DETERMINATION OF THE CARRYING CAPACITY OF BOCA DE CAMICHIN ESTUARY, MEXICO, IN REFERENCE TO OYSTER CULTURE

Watershed & Integrated Coastal Zone Management/Experiment/07WIZ02UH

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ABSTRACT

A study was conducted at the Boca de Camichin Estuary, Nayarit, Mexico, to determine the carrying capacity of the lagoon in order to inform management decisions for the oyster industry and guide watershed management efforts. The findings indicate that the estuary is predominantly heterotrophic throughout the three principal seasons. Although nutrient loads and oxygen demands are high, the estuary does not yet experience notable eutrophication, although it may be on the verge of this in some areas. Eutrophication is largely prevented by the high water inputs from the river and ocean. Any infrastructure development or increased nutrient inputs could move the system towards an eutrophic state. Hence care should be taken in planning any development projects or expansion of current industries, including oyster farming.

INTRODUCTION

Coastal lagoons are among the most important ecosystems on the plant and generally have high levels of biodiversity. For example, coastal lagoons host the highest number of vertebrates in the world: 50 order, 445 families and approximately 22,000 species (Ray 1991; Toledo 2003). They form the basis for the rich fisheries and aquaculture industries of Mexico, as well as providing food and livelihoods to coastal residents (Alonso-Rodriguez and Paez-Osuna 2001). A coastal lagoon is defined as a depression in the coastal zone that is connected to the open sea with some sort of protecting barrier island (Lankford 1997). Mexican coastal lagoons have 12,555 km^2 of water surface (Cardenas 1969). Water quality in most Mexican coastal lagoons has deteriorated in recent years due to increasing populations and human activities (NRC 2000), resulting in significant increases in organic material and nutrients such as nitrogen, phosphorus. The shrimp industry has also contributed to inputs of organic nutrients (Paez-Osuna et al. 1997). All of Mexico's lagoons and their resources are considered to be at risk for significant impacts from pollutants.

This study focuses on modeling the carrying capacity of an important coastal lagoon, Boca de Camichin, Nayarit. This area is the site of the southern oyster culture industry and is an important fisheries and tourism area. Data was collected on dissolved nutrients, meteorological conditions, hyrdology and oceanographic conditions to determine the tendency to transform, transport, accumulate or export organic nutrients. The study used the recommended methods of the LOICZ commission (Land-Ocean Interactions in the Coastal Zone) for modeling estuary carrying capacity, and hence the results can be compared to other estuaries in Mexico and in other countries. The results are intended to inform coastal managers and stakeholders, particularly the oyster farmers located in the areas. The oyster industry is a valuable economic driver in the impoverished region of Nayarit; hence the importance of managing it in a sustainable manner as there has been some concern in recent years that expansion of the oysters farms in this narrow estuary or upriver activities might lead to the carrying capacity of the system being exceeded.

STUDY SITE

The Boca de Camichin is a narrow estuary located in the Municipality of Santiago Ixcuintla (from 21º 37’ to 22º 16’ N and from 104º 53’ to 105º 39’ E) in the State of Nayarit. Boca de Camichin has approximate 1078 inhabitants (587 males and 491 females) in 256 families. It is located 5 masl (INEGI 2005a). This coastal lagoon is located at the mouth of the San Pedro River (from 21° 43' 26’’ to 21° 45' 41’’ N and from 105° 29' 2’’ to 105° 30' 22’’ E). The San Pedro River watershed is 26,480 km2 in size and has 84,314 inhabitants (INEGI, 2005b). The municipality has 54,037.27 ha in agriculture and up close to 50,000 farmed animals (cows, pigs, sheep, etc.). This area is part of the larger wetland system known as the Marismas Nacionales (National Wetlands), an area of national significance due to its extensive wetlands and mangrove areas (20% of the national total) (Figure 1).

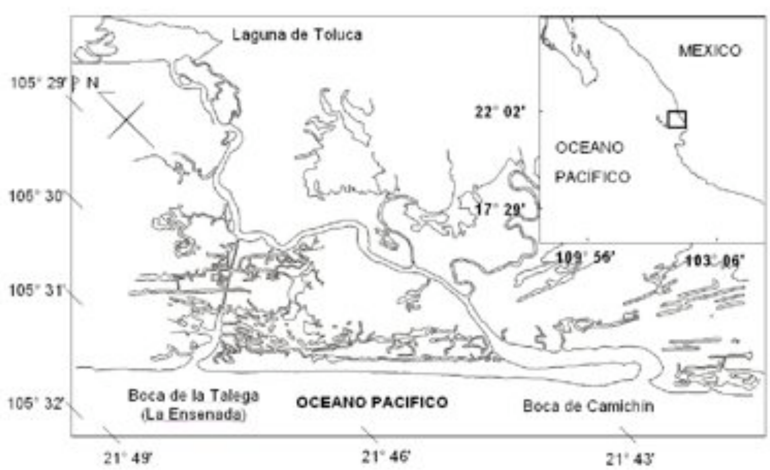

Figure 1. Boca de Camichin Estuary system.

Boca de Camichin has a hot-dry climate, with a rainy season between June and October with the highest rain levels between July and September. The hottest months are from May to October, with June and July being the hottest months (Table 1).

Table 1. Precipitation and temperature in Nayarit State. Source: CNA (2009)

Month	Average precipitation (mm) Period (1941-2005)	Average temperature (°C) Period (1980-2004)
January	18.8	20.4
February	9.8	20.8
March	4.5	22.0
April	4.0	23.8
May	7.4	25.6
June	136.2	27.1
July	280.5	26.4
August	277.2	26.3
September	222.6	26.2
October	76.0	25.5
November	15.3	23.4
December	16.3	21.1
Annual	1068.7	24.1

METHODS

There are five "rainy" months from June to October, during which 93% of the annual precipitation occurs. There are considered to be three seasons, "rainy", "dry/cold" and "dry/hot". Three months representative of these seasons were chosen as months during which sampling would occur: October (rainy), February (dry/cold) and April (dry/hot). Water samples were collected from Boca de Camichin during these months by CIAD and UAS personnel. Sampling stations within the estuary are shown in Table 2 and Figure 2.

At each sampling station, temperature, salinity, pH, turbidity and dissolved oxygen were measured. One thousand milliliters of water were also taken for evaluation of nitrates, nitrites, ammonia, orthophosphates and chlorophyll *a*, according to the methods described by Parsons et al. (1984), total soluble phosphorus and total particulate phosphorus (Valderrama 1981) and organic material (NMX-AA-034-SCFI-2001).

Table 2. Geographic positions of sampling stations at Boca de Camichin.

Station	Geographic location	
	Longitude	Latitude
1	21º 43' 16.9''	105º 29' 39.6''
2	21º 43' 47.0''	105º 30' 01.1''
3	21º 43' 49.8''	105º 29' 06.5''
4	21º 44' 11.2''	105º 29' 21.5''
5	21º 44' 29.6''	105º 29' 35.4''
6	21º 44' 39.5''	105º 29' 41.7''
7	21º 44' 58.9''	105º 29' 48.5''
8	21º 45' 10.9''	105º 29' 53.6''
9	21º 45' 39.6''	105º 29' 48.0''
10	21º 47' 16.4''	105º 29' 36.8''
11	21º 48' 48.6''	105º 30' 11.7''
12	21º 49' 55.5''	105º 28' 47.8''
13	21º 51' 17.1''	105º 28' 53.6''
14	21º 48' 32.9''	105º 31' 20.2''

Figure 2. Sampling stations at Boca de Camichin. Source: http://earth.google.com/.

To determine the carrying capacity of the estuary system, the model developed by LOICZ (Gordon et al. 1996) was used. This model was chosen due to its simplicity and demonstrated utility as it has been used in multiple estuarine systems around the world, allowing the sharing of biogeochemical budgets of coastal ecosystems Since the model is based on conservation of mass, it is necessary to have data on all inputs and outputs in the system. The model is based on data and modeling of nitrogen and phosphorus budgets, hydraulics, salinity profile and the stoichiometry of the net ecosystem metabolism.

RESULTS

WATER QUALITY

Dry/hot season (April 2008)

Water quality during April, 2008, demonstrated less homogeneity than in October (rainy season) and February, 2009 (dry/cold season). Maximum temperature in the upper zone was 28.5 °C with minimum values found in the middle of the estuary (24.2 °C) and at the mouth (24.4 a 24.8 °C). There was no significant variation in salinity throughout the estuary, although conditions indicated a marine influence with salinity between 34 and 35 ppt. Values for pH ranged from 7.46 y 7.88, with the maximum values found at the mouth and the minimum in the upper reaches. The maximum pH values were correlated with maximum dissolved oxygen levels (8.15 mg/l), which suggests a possible phytoplankton bloom in this area. This was corroborated by the high chlorophyll *a* levels (13.8 ± 0.7 mg/m^3). Phosphorus was homogeneously distributed across the estuary, varying between 0.070 ± 0.003 and 0.097 ± 0.027 mg/L. Concentrations of orthophosphate were higher near the open ocean and the upper river stations, ranging between 0.095 ± 0.000 and 0.115 ± 0.005 mg/L. In the case of nitrogenous compounds, particularly nitrates and ammonia, the highest levels occurred in the upper river areas, with values of 0.017 to 0.023 mg/L for nitrates and 0.034 ± 0.005 to 0.046 ± 0.004 mg/L for ammonia. Nitrates did not vary significantly between stations and averaged 0.005 mg/L.

Wet season (October 2008)
Surface water temperatures were homogenous between sampling stations during the October 2008 sampling periods, varying between 31.5 y 33.7 ºC, similar to the inter-station homogeneity found during the dry/hot season in April. Maximum salinities were found near the mouth with values around 26 ppt and 11 ppt near the two mouths, while minimum values were found in the estuary and upper reaches (0-1 ppt), demonstrating a clear riverine influence. pH measurements revealed minimum values in the upper river areas with values of 6.85 to 6.92 and the maximum in the open ocean with 8.13 and 8.14. Dissolved oxygen ranged from 4.01 to 7.70 mg/L with upper values in the open ocean zone and lower values in the middle of the estuary. In the case of nutrients, maximum phosphorus values were found in the interior of the estuary, with values ranging from 0.184 to 0.201 mg/L. Orthophosphate values demonstrated a pattern similar to that found for phosphorus, with maximum value in the interior of the estuary (0.124 ± 0.006 to 0.139 ± 0.005 mg/L) and lower values at the mouth and upper river areas (0.056 ± 0.005 to 0.119 ± 0.002 mg/L). Nitrites and ammonia had higher values in the interior of the estuary (0.008 ± 0.005 a 0.062 ± 0.007 mg/L ammonia and 0.013 ± 0.001 a 0.016 ± 0.000 mg/L nitrites). The highest value for nitrate was found in the open ocean with values ranging between 0.057 and 0.076 mg/L.

Dry/cold season (February 2009)
During the February 2009 sampling period, surface temperatures were homogenous with values being only slight higher in the upper river areas. The lowest values were at the interior of the estuary and towards the mouth. Salinity varied considerably, with the highest values near the mouth (36 ppt) and diminished toward the upper river area (8 ppt). pH values during this time were between 7.60 and 7.90. The maximum pH was near the mouth and in the upper river zone. Dissolved oxygen varies between 7.6 and 13.2 mg/L. Dissolved oxygen was stable throughout the area, with values between 1.0 ± 0.2 y 4.8 ± 2.0 mg/m^3. In the case of nutrients, maximum concentrations of total phosphorus were found in the interior of the estuary with values of 0.056 ± 0.000 a 0.078 ± 0.000 mg/L. Orthophosphate levels were similar to those observed for total phosphours with the maximum values found in the estuary in the range of 0.097 ± 0.002 mg/L, and with lower values near the mouth ranging between 0.024 ± 0.001 a 0.039 ± 0.003 mg/L. Ammonia and nitrates were highest near the interior of the estuary with 0.075 ± 0.005 to
0.131 ± 0.005 mg/L for ammonia and 0.061 a 0.114 mg/L for nitrates. Nitrite values were relatively low at all stations. At some points the levels were low enough that they could not be detected, and maximum concentrations were 0.007 ± 0.001 mg/L.

SEASONAL CHANGES
Precipitation and salinity
During the dry/hot season (April 2008), precipitation was 5.31 mm/month and salinity averaged 35 ppt, occasionally rising. During the wet season (October, 2008), precipitation was 198.66 mm/month, thereby reducing salinity to 1.14 ppt. During the dry/cold season (February, 2009), precipitation was 15.05 mm/month and salinity averaged 27.5 ppt.

Dry/hot season
Hydraulic balance

The hydraulic balance was calculated. Input due to precipitation was 5.31 mm/month, representing 366. 4 m^3/day for the entire system. There was also an input of 220,611 m^3/day of water from the San Pedro River. Evaporation was calculated to be 387.1 m^3/day. The total water input exceeds losses by 220, 590 m^3/day. Water exchange with the Pacific Ocean due to tides and currents was estimated to be 15.3 million m^3/day. It is therefore estimated that it takes 0.4 days to completely exchange the water in this estuary season.

Nutrient budgets and system metabolism

The phosphorus balance for the estuary is 19.11 tons/month, with 2.14 tons/month coming from the river. The nitrogen balance for the system was 90.86 tons/month with 1.57 tons/month coming from the river. The high concentrations of nitrogen and the oxygen requirements to process this are higher than the oxygen liberated through photosynthetic processes. The system is therefore predominantly a net heterotrophic system during this time, with a possible tendency towards eutrophication (Table 4).

<u>Rainy season</u>

Hydraulic balance

During this season the system received 1.63 million m^3/day of water from the San Pedro River along with 13,77.9 m^3/day in precipitation. Losses from evaporation were 387.1 m3/day. Inputs were therefore greater than losses, so that the system exported water to the ocean, approximately 16.3 million m3/day. Water exchange due to currents and tides was 9.1 million m3/day with the ocean. As the system has an approximate volume of 6.0 million m3/day, the rate of exchange is 0.82 days so that the residence time of water is approximately the same as in the dry/hot season.

Nutrient budgets and system metabolism

The system's phosphorus balance was 74.53 tons/month, with 130.45 tons/month coming from the San Pedro River. The nitrogen balance was 20.69 tons/month with 23.53 tons/months. As in the case of the dry/hot season, the high concentration of nitrogen and oxygen requirements to process this are greater than the oxygen produced by photosynthesis and therefore the system's metabolism is heterotrophic.

<u>Dry/cold season</u>

Hydraulic balance

The system received 3.9 million m3/day from the San Pedro River with 1,0404.4 m3/day from precipitation. Losses from evaporation were 387.1 m3/day. The system therefore exported water to the ocean, approximately 3.9 million m3/day. The water exchange due to currents and tides was 22.6 million m3/day. Water turn over in the system was 0.3 days.

Nutrient budgets and system metabolism

The system's phosphorus balance was 90.62 tons/month, with 23.16 tons/month coming from the San Pedro River. The nitrogen balance was 162.78 tons/month with 24.21 tons/months. Once again, the high concentration of nitrogen, and the oxygen requirements to process this, are greater than the oxygen produced by photosynthesis and therefore the system's metabolism is heterotrophic (Table 3).

Table 3. Flows of phosphorus and nitrogen, primary productivity and system metabolism in the Boca de Camichin, Nayarit.

	Dry/hot Season 19 April 2008	Rainy Season 5 October 2008	Dry/cold Season 2 February 2009
Phosphorus balance (tons/month)	19.11	74.35	90.62
Phosphorus from San Pedro River (tons/month)	2.14	130.45	23.16
Nitrogen balance (tons/month)	90.86	20.69	162.78
Nitrogen from San Pedro River (tons/month)	1.57	23.53	24.21
Primary productivity (g/m^2/month)	-123.39	-480.01	-585.03
Metabolism	Heterotrophic	Heterotrophic	Heterotrophic

CONCLUSIONS

The Boca de Camichin estuary system is primarily dominated by heterotrophic processes originating mostly from the large amount of organic material. The mass balance indicates that the interior of the estuary accumulates high concentrations of phosphate (19-90 tons/month) and nitrogen (90-162 tons/month). The heterotrophic nature of the system indicates that there is greater oxygen consumption than is produced by photosynthetic processes. Despite this, levels did not reach the eutrophic state, possibly due to the high volume and rapid rate of water exchange. Maintaining this dynamic is essential to maintaining the productivity of this system and preventing eutrophication. Any reduction water flows from the river, increases in nutrient input or reduction in exchange with the ocean runs the risk of generating sites within the system that may become eutrophic. Infrastructure creation as the region grows may pose a particular risk to this area, damaging not only the ecological balance in this estuary, but also the associated oyster culture, fisheries and by association, the growing tourism in this area.

During the dry/hot season, the system receives significant inputs from the ocean, as indicated by high salinities throughout the system and low water levels in the San Pedro River. During the rainy season, this is reversed as the freshwater inputs from the river dominate the system and salinity falls, even at the mouth of the estuary. An intermediate situation is observed during the dry/cold season when the flow of the river begins to diminish. The main canal formed within the narrow estuary has a depth of 3-6 meters, which lends itself to high water flow.

According to the findings of this study, the carrying capacity of this system may be close to a tipping point in terms of whether eutrophication may occur. The large input of organic materials, possible from urban, agricultural and aquaculture sources, produces a high demand for oxygen, which could eventually lead to eutrophic conditions if any factor within the system is altered in the future. The current oyster culture activity could be at risk if eutrophication occurs. It is therefore recommended that any expansion of the industry be limited, or at least conducted in such a manner that large increases in organic material do not occur. It is important to note, however, that it is more likely that changes will occur to the system from development in the upper watershed, or through restrictions to the flow of the San Pedro River as increased demand for freshwater occurs. It is therefore important that decision-makers and other stakeholder become aware of the sensitive status of the coastal estuaries and the possible social and economic losses that will occur if the ecological balance is altered.

The full report which contains all data is available from the principal author, Dr. Omar Calvario Martinez at: ocalvario@ciad.mx

BENEFITS

Approximately 700 people who culture oysters at Boca de Camichin benefited from this study as well as five institutions which participated or which received the results. Given the importance of the findings, the full report is being distributed to decision-makers and other stakeholders in the municipality, as well as to stakeholders working in natural resources management in the area.

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