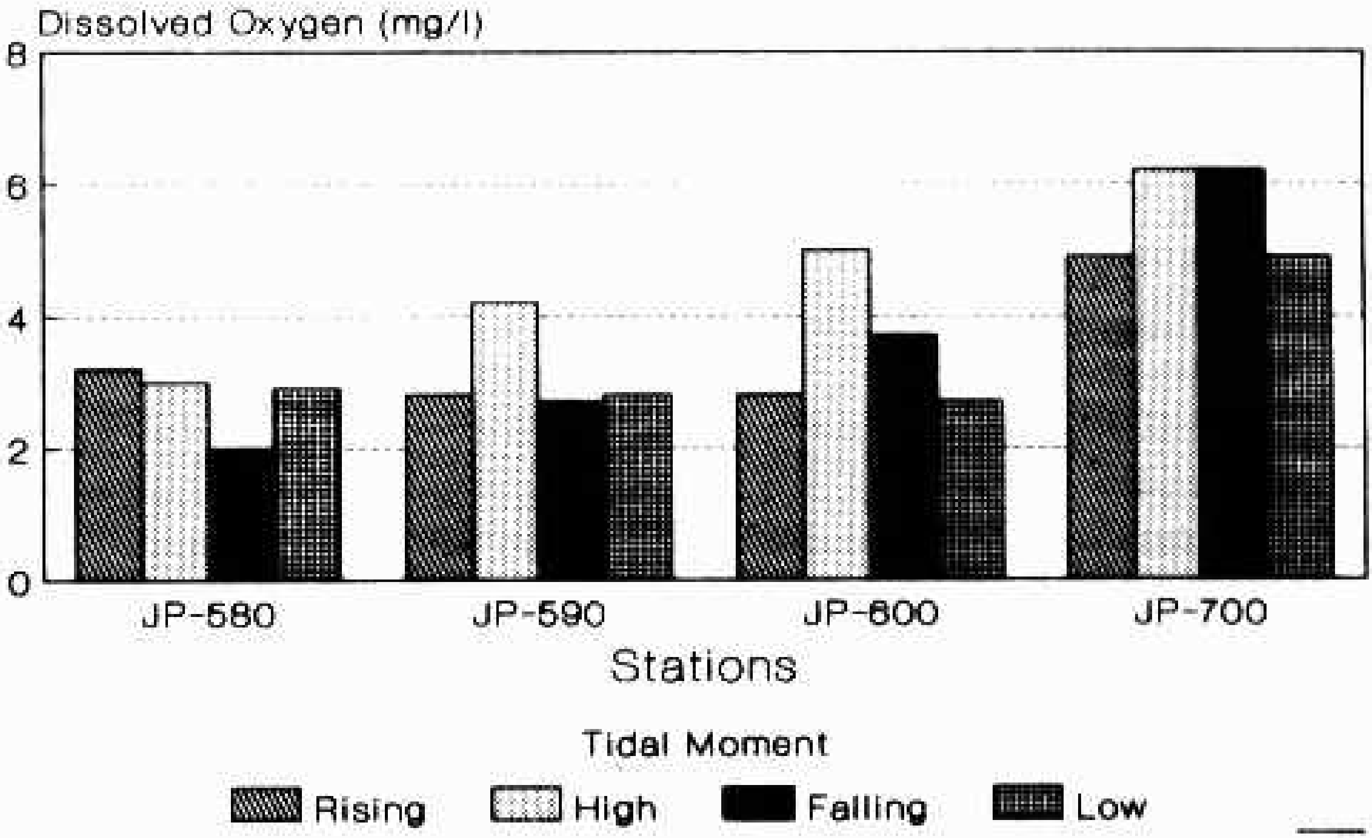

FIG. 4 — Dissolved oxygen concentrations at different tide heights for the Jacuipe estuary (Data from VERONESE, 1983).

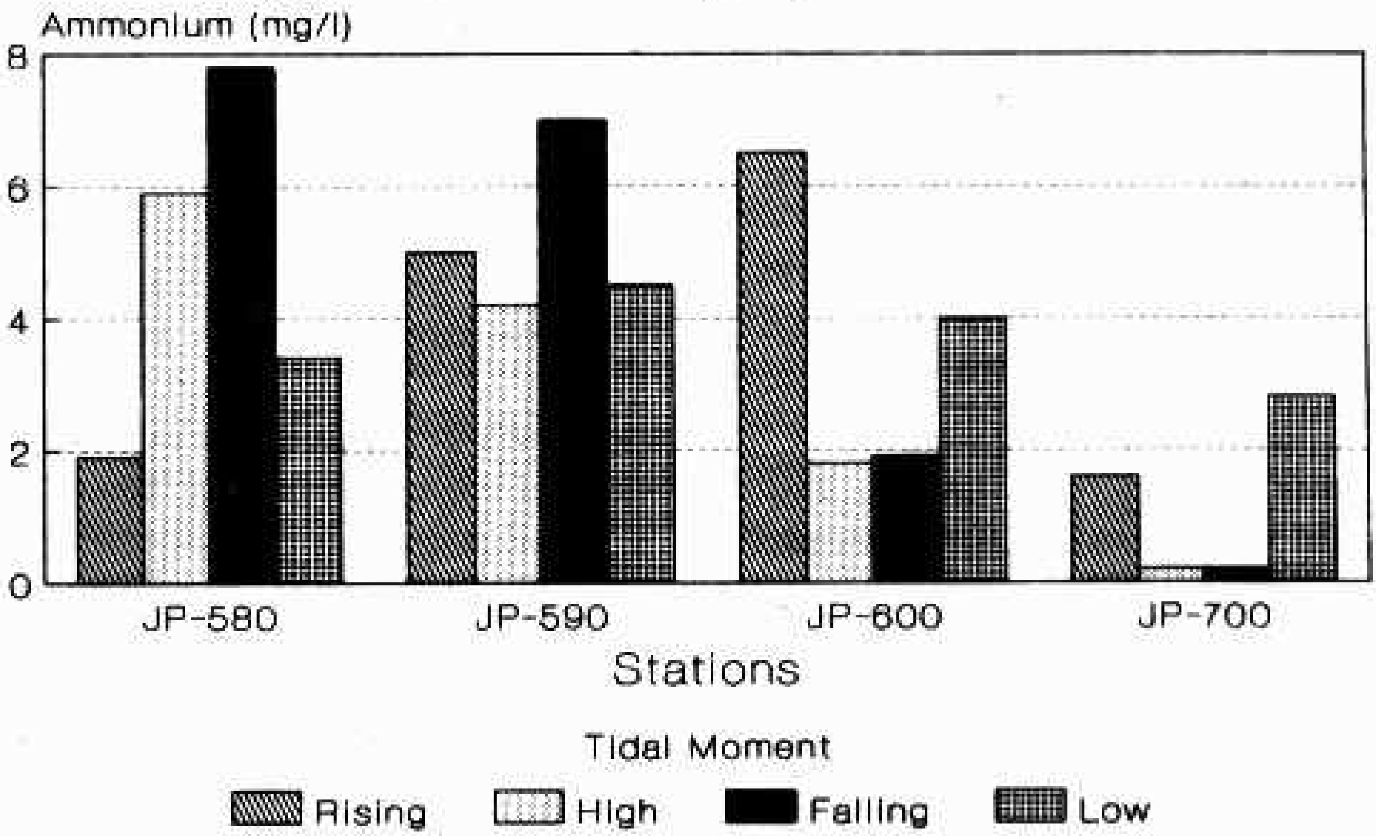

FIG. 5 — Ammonium concentrations at different tide heights for the Jacuipe estuary (Data from VERONESE, 1983).

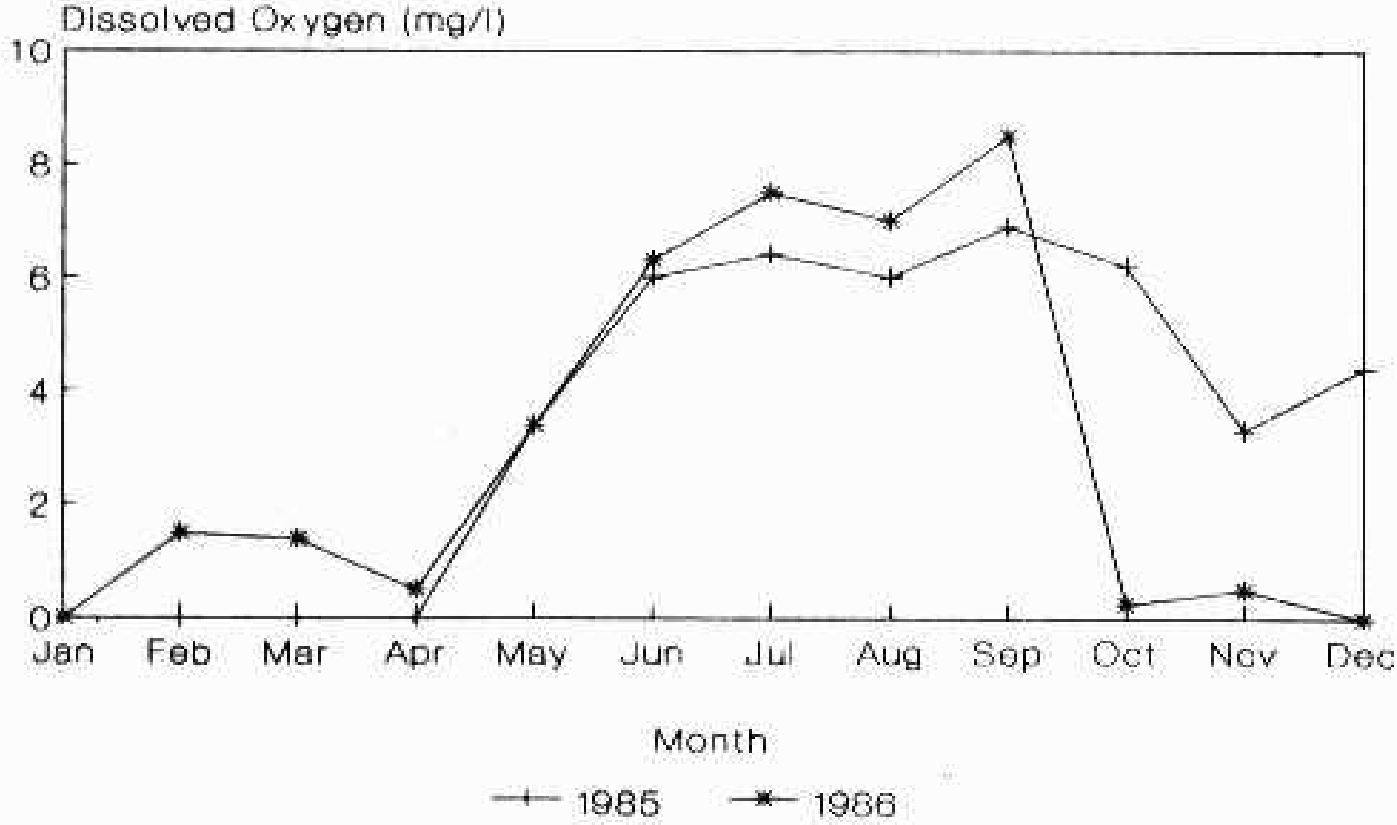

FIG. 6 — Results for dissolved oxygen for the Jacuipe estuary for the years 1985 and 1986 at the station JP–2060 (Data from BRAZIL, CRA, 1985, 1986).

similar increase afterwards until it began operating again in October.

The amount of untreated municipal sewage pumped into the rio Jacuipe in 1980 was calculated to be equivalent to 4200 kg BOD/day for the population living along the river. This would correspond to 4830 kg BOD/day for 1991. The quantities of sewage do not seem to affect water quality as much as the sugar-cane industry and the Petrochemical District.

Considering the fact that the sugar-cane processing plant produces anoxic effluent (0.0 mg/l) and that normal oxygen levels for the rio Jacuipe (15 m^3/s) are around 6.0 mg/l, the actual O_2 concentrations (0.5 mg/l) found in these waters, implies a discharge of at least 12 m^3/s of sugar-cane effluent. Indeed the quantities of residue from sugar-cane plants in Brazil are enormous and reach 13 litres for one kilogram-litre production. Another point to be taken into account in relation to the pollution of the river from sugar-cane processing is that the sugar-cane plant functions mostly during the dry season.

With the break of the Santa Helena Dam several impacts have affected the Jacuipe estuary: (1) a sudden large volume of freshwater, which temporarily changed the salt water content; (2) mechanical destruction of the mangrove fringe, due to the force of the wave; (3) increased deposition of predominantly inert mineral solids, which, for some months, altered the character of the mangrove bed. Although no specific study was lauched at the time, WALLNER (pers. com.) noticed effects on the oyster population, which almost disappeared from the estuary. The mangrove plants nearest to the stream channel were washed away by the wave. At present, six years after the accident, all impacted areas have again been covered by organic material of allocthonous origin, the trees have recolonized the impacted sites, and the oysters again, show high densities in several sites along the estuary (WALLNER et al (1991). Observing fisheries in the region, MALBOISSON (pers. com.) recorded that some fish, oysters, swimming crabs, and prawns have some economic significance for the region.

CURRENT ENVIRONMENTAL STUDIES

A one year study carried out by SILVA et al. (1989) between December/87 and December/88 revealed that during mean spring low-tides the oxygen concentrations in the Jacuípe estuary were always lower than the limits established by Resolution Nº 20 of the National Environmental Council (CONAMA) for estuarine regions. The Capivara Pequeno stream, which receives the treated effluent from CETREL, showed a high level of degradation in water quality: anoxic conditions throughout the year, phenyl concentrations one hundred times above the levels recommended by Brazilian and international legislation (0,001 mg/l) and high values for BOD. Diel studies carried out by ECOLOG (1990) in the estuary of the rio Jacuípe confirmed these previous results. However, two different situations could be defined for the estuary along the year.

1) During the dry season there exists a large variation in the concentration of dissolved oxygen due to the low river flow and the consequently low dilution rate. Oxygen concentrations are at their lowest during the low tide. The rising tide raises the oxygen

concentration due to the influx of highly oxygenated seawater and the consequent dilution of the effluent (FIG. 7).

2) During the rainy season, when the volume of freshwater is high causing greater dilution of the effluents, the influence of the ocean is less significant than during the dry season. The variation in oxygen concentrations is smaller than in the dry season, and the saline intrusion in the estuary creates a saline wedge, tyipical for this time of the year (FIG. 8).

A preliminary study, carried out on the epidermis of mangrove leaves, demonstrated severe changes in the plants inhabiting the area of effluent impact. The leaves were also smaller than those from a non-polluted region used as a control area. The leaves from the estuarine part of Capivara Pequeno also showed an increase in cellular disorganization when compared with those from the mouth of the estuary (ECOLOG, 1989).

In order to assess the availability of heavy metals (Cu, Zn, Pb and Cd) in the dissolved as well as in total form, a survey on *Enteromorpha* sp. (macroalgae) and *Crassostrea rhizophorae* (mangrove oyster) was carried out by DA SILVA et al. (1989). The results showed that the concentrations of Cu, Cd and Zn for three different stations (JP—650, JP—680 and JP—700), all of them under the influence of the industrial effluent, were very small, and that Pb was well under the limit of detection of the AAS. Using *Enteromorpha* sp. as a biomonitor (WALLNER, 1986) the following heavy metal concentrations would be expected to be found in the water: 1.36 for Cu, 4.54 for Zn, 0.091 for Cd, and 0.77 for Pb (ppm). These results indicate that the availability of these metals in the dissolved fraction is indeed very small. The total heavy metal content of mangrove oysters from the Jacuipe estuary and from an upolluted estuary were sampled. The final results showed that values for Cu and Cd in oysters from the Jacuipe estuary were not very different from those taken from the Itariri estuary (control station). However, Zn was comparatively higher in the Jacuipe estuary, moreover these values were even higher than literature values for other oyster species (WONG et al., 1984; PHILLIPS & MUTTARASIN, 1985).

The impact symptoms were brought about in the estuary by the high toxicity of the organic effluent (MATC = 0.47% effluent/volume

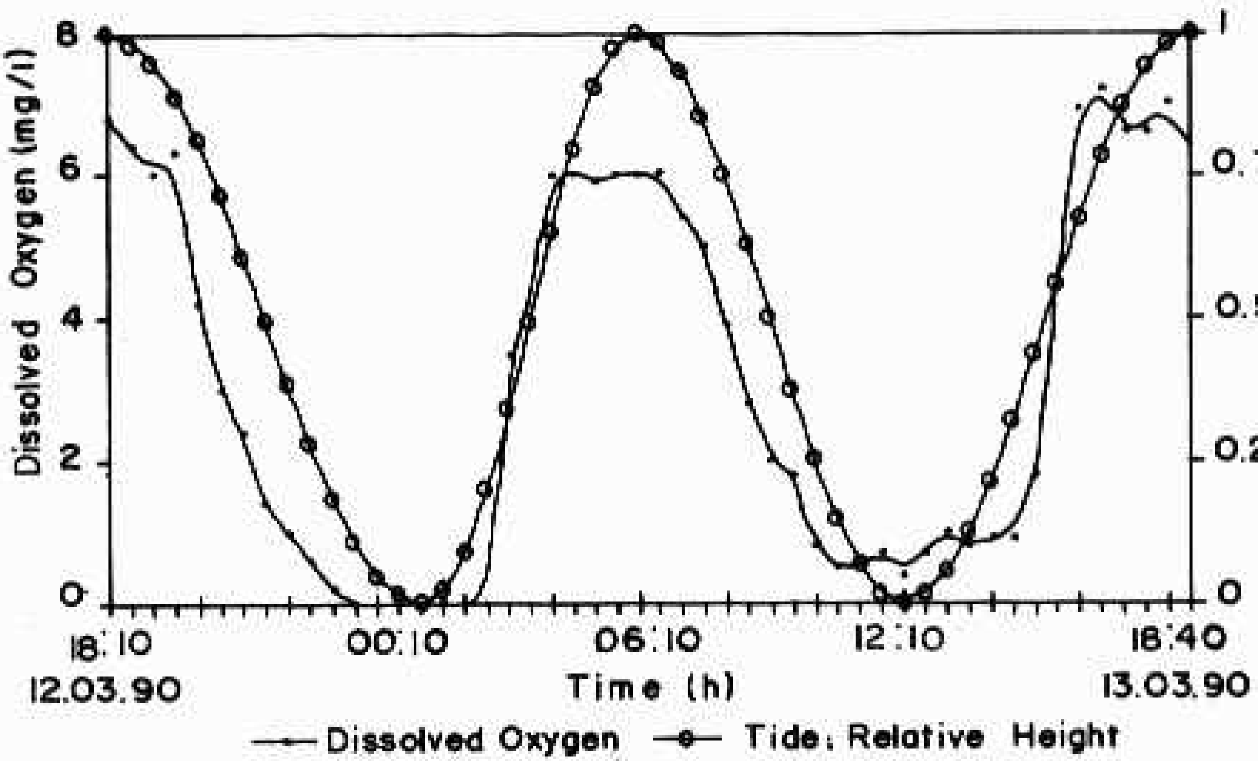

FIG. 7 – Variation of the dissolved oxygen concentration at the surface and the virtual tidal height in a hours sampling cycle in the estuary of the rio Jacuipe (sampling intervals of 30 min) – March, 1990 (dry season).

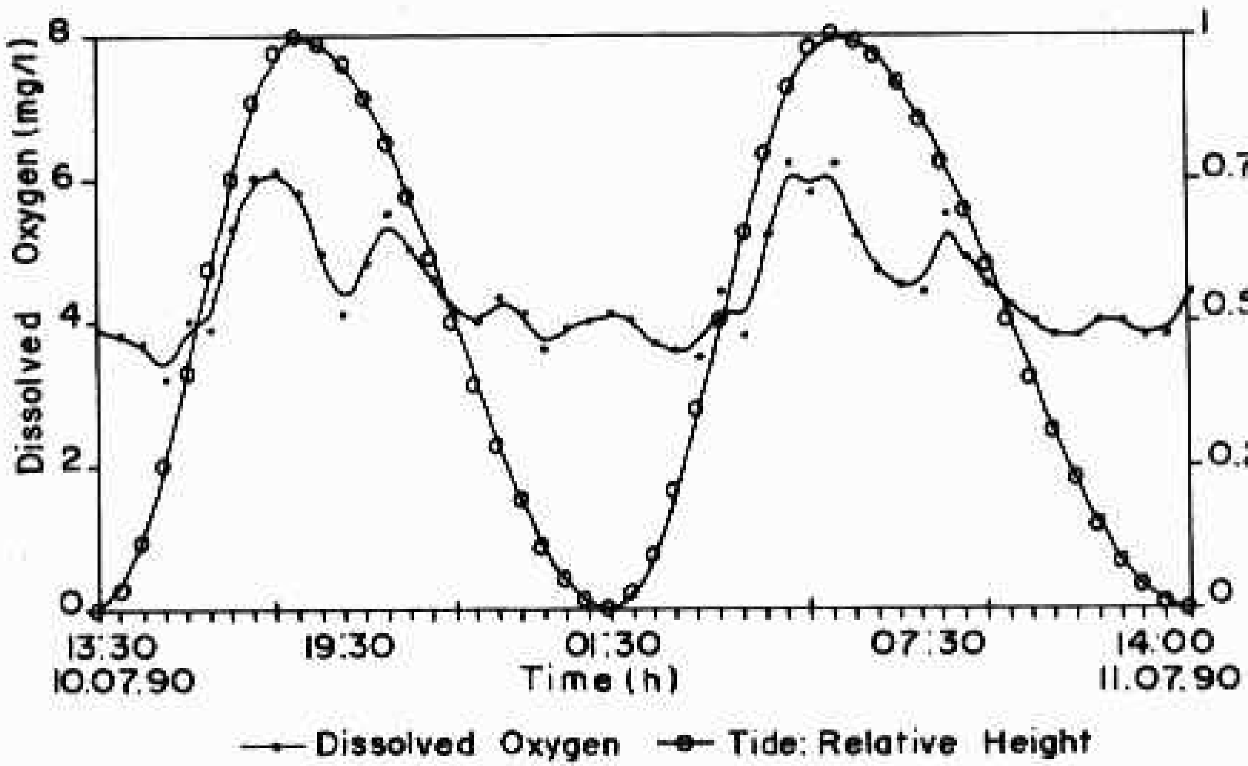

FIG. 8 – Variation of the dissolved oxygen concentration at the surface and the virtual tidal height in a 24 hours sampling cycle in the estuary of the rio Jacuípe (sampling intervals of 30 min) – July, 1990 (rainy season).

of dilution water, for *Artemia,* 48 h test) (ECOLOG, 1989), in combination with a high organic load, because some materials (refractory compounds) present in the "cocktail" cannot be decomposed by the microorganisms of the sludge, and thus go directly into Capivara Pequeno stream and the Jacuípe estuary.

CONCLUSIONS

The disturbance of the Jacuípe river basin has resulted in an estuary with a high level of impact on its biological communities. This imbalanced situation affects the touristic and economic potential of the estuary, and also diminishes the productive activities that could developed there. At present, the dilution level offered by the stream, the river and even by the estuary is small, and is unable to absorb the organic and inorganic load of effluents originating from the petrochemical industries. Therefore, the decision to transfer the effluents to a receiving water body with a greater dilution potential is welcome, and indeed necessary, as it will result in a gradual recovery of the original water bodies from their accumulated contamination. It will certainly take place in a short period of time as most of the pollution is organic in origin, and this pollution source be stopped at once.

In summary, the research conducted so far has demonstrated that both the Capivara Pequeno stream and Jacuípe estuary show a high level of degradation on their structure and function. However, in spite of playing a very important role in the distribution and dispersion of pollutants in coastal ecosystems, the current and velocity patterns together with the water stratificiation have not been sufficiently analysed. The results of the monitoring program of 1987-1989 (SILVA et al, 1989, 1991) are themselves not sufficient to describe with precise certainty the behaviour of the estuarine waters and more studies in this field are necessary, considering the future establishment of new communities and conditions along the Capivara Pequeno stream and the Jacuípe estuary.

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REFERENCES

BRAZIL, CRA (Centro de Recursos Ambientais). Avaliação da Qualidade dos Recursos Ambientais. Gerência de Avaliação e Controle de Impactos Ambientais, 1983. (Final Report).

BRAZIL, CRA (Centro de Recursos Ambientais). Avaliação da Qualidade dos Recursos Ambientais. Gerência de Avaliação e Controle de Impactos Ambientais, 1985. (Final Report).

BRAZIL, CRA (Centro de Recursos Ambientais). Avaliação da Qualidade dos Recursos Ambientais. Gerência de Avaliação e Controle de Impactos Ambientais, 1986 (Final Report).

ECOLOG. Estudo das influências dos efluentes do polo Petroquímico de Camaçari no Rio Capivara Pequeno e no Estuário do Rio Jacuípe. CETREL – 1989. 23p. (Internal Report).

ECOLOG. Estudos das influências dos efluentes do polo Petroquímico de Camaçari no Estuário do Rio Jacuípe – Parte III. CETREL – 1990. 32p. (Internal Report).

FAIRBRIDGE, R.W. The estuary: Its definition and geodynamic cycle. In: OLAUSSON, E., CATO, I. (eds). *Chemistry and Biogeochemistry of Estuaries*. Chichester: John Wiley & Sons Ltd., 1980. p.1-35.

NOGUEIRA, V.P. et al. Proposta de enquadramento da Bacia Hidrográfica do Rio Jacuipe. CEPED (Research and Development Centre from the state of Bahia), 1976. 13p. (Internal Report).

PAREDES, J.F., FREITAS, R.R. Estudos do Meio Ambiente. I. Levantamento ecológico do estuário do Rio Jacuípe. CEPED, 1977. 26p. (Internal Report).

PHILLIPS, O.J.H, MUTTARASIN, K. Trace metals in bivalve molluscs from Thailand. *Marine Environmental Research*, v.15, p.215-234, 1985.

SILVA, E.M., LANDIM, H.B., PASENAU, H., MALBOISSON, J., VALENTE, M.C., WALLNER, M. MACEDO, N.A. Avaliação das influências dos efluentes da CETREL no Rio

Capivara Pequeno e Estuário do Rio Jacuípe. 1989, 20p. (Internal Report).

SILVA, E.M., WALLNER, M., PASENAU, H. A 24 h cycle of hydrological factors in the estuary of the Jacuipe River, Camaçari, Bahia, Brazil. Abstract of the III INTERNATIONAL CONGRESS OF ENVIRONMENTAL CHEMISTRY, 1991, Bahia. *Proceedings...* Bahia, 1991.

VERONESE, G. Comportamento da qualidade de um estuário em função da evolução do ciclo de marés. In: XII BRAZILIAN CONGRESS OF ENVIRONMENTAL AND SANITARY ENGINNERING, 1983. *Proceedings...* 22p.

WALLNER, M. Monitoramento para cobre, zinco, cádmio e chumbo em estuários tropicais brasileiros, utilizando *Enteromorpha* sp. como organismo monitor. Rio Grande, Fund. Univ. Rio Grande, 1986. 86p. (MSc. Dissertation).

WALLNER, M., MACEDO, N.A., SILVA, E.M. da. Heavy metals concentrations and anatomical studies of mangrove plants at the estuary of the Jacuipe River. III INTERNATIONAL ENVIRONMENTAL CHEMISTRY CONGRESS IN BRAZIL, 1991, Proceeding..

WONG, M.H., CHOY, C.K., LAU, W.M., CHEUNG, Y.H. Heavy metal contamination of the Pacific Oyster (*Crassostrea gigas*) cultured in Deep Bay, Hurra King. *Environmental Research*, v.25, p.302-309, 1984.