Aquaculture impacts on the water quality and plankton community in a mangrove ecosystem in Brazil

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Abstract

Mariculture has become an important source of human food and its production is likely to expand well in Brazil for the foreseeable future. However, mariculture has caused direct and indirect negative impacts on the coastal ecosystem. To assess the impacts caused by a shrimp culture farm at the Goiana mangrove area the water and plankton community were studied. Samples were obtained from May/1997 to January/1999, before and after the farm implantation. Mariculture facilities reduced around 20% of the mangrove area. An intensive mixture of the marine and freshwater fluxes occurred in the system, dominating the marine. The dissolved oxygen was under saturation at low tide, indicating a polluted area, and saturated at the river mouth, due to the marine influence. High overall nutrient concentrations indicated a eutrophic area. Primary productivity increased from 1997 (~14 mgC h⁻¹ m⁻³) to 1999 (~25 mgC h⁻¹ m⁻³). Chlorophyll-a was also high (~15 mg m⁻³) and presented the same pattern. The marine eurihaline plankton dominated the area. The plankton biomass varied from 86.28 mg.m⁻³ (May/97) to 3086.29 mg.m⁻³ (January/98). Phytoplankton average density was 53,278,000 cel L⁻¹ and the zooplankton 40,542 ind m⁻³. Failure to acknowledge the life-support function of mangroves is one explanation of the uncontrolled expansion and intensification of shrimp aquaculture in Brazil, which has led other countries to self-pollution and disease problems.
1 Introduction

The development of shrimp farms in mangroves and estuaries areas in Brazil has generated some negative impacts to the ecosystem and to its adjacent areas. These negative impacts among others are: a loss of biodiversity, the use of pollutants, eutrophication of the surrounding waters, water sewage, carrying capacity of the lands, the use of mangroves areas, the use of lands outside mangroves areas, intrusion of sea water, decreasing of fisheries production, loss of function of mangroves as flood control and beach protectors, loss of many kinds mangroves products and loss of possibility of a newly formed mangrove.

In recent years there has been increasing awareness of the fact that mangrove ecosystems provide free of charge many valuable ecological services [1,2,3]. These services are key features which sustain economic activities in coastal areas throughout the tropics. Destruction of this ecosystem continues, however, in spite of this understanding of their importance.

On the other hand, the general lack of ecological knowledge by politicians and valuators, among others, is an important determinant to the undervaluation of mangroves. Consequently, these are considered as wastelands and are therefore prime candidates for conversion into alternative uses like shrimp aquaculture, which directly generate marketable products [3].

The River Goiana estuarine system located at the extreme north of Pernambuco State had part of its central area converted to shrimp aquaculture at the end of 1997. This system has one of the biggest mangrove forests of Pernambuco, with an important role as nursery grounds for many commercially important species. This has generally been attributed to the abundant food supply in comparison to adjacent marine areas.

This paper outlines the impacts of the implantation of a shrimp farm on the water quality and plankton community at the Goiana estuarine ecosystem.

2 Material and methods

The Goiana estuarine system is located at 7°32'–7°35'S and 34°50'–34°58'W, about 50 km north of Recife, Pernambuco State, Brazil. (Figure 1). This system is formed by the rivers Goiana and Mega6, and between these rivers there is the Tariri Island, located centrally, which was converted to 300 ha shrimp (the exotic Litopenaeus vannamei from the Pacific Ocean) ponds.

The climate is warm–humid, pseudo-tropical (Koppen As') with mean annual temperature 24°C and rainfall 1500–2000 mm.yr\(^{-1}\), concentrated from March to August. Humidity is higher than 80%. Predominant winds are from the southeast. The former Atlantic plain forest has largely been replaced by sugar cane culture.

Samples for hydrology and plankton were collected every four months during consecutive diurnal high and low tides, from May/1997 to January/1999, in four fixed stations, two at the River Mega6 estuary (stations 1 and 2), the first located close to the water system captation to the ponds; and two (stations 3 and 4) at the Goiana River estuary where the aquaculture wastewater is discharged (Figure 1).
Hydrological data were collected at the surface with a Nansen bottle. Water temperature—reversion thermometer affixed to Nansen bottle; salinity—Mohr-Knudsen method [4]; pH—Beckman Zeromatic II pHmeter; dissolved oxygen—Winkler method [4]; nutrients [5,6]; water transparency—Secchi disc. Samples for the determination of Chlorophyll-a were collected with a one-liter Van Dorn bottle at the surface. Chlorophyll-a was measured according to Strickland and Parsons [7]. Phytoplankton primary productivity was measured through the $^{14}$C method [8].

Figure 1: The Goiana area, coast North of Pernambuco, Brazil, showing sampling stations.

Plankton sampling at Goiana was done with a standard plankton net 1m in length, with a 30 cm mouth diameter and a mesh size of 65 micrometers fitted with a flowmeter (Hydrobios, Kiel); three minute horizontal subsurface hauls were made at each station. Samples were preserved in a 4% buffered formalin/seawater solution. Plankton biomass was obtained by the wet weight method [9]. The phytoplankton composition was based on the identification of the specific and infra-specific taxa. For this analysis, subsamples of 0.5 ml were counted under a binocular microscope. Zooplankton species were identified until the lowest taxonomic unit possible and taxon abundance (per cubic meter) counted under a microscope (1 ml subsample). These samples were taken with a Stempel-pipette of each entire sample (250 ml).
3 Results

3.1 Hydrology

At Goiana, water temperatures were high with a thermic amplitude of 3.30°C. Lowest temperatures (minimum 26.8°C) were measured in the rainy season (May/97) and highest temperatures (maximum 30.1°C) in the dry season (January/99).

![TEMPERATURE](image1)

![SALINITY](image2)

![DISSOLVED OXYGEN](image3)

Figure 2: Water temperature, salinity and dissolved oxygen saturation in the Goiana estuarine system, from May/1997 to January/1999.
Salinity at the Goiana estuarine system varied from a minimum of 2.67 psu in the rainy season (May/97) to a maximum of 37.10 psu in the dry season (January/99) (Figure 2). High tide presented higher values. An increase in salinity occurred from 1997 to 1999, changing the estuary from an oligohaline to a polyhaline regime indicating a strong marine influence due to “El Niño”.

At the Goiana estuarine system the dissolved oxygen concentrations (DO) showed a clear trend to decrease from the rainy (May) to the dry (January) season during high tide; and to decrease from the end of the rainy season (September) to the dry season (January) during low tide. Higher values were registered at stations 3 and 4 (Goiana River). The DO ranged from 1.54 ml L⁻¹ (28.85% saturation) in station 1 to 5.75 ml L⁻¹ (122.86% saturation) in station 4, both at the rainy season. Significant oxygen depletion was found during low tides in the estuary inner areas during the dry season. At high tides most DO values were high and over saturated (Figure 2).

Most analyzed samples (85%) presented BOD (Biochemical Oxygen Demand) under 5 mg L⁻¹, but 15% of the samples (low tides, inner station of Goiana River) presented values between 6 and 7.2 mg L⁻¹.

pH was above 7 in all stations. Water transparency was reduced during low tides of the rainy season (minimum of 0.5 m) in 1997, due intensive fine clay resuspension. High tides presented higher transparencies.

Nutrients (NO₂, NO₃, PO₄ and Si O₄) at Goiana estuarine system were variable, but in general were higher in the rainy season and low tides. Nutrients levels generally were indicative of eutrophy. It was registered an increase in nutrient concentrations from 1997 to 1999. Ammonia minimum value was 0.012 μmol L⁻¹ (May/97, high tide, stations 3 and 4) and maximum 0.927 μmol L⁻¹ (September/98, station 1). Nitrite varied from 0.01 μmol L⁻¹ (January/98, high tide, station 4) to 2.12 μmol L⁻¹ (January/98, low tide, station 3). Nitrate varied from 0.365 μmol L⁻¹ (September/97, high tide, station 3) to 3.368 μmol L⁻¹ (January/99, low tide, station 3). Phosphate varied from 0.163 μmol L⁻¹ (September/97, high tide, station 4) to 1,873 μmol L⁻¹ (January/99, low tide, station 3). Silicate varied from 6.32 μmol L⁻¹ (May/97, high tide, station 4) to 829.532 μmol L⁻¹ (January/98, low tide, station 1).

3.2 Primary production and Chlorophyll-a

At the Goiana estuarine system a high primary productivity was registered increasing from 1997 (~14 mg C h⁻¹ m⁻³) to 1999 (~25 mg C h⁻¹ m⁻³). The minimum was 3.05 mg C h⁻¹ m⁻³ and the maximum 32.00 mg C h⁻¹ m⁻³. Lower values were found at Station 2, during high tide of the dry season and higher values at station 3 low tide of the dry season.

The Goiana system showed an increase in chlorophyll-a concentration from 1997 to 1999. The minimum was 2.03 mg m⁻³ (September/97, high tide, station 2) and the maximum 18.00 mg C h⁻¹ m⁻³ (January/1999, low tide, station 3).
3.3 Plankton biomass

The plankton biomass varied from 86.28 mg m\(^{-3}\) (May/1997) to 3,086.29 mg m\(^{-3}\) (January/1998). Higher values were registered during the dry season and high tides (Figure 3).

3.4 Phytoplankton

A total of 68 species were identified in the Goiana estuarine system contributing the diatoms to 87% of the community followed by Pyrrophyta (8%), Cyanophyta (3%), Euglenophyta (1%) and Chlorophyta (1%). *Actinoptychus splendens, Coscinodiscus centralis, Nitzschia sigma, Biddulphia regia, B. laevis, Bacillaria paradoxa* and Phytoflagellata were abundant in both seasons. *Euglena acus* was abundant (8%) in station 3 during the rainy season (May/98). A sharp increase in number of cells was observed from 1997 to 1999. Phytoplankton density varied from 135,000 cel L\(^{-1}\) in the rainy season (May/97, station 2, low tide) to 7,368,000 cel L\(^{-1}\) in the dry season (January/99, station 4, low tide) (Figure 4). A marked seasonal variation was observed, with higher densities in the dry season. Phytoplankton average value at low tide was 5,517,000 cel L\(^{-1}\) and at high tide 5,139,000 cel L\(^{-1}\), showing small difference between tides.

![Figure 3: Plankton biomass in the Goiana estuarine system, from May/1997 to January/1999.](image)

3.5 Zooplankton

The zooplankton presented 52 taxa. Copepoda outranked with 14 species, followed by Rotatoria (10 species) and Protozoa (10 species). The meroplankton was represented by Polychaeta larvae (dominated by spionids), Gastropoda
larvae, nauplius of Cirripedia and zoeae of Brachyura with large distributions in the area, sometimes dominating the community. The zooplankton abundance varied from 2,232 ind m\(^{-3}\) to 129,384 ind m\(^{-3}\) and increased from 1997 to 1999 (Figure 5), showing the influence of the farm wastewater on the system enrichment. The presence of Polychaeta larvae in large numbers is indicative of this organic pollution. However, the nauplii of Copepod constituted the bulk of the zooplankton.

![Figure 4: Phytoplankton density in the Goiana estuarine system, from May/1997 to January/1999.](image)

![Figure 5: Zooplankton density in the Goiana estuarine system, from May/1997 to January/1999.](image)
The zooplankton was essentially composed of typical marine euryhaline species. The most common Copepoda were *Parvocalanus crassirostris*, *Acartia lilljeborgi*, *Oithona hebes* and *Euterpina acutifrons*, in all life cycle stages.

### 4 Discussion

The estuaries are trophically connected with the surrounding intertidal mangrove forests as a source of detritic organic matter, nutrients, dissolved and particulate organic matter, bacterial populations and larvae, among others. Leaf litter on the forest floor represents a major source of organic matter and nutrients outwelling from mangroves to adjacent waters [10].

However, the conversion into shrimp ponds constitutes the main threat to mangroves in many countries. As a paradox, the productivity and sustainability of these aquaculture systems are heavily dependent on viable mangrove ecosystems, which provide ecological services like water quality maintenance and buffer against natural disturbances, as well as resources like seed, spawners and feed from mangrove-associated fisheries [3,11,12]. Thus, the continual provision of goods and ecological services from viable mangrove ecosystems is a prerequisite for the productivity and sustainability of shrimp aquaculture.

The hydrobiological studies at the Goiana estuarine system revealed some natural and some anthropic changes that caused a decrease in the environment quality.

The salinity showed that from 1997 to 1999 the dilution of marine waters by the rivers and rainfall was small due the influence of “El Niño”, which sharply reduced the amount of rain. Besides this, the decrease in mangrove area for pond construction possibly caused the intrusion of sea water, changing the system from a limnetic-polyhaline regime to a polyhaline regime.

The Goiana ecosystem showed low oxygen concentrations upstream, close to the shrimp farm wastewater discharge, being the area classified as a semi-polluted to polluted zone according to the classification of Macêdo & Costa [13]. Although polluted, the pH varied from neutral to alkaline, showing that the area is resilient and in a reversible phase in relation to hypoxia not affecting the carbon dioxide balance. This fact can be confirmed in relation to BOD values which were quite low (< 5 mg L⁻¹), with few values over 7. According to Flores Montes [14], BOD > 7 mg L⁻¹ means organic pollution. Critical dissolved oxygen values combined with large amounts of nutrients indicated the presence of a large amount of organic matter. Besides, the large amount of silicate in the inner area of the Megaãó estuary could be the result of the pumping water activity to the ponds in a small depth area, liberating silica from the sediment.

The high loads of nutrients in the Goiana ecosystem due to aquaculture inputs led to eutrophication. Fortunately, this is a point source which is easy to identify and control; therefore reductions in the high loads to the Goiana estuary is possible. The nutrients have caused increases in water column phytoplankton primary production. Since high nutrient concentrations were characteristic of the turbid, lower salinity waters, close to the ponds discharge, productivity in the
The rainy season was light limited. However, during the dry season primary productivity and chlorophyll-a were high and the phytoplankton bloomed profusely for a few days when growth conditions were optimal. These blooms are part of the normal cycle in healthy estuaries [15]. However, if extra nutrients are continuously available, as is the case in the Goiana system, the blooms can persist longer causing an unbalanced condition. The dominant diatoms species are considered indicators of Brazilian estuaries [16,17,18,19].

Zooplankton was dominated by Copepoda, which made up nearly 27% of the total number of taxa registered and 65% of total abundance. The dominance of Copepoda in Brazilian tropical estuaries has already been described by Tundisi [20]. The most abundant species found in the present research are typical of estuarine waters [21]. The zooplankton density doubled from 1997 to 1999. The high density of *Favelia ehrenbergi* and Polychaeta larvae, are indicative of high quantities of wastewater. On the other hand, the abundance of Gastropoda veliger, *Oithona hebes*, and copepod nauplius show that the estuary is resilient and in a relatively good condition, mainly due to the marine influence.

Another problem related to mariculture in the Goiana estuary is the effect of the cultivated exotic species *Litopenaeus vannamei*. The deliberate introduction of species from other parts of the world is commonplace and constitutes a biological “complication” to the receiving environment. Many exotic taxa are ecologically aggressive invaders whose effects in a new area cannot be predicted reliably in advance, and which may adversely affect ecologically sensitive (often specialized and endemic) taxa when they arrive [22]. Other important consequence is that this shrimp might carry a virus disease and the possibility of infection of the native shrimp population by the introduced pathogen is of considerable concern. Studies carried out by Ramos-Porto [23] about penaeids in Pernambuco coastal area revealed the presence of *Litopenaeus vannamei*, which escaped from the ponds and is colonizing the region. The effects of this species on the biodiversity and ecosystem ecology in Brazil are not known.

**References**


