



## Seasonal effects of wastewater to the water quality of the Caeté river estuary, Brazilian Amazon

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### ABSTRACT

Bragança's socioeconomic situation is highly dependent on estuarine and marine biological resources that are influenced by tidal cycles and climatology. Field measurements (hydrological, hydrodynamic and microbiological variables) were taken in the most urbanized zone from Caeté estuary to characterise the quality of the local environment. During the dry period, the estuary was more eutrophic and presented the highest temperature (30.5°C in Oct./06), salinity (17 psu in Feb./07), pH (8.24 in Feb./07) and fecal coliform (>1000 MPN/100 ml in Dec./06 and Feb./07) values. The phytoplankton *Cyclotella meneghiniana*, *Coscinodiscus centralis* and other r-strategist species were observed. The lack of basic hydric canalization was responsible for the local contamination, especially during the dry period when more concentrated wastewater from the city was emitted into the estuary, showing the human influence on the reduction of local estuarine water quality. In Bragança, the fishery is considered one of the main economic activities so, this contamination is worrisome because a large part of the local economy depends on biological resources and, thus, the contamination could negatively affect the environmental health of this Amazon ecosystem.

**Key words:** Equatorial estuary, temporal variation, eutrophication, northern Brazil.

### INTRODUCTION

The coastal zone is a transitional region between the continent and the marine environment, and in tropical areas it presents some of the most valuable and productive ecosystems of the world (e.g. mangrove forest and estuaries). However, many changes are taking place within the coastal landscape as a result of population growth and rapid urbanization (e.g. Lozano et al. 2005, Steffy and Kilham 2006, Pereira et al. 2007a).

In the last decades, some social and environmental problems have emerged in the coastal zones worldwide, due to rapid urban development including industrial, port, commercial, agriculture, aquaculture, fish-

eries and tourism activities. These activities need efforts to conserve and recover the productivity of coastal resources and water quality, as well as to improve the health of coastal communities (Linton and Warner 2003, Burak et al. 2004, Chen et al. 2005, Lau 2005).

The Brazilian Amazon represents about 35% of the country's 8,500 km long coastline (Isaac and Barthem 1995), and 85% of the mangroves in Brazil are found in this section of coastline. The mangroves in the Brazilian Amazon coast represent the second largest continuous worldwide mangrove system on the planet (Lara 2003).

Located in the northeastern state of Pará, Bragança is one of the most important cultural and historical cities in the Amazon littoral. The local socioeconomic situation is directly dependent on biological resources, which

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are influenced by macrotidal cycles and climate (Glaser and Diele 2004, Souza Filho et al. 2006, Barbosa et al. 2007, Pereira et al. 2007b). The lack of public services is also responsible for some of the environmental problems observed in the Caeté estuary, which is the main estuary of this county (Guimarães et al. 2009). The aim of this study was to characterise the water quality and the aim at the effects of human urbanization practices on the environmental status of this Amazon estuary.

### STUDY AREA

The Bragantian coastal plain is located between the Maiaú and Caeté river bays ( $00^{\circ}46' - 1^{\circ}00'S$  and  $46^{\circ}36'' - 46^{\circ}44'W$ , Cohen et al. 2004). Bragança represents the third most productive fishing area in the State of Pará and its main harbours are located in the Caeté estuary, which includes the city's main river (Silva et al. 2006, Guimarães et al. 2009) (Fig. 1).

The regional climate in the studied area is equatorial humid with two main seasons, a rainy and a dry period. The rainy period, which normally occurs between January and June, is characterised by a mean rate of rainfall exceeding 2,200 mm and temperature values up to  $30^{\circ}C$ . On the other hand, the dry period, which occurs between July and December, presents higher insolation and evaporation rates, a mean rainfall of 100-200 mm and temperature values up to  $32^{\circ}C$ . The wind also has a seasonal pattern, with the strongest winds occurring during the dry season, and more moderate winds occurring during the rainy period (Martorano et al. 1993, Lara 2003).

The area's tides are semidiurnal with a maximal tidal height between 4 and 6 m. Tidal currents usually reach higher values ( $\sim 1.5 \text{ m.s}^{-1}$ ) during the equinoctial spring tides (Cohen et al. 1999).

About 57,000 people live in Bragança's urban area and the local economy is based on fisheries, commerce, agriculture and tourism (IBGE 2003).

### METHODS

Precipitation data were furnished by a meteorological station from the Instituto Nacional de Meteorologia (INMET) located in Tracuateua (about 40 km from Bragança harbours). Water sampling was carried out bi-monthly at one fixed station (Fig. 1), totaling of one

year of sampling collection on the waterfront of Bragança. Each sampling was performed during spring tides over a 24h-period near the city's main harbour (located approximately 36 km from the Atlantic Ocean and therefore at the upper estuary, according to Barletta et al. 2005) between April/2006 and February/2007. During each sampling period, physical (tide and currents, measured at every 10 min), chemical (hydrological data, collected at every 6 h) and biological (microphytoplankton and fecal coliform, collected at every 6 h) variables were measured in the sub-surface water (0-3 m depth). The water transparency was measured using a Secchi disc between 10 am and 14 pm.

Hydrological and microbiological data (pH, dissolved oxygen, dissolved nutrients, chlorophyll *a* and fecal coliform) were obtained from the analysis of water samples collected with Niskin oceanographic bottles. Water salinity and temperature were obtained using a CTD (XR-420, RBR). Sub-surface current speeds were measured using a Sensordata SD6000 current metre. The variation in local water levels was simultaneously surveyed using a graduated pole fixed in Bragança's harbour. Additional sub-surface samples were collected with a plankton net with a mesh size of  $64\mu\text{m}$  to characterise microphytoplankton composition. Field and laboratory studies followed methodologies used by the American Public Health Association (2004) and other analytic manuals (e.g. Strickland and Parsons 1968, 1972, Grasshoff et al. 1983). The floristic composition was assessed by identifying specific and infra-specific taxa using specialized bibliography (Cupp 1943, Sournia 1975, Ricard 1987, Tomas 1997).

The main human activities that affect direct or indirectly the water quality of this estuary were observed around the studied area.

The normality and homogeneity of hydrological data (salinity, temperature, pH, dissolved oxygen, dissolved nutrients such as nitrite, nitrate, phosphate and chlorophyll *a*) were tested using Lilliefors (Conover 1971) and Bartlett's Chi-square tests (Sokal and Rohlf 1969), respectively, in the STATISTICA 6.0 package (StatSoft 2001). When the analysed data were not normal,  $\log(x + 1)$  transformations were performed to achieve near-normal distributions, and one-way ANOVA tests were used to find differences in the hydrological

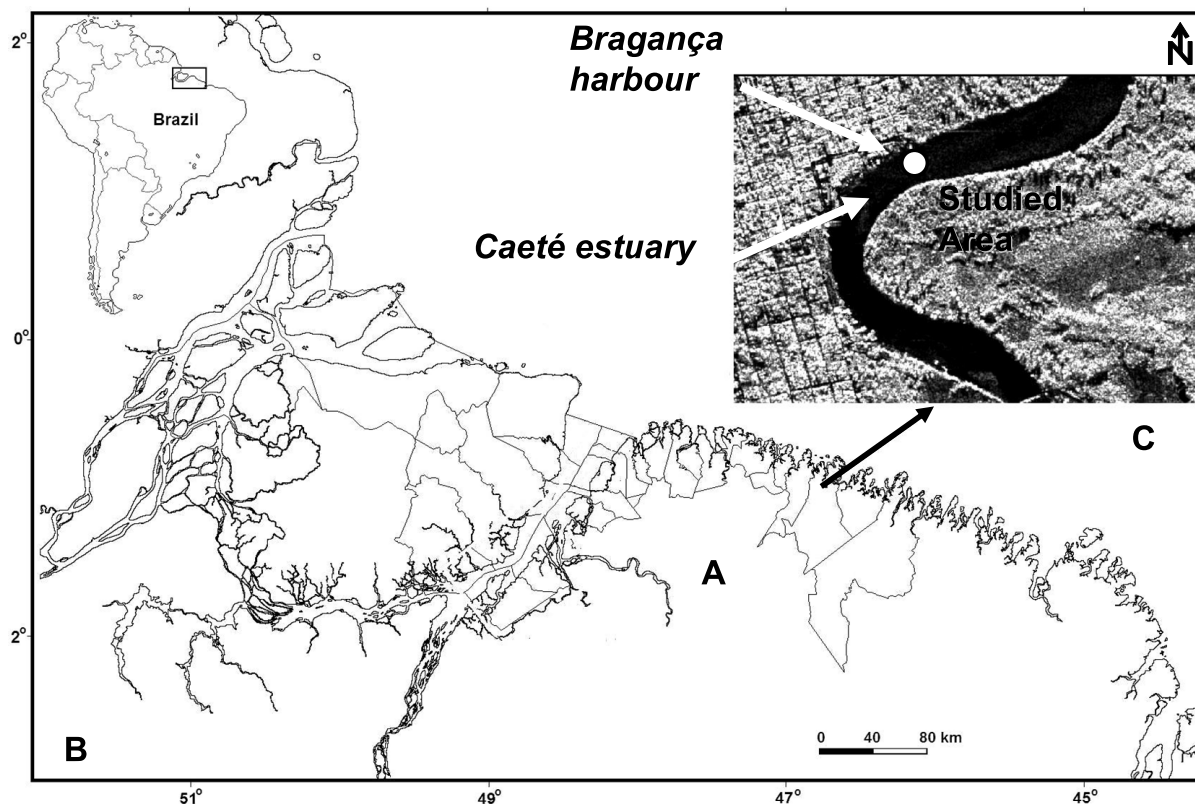


Fig. 1 – Pará State coastal area (A) (made by Souza-Filho), Northern of Brazil (B) and Bragança harbour with the position of the sampling station (C).

parameters between seasonal periods with a significance level of 0.05. However, when the variances were heterogeneous, a non-parametric Mann-Whitney  $U$ -test was applied (Zar 1999) using the same significance level referred to above (0.05).

### RESULTS

The Caeté estuary is strongly affected by human activities in several different ways. The lack of basic hydric canalization in Bragança city, for example, affects the water quality of this estuary, particularly in the more urbanised zones where the most concentrated domestic, hospital and commercial sewage is emitted daily. In addition, on the waterfront of the city there are public markets, fishery harbours and ice factories that contribute directly to organic and inorganic contamination of the Caeté estuary.

Physical, chemical and biological data showed strong seasonal variations due to the very well-defined climatic seasonal structure. The regional climate in the

studied area is highly seasonal with two main seasons, dry and rainy. During the studied period, the dry period occurred from July/06 to February/07, characterised by a rainfall rate of 384.5 mm. The rainy period comprised January/06 until June/06 and was characterised by a rainfall rate of 2,363.1 mm. Constant and strong winds were registered during the dry period (in general higher than  $>4 \text{ m.s}^{-1}$ ), while strong gusts were observed during the rainy period.

Hydrodynamic data showed a predominance of high energy conditions during the year, which were characterised by stronger currents as a consequence of the elevated wind intensities (during the dry period) and high rainfall rates (during the rainy period). The maximal variation of the water level was 4.8 m in December/06 (strong winds) and the maximal tidal current was higher than  $1.2 \text{ m.s}^{-1}$  in April/06 (equinoctial spring tide). During the rainy period, maximal tidal currents (Fig. 2) were observed mainly during the ebb tide due to an increased outflow of the Caeté estuary. During the

dry period, the highest tidal current intensities (Fig. 2) were observed during the flood tide, possibly as a consequence of strong winds and due to the decrease in the Caeté river outflow.

During the rainy period, salinity values ranged between zero (April and June/06) and 0.60 psu (August/06), while the temperature ranged between 26.10°C (June/06) and 28.90°C (August/06). Values for water pH ranged between 6.09 (April/06) and 7.63 (August/06), while water transparency ranged between zero (April/06) and 20 cm (June/06) due to high suspended particulate material and high nebulosity. Dissolved oxygen concentrations were significantly higher ( $F=12.39$ ,  $p=0.0019$ ) during this period and ranged between 4.10  $\text{m.L}^{-1}$  (August/06) and 8.40  $\text{mg.L}^{-1}$  (June/06). Chlorophyll *a* concentrations ranged from 5.06  $\text{mg.m}^{-3}$  (August/06) to 28.09  $\text{mg.m}^{-3}$  (April/06) with slightly higher values during the rainy period, although no significant differences were observed between the studied seasons (Fig. 3). With respect to dissolved nutrient concentrations, the maximum observed values were 0.36  $\mu\text{M}$  (in April/06) for nitrite, 14.42  $\mu\text{M}$  (in August/06) for nitrate and 0.83  $\mu\text{M}$  (in August/06) for phosphate (Fig. 3).

In the dry season, the low rainfall contribution, the low continental freshwater input and high insolation and evaporation rates were responsible for significantly higher values of temperature ( $F=31.73$ ,  $p<0.05$ ), salinity ( $U=2.00$ ,  $p<0.05$ ) and pH ( $F=24.88$ ,  $p<0.05$ ). Temperatures oscillated between 27.80°C (February/07) and 30.50°C (October/06), while salinities values ranged from 0.30 psu (October/06) to 17 psu (February/07). Values for pH ranged between 7.04 (October/06) and 8.24 (February/07). The lowest dissolved oxygen and chlorophyll *a* concentrations were observed during the dry season and ranged from 3.0  $\text{mg.L}^{-1}$  (December/06) to 7.50  $\text{mg.L}^{-1}$  (February/07) and 3.86  $\text{mg.m}^{-3}$  (October/06) to 19.52  $\text{mg.m}^{-3}$  (February/07) (Fig. 3), respectively. Nitrate and nitrite values were significantly higher during this season ( $F=107.01$ ,  $p<0.05$ ;  $U=24.00$ ,  $p<0.05$ , respectively) with maximum respective values of 5.07  $\mu\text{M}$  (nitrite- $\text{NO}_2$ , December/06) and 59.35  $\mu\text{M}$  (nitrate- $\text{NO}_3$ , February/07). Phosphate- $\text{PO}_4$  concentrations, which reached a maximum value of 6.60  $\mu\text{M}$  in October/06, did not differ between seasons (Fig. 3).

Fecal coliform data showed that the maximum values also occurred during the dry season ( $>1100$  MPN/100 ml) in December/06 and February/07, while the lowest values were observed during the rainy period (110 MPN/100 ml) in April/06 (Fig. 4).

In the studied area, the micropycoplankton community was made up of 132 taxa, of which 97% were Bacillariophyta (diatoms). Dinophyta (1.50%) and Cyanophyta (1.50%) were less represented groups.

Diatoms were represented by three classes, nine sub-classes, 20 orders, 34 families and 52 genera. *Coscinodiscus* Ehrenberg (15 taxa), *Nitzschia* Hassall (11 taxa) *Chaetoceros* Ehrenberg (six taxa) were the predominant genera. Five genera of Bacillariaceae and four genera of Triceratiaceae were observed, making these the most frequently-observed families. Well-represented species were *Coscinodiscus centralis* Ehrenberg, *Coscinodiscus concinnus* Wm. Smith, *Coscinodiscus perforates* Ehrenberg, *Dimeregramma minor* (Gregory) Ralfs, *Ditylum brightwellii* (West) Grunow, *Odontella sinensis* (Greville) Grunow, *Thalassionema frauenfeldii* (Grunow) Hallegraeff, *Cyclotella meneghiniana* Kützing and *Asterionellopsis glacialis* (Castracane) Round.

The occurrence of r-strategist species, such as *Asterionellopsis glacialis*, *Coscinodiscus centralis*, *Cyclotella meneghiniana* and *Skeletonema* spp., which were mainly observed in the dry periods, suggested local eutrophication.

*Dimeregramma minor* was the most abundant species, representing between 56% and 82% of the total number of cells counted in the samples.

## DISCUSSION

In general, the rainy period in the Pará State comprises the months from January to June, while the dry period occurs during the remaining months of the year (Martorano 1993). However, in the present study, the rainiest months were observed from April to August/2006, while the dry period occurred between the months of September/2006 and February/2007. Due to the delay of the rainy period, it was possible to observe an elevated difference of the hydrological data between April/06 (rainy period) and February/07 (dry period). This pattern of rainfall was also recorded by Moraes et al. (2005), in a study that analysed a historical data series of 23 years

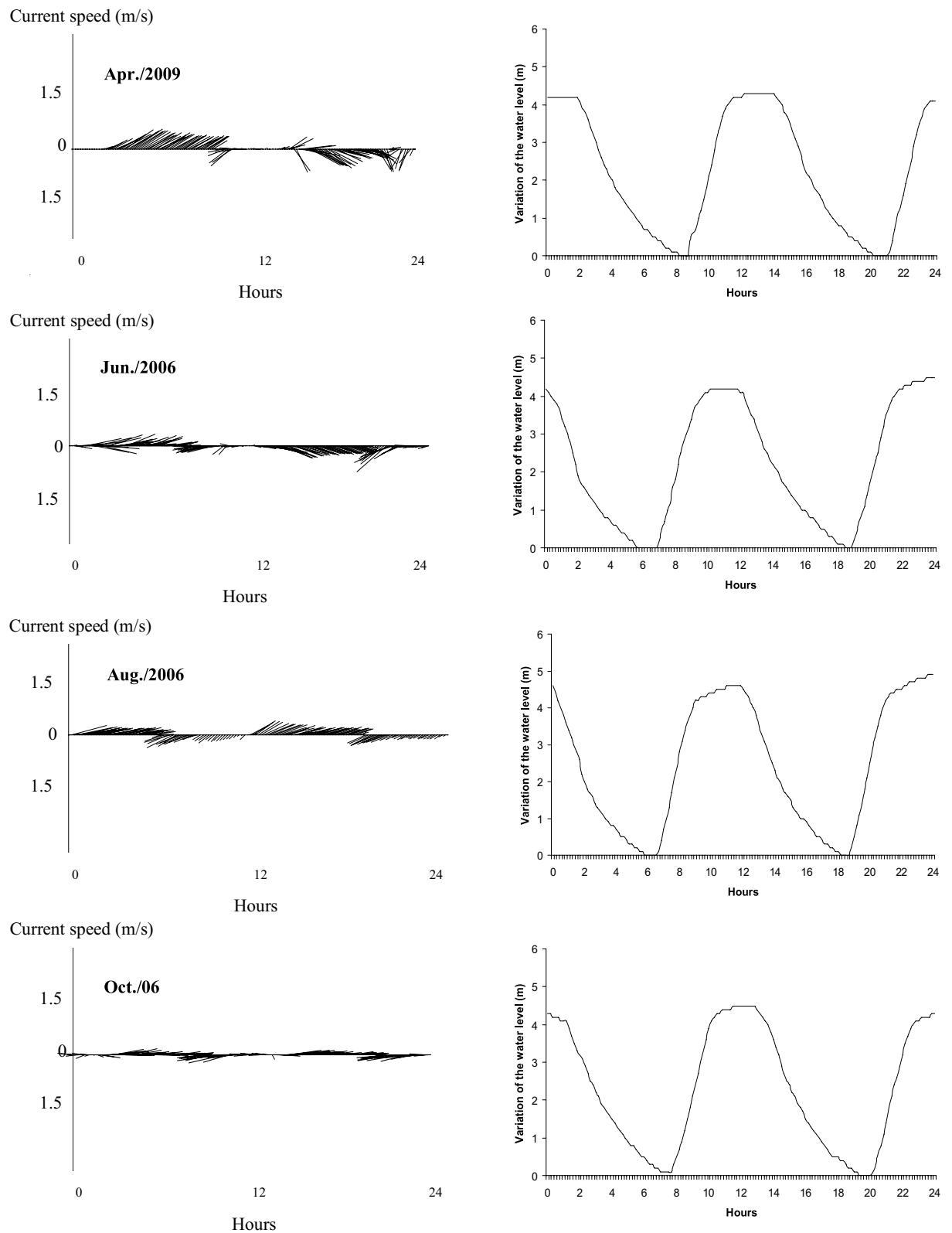


Fig. 2 – Hydrodynamic data recorded between April/06 and February/07, during spring tides, in the Caeté estuary.

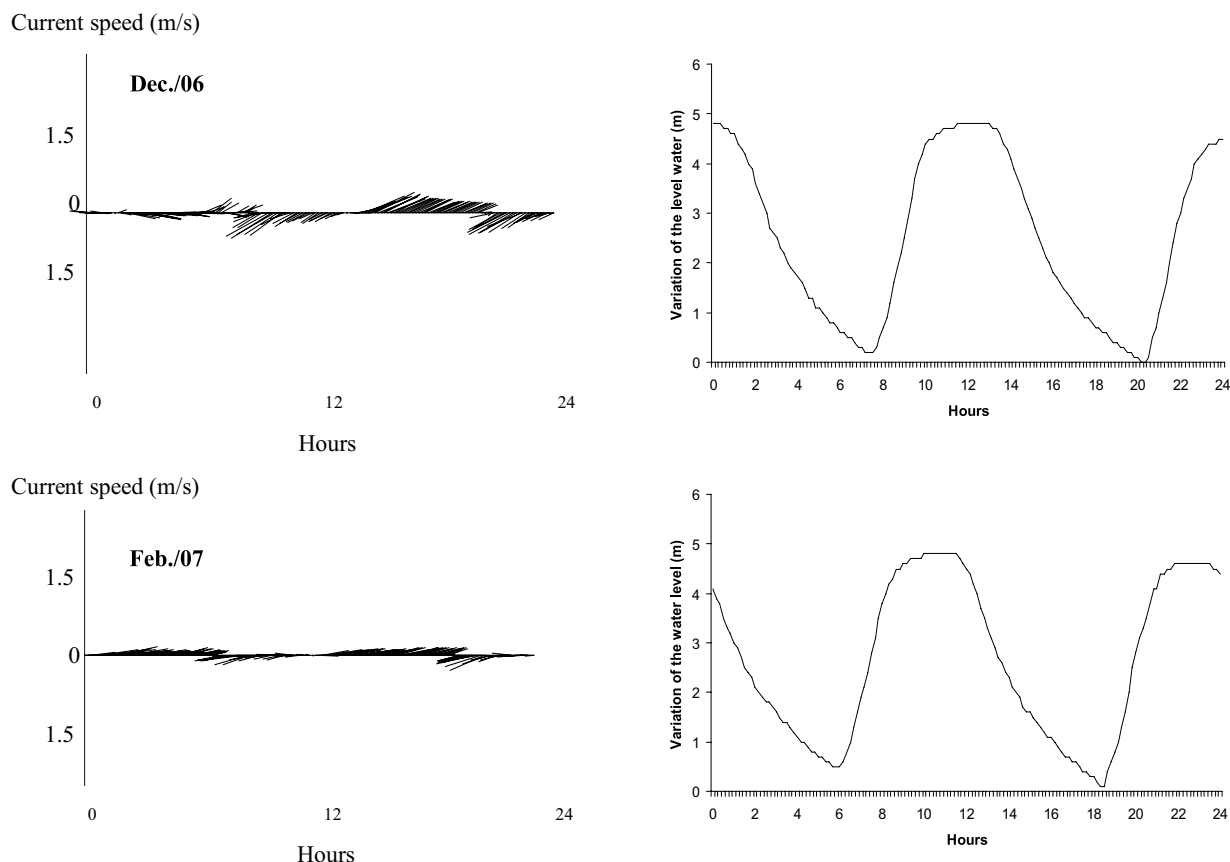


Fig. 2 (Continuation) – Hydrodynamic data recorded between April/06 and February/07, during spring tides, in the Caeté estuary.

(1976-1998) and reported a conspicuous delay in the beginning of the rainy period in the Bragantine zone when compared to other zones of the Pará State.

The strong hydrodynamic regime in the Amazon estuaries is a consequence mainly of macrotidal cycles, high tidal current intensities and strong trade winds (Meade et al. 1985, Figueroa and Nobre 1990, Beardsley et al. 1995, Marengo 1995, Geyer et al. 1996, Monteiro et al. 2009, Pereira et al. 2009).

In the studied area, tidal asymmetry was recorded in the two seasons and the tidal current data showed differences (period and intensity of the tidal currents) between the ebb and flood tides. In the Amazon coastal zone, the mangrove system and creeks, the presence of many estuaries, as well as the occurrence of sand banks, may be responsible for the local tide asymmetry (Mazda et al. 1995, Lam-Hoai et al. 2006, Pereira et al. 2009, Monteiro et al. 2009). Observations of current speed showed that, during the dry period (when the estuarine

water is most contaminated and the flood tide current is stronger), the organic contaminants may be transported to the upper part of the Caeté estuary. During the rainy period (when ebb tide currents are stronger), the organic contaminants seem to be transported to the lower part of the estuary. Silva et al. (2006) and Guimarães et al. (2009) showed that organic and inorganic contaminants emitted into the Caeté estuary have affected the environmental quality and human health in the upper part of this estuary.

The high variability in the rainfall rates commonly found in the equatorial zone during the rainy period was responsible for the lowest salinity, temperature and transparency values during this season. In addition, the pH ranged from slightly acid to alkaline, showing the effects of freshwater input from rainfall and river runoff on estuarine waters. Conversely, the high dissolved oxygen concentrations observed during the rainy period indicated a higher water-atmosphere interaction due to the

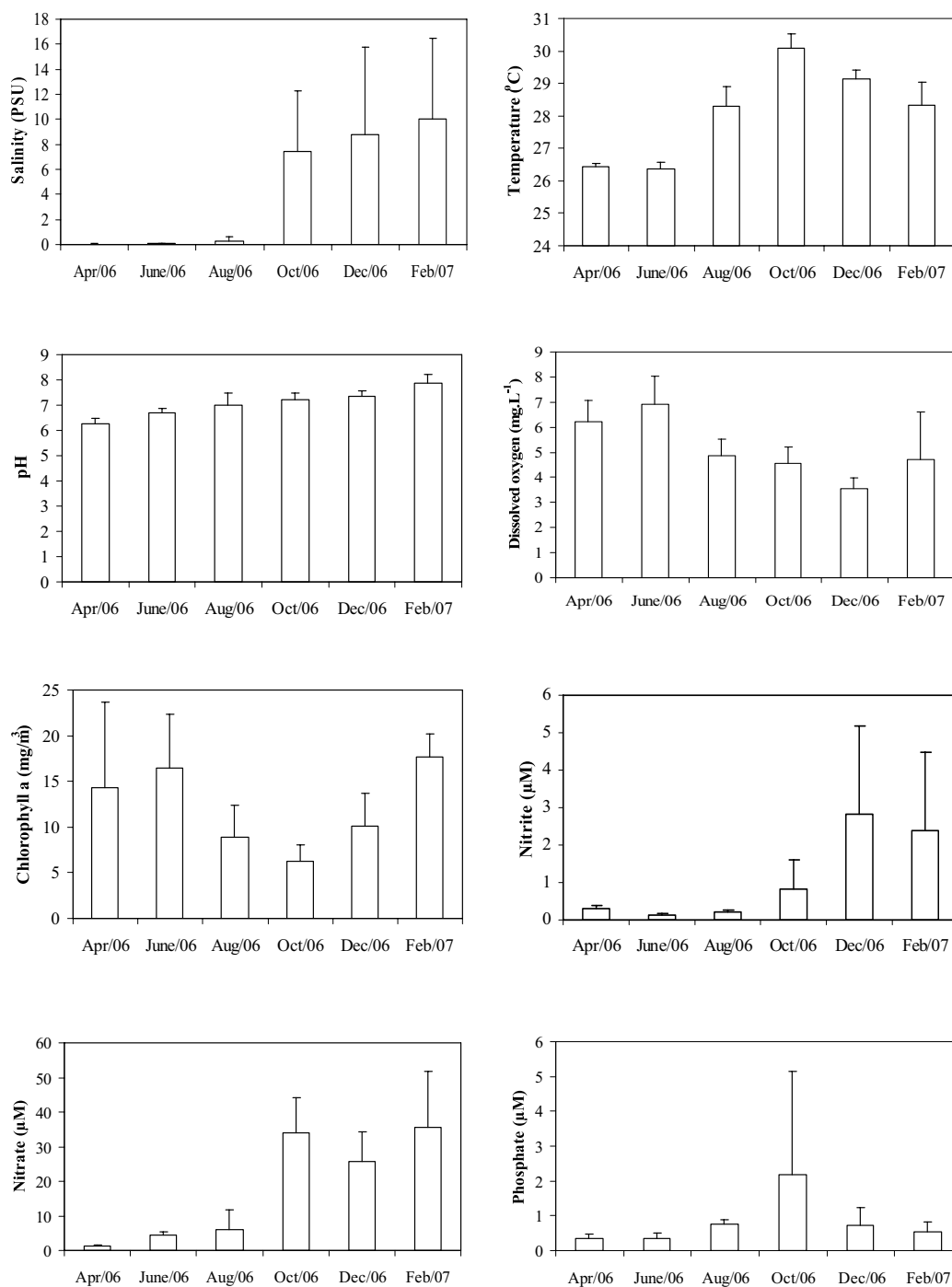


Fig. 3 – Mean hydrological values between April/06 and February/07, in the Caeté estuary.

high local hydrodynamic regime and turbulent mixture that contributed to the presence of highly oxygenated freshwater in the superficial layer. The highest chlorophyll *a* concentrations (Fig. 3) during the rainy period were also associated with the highest dissolved oxygen

concentrations. During the rainy period, urban outfall was diluted as a result of the high pluvial water input and the high river discharges into the Caeté estuary, consequently decreasing the dissolved nutrient concentrations. In addition, the high chlorophyll *a* concentration (indi-

cated by the elevated phytoplankton density) may also have contributed to the observed decrease in the nutrient values. In non-stressed coastal zones, the highest nutrient concentrations can be found during the rainy period due to the river run-off, contribute to the occurrence of high chlorophyll *a* concentrations due to increased phytoplankton biomasses.

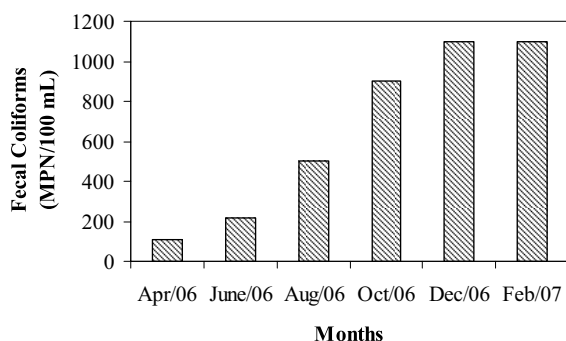


Fig. 4 – Fecal coliform values between April/06 and February/07, in the Caeté estuary.

In the dry season, the pH remained alkaline, indicating the strong influence of marine waters on the estuary. Alkalinity is also a common feature of coastal Amazon environments, as noted by Martinelli et al. (2002), Costa et al. (2008, 2009), Silva et al. (2009) and Magalhães et al. (2009) in the Maranhão and Pará States. Besides being influenced by dissolved salt content in the water, pH can be also affected by biological, physical and chemical processes (tidal cycles, respiration and photosynthesis effects, for example). In general, pH attains elevated values due to the consumption of carbon dioxide by phytoplankton and the consequent liberation of oxygen during elevated photosynthetic activity periods (Flores Montes et al. 1998). However, this was not observed in the studied area. The lowest dissolved oxygen concentrations registered in this season are possibly related to the lowest observed photosynthetic activity (low chlorophyll *a* concentrations). In addition, the highest dissolved nutrient concentrations recorded during this season may be attributed to the input of more concentrated domestic and commercial sewage into the Caeté estuary. The low estuarine depths (up to 10 m in the high spring tide) and the high water column mixture (as a consequence of the strong winds in the second half of the year and of the occurrence of equinoctial spring tides between September and October) were also

responsible for the re-suspension of nutrients from the bottom during the second semester.

The discharge of domestic, medical and commercial sewage concentrates, as well as of others organic and inorganic contaminants from public markets, fishery ports, ice factories and the Cereja River also contribute to the contamination of the Caeté estuary in the studied sector (Gorayeb et al. 2006, Guimarães et al. 2009). During the dry season, the input of more concentrated domestic and commercial sewage into the Caeté estuary contributed to the highest fecal coliforms values observed. On the other hand, the lowest fecal coliform values were registered in April/06 due to the dilution of urban outfalls as a consequence of the high rainfall rate and the occurrence of an equinoctial spring tide (high tidal height and strong currents).

In equatorial and tropical zones, the rainfall patterns and some human activities (e.g., lack of an efficient sanitary system, lack of urban cleanness, factories and harbour activities) are responsible for controlling physical-chemical variables, and consequently the abundance, distribution and diversity of different estuarine organisms (Koenig et al. 2003, Lam-Hoai et al. 2006, Silva et al. 2009).

Planktonic organisms make up the base of estuarine and marine food webs and perform key functions in transforming the chemical and physical forms of nutrients and contaminants and transporting these materials to higher trophic levels (Thompson et al. 2007). As a result, these organisms have a high value as biological indicators of water quality due to their high growth rates in response to abiotic and biotic oscillations (Day et al. 1989, Espino et al. 2000, Gómez and Licursi 2001). Species that indicate environmental eutrophication were observed by Lacerda et al. (2004) and Pereira et al. (2005) in contaminated urban areas, showing the high nutrient assimilation efficiency of these organisms (Smetacek 1998).

The predominance of diatoms in coastal waters is reported worldwide (Tilstone et al. 2000, Gin et al. 2000, Huang et al. 2004, Eskinazi-Leça et al. 2004, Örnólfssdóttir et al. 2004, Sousa et al. 2008), and indicates their ability to adapt to non-stratified, turbulent (Smayda 1980, Tilstone et al. 2000, Smayda 2002) and nutrient-enriched waters (Tundisi 1970) such as those



observed in the studied area.

The occurrence of macrotidal regimes (high energy) in the Amazon littoral zone and the high turbulent mixture and bottom sediment re-suspension could contribute to the presence of phytobenthonic species in the pelagic environment (Sousa et al. 2008). In the studied area, the high hydrodynamic regime contributed to the presence of tychoplanktonic species in the water column, such as *Dimeregramma minor* that was the most abundant species found during both seasons.

### CONCLUSION

Regional climatic conditions, the macrotidal regime and human-induced activities combine to control the water characteristics in the studied area. The lack of basic hydric canalization was mainly responsible for the contamination in the Caeté estuary. This was particularly true during the dry period, when more concentrated domestic and commercial sewage was emitted into this estuary and when the highest number of r-strategist species was found. This observation is concerning because a large part of the local economy depends on the biological resources of the estuary and its contamination could negatively affect the environmental health of this Amazon estuarine ecosystem in the near future.

Government authorities should improve local services by constructing a sanitary collection system, offering an efficient urban cleanness, controlling market, medical and ice factory garbage disposal and constructing an efficient sewage treatment plant to promote the treatment of sewage, as well as to control the wastewater input into the Caeté estuary in order to mitigate the observed problems.

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### RESUMO

A situação socioeconômica de Bragança depende principalmente dos recursos biológicos estuarinos e marinhos, que são influenciados pelos ciclos de marés e climatologia. Coletas oceanográficas (com medidas de variáveis hidrológicas, hidrodinâmicas e microbiológicas) foram realizadas na área mais urbanizada do estuário do Caeté, para caracterizar a qualidade das águas no setor estudado. Durante o período seco, o estuário foi mais eutrófico e apresentou os maiores valores de temperatura (30,5°C em Out./06), salinidade (17 psu em Fev./07), pH (8,24 em Fev./07) e coliformes fecais (>1000 MNP/ 100 ml em Dez./06 e Fev./07). As espécies fitoplanctônicas *Cyclotella meneghiniana*, *Coscinodiscus centralis* e outras espécies r-estrategistas também foram observadas. A falta de saneamento básico foi responsável pela contaminação local, especialmente durante o período seco, quando o esgoto foi lançado mais concentrado no estuário, mostrando a influência humana na redução da qualidade da água estuarina estudada. A pesca é considerada uma das principais atividades econômicas do município de Bragança e, portanto, esta contaminação poderá afetar negativamente a qualidade ambiental deste ecossistema amazônico.

**Palavras-chave:** Estuário equatorial, variação temporal, eutrofização, norte do Brasil.

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