

Variation on the Fluxes of Nutrients in an Urban Lagoon by Seasonal Effects and Human Activities

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Abstract

This document to examine the changes occurred in the flux of nutrients and NEM during dry season and rainy + north wind season in the Caleta system located within the Términos lagoon natural reserve which presents negative impacts caused by discharges of urban wastewater. Salinity, dissolved oxygen, chlorophyll *a*, nitrogen and phosphorus were monitored during nine months considering the dry, rainy and north wind season. Storms caused sediment disturbances which increased the amount of nutrients into the Caleta system as well as the phytoplankton production (25 mg m^{-3}). The system shows longer times of water renovation during the summer (21 d) unlike (6 d) during the rainy + north wind season. On one hand, the ΔDIP values during dry season ($0.0049 \text{ } \mu\text{mol m}^{-2} \text{ d}^{-1}$), establishes the system as producer and exporter of DIP into the ocean; on the other hand, the ΔDIP during rainy + north wind seasons ($-0.0039 \text{ } \mu\text{mol m}^{-2} \text{ d}^{-1}$) suggests the importation of phosphorus from the ocean. Likewise, the system exports DIN ($0.0031 \text{ } \mu\text{mol m}^{-2} \text{ d}^{-1}$) during the summer and imports DIN ($-0.0048 \text{ } \mu\text{mol m}^{-2} \text{ d}^{-1}$), during the rainy + north wind seasons. The negative values of fixation-denitrification and NEM during the summer turn the system into a nitrogen sink. Seasonal changes were present in the system, dominated by heterotrophic NEM during summer with higher nitrogen fixation; while an autotrophic NEM dominated during winter.

Keywords: Términos Lagoon; Nutrients balance; Nitrogen; Net metabolism

Introduction

The coastal lagoon and the estuaries are zones of mixture exchange of epicontinental and marine water masses passing by natural inlets, artificial streams or tides that, along with the morphology and dynamic of the currents favor different environments that are considered as an adequate habitat for a significant number of important species at a commercial level [1]. The exchange and balance of energy and materials in the different kinds of coastal water bodies are considered as spatial and temporal variables that depend on continental and marine contributions, local morphology and bathymetry, and even on regular and eventual climatic factors (north wind and hurricanes) that characterize the region. Heterogeneous and controversial results are obtained as a result of the high number of factors involved in such exchange [2,3]. Some studies have reported that events such as tropical storms and hurricanes can have a direct impact on salinity and increase the concentration of nutrients, phytoplankton and organic matter as well as to cause hypoxia ($\text{DO} < 2 \text{ mg l}^{-1}$)/anoxia ($\text{DO} = 0 \text{ mg l}^{-1}$) in estuaries [4,5].

Pluvial runoffs typically provide nitrogen to water bodies. Some studies suggest that one month after a storm or hurricane the chlorophyll concentration can reach values up to $20 \mu\text{g l}^{-1}$ [5]. When phytoplankton dies it sediments favoring mineralization in the water column. The nitrogen and phosphorous fluxes increase, as well as the nitrification rates. After a storm, Smith and Caffrey [6] reported increases in the nitrification rates in shallow areas of Escambia Bay, Florida. Shallow areas are susceptible to disturbances and sediment resuspension.

Primary production, respiration and net ecosystem metabolism (NEM) vary through ecosystems, going from highly productive to oligotrophic. NEM is a useful indicator of ecosystem level trophic conditions. If NEM is positive, the system is autotrophic and suggests that internal production of organic matter dominates, while if NEM is

negative the system is heterotrophic and relies on external sources of organic [7]. Since primary production and respiration vary in aquatic ecosystems, is useful to determine NEM [8] in ecosystem principally when are affected by the human activities.

The study of coastal lagoons and estuaries requires the analysis of the interaction between land and marine zones as well as the factors that alter their original characteristics caused by the growing anthropogenic activity that cause local and regional changes having an impact in the primary production and fishing [9,10]. The major contribution of water and nutrients can come of the discharges of wastewater, being the nitrogen one of the factors for the process of eutrophication. When the organic wastes volume increases in the water column, the removal capacity decreases until the oxygen runs out. The combination of the chemical and biological processes where the organic charge is mineralized is known as self-depuration process.

The constant incorporation of organic compounds from fertilizers, wastes, urban development and aquaculture have significantly raise the nitrogen rates in estuaries [11], increasing the presence of algae and chronic effects over several organisms and diminishing the levels of oxygen in the water which could leads to eliminate nitrification [12]. Studies have reported that the salinity, temperature, chlorophyll concentrations, solar irradiance, nutrient loading, organic loading and residence time are important factors to control metabolic rates; however, the nutrients and organic loading have been hypothesized

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to explain variations in rates of net ecosystem metabolism in different estuaries [7].

The objective of this study is to estimate the nutrient fluxes and net metabolism during dry, rains and north wind seasons within the area of the Caleta lagoon located in Isla of Carmen, Mexico. This lagoon has an estimated longitude of 7 km and an approximate depth of 1.5m; the presence of mangroves is scarce and the lagoon connects with Términos lagoon and the Gulf of Mexico at the West. The water column has been affected by urban wastewater discharges and high concentrations of organic matter and nutrients (N and P).

Materials and Methods

Study area

Isla of Carmen is a sand barrier located at the southern extreme of the Gulf of Mexico between 91° 15' and 92° 00' west and 18° 15' and 19° 00' north. It measures approximately 37.5 km long and 3 km wide, it is separated from the continent by two inlets called: Channel West and Channel East (Figure 1). Términos lagoon is located at the southern extreme of Isla of Carmen, the lagoon measures 2,500 km² approximately; its average depth is 3.5 m [13].

The study area, Caleta lagoon is located at the western extreme of Isla of Carmen, it measures 7 km long, and average depth of 1.5m. The system has an area of 140 000 m² and a volume of 210 000 m³, that communicates at the west with Términos lagoon and the ocean (Figure 1). Oil companies, fisheries and urban development's surround this area,

and discharge 613,260 m³ of wastewater every year, affecting negatively the ecosystem. The communication that exists between Caleta lagoon, Términos lagoon and the ocean put at risk the recreational character of the main beaches in Isla of Carmen. The analysis of wastewater reported by System of Water and Sewer of Carmen (SMAPAC) in 2007 showed that the three most important treatment plants in the city present high values of nitrogen (99.13 mg l⁻¹), phosphorus (19.64 mg l⁻¹), and biochemical oxygen demand (212 mg l⁻¹) (Table 1). On the other hand, urban wastewater effluents clandestine are discharged to the Caleta which have not been quantified in volume and concentration of contaminants.

The coastal zone have diurnal tides with a mean range of 0.4 m that can go from -0.5 to 0.7 m.; the tides force the lagoon through Channel west and Channel East and produce a mixing of water masses within Términos lagoon. The weather is humid and tropical; the average annual precipitation is measured to be 1100-2000 mm. The Términos lagoon region present three distinct seasons: north wind season (from November to February), rains season (from June to October), and dry season (from March to May). The average temperature oscillates between 17°C and 35°C. Mangroves and plants in flood areas mainly form the dominant habitat; that have disappeared mainly as a result of indiscriminate deforestation and the use of soil to build urban development's [13].

Salinity, dissolved oxygen, chlorophyll *a*, total nitrogen and total phosphorous were monitored within the Caleta lagoon at 2.0 km and 5.0 km. The temperature, salinity, pH and dissolved oxygen were

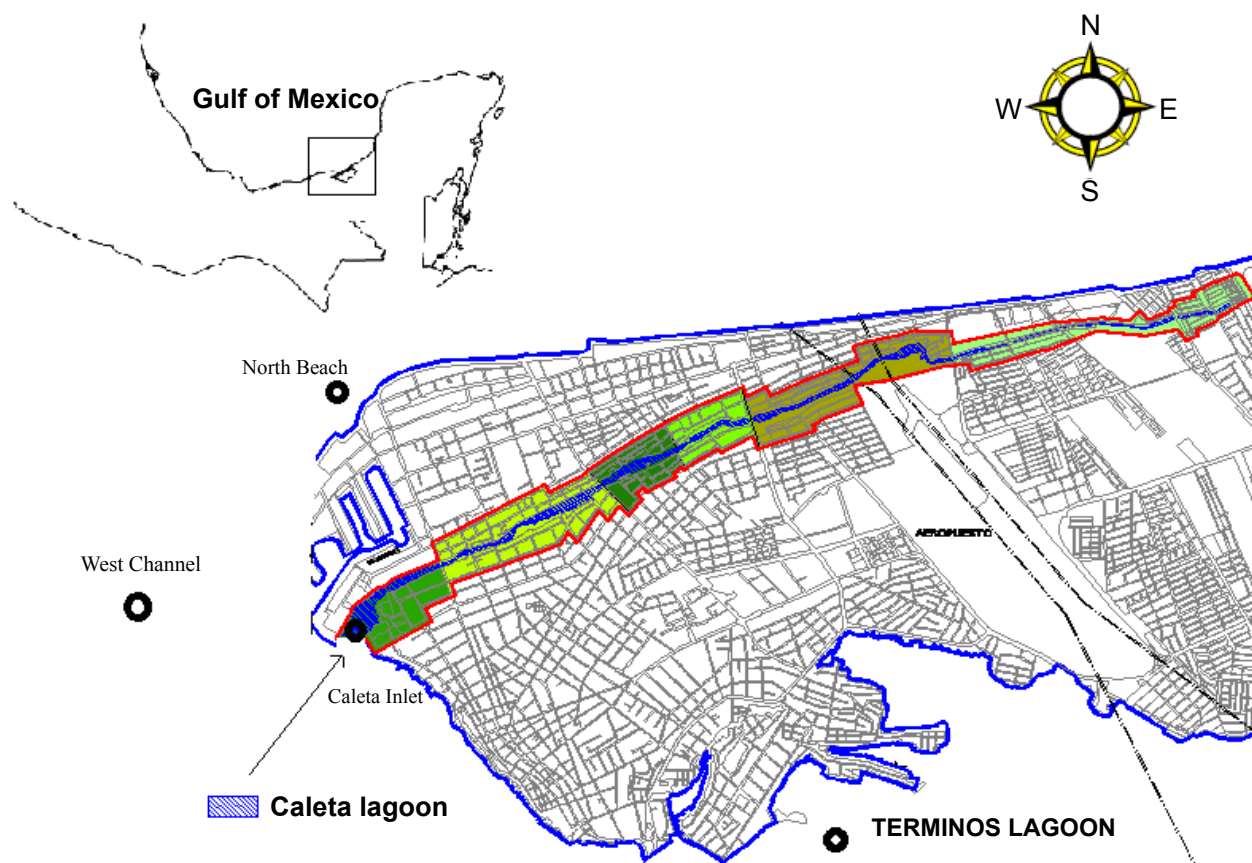


Figure 1: Location of the study area (Caleta lagoon) at Carmen City, Campeche.

Parameter	Units	Wastewater Treatment Plants effluents		
		WTP 1	WTP 2	WTP 3
Temperature	°C	26.3	27	27
pH	---	7.96	7.47	7.10
Total Nitrogen	mg l ⁻¹	99.13	18.64	3.10
Total Phosphorus	mg l ⁻¹	19.64	3.75	4.22
Fat and oil	mg l ⁻¹	20.26	8.03	10.75
Biochemical oxygen demand (BOD)	mg l ⁻¹	212	28	43.0
Suspended solids	mg l ⁻¹	117	27	40
Faecal coliform	MPN 100 ml ⁻¹	9	<3	<3

Table 1: Characterization of Wastewater Treatment Plants (WTP) effluents discharged into Caleta lagoonal system (SMAPAC, 2007).

measured in situ with a Sonda Hydrolab Data 4 placed on the surface of the water in every station; at the same time, other samples of water from the surface were collected with a Van-Dorn bottle. The samples were preserved at 4°C and the same day were sent to the Environmental Science laboratory at the Autonomous University of Carmen to determine the amount of phosphorous (P-PO₄), total nitrogen (TN) through the NT Kjeldahl method, the BOD was determined through the five-days incubation method [14], and the chlorophyll a (Chl a) was determined according to the techniques described on the Standard method [14], the analysis were carried out in a 24 hours period.

Additionally, samples of water were collected in sites near to the Caleta lagoon: Términos lagoon, Caleta inlet, channel west and north beach, to determinate the impact of the urban wastewater effluents. The samples were collected during the three distinctive seasons (north winds season, dry season and rainy season), more specifically during January, February, March, May, June, July, October, November and December. The salinity rates, dissolved oxygen and chlorophyll *a* obtained during the north wind and rainy season were an averaged. The estimation of conservative materials (water and salt), non-conservative materials (nutrients), and NEM was based on the method proposed by Hernández-Ayón et al. [15].

Salt and water budget: To obtain the salt and water budget in Caleta lagoon was according to the equation ($dV_{\text{system}}/dt = 0 = V_Q + V_P + V_E + V_G + V_O + V_R$), so that the residual volume (V_R) compensated the net gains or losses of fresh water, according to the equation:

$$V_R = -(V_Q + V_P + V_E + V_G + V_O)$$

Where the freshwater inputs considered were: V_Q as wastewater discharged; V_G : Groundwater; V_P : Precipitation; V_E : Evaporation and V_O : Outfalls.

During this study, the urban wastewater input (V_Q) in the Caleta system, was considered to be the same during the rain, dry and north winds season. The values estimated of the diverse contributions of water that input to the system during the climatic seasons is showed in the Table 2. It was considered that dissolved salt was eliminated or added to the Systems via mixing (V_X) and advection (V_R) as described in equation [16].

$$V_X = \frac{(-V_R S_R)}{S_{Ocn} - S_{Syst}}$$

Where S_{Ocn} is the salinity in the ocean; S_{Syst} the salinity in the system and S_R is the average salinity between Caleta lagoon and the sea. Based on this information, the residence time (τ) was estimated with the equation:

$$\tau = \frac{V_{Syst}}{V_X + |V_R|}$$

Nutrients budget: In order to estimate the non-conservative flux of nutrients, an equation similar to the salt and water equation was used. The only exception is that the non-conservative term (ΔY) was included which indicates whether the system is a net source sink of these materials:

$$d(VY)/dt = V_Q Y_Q + V_P Y_P + V_G Y_G + V_E Y_E + V_R Y_R + V_X (Y_{Ocn} - Y_{Syst}) + \Delta Y$$

The equation that represents the phosphorus flux is:

$$\Delta DIP = V_R DIP_R - V_X (DIP_{Ocn} - DIP_{Syst})$$

Where DIP_{Ocn} and DIP_{Syst} represent molar concentrations of inorganic phosphorous in the adjacent sea and in la Caleta lagoon; DIP_R is the concentration associated to residual flux (average between DIP_{Ocn} and DIP_{Syst}). The same equation was used to estimate ΔDIN .

NEM and (Nfix-Denit) estimation: The NEM (production-respiration) and the balance between nitrogen fixation and denitrification (nfix-denit) were estimated stochiometrically based on dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN), assuming a Redfield relation for the carbon: phosphorus (C:P) ratio of 106:1, and for nitrogen : phosphorus (N:P) ratio of 16:1, as indicated below:

$$NEM = \Delta DIP \times 106$$

$$(nfix - denit) = \Delta DIN_{obs} - \Delta DIN_{exp}$$

$$= \Delta DIN_{obs} - \Delta DIP \times 16$$

Where, ΔDIN_{obs} is the non-conservative flux of DIN, ΔDIN_{exp} is the expected non-conservative flux of DIN calculated according to the Redfield ratio ($=16 \times \Delta DIP$), and ΔDIP is the non-conservative flux of DIP.

Estimation of biochemical oxygen demand (BOD): To estimate BOD eliminated from urban wastewater discharged into Caleta system, values of 200 mg l⁻¹ were considered for the three seasons (dry, rains and north winds). The equation below was used [17].

$$\frac{S}{S_o} = \frac{1}{1 + k \left(\frac{V}{Q} \right)}$$

Where

S = BOD of the effluent (mg l⁻¹)

S_o = BOD of the affluent (mg l⁻¹)

k = Constant of elimination

Freshwater inputs	Rains + winds north season (m³ annual)	Dry season (m³ annual)
Wastewater discharged (V_Q)	613 260.00	613 260.00
Groundwater (V_G)	0	0
Precipitation (V_P)	280 000.00	128 800.00
Evaporation (V_E)	196 000.00	235 200.00
Outfalls (V_O)	0	0

Table 2: Water contributions in the Caleta system.

V = Volume of the system

Q = Exchange flow ($\text{m}^3 \text{d}^{-1}$)

The relation V/Q represents the residence time (τ), which was calculated from the salt and water budget for every season. The elimination constant (k) was adjusted according to the temperature used the equation

$$\frac{K_T}{K_{20^\circ \text{C}}} = \theta^{T-20}$$

Where K at 20°C was 2.5 and θ was 1.6. K_T was obtained from the average temperature in the water column during the dry season (30°C), and rains+north wind season (26°C).

Results

The salinity in the sampling stations (Términos lagoon, Channel west, Caleta inlet and North beach) showed significant differences (ANOVA, $P=0.002$) between the climatic seasons. At the beginning of the dry season, the salinity increased from 12 to 32; however, the higher values were reported during the rains season (June) increasing from 34 to 36, finally they decreased during the north wind season (December, January and February) from 18 to 20 (Figure 2). The average salinity in the Caleta system was 28 during the dry season and 8 during the rains and north wind season (Table 3).

In contrast, pH (8.0-9.1) did not show significant variations (ANOVA, $P=0.645$) between the seasons and the sampling stations.

The minimum surface water temperature during the north wind season was 27°C and at the beginning of the dry season was 28°C . The months of June and July (rains season) presented the highest temperature of 32°C (these data are not shown in this study).

The oxygen concentration showed significant differences ($P=0.0012$) between the climatic seasons. Intervals of 8- 9 mg l^{-1} were obtained during the dry season in every sampling station located in the adjacent sea. The oxygen levels decreased during the rains and north wind season (6 mg l^{-1}) (Figure 3). As for the Caleta system, the lowest average concentration of oxygen (2.6 mg l^{-1}) was obtained at the upper section of the system (5 km) during the dry and rains+north wind season; while the average concentration of oxygen was similar to the observed in the adjacent sea in the section to 2 km of the stream and at the Caleta inlet.

The average concentrations of DIN and DIP during the dry season were higher in Caleta system (0.140 and 0.685 mmol l^{-1}), with respect to the adjacent sea showed concentrations of 0.035 and 0.501 mmol l^{-1} . During the rain and north wind season, the DIN and DIP contents slightly increased at the adjacent sea (0.058 and 0.371 mmol l^{-1}) while in the Caleta system they were 0.030 and 0.208 mmol l^{-1} . It is worth mentioning that during the dry season the nitrogen concentration was higher in both, the Caleta system and the adjacent sea, while the content of phosphorus was higher only in the Caleta system (Table 3).

The content of chlorophyll *a* varied considerably during the months of study. The highest concentrations of chlorophyll *a* were obtained during the rains and north wind season unlike the dry season

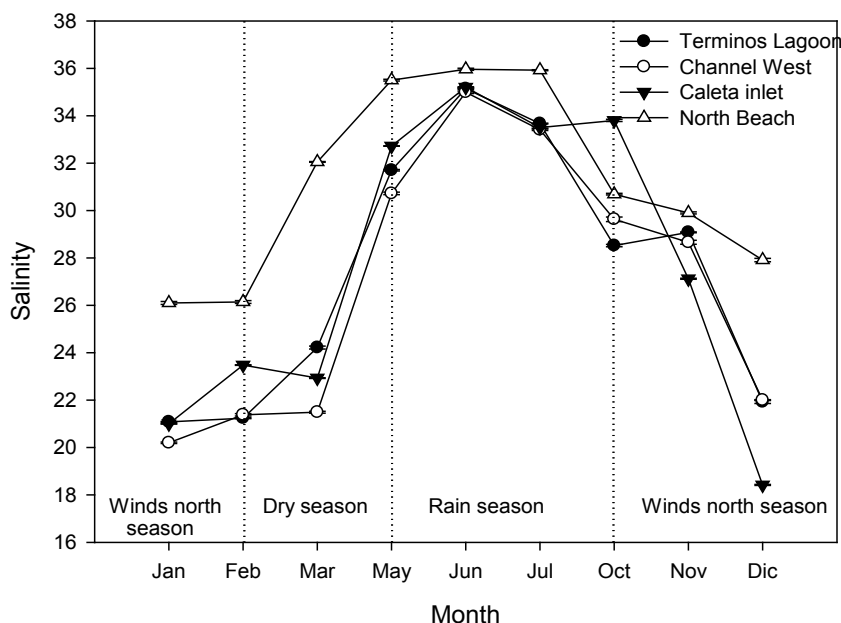


Figure 2: Salinity variation during the three climatic seasons and sampling months.

Season		Salinity	DIP (mmol l^{-1})	DIN (mmol l^{-1})
Dry	Ocean	35	0.035 ^a	0.501 ^a
	Caleta System	28	0.140 ^b	0.685 ^a
Rains + Winds north	Ocean	24	0.058 ^b	0.371 ^b
	Caleta System	8	0.030 ^a	0.208 ^b

* Different letters showed significant differences (Tukey, $\alpha = 0.05$)

Table 3: Average concentration of salinity and nutrients in Caleta system and the adjacent sea.

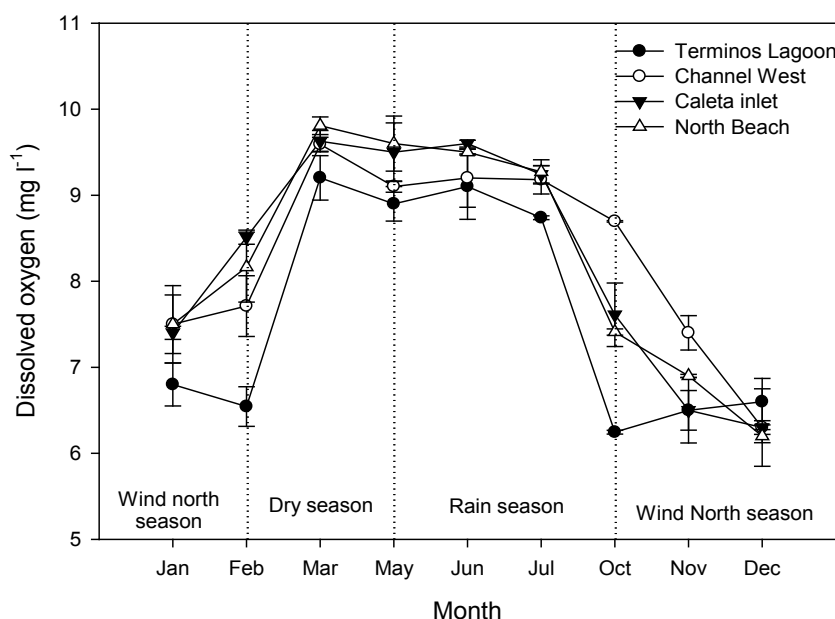


Figure 3: Average concentration of oxygen during the months of study in Caleta system as well as in the adjacent sea.

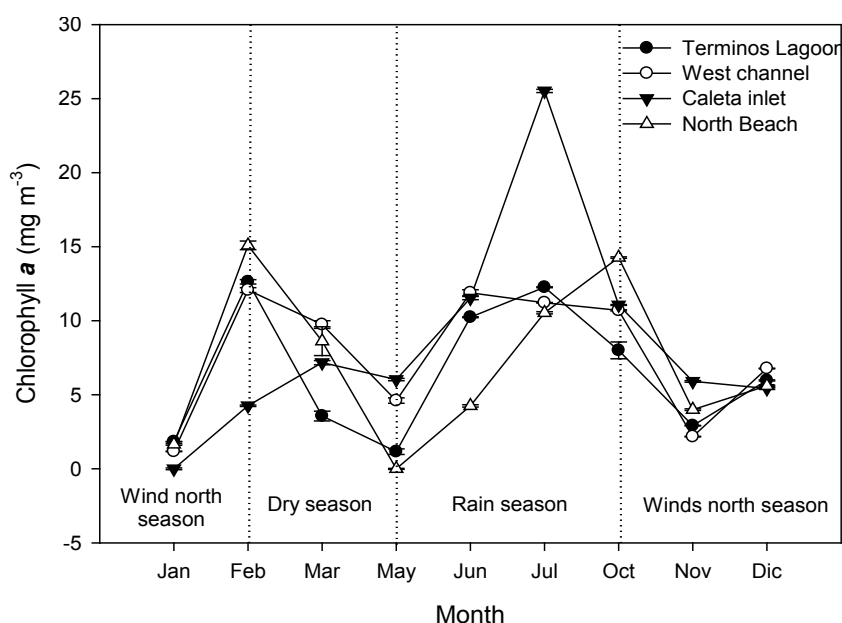
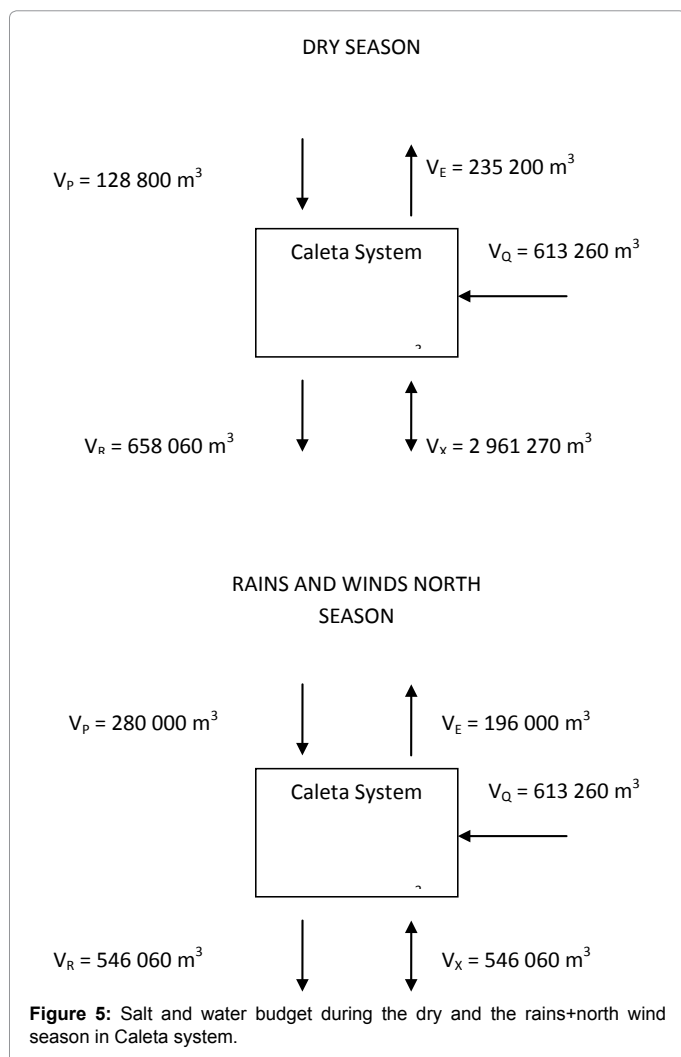


Figure 4: Average concentration of chlorophyll *a* (mg m⁻³) during the months of study in Caleta system and the adjacent sea.

were the lowest concentrations obtained. In the course of the year, it was possible to perceive two important increments of chlorophyll *a*, however the month february is considered as a month of transition between the north wind season and the dry season, while July and October are considered as months of storms. Thus, after storm events the contents of chlorophyll *a* tend to increase, while they decrease during the dry season. The Caleta inlet station presented a high content of chlorophyll *a* (25 mg m⁻³) during the rains and north wind season, in contrast to the internal zone of Caleta system (13.0 mg m⁻³) and the adjacent sea of 10 mg m⁻³ (Figure 4).

The salt and water budget indicated residence times (τ) of 21 and 6 days during the dry and rain + north wind season, respectively (Figure 5). The positive values of ΔDIP (0.0049 $\mu\text{mol m}^{-2} \text{d}^{-1}$) during the dry season at the Caleta system make of it a DIP producer and probably an exporter of this nutrient into the ocean; while during the rains season, the negative value of ΔDIP (-0.00077 $\mu\text{mol m}^{-2} \text{d}^{-1}$) suggests that the system may import phosphorous from the ocean. As a consequence, NEM values are negative during the dry season, while they are positive during the rains season; this indicates changes through the year: system heterotrophic in the dry season and system autotrophic in the rains+north wind season (Table 4). The ΔDIN values presented



Season	ΔDIP	ΔDIN	nfix-denit	NEM
	$(\mu\text{mol m}^{-2} \text{d}^{-1})$			
Dry	0.0049	0.0031	-0.075	-0.522
Rains + Winds north	-0.00077	-0.0048	0.0074	0.081

Table 4: Flux of non-conservative nutrients and stoichiometrically calculations based on Caleta system.

a similar trend. The system exports DIN to the ocean during the dry season and imports it during the rains+north wind season (Table 4). The negative indicator for nfix-denit and NEM during the dry season is associated to the system as nitrogen sink (Table 4).

The analysis realized to determine the elimination of the BOD showed that from an initial concentration of 200 mg l^{-1} , which is contained in the urban wastewater, showed that the organic matter is oxidizes until it reaches a minimum concentration of 8.56 mg l^{-1} (dry season) and 44.05 mg l^{-1} (rain season) at the Caleta inlet and along 7 km. This represents 96 % and 78 % of BOD eliminated during the dry season and the rain +north wind season, respectively.

Discussion

The salinity varied considerably between the climatic seasons. There was a gradually increased during the dry season and reached maximum values at the beginning of the rains season, finally the levels

decreased during the north wind season. All this, suggests that the dilution processes contribute to the salinity decrease during the north wind season. Salinity increased at the beginning of the rains season, this is probably due to a high evaporation rate [18] linked to high temperatures in the water surface.

Within the Caleta system, salinity variations as consequence to the volumes of water that flows into the system and the amount of evaporated water. During the rains season, salinity decreased significantly as a consequence of pluvial runoffs and wastewater discharges; on the contrary, during the dry season there were only two contributors: wastewater and the adjacent sea. This suggests that the exchange of salt and water within the system depends on the contributors; hence the need to carry out annual studies to describe the system correctly by considering the changes caused by hurricanes and north wind season.

It is a fact that the system presents a higher input of wastewater per year ($613,260.00 \text{ m}^3$) compared to the precipitation volume during the dry season and the rains+north wind season (Table 2). This implies that, high contributions of different pollutants could be altering the ecosystem and affecting to the species; a potential risk to the public health is also present.

Accumulation and re-suspension of organic components contribute to decrease the oxygen rates, as observed during the rains and north wind season. The Términos lagoon and adjacent lagoons have reported similar results [19-21] suggested that when the organic material increases after the rains season, the microorganisms decompose such organic material removing the oxygen from the column of water. Particularly, in the area of exchange between Términos lagoon and the sea, the oxygen concentration increases during March and May (dry season), and reach its highest values during June and July (rains season). A high content of oxygen in the water column is related to high concentrations of chlorophyll *a*; however, in the present study this phenomenon was only observed during the rains season (Figure 4). That could be caused by high amounts of nutrients being removed by phytoplankton which concentration increases during June and July. Some studies suggest that phytoplankton and phyto-benthos removed not only the nutrients imported from the sea but also the nutrients that come from the sediment. The influence of sediment over the nutrients regeneration enriching the water column it is not despicable, specially regarding ammonium, phosphate and silicate [22]; such phenomena occurs mainly in the Caleta lagoon during the dry season where high concentrations of DIN are present. Given the shallow depth of the system, nitrogen can move from the sediment to the water column. It has been proved that nitrogen net mineralization rates can be relatively low during most of the year, increasing from June to August probably because of temperature and microbial activity in the sediment [23]. Some studies suggest that the sediments are decisive since ammonium is the main source of exchangeable nitrogen at the sediment-water interface [24]. That could explain the nitrogen enrichment in the water column during the dry season as well as its immediate consumption during the rains and north wind season, favoring the increase of chlorophyll *a* at Caleta inlet station.

Such seasonal changes regarding the nitrogen concentration rates are partially associated to the nutrients from wastewater and other external inputs. During the dry season, high concentrations of DIN show that the system is mainly controlled by biological processes instead of external-physical inputs that liberate nitrogen into the water column as a subproduct of degradation (heterotrophic system). While, during the rains and north wind season, the negative fluxes of DIN

indicate that the Caleta lagoon system works as a sink and presents the main characteristics of an autotrophic system; this suggests that after storms the rates of chlorophyll *a* increase. During June, July and August when the biggest storms take place, the month of July reported the highest rates of chlorophyll ($10\text{--}25\text{ mg m}^{-3}$). Hagy et al. [5] reported similar observations at Pensacola Bay where a phytoplankton bloom with chlorophyll *a* concentrations of $20\text{ }\mu\text{g l}^{-1}$ took place a month after hurricane Ivan suggesting that the dead biomass at the bottom of the water column initiates decomposition processes generating nitrogen and increasing NH_4^+ , DIP and $\text{NO}_3^- + \text{NO}_2^-$ fluxes as well as increasing the nitrification rate potential [6].

During the summer, the Caleta lagoon presents heterotrophic characteristics and nitrification processes dominate; similar results were reported by Valenzuela et al. [10] at the Lobos Lagoon in Mexico. Such heterotrophic conditions are associated to organic loads from mangroves and its biological degradation. Studies suggest organic loads from mangroves can modify the nitrogen and phosphorus fluxes in estuaries and can be net sources of nutrients. On the other hand, studies have reported that the mangrove detritus are equivalent to $345\text{ g C m}^{-2}\text{ year}^{-1}$ [25,26]. The amount of nutrients exported by mangroves can be higher to the amount exported by rivers during the dry season (31.39 ton) and the rains season (55.14 ton), hence, the amounts of nutrients exported by mangroves are higher than the amounts received [3-27].

Heterotrophic conditions have been reported in systems as Bahía de San Quintín, Baja California, México; studies by Hernández-Ayón et al. [15] suggest that during the summer external inputs of organic matter present in such quantities that respiration exceeded photosynthesis. Under such conditions, it is evident that the Caleta lagoon system receives high inputs of organic matter from local mangroves as well as from urban wastewater; after its degradation, organic matter releases nitrogen in the water column and turns the system into a nitrogen exporter.

The DIP fluxes show that, during the dry season the Caleta lagoon system export phosphorus to the adjacent sea, while during the rains+north wind season the system works as sink. The rates of imported phosphorus were lower than the rates of exported phosphorus, hence it is quite probable that most of it comes from urban wastewater discharges as well as from biological processes. The phosphorus mineralization rates within the lagoon system can vary according to the water temperature, oxygen and $\text{NO}_3^- + \text{NO}_2^-$ concentration as well as the contents of iron which is an important element for the phosphorus release [28]. Some studies demonstrate that positive fluxes of DIP, like the ones observed as Escambia Bay, are linked to phosphorus release from the sediment to the water column; those areas with anoxic conditions presented the highest concentrations ($\text{DO}=0.9\text{ mg l}^{-1}$) [6].

Moreover, the increase in the microbial metabolism contributes to create anoxic conditions caused by the consumption of nutrients and organic matter, during this process iron and phosphorus are reduced and released [29]. The increasing phosphorus levels in the water column, suggest that when temperatures are high (summer) the sediment in the Caleta lagoon system releases such nutrient which enriches the system and presents positive fluxes ($0.0049\text{ }\mu\text{mol m}^{-2}\text{ d}^{-1}$); such phenomenon confirms the phosphorus exportation during the dry season.

Phosphorus bioavailability depends on the capacity of the sediments and suspended particles to release or sequester phosphates, which under such conditions keeps its concentration under a narrow

interval of values [30] which limits the availability of this nutrient to phytoplankton. The short-term effects in suspended sediments lead to a highly effective performance due to phosphates dissolved among phytoplankton and sediment particles [24].

Phosphorus dynamics is related to adsorption and desorption processes. Orthophosphate ions interact with the surface of suspended particles in such way that when DIP concentrations rise particles adsorb phosphorus; when such concentrations decrease phosphorus desorbs to compensate the nutrient in the water column [31]. Aquatic sediments can be phosphorus-rich if they present an important fraction of muds and clay because these particles are so small that they represent a greater surface, besides Fe and Al oxides that cover them can adsorb important quantities of phosphorus [32,33]. Some experiments based on adsorption-desorption in sediment by Ortiz-Hernandez et al. [34] at Bahía San Quintín, Baja California, México, suggest that adsorption is the dominant effect of suspended particles on DIP, specially when there are high concentrations of small particles, hence adsorption in a particles concentration of 0.1 g l^{-1} is higher in sandy mud sediment (0.93 l g^{-1}), unlike fine grains of sand (0.62 l g^{-1}); such differences are based on the number of active sites as a result of different grain sizes.

Previous granulometric studies show that Caleta lagoon system presents a higher concentration of sand (73.5 – 94 %), while fractions of muds are from 0.5 to 22.5 %; and clay from 4.0 to 9.5 %; suggesting that the system can present sandy muds sediment in greater proportions. On the other hand, in this kind of sediments it is more common to find higher concentrations of Fe (110.01 ppm). This is due to the fact that sediment favors the adsorption processes, thus during the rains season the phosphorus contents decrease because particles increase in the water column, while during the dry season desorption processes take place because the water column presents low mixing levels. The decrease in the phosphorus rates during the rains season forces the system to import this nutrient from the adjacent sea and can be demonstrated based on the following values: NEM (positive) 0.081 and ΔDIP (negative) 0.00077.

The impact of the wastewater discharges into the system based on BOD estimation and elimination it is an evidence that throughout the 7 km of the Caleta system, there is a reduction from 96 % (dry season) to 78 % (rains + north wind season), while BOD levels at the Caleta inlet can drop to reach 0.0035 mg l^{-1} (dry season) and 0.17 mg l^{-1} (rains + north wind season). Data obtained from water samples indicate that the BOD content was ($0.2\text{--}1.2\text{ mg l}^{-1}$); low BOD levels at the Caleta inlet are the reason for the great capacity of the system to decompose organic matter. Although in this analysis organic contribution from mangroves was not considered which would increase the organic input in the system, it is possible to conclude that the system presents high self-depuration levels that favor flux dynamics of nitrogen.

Conclusions

Caleta lagoon system shows seasonal changes. The dry season is characterized by a heterotrophic system that exports nitrogen and phosphorus, while the rains season is characterized by a heterotrophic system that imports nutrients from the adjacent sea. During the summer, high concentrations of DIN indicate that the system is mainly controlled by biological processes instead of external physical inputs; hence nitrogen is released into the water column as a sub product resulting from the degradation of organic matter present in wastewater and mangrove detritus.

During the summer, the system exports phosphorus to the adjacent sea, whereas during the rains and north wind season such nutrient is

imported. Given that the phosphorus import is low compared to the export during the dry season, it is possible that adsorption-desorption processes are associated to the dynamics of such nutrient in Caleta lagoon system; in other words, during the rains season the amount of particles increase in the water column and P can be adsorbed and decrease its content; in contrast, during the dry season desorption processes could be present.

BOD levels in wastewater are reduced when they come into the Caleta lagoon system, which indicates that it presents good levels of self-depuration with residence time equivalent to 21 day during the dry season and 16 day during the rain and north wind season.

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