Changes in the hydrological characteristics of Chabihau coastal wetlands, Yucatan, Mexico, associated with hurricane Isidore impact

Eduardo Batllori * & José L. Febles
CINVESTAV, Research and Advanced Studies Center of I.P.N., Human Ecology Department., Km 6 Antigua
Carretera a Progreso, A.P. 73, Cordemex, Merida, 97310, Yucatan, Mexico
* [E-mail: batllori@mda.cinvestav.mx ]

Received 22 May 2006, revised 14 May 2007

This paper describes changes in the hydrologic behavior of Chabihau coastal lagoon, Yucatan, Mexico, associated with the impact of Hurricane Isidore (2002) and the construction of hydraulic infrastructure in coastal highways, through the spatiotemporal analysis of the water physicochemical variables, from the 1999 flood season to the 2005 dry season. The coastal wetlands were subdivided into three areas: San Crisanto swamp in the west, Chabihau lagoon in the center, and Santa Clara swamp in the east. After the hurricane impact and construction of bridges in the coastal dune, stronger tide’s ebb into the Chabihau lagoon was recorded, changing it from a hyperhaline system to an euryhaline one. On the other hand, changes to hyperhaline conditions were observed in Santa Clara swamp during dry and flood seasons. After the hurricane, negative redox values were recorded throughout the entire Chabihau wetlands, in addition to a reduction in dissolved oxygen and pH, during both dry and flood seasons. This situation determined dominance of reductive processes in the three areas, with low temporal variability. If the salinization process continues in the Santa Clara swamp, changes may occur in the structure and composition of the mangrove forest.

[Key words: Coastal wetlands, hurricane Isidore, hydraulic infrastructure, Yucatan, Mexico, Chabihau wetland]

Introduction
The hydrologic conditions of coastal wetlands affect many abiotic factors, including those related with organic matter oxidation and reduction processes, nutrient and oxygen availability, water and sediment salinity\(^1,2\). This determines the flora and fauna that may develop in the ecosystem. Consequently, this biological development alters the wetland hydrologic conditions, reinitiating the cycle with different levels of organization and complexity, depending on the level of inundation, input and output flows, geomorphology and sediment relief.

Coastal wetlands affected by ocean tides are generally more productive than those that are occasionally flooded, as well as alternation between dry and flood seasons may lead to optimal conditions for detritus decomposition\(^3\). On the other hand, the anaerobic condition that may develop in areas that are permanently flooded may considerably delay this decomposition process\(^3\). Nutrient cycling may also be very fast in situations of high water exchange, making many nutrients available for plants due to changes in pH and the soil redox potential\(^4\).

Coastal ecosystems in Yucatan present particular characteristics due to their karstic origin and the absence of surface rivers. These are systems created by the dynamics of the sea currents that form a barrier island or coastal dune, and lagoon systems – open or enclosed – which, due to underground freshwater input through springs, acquire a brackish character in some sites, and hyperhaline conditions in others, as in the case of Chabihau wetlands. The most severe human induced problems that affect coastal wetlands in Yucatan are related to 1) road construction, 2) opening of ports, 3) population growth, 4) saltwater intrusion through coastal sandbar breaches, and 5) freshwater springs sedimentation. Due to these factors, Batllori et al.\(^5\) reported a loss of 1.3 km\(^2\)/year of mangrove forest, from 1948 to 1991, in the Yucatan’s northwest coastal wetlands.

The main objective of this study is to describe changes in the hydrologic characteristics of the Chabihau wetlands, associated with the impact of hurricane Isidore and the construction of hydraulic infrastructure in coastal roads, through the spatiotemporal analysis of the water physicochemical variables, from the 1999 flood season to the 2005 dry season. This study is important to understand the spatial and temporal changes and the organization of the ecosystem to the new hydrological conditions, due
to structural changes generated by the hurricane. Also, this environmental information is a key to understand the social adaptive response to the potential biological resources appropriation in the transformed ecosystem.

**Study area**

There are three urban localities in this wetland, San Crisanto, Chabihau and Santa Clara, connected by a road network in the coast as well as inland, which modifies water flows and sediment transport. Among the roads that section the lagoon, from north to south, there is one that joins San Crisanto with Sinanche, the one that goes from Chabihau to Yobain, and the Santa Clara – Dzidzantun road. The hydraulic infrastructure associated with these roads in flood areas includes 36 culverts of different dimensions (less than 0.45 m wide - most of which operate deficiently -) before year 1999, and eleven with 3.5 m wide bridges built after 2000. In fact, the first mentioned highway is established as a blockage of lateral water flow between the east side and the west side, creating very different environmental conditions due to variation in water salinity.

This ecosystem is quite vulnerable to hurricane impact. Both Hurricane Gilbert in 1988 and Hurricane Isidore in 2002 caused breaches in the sand barrier, connecting the sea with the lagoon in the eastern part of the Chabihau locality, changing the system from seasonal flooded to tide-dominated. This situation has brought on social and economical benefits, such as an increase in fishing for self-consumption - mainly shrimp in the winter.

Since June 1997, the local government constructed a floodgate system in coastal road (4 meters wide) near the village of Chabihau, which allows for controlled sea-water flow and the release of brackish or hyperhaline lagoon water, at the same time allowing for periodic harvesting of some species, under conditions of seasonal semi-captivity (shrimp, crab and fish). In 2003, two road bridges were built over the mouths that were opened by Hurricane Isidore in 2002, one 24-m wide in the eastern border of the urban area of the Chabihau locality, and the other, 12-m wide, near Santa Clara. In all of these sites there is now an important water exchange between sea and lagoon, in such a way those changes are expected in the water quality in the ichthyofauna and in the vegetation structure, mainly of the mangrove, which is important as a refuge for species and productive base for strategic subsistence fisheries, both locally and regionally.

The Chabihau coastal lagoon and swamp (salt flats and basin mangrove), extends for 17 km, from the San Crisanto to Santa Clara roads, and covers a surface area of approximately 45 km², of which 34 km² are occupied by the lagoon with permanent water (11.49 km²) and swamp (22.51 km²), and 11 km² of flooded low forest and savannah. These wetlands are protected by a sand barrier with coastal dunes that barely exceed 300 ha (Fig. 1). The climate is hot and dry, with a mean annual temperature of 26°C. Annual precipitation is 600 mm, while evaporation exceeds 1800 mm per year. Rainy season begins in May, with the rainiest months being June and September. A short dry period occurs in July and August, and starting from October, precipitation is reduced. The less humid months are February, March and April. The prevailing wind direction is from the NE, E and SE, followed by winds from the north (October to March). Tides are diurnal with amplitudes < 1 m. The tide level is lower between March and August while the highest level occurs after October, related with the north winds.

In the southwestern part of the study area, 2 km from the coast toward Sinanche, natural terrain heights reach 1 m above mean tide (m) (high swamp); toward the coast, extends a plain with average values
of 0.5 m (middle swamp). A depression of the land is observed in the east toward Chabihau, with values between –0.2 and –0.7 m (low swamp). In Santa Clara, topographic heights of –0.2 m predominate; elevations of 0.3 m can be found in the entire northern extension and of 0.5 m in the southern portion. The sand barrier reaches heights near of 3 m, protecting the lagoon from the tide, waves and wind forces. The volume of water in this lagoon is approximately $17 \times 10^6$ m$^3$.

**Materials and Methods**

In 1999, a hydrologic monitoring network was built, with 22 permanent stations distributed to the East and West (E and O) of the San Crisanto, Chabihau and Santa Clara wetland roads (Fig. 1), and located at different sites of the wetlands (high swamp -HS, middle swamp -MS, low swamp -LS, springs, floodgate and sea). The sampling was conducted on a monthly basis and in the morning. In order to measure the water depth, a calibrated wood beacon was installed in each site; an YSI model 85 multi-analyzer was used to record salinity (ranging from 0 to 80 psu, ±0.1), temperature (ranging from -5 to 65°C, ±0.1), and dissolved oxygen (ranging from 0 to 20 mg/L, ±0.3). Salinity values over 80 psu were estimated using an ATAGO refractometer (ranging from 0 to 28%, ±0.2). Values of over 280 psu were estimated with 50% dilution. Salinity values were classified according to Mitsch & Gosselink\textsuperscript{1} for marine and estuarine environments.

The YSI pH100 analyzer was used to measure pH (ranging from -2 to 16, ±0.01) and redox potential (ranging from -1999 to 1250 mV, ±1). A total of 43 sampling events were conducted throughout the network from July 1999 to July 2005, with the exception of the year 2003, in which only one sampling event took place. This way, 26 sampling events occurred before Hurricane Isidore in September 2002 and 17 events after the hurricane.

The values were grouped into two seasons, in relation to flood periods (September-February) and dry (March-August) respectively. The September to February period corresponds to the end of rainy and the north wind seasons (fall-winter), when the greatest volume of groundwater discharging into the coastal system by springs and the highest ocean tide elevation are recorded \textsuperscript{9-11}. As a complement, rainfall data for the Telchac Puerto station, for the 1999-2005 period, were obtained from the Mexican National Water Commission.

The data were processed in Excel for windows (2002) for each station and per parameter, for the 43 events (5,676 data in total). Measures of central tendency such as mean, standard deviation and variation coefficient were taken. The log10-transformed data of each parameter and each area were submitted to a two-way analysis of variance, with seasons (dry or flood) and sites as factors. A Spearman nonparametric correlation analysis was conducted to determine the degree of association among sites. The information of each parameter was incorporated into the SURFER V.8 program, obtaining graphics, with their respective values in isolines.

**Results**

The general seasonal average of the data during the study period (June 1999 to July 2005) is shown in Table 1. Among other characteristics, the one that stands out is the wetlands hyperhaline character, in addition to it being a very shallow, warm water body, with oxygen levels near 4 mg/l. Water depth was the parameter with greatest seasonal variation (CV = 60.5%), followed by redox and water salinity values (49% and 46%, respectively).

The general spatial average of the data (1999 to 2005) is shown in Table 2. In terms of salinity, depth, temperature and redox, mean values were higher in the Eastern swamp portion of the wetland roads than in the Western swamp portion.

<table>
<thead>
<tr>
<th>Chabihau wetlands</th>
<th>San Crisanto swamp</th>
<th>Chabihau lagoon</th>
<th>Santa Clara swamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity (psu)</td>
<td>41.62 (46.2)</td>
<td>61.57 (70.9)</td>
<td>41.35 (33.4)</td>
</tr>
<tr>
<td>Depth (cm)</td>
<td>20.16 (60.5)</td>
<td>10.23 (128.9)</td>
<td>18.02 (43.5)</td>
</tr>
<tr>
<td>Temp (°C)</td>
<td>29.09 (2.5)</td>
<td>28.78 (13.1)</td>
<td>29.45 (10.2)</td>
</tr>
<tr>
<td>$O_2$ (mg/l)</td>
<td>4.36 (23.3)</td>
<td>3.29 (76.3)</td>
<td>5.19 (59.0)</td>
</tr>
<tr>
<td>pH</td>
<td>8.17 (2.7)</td>
<td>8.17 (8.1)</td>
<td>8.21 (9.3)</td>
</tr>
<tr>
<td>Redox (mV)</td>
<td>-68.82 (49.4)</td>
<td>-13.91 (651.7)</td>
<td>-76.81 (325.4)</td>
</tr>
</tbody>
</table>
Table 2—Spatial average of hydrological parameters at Chabihau wetlands, Yucatan, 1999-2005, (Variation Coefficient %).

<table>
<thead>
<tr>
<th></th>
<th>Salinity (psu)</th>
<th>Depth (cm)</th>
<th>Temperature (°C)</th>
<th>O₂ (mg/l)</th>
<th>pH</th>
<th>Redox (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EHS</td>
<td>62.82 (97.31)</td>
<td>5.68 (64.72)</td>
<td>29.70 (8.26)</td>
<td>3.06 (76.33)</td>
<td>8.00 (2.10)</td>
<td>-137.00 (252.00)</td>
</tr>
<tr>
<td>EMS</td>
<td>69.70 (51.18)</td>
<td>23.09 (80.12)</td>
<td>30.18 (4.08)</td>
<td>3.92 (39.60)</td>
<td>8.14 (1.35)</td>
<td>-82.87 (81.00)</td>
</tr>
<tr>
<td>ELS</td>
<td>64.56 (64.88)</td>
<td>29.09 (57.77)</td>
<td>29.59 (2.44)</td>
<td>4.54 (31.05)</td>
<td>8.18 (1.80)</td>
<td>-59.89 (40.62)</td>
</tr>
<tr>
<td>WHS</td>
<td>22.28 (107.55)</td>
<td>7.85 (47.62)</td>
<td>28.00 (6.47)</td>
<td>2.58 (23.04)</td>
<td>8.39 (7.04)</td>
<td>-69.48 (136.20)</td>
</tr>
<tr>
<td>WMS</td>
<td>27.56 (130.51)</td>
<td>18.24 (69.25)</td>
<td>28.41 (11.16)</td>
<td>4.46 (43.29)</td>
<td>8.04 (4.14)</td>
<td>-64.82 (29.76)</td>
</tr>
<tr>
<td>WLS</td>
<td>35.41 (83.33)</td>
<td>15.81 (13.68)</td>
<td>29.57 (4.95)</td>
<td>5.52 (18.74)</td>
<td>8.65 (0.55)</td>
<td>-44.48 (15.65)</td>
</tr>
<tr>
<td>Floodgate</td>
<td>39.33 (24.65)</td>
<td>43.92 (25.88)</td>
<td>28.80 (12.26)</td>
<td>4.72 (53.73)</td>
<td>8.17 (8.08)</td>
<td>-87.56 (181.49)</td>
</tr>
<tr>
<td>Spring</td>
<td>18.56 (41.33)</td>
<td>17.62 (51.88)</td>
<td>29.20 (2.20)</td>
<td>4.94 (12.27)</td>
<td>7.94 (1.17)</td>
<td>-62.25 (91.70)</td>
</tr>
<tr>
<td>Sea</td>
<td>34.37 (1.66)</td>
<td>28.34 (1.41)</td>
<td>5.52 (2.04)</td>
<td>7.98 (0.80)</td>
<td>11.06 (174.22)</td>
<td></td>
</tr>
</tbody>
</table>

Figures 2-4, on spatial-temporal distribution of the different parameters for each transect, show changes in the water physicochemical characteristics, particularly in the low portion of the swamp in Santa Clara, with an increase in salinity, whereas in the middle and low part of Chabihau, salinity decreased. Another relevant aspect is that the levels of dissolved oxygen, pH and potential redox decreased, which could be related with a dominance of organic matter reduction processes over oxidation processes. San Crisanto was the area with less change.

In terms of average values before and after the hurricane, and the construction of bridges, differences in salinity and pH were found in all transects. In San Crisanto and Santa Clara, differences were observed in depth and temperature, while dissolved oxygen only showed differences in Santa Clara (Table 3, 4).

Before hurricane Isidore (2002), high redox potential values were observed, with very high variation coefficients. In Santa Clara, average redox values were positive in both dry and flood seasons. Nevertheless, there were no differences in redox potential between dry and flood season in the three transects (Table 4). Before the hurricane, pH values were above 8.5 and only decreased in San Crisanto during dry season (with average values of 7.7), showing significant differences between seasons (Table 4). In Chabihau and Santa Clara, pH values remained above 8.4, in both dry and flood seasons. Oxygen values were ≥4.0 mg/l, with highest values during dry season. None of the transects exhibited differences in oxygen between dry and flood seasons (Table 4). Greater variability in water depth levels was observed (as in Santa Clara). Temperature and depth exhibited differences in the three transects, between dry and flood seasons (Table 4). The San Crisanto and Chabihau areas displayed hyperhaline conditions before the hurricane in both dry and flood seasons; Santa Clara had brackish water in both seasons, with lower values during dry season (26 psu). Before the hurricane, both San Crisanto and Santa Clara displayed differences in salinity between dry and flood seasons.

After the hurricane, negative redox values were recorded for all the areas during both dry and flood seasons, with low seasonal variability, and significant differences were not found between dry and flood seasons in all the areas (Table 4). The swamp water exhibited a decrease in pH, with values of 7 for both dry and flood seasons. In the Chabihau lagoon, water depth decreased; however, it increased in San Crisanto and Santa Clara, particularly in dry season, which could be controlled by sediment transport and tides. Significant depth differences were observed in all the areas and between seasons. A decrease in dissolved oxygen, down to 3 mg/l, was recorded, with high variability, and a significant drop in dry season. Differences between seasons were only observed in the Santa Clara swamp. Average temperatures in San Crisanto increased in both dry and flood seasons. Water salinity in Chabihau had marine conditions in both seasons, as in Santa Clara during flood season. Differences were not observed between seasons, except for San Crisanto. Here, hyperhaline conditions were recorded only during the dry season, as in Santa Clara. The latter means that a salinization process began in the middle and low areas of the Santa Clara swamp. It is important to point out that the seasonal variation coefficients, per area, of all the parameters, were lower after Hurricane Isidore.

If we consider the dry season, before and after the hurricane, we can observe differences in water
temperature in San Crisanto, while Chabihau exhibits differences in salinity and pH. In Santa Clara, differences were observed in all the parameters except for redox potential. Now, regarding flood seasons before and after the hurricane, San Crisanto displayed differences in temperature, salinity, depth and pH; Chabihau displayed differences in salinity, depth and pH; and Santa Clara only exhibited differences in salinity (Table 4).

In the meteorological station of Telchac Puerto, located 6 km from Chabihau lagoon, lower precipitation was recorded in 2000 and 2001 (374 mm and 590 mm, respectively), when hyperhaline conditions were observed in the lagoon, in dry as well as flood season. Subsequently, in 2002, accentuated by the effect of Hurricane Isidore, a precipitation of 860 mm was recorded, promoting the lowest salinity recorded in the lagoon. In 2004, higher rainfall was recorded (944 mm), however, the effect of the bridges and the increase in water exchange with the sea did not allow reaching the minimum salinity values recorded previously.

**Discussion**

The water temperature is a limiting factor for many aquatic organisms such as fish and mangroves, which

---

Fig. 2—San Crisanto transect. Temporal Distribution of A) water salinity (psu), B) Temperature (°C), C) Depth (cm), D) O$_2$ (mg/l), E) pH and F) REDOX (mV) (1999-2003 and 2004-2005). [EHS: East High Swamp, EMS: East Middle Swamp, ELS: East Low Swamp and SEA].
## Table 3—General average of hydrological parameters before and after hurricane Isidore, and by season, at the Chabihau wetlands (Variation Coefficient %)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before hurricane 1999-2002</th>
<th>After hurricane 2002-2005</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Dry season</td>
</tr>
<tr>
<td>Salinity</td>
<td>50.45 (85.56)</td>
<td>60.14 (82.69)</td>
</tr>
<tr>
<td>Depth</td>
<td>11.27 (74.62)</td>
<td>8.90 (83.33)</td>
</tr>
<tr>
<td>Temperature</td>
<td>27.78 (11.72)</td>
<td>29.10 (8.72)</td>
</tr>
<tr>
<td>O₂</td>
<td>3.72 (40.24)</td>
<td>3.78 (41.15)</td>
</tr>
<tr>
<td>pH</td>
<td>8.17 (6.57)</td>
<td>7.84 (7.47)</td>
</tr>
<tr>
<td>Redox</td>
<td>-4.88 (1053.47)</td>
<td>-2.83 (1125.94)</td>
</tr>
</tbody>
</table>

## Table 4—Analysis of Variance at Chabihau wetlands (* p=0.05  95 %).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>F</th>
<th>Sig.</th>
<th>F</th>
<th>Sig.</th>
<th>F</th>
<th>Sig.</th>
<th>F</th>
<th>Sig.</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity</td>
<td>7.545</td>
<td>0.007 *</td>
<td>8.157</td>
<td>0.005 *</td>
<td>28.001</td>
<td>0.001 *</td>
<td>1.821</td>
<td>0.127</td>
<td>7.703</td>
<td>0.001 *</td>
</tr>
<tr>
<td>Depth</td>
<td>13.006</td>
<td>0.000 *</td>
<td>5.708</td>
<td>0.018 *</td>
<td>2.621</td>
<td>0.113</td>
<td>3.881</td>
<td>0.054</td>
<td>8.413</td>
<td>0.005 *</td>
</tr>
<tr>
<td>Temperature</td>
<td>19.715</td>
<td>0.000 *</td>
<td>14.009</td>
<td>0.000 *</td>
<td>14.243</td>
<td>0.000 *</td>
<td>8.690</td>
<td>0.004 *</td>
<td>9.992</td>
<td>0.002 *</td>
</tr>
<tr>
<td>O₂</td>
<td>1.345</td>
<td>0.248</td>
<td>1.698</td>
<td>0.195</td>
<td>0.310</td>
<td>0.581</td>
<td>0.517</td>
<td>0.475</td>
<td>1.283</td>
<td>0.260</td>
</tr>
<tr>
<td>pH</td>
<td>0.042</td>
<td>0.838</td>
<td>0.483</td>
<td>0.495</td>
<td>0.262</td>
<td>0.636</td>
<td>0.558</td>
<td>0.489</td>
<td>0.013</td>
<td>0.909</td>
</tr>
<tr>
<td>Redox</td>
<td>5.309</td>
<td>0.024 *</td>
<td>12.377</td>
<td>0.001 *</td>
<td>0.574</td>
<td>0.454</td>
<td>1.335</td>
<td>0.255</td>
<td>5.058</td>
<td>0.031 *</td>
</tr>
</tbody>
</table>

## Table 5—Average of hydrological parameters before and after hurricane Isidore, and by season, at the Chabihau wetlands (Variation Coefficient %)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before hurricane 1999-2002</th>
<th>After hurricane 2002-2005</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Dry season</td>
</tr>
<tr>
<td>Salinity</td>
<td>50.45 (85.56)</td>
<td>60.14 (82.69)</td>
</tr>
<tr>
<td>Depth</td>
<td>11.27 (74.62)</td>
<td>8.90 (83.33)</td>
</tr>
<tr>
<td>Temperature</td>
<td>27.78 (11.72)</td>
<td>29.10 (8.72)</td>
</tr>
<tr>
<td>O₂</td>
<td>3.72 (40.24)</td>
<td>3.78 (41.15)</td>
</tr>
<tr>
<td>pH</td>
<td>8.17 (6.57)</td>
<td>7.84 (7.47)</td>
</tr>
<tr>
<td>Redox</td>
<td>-4.88 (1053.47)</td>
<td>-2.83 (1125.94)</td>
</tr>
</tbody>
</table>
present problems when growing in temperatures of over 42°C. The effect of the increased temperature, particularly in the San Crisanto area, may play a role in certain important reactions such as the accelerated decomposition of organic matter, nitrification, and biological processes such as germination and the development of mangrove seedlings. The salinity gradient and the water level, contribute to the distribution of different species throughout the wetlands, while their seasonal variations determine the vegetation composition.

The high concentrations of salt may inhibit enzymatic activity, protein synthesis and respiration rate. Red mangrove (Rhizophora mangle) can grow in deeper water with sediment salinity under 40 psu; however, black mangrove (Avicennia germinans) can grow in saline substrata of more than 50 psu and in shallower areas with short hydroperiod.
Critical parameters for the development of mangroves are 1) nutrients (nitrogen and phosphorus), 2) superficial and soil salinity, 3) temperature, 4) rainfall and evapotranspiration, 5) tides, 6) geomorphology and 7) topography. However, Odum & Johannes comment that radicular gas exchange is the mangrove forest’s “Achilles heel”. Siltation and soil salinity interferes with both the forest’s nutrient cycling, and gas exchange between the rhizosphere and the water column or atmosphere.

If we consider the water’s most saline conditions, recorded in Santa Clara after the construction of the bridges in 2003, where vegetation with greatest structural development was observed, we can expect changes in the mangrove forest structure and composition, with stress symptoms and characteristics similar to those recorded in Chabihau.

Before Hurricane Isidore and the construction of bridges, the water of Chabihau wetlands was under aerobic conditions, particularly in Santa Clara, and during dry season in the rest of the areas. This may be
related to 1) rate of oxygen transport through the
water – atmosphere – soil interface, 2) a small
population of oxygen consuming organisms, 3) the
photosynthetic production of oxygen by algae inside
the water column or at the bottom, 4) surface mixing
by springs and 5) winds.

Phosphorus is vital for life; however, it may not be
available for plants and micro-consumers due to
precipitation of insoluble phosphate with ferric iron,
calcium and aluminum under aerobic conditions or
conditions of pH over 8 (ref. 1,23) (this is particularly
important in a karstic high alkaline water, like in
Yucatan Peninsula), thus, the low biological
productivity in the lagoon before the hurricane.
Valdes & Real 22 mention that for the case of Chelem
Lagoon, on the central coast of Yucatan, phosphorus
showed significant correlation (r = -0.77, p ≤ 0.05) with
pH, indicating that phosphorus precipitation and
dissolution are regulated by pH.

Main topobathymetric changes (2000 and 2004) in
the lagoon and littoral area of Chabihau, and the
distribution of surface sediment, before and after
Hurricane Isidore, were recorded. The hurricane
moved large amounts of mud (10 to 20 cm thick in
some sites), making the lagoon slightly deeper toward
Santa Clara and San Crisanto, exporting large
amounts of fine sediment and organic matter to the
littoral area with the tides – a washing process that
continues until today and have a strong effect on the
system productivity on the mid- and long-term. This
explains why these two areas increased in water depth
after hurricane. Before the hurricane, the salinity of
the lagoon water discharge to the sea, through the
floodgate, was 70 psu in the dry season; however, sea-
water salinity was never > 41 ups. After the hurricane,
in the same season, this value never raised to 41 and
37.6 psu in the floodgate and sea, respectively.

Zaldivar23, found important relationships between
the mangrove community structure and the physical
and chemical characteristics of the sediment in the
Chuburna-Sisal swamp, located in the northwest of
the Yucatan coast and connected to the sea by two
water floodgates, since Hurricane Gilbert (1988).
Salinity (r= −0.72, p≤0.05) and redox potential
(r= −0.61, p≤0.05) were the sediment characteristics
that best explained the mangrove trees’ height,
density and basal area. This author also found highly
reduced conditions (~389 and −10 mV), mainly
during flood season, while in dry season the values
tended to be close to zero.

This is quite similar to Chabihau wetlands which,
after hurricane Isidore and the construction of bridges,
showed reduced conditions throughout the year. With
the redox values recorded in Chabihau wetlands, one
may expect conditions where iron is predominantly
found in a reduced form, just like nitrogen, with
active transformation of sulfur and carbon1,24. This
could lead to high toxicity of free sulfur when in
contact with plant roots, particularly R. mangle, since
A. germinans is more tolerant25. Phosphorus solubility
is therefore increased under anaerobic conditions or
with pH values lower than 7. In the case of Chelem
Lagoon, Valdes & Real2 found a direct and significant
correlation between the presence of phosphorus and
chlorophyll-a concentrations in the water. This
phosphorous availability may increase the biological
productivity in the lagoon, and this could be related
with capture of fish species by inhabitants of the three
localities. More than 8 tons of shrimp have been
collected, and the ichthyofauna, for example,
increased from 18 species before the hurricane to 34
species after, particularly euryhaline species, and a
wide variety and quantity of aquatic birds.

Acknowledgement
Authors are thankful to the local government of
Yucatan and the National Science and Technology
Council (CONACyT) for supporting the project:
Evaluation of Socio-environmental Changes in the
Chabihau Wetlands, Caused by Hurricane Isidore and
Prevention Strategies to cope with Future
Meteorological Phenomena (2003-2004). The
National Water Commission (CONAGUA) provided
climatic data for Telchac. Physicochemical data from
July 1999 to February 2000 correspond to samplings
conducted by Rocio Rendis Ruz. Jorge Novelo helped
with field work and data organization.

References
1 Mitsch W & Gosselink J, Wetlands, (Van Nostrand
2 Valdes D S & Real E, Variations and relationships of
salinity, nutrients and suspended solids in Chelem coastal
lagoon at Yucatan, Mexico, Indian J. Mar. Sci., 27
3 Odum E P, Ecologia, (Nueva Editorial Interamericana.
4 Twilley R R, Properties of mangrove ecosystems related to
the energy signature of coastal environments, in: Mangrove
ecosystems and energy signature of coasts, edited by C. Hall
Boulder, (University of Colorado Press, USA) 1995, pp. 43-
62.


Garcia E, Köppen’s climatic system modifications, (Instituto de Geografía, UNAM, Mexico) 1988, pp. 243. (In Spanish).


Rabinowitz D, Early growth of mangrove seedlings in Panamá, and an hypothesis concerning the relationship of dispersal and zonation, *J. Biogeogr.*, 5 (1978) 113-133.


Zaldivar A, Structure and productivity patterns changes in mangroves under environmental gradients in a karstic coastal lagoon of the Yucatan Peninsula (SE, Mexico), M.Sc. thesis. CINVESTAV-IPN, Mexico, 2004. (In Spanish)