Paper from: *Coastal Environment,* CA Brebbia (Editor).
ISBN 1-85312-921-6

Trophic status in coastal waters of the Yucatan Peninsula (SE, Mexico) using water quality indicators

J. A. Herrera-Silveira, I. Medina-Gómez, N. Aranda-Cirerol, A. Zaldivar, J. Ramírez, & J. Trejo
Primary Production Laboratory, CINVESTAV-IPN, U, Merida, Mexico.

Abstract

Yucatan Peninsula Coastal ecosystems are being subjected to increasing anthropogenic stresses such as recreational tourism, port development, overfishing, aquaculture as well as population growth, which are affecting coastal water quality. In order to establish a base-line of the trophic status of different zones along the Yucatan littoral, several seasonal surveys were conducted between 2000 and 2001 in 12 localities, four coastal zones, five bays or coastal lagoons and three ports. Water quality variables analysed were salinity, dissolved oxygen, transparency, dissolved inorganic nitrogen, silica and phosphorus, Chlorophyll-*a* (Chl-*a*) as well as various indexes were determined. Results indicate different expression of symptoms. The ports and some coastal lagoons are in eutrophic conditions as shown by high Chl-*a* concentrations (>20 mg/m^{-3}) and the levels of dissolved oxygen (<2 mg/l), while other areas with low urban development the symptoms of low Chl-*a* (<2 mg/m^{-3}) and high levels of dissolved oxygen (>5 mg/l) suggesting oligotrophic condition. These results highlight the need for a comprehensive regional strategy to address this potential problem. We recommend a study of trophic condition together with information on nutrient sources and land use as a tool to provide a basis for setting regional priorities for management, monitoring and research.

1 Introduction

An indicator is a signal of the environmental condition, which should need additional research or remediation actions. The environmental indicators of

Paper from: *Coastal Environment*, CA Brebbia (Editor).
ISBN 1-85312-921-6

quality are monitoring by different purposes: as obtain information on the condition and tendency of the ecosystem or as source of monitoring criteria. There are many indicators according with the specific problem.

Water quality is obtained through a series of variables which are related to pollutants or to processes as indicators, in order to have a qualification of the condition of a specific water body, and the maximum permitted concentration to not set in stress the aquatic life and its human been use in any way (recreation, agriculture, industrial, direct consumption, others).

The quality of the general environmental conditions of the ecosystems of the coastal zone, has promoted anthropogenic activities such as aquaculture, fisheries, tourism and industry, all of them affecting negatively their environmental services, through the unbalanced of the inputs, biogeochemical cycles, exportation, accumulation and others, giving symptoms of eutrophication as hypoxia/anoxia, increase of the turbidity, and high chlorophyll-a, nitrogen and phosphorus concentration [1].

The activities in the coastal zone can be sustainable if it is determined that the relative contribution of characteristic and key processes which favored a good water quality in different coastal ecosystems. Therefore, their vulnerability to cultural eutrophication reduces their environmental quality and their potential use of each ecosystem.

The Yucatan Peninsula (YP; Fig. 1) is experiencing an explosive increasing of coastal activities as aquaculture, tourism and ports, as a consequence of this development harmful algal blooms, fish kills, and cholera events becoming common. Additionally, as the fresh water goes towards the coastal are through groundwater discharges as springs [2], the coastal zone is highly vulnerable to change its environmental quality, however, until now no effort had been made to establish the present condition of the water quality. This study has the objective to establish the base line of the water quality of various coastal ecosystems of the YP through their trophic status, in order to support the politics on the water management.

2 Site description

The hydrographic basin of Yucatan show some particular features such as no topographic elevations, no rivers, the karstic type of soil which favor infiltration of the water from precipitation toward the aquifer, and an important groundwater web which discharge in the coastal zone through springs and non-point sources about 9 millions m^3/year/km coast, with this input all classes of pollutants from different sources are introduced to coastal ecosystems.

With a population of 4 millions in 2000 and a natal rate of 2.2%, greater than the national average (1.7%), the expected coastal development is growing and with it environmental problems are expected.

Mean precipitation is 1,190 mm/year, from this 80% is lost through evapotranspiration and the rest reaches the aquifer, this being the unique freshwater source. The weather pattern is characterized by three seasons: dry

Paper from: *Coastal Environment,* CA Brebbia (Editor).
ISBN 1-85312-921-6

(March to June), wet (July to October) and northwinds called locally as "nortes" (November to February).

The selected sites for this study (Fig. 1) include coastal ecosystems as coastal sea (CO) (Campeche, Sisal, Progreso, Nizuc), coastal lagoons or bays (L/B) (Celestún, Dzilam, Bojorquez, Ascensión and Chetumal), and ports (PO) (Sisal, Progreso Dzilam).

Campeche (S1), located in the Gulf of Mexico, is a coastal city with an estimated population of 1 million people, fisheries and tourism are the main activities.

Celestún (S2) is a coastal lagoon in the west coast of the YP, a fisherman town, were the tourist activities are growing due its natural scenarios.

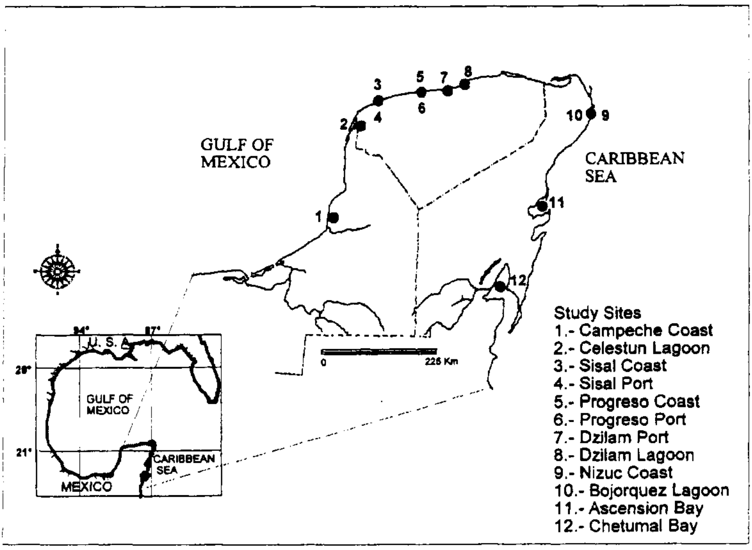

Figure 1: Map of the Yucatan Peninsula showing the sampling sites.

Sisal (S3), located in the north of YP, in the Gulf of México, is a fisherman town with an incipient tourism development, a port (S4) that receive 300 boats daily and a fishery processing plants, no waste treatments are available to them. A 70 ha shrimp farm is operating since 1998, its waste discharge directly to sea.

Progreso (S5) is the most important beach for local tourism with more than one million of visitors during summer. It includes the most important port (S6) of the YP, the largest fishery processing plants no wastewater treatment is available.

Dzilam (S7), in the north coast of the YP, is a coastal lagoon considered been in pristine conditions, its nutrient sources are natural springs and runoff. The activities in the area include the lobster fishery and the port (S8) with fishery processing plants and their facilities support 400 boats.

Paper from: *Coastal Environment*, CA Brebbia (Editor).
ISBN 1-85312-921-6

Nizuc (S9), located in the east coast of YP in the Caribbean Sea belong to Cancún zone, where the tourism and aquatic recreational activities are the major impacts.

Bojorquez (S10), a coastal lagoon in the Cancún zone, is bordered by all kind of tourism facilities, marinas, houses, hotels, restaurants, others. The waste treatment facilities are not sufficient for the demand, and the water treatment is incomplete.

Ascensión (S11) a bay located in the Caribbean Sea, is considered in good environmental conditions, no human developments are present yet, however, due to its scenic beauties, tourism development is growing.

Chetumal (S12) is a bay in the frontier with Belize, where tourism and fisheries are the main activities. The south region is impacted by the Río Hondo discharges, and the wastewater from the Chetumal and Calderitas towns.

The nutrient sources in the region are mainly domestic and industrial sewage, groundwater discharges and runoff.

3 Material and methods

In order to establish the water quality according with the trophic status of different coastal ecosystems of the YP, seasonal (dry, wet, northwinds) field trips sampling were carried out during 2000-2001. In each site and sampling field three stations were sampled. The location of the stations in coastal lagoons and ports were along to the salinity gradient or from the inner to the outer zone. In the case of coastal sites, the stations were located 500m from the beach, the central station in front of the town, and the others two one at each side separated 500m from the central station. In each sampling site *in situ,* temperature, dissolved oxygen and salinity were recorded with a multiprobe YSI-85: Surface water samples were collected and used for analysis of dissolved inorganic nutrients as nitrites (NO_2^-) , nitrates (NO_3^-), ammonium (NH_4^+) soluble reactive phosphorus (SRP), soluble reactive silica (SRSi) and Chlorophyll-*a* (Chl-*a)*, all of them performed following standard methods [3].

3.1 Variability analysis among type ecosystems

The sites were grouped according their ecosystem class (Fig. 1) as: coastal (CO), lagoons or bays (L/B), and ports (PO), and a one-way non-parametric ANOVA was done to determine differences between hydrographic variables per class, and were expressed in box and whisker plots, differences in parameters among zones were quantified using Krus-kal-Wallace test with significance set at $p<0.05$.

Paper from: *Coastal Environment*, CA Brebbia (Editor).
ISBN 1-85312-921-6

3.2 Trophic status

The twelve sampling sites of YP are enriched with nutrients from natural and cultural nutrient discharges, therefore for determinate the water quality it was necessary to use an index for assessing trophic status. In this case the nutrient eutrophication index applied was:

$$TI = \frac{C}{C - \log x} + \log A$$

Where TI is the nutrient eutrophication index, C is the log of the total loading of a given nutrient in an area and x is the total concentration of this nutrient at certain station. The values generated thus provide a continuous assessment of water quality and their significance is: for eutrophic waters TI is higher than 5, for mesotrophic waters it ranges from 5 to 3 and for oligotrophic waters it is lower than 3 [4]. This index was designed to be specific for each nutrient, dimensionless with application to various types of water, sensitive to stressful effects of eutrophication and simple for gathering data and for calculation.

4 Results and discussion

4.1 Variability analysis among ecosystem classes

Temperature variability was similar between CO and L/B (Figure 2a). The highest mean values corresponded to semi-enclosed systems (L/B-29 °C). The variability between L/B and CO sites does not show significant differences, however, they do respect PO sites where the lowest mean temperature were observed, as due to the shallowness of the water in L/B systems and relative low level of turbulent mixing respect to the others system.

The greatest variability in salinity was observed in L/B systems, as well as the lowest mean (22 psu); being significant different from CO and PO sites (Figure 2b). Those coastal ecosystems are strongly influenced by groundwater discharges, determining their hydrological variability [5].

Mean dissolved oxygen concentrations were lower in PO sites (4 mg/l) and significant different from CO and L/B sites (5.8 mg/l), although L/B showed higher variability (Fig. 2c). The low concentrations in L/B and PO sites, suggest intense organic matter production/consumption processes, while in L/B systems the organic matter source is autochthonous mainly submerged aquatic vegetation, and in PO sites comes from anthropogenic sources as sewages [6].

Paper from: *Coastal Environment*, CA Brebbia (Editor).
ISBN 1-85312-921-6

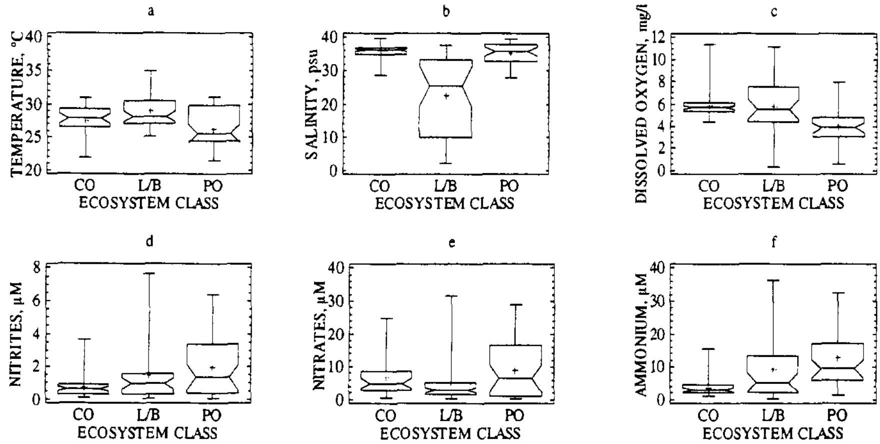

Figure 2: Box-and-whisker plots of temperature, salinity, dissolved oxygen, NO_2, NO_3, and NH_4, for each system class: coastal (CO), lagoons or bays (L/B) and ports (PO), of Yucatan Peninsula.

The highest mean (1.92 µM) and variability of NO_2^- was observed in PO sites, while the lowest corresponded to CO sites (0.76 µM); with a significant difference between them (Fig. 2d).

As NO_2^-, the NO_3^- concentrations showed wide variability and higher mean value (8.99 µM) in PO than the other system classes (Fig. 2e). However, the outlier values (>30 µM) were observed in L/B systems as a consequence of pulses of groundwater inputs [5].

Ammonium concentrations were relatively higher in PO sites (12.62 µM) than L/B localities. However, both showed higher variability (Fig. 2f), suggesting intense decomposition processes favoring eutrophic conditions, while adjacent marine zones showed low variation and also the lowest mean NH_4^+ concentration (3.55 µM).

Phosphorus concentrations showed a consistent pattern along the three different system classes and slightly higher variability in L/B sites. No significant differences were observed among system classes (Fig. 3a).

The highest mean SRSi concentrations corresponded to L/B systems (81 µM), as well as the wider variability (Fig. 3b), which make these semi-enclosed systems as significant different from the whole Yucatan coastal zone. The main source of SRSi comes from groundwater [5]. The lowest concentrations were observed in CO sites (8.41 µM).

Chl-*a* concentrations in CO and PO sites, show higher variability than L/B. The highest mean was observed in PO sites (12.63 mg/m^3), indicating eutrophic condition. Sites as L/B showed the lowest mean Chl-*a* (1.77 mg/m^3) as well as less variability (Fig. 3c), in these ecosystems the main primary producers are the seagrasses and macroalgae [6].

Paper from: *Coastal Environment*, CA Brebbia (Editor).
ISBN 1-85312-921-6

In general, water quality variability in each ecosystem class of the YP, is influenced by different forcing functions. In the coastal systems marine water and springs are the main nutrient sources, however, the resuspention by tides and waves may be playing an important role in the biogeochemical cycles. On the other hand, in coastal lagoons and bays, the groundwater discharges, runoff and biogeochemical processes as decomposition of organic matter are the main nutrient sources. However, in the ports the poor water quality should be as consequence of sewage discharge and high residence time [7].

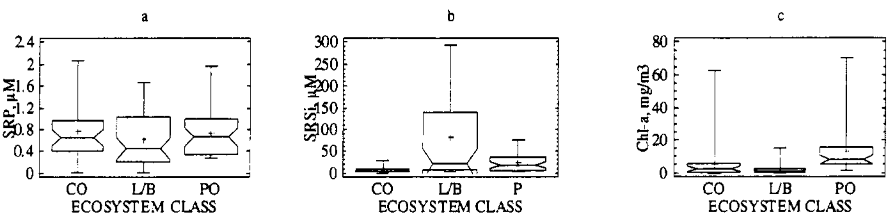

Figure 3: Box-and-whisker plots of SRP, SRSi, and Chl-*a*, for each system class: coastal (CO), lagoons or bays (L/B) and ports (PO), of Yucatan Peninsula.

4.2 Trophic status

The graphical representation of trophic status trough the trophic index for each nutrient is given in Figure 4 and shows their values for the twelve sampling sites; furthermore, this criterion was used with Chlorophyll-*a*.

It is seen that trophic status for the twelve sites is different for each nutrient; thus, water quality depends on it. For nitrite, mesotrophic waters were found in Celestún (S2), Sisal (S4), Dzilam(S8) and Chetumal (S12), the other sites have oligotrophic waters.

With respect to nitrate the water quality or YP was diverse, only Ascensión (S11) was oligotrophic while Campeche (S1), Sisal (S3), Progreso (S5), Progreso (S6) and Chetumal (S12) were mesotrophic, and Celestún (S2), Sisal (S4), Dzilam (S7-S8), Nizuc (S9) and Bojórquez (S10) were eutrophic, however, these states may be their natural condition as in Celestún and Dzilam (S7) were the NO_3 source comes from freshwater springs, in contrast with the others sites were the source of these nutrient probably comes from human activities favoring the cultural eutrophication.

For the ammonium, the Ports of Sisal, Progreso, Dzilam and Chetumal Bay were eutrophic, suggesting that domestic, industrial sewage and river discharge favored this condition. However, the others sites were mesotrophic, suggesting a potential enrichment of the coastal waters of YP with reduced forms of N.

Paper from: *Coastal Environment*, CA Brebbia (Editor).
ISBN 1-85312-921-6

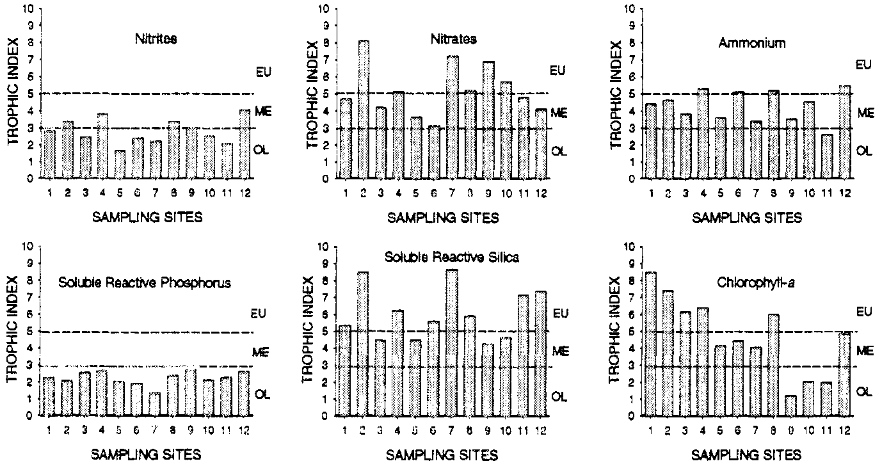

Figure 4: Values of *TI* for the five nutrients: nitrite (NO_2^-), nitrate (NO_3^-), ammonium (NH_4^+), phosphorous (SRP), silicon (SRSi) and chlorophyll *a* (Chl-*a*), eutrophic waters (EU), Mesotrophic waters (ME), Oligotrophic waters (OL).

The *TI* for the phosphorous was lower than 3 in all sampling sites, therefore oligotrophic, according with the fact that in karstic zones the concentration of this nutrient is low as a consequence of its affinity with the calcium carbonate [5], and should be the limiting nutrient for phytoplankton growth.

The *TI* for silica was eutrophic in sites with the influence of groundwater springs and natural runoff as Celestun (S2), Dzilam (S7), Ascension (S11) and Chetumal (S12), while the mesotrophic condition prevailed in the others sites.

The *TI* of Chl-*a* shows high variability and should be related with the general oceanographic conditions of the Gulf of Mexico and Caribbean waters particularly transparency. According to this, oligotrophic conditions prevailed in Nizuc (S9), Bojorquez (S10) and Ascension (S11), located in Caribbean region; Progreso (S5-S6) and Chetumal (S12) were mesotrophic, while the other sites were eutrophic.

Table 1. Average, minimum and maximum value for each variable observed in the coastal ecosystems of Yucatan during 2000-2001.

	Temp. °C	Sal. psu	D.O. mg/l	NO_2 µM	NO_3 µM	NH_4 µM	SRP µM	SRSi µM	Chl-*a* mg/m^3
Average	27.5	31.2	6.5	1.37	6.8	8.4	0.71	37.9	6.5
Minimum	21.4	2	0.3	0.03	0.09	0.98	0.03	0.1	0.01
Maximum	34.4	39.8	11.3	2.06	31.6	36.1	2.06	292	70.6

Sites as Celestún (S2). Dzilam (S7) and Ascensión (S11) are influenced by groundwater discharges and their eutrophic condition for NO_3 and SRSi should be considered as part of their natural biogeochemical processes.

Paper from: *Coastal Environment,* CA Brebbia (Editor).
ISBN 1-85312-921-6

However, the ports (S4-S6-S8,) are clearly eutrophic by cultural factors, as sewage from fishery processing plants favored by its geomorphology conditioning high water residence time.

Others sites as Campeche (S1), Progreso (S5), Bojorquez (S10), and Chetumal (S12) are eutrophic by anthropogenic activities such as domestic sewage, tourist activities and river discharges.

The case of Nizuc (S9), is particularly interesting because in spite that is located in a oligotrophic region, it shows a clear tendency toward mesotrophic status due the *TI* of NO_2, NH_4 and SRP are higher (Fig 4) than the others Caribbean areas. In this site the recreational aquatic activities as snorkeling, the presence of an aquatic park and runoff should be favoring its trophic shift.

The water management strategies in the aquatic ecosystems of YP should consider the carrying capacity of visitors in recreational areas, domestic and fishery industry sewage control, the use of alternative technologies to waste treatment like artificial wetlands as biofilters, because the karstic features of the soil in the region make expensive the traditional treatments, and this kind of systems in many cases are not fully efficient.

References

[1] Urban, E.R., Mallory L. & Taylor, C., (eds.), *Priorities for Coastal Ecosystem Science,* National Research Council, Washington, D.C., 1996.

[2] Herrera-Silveira, J.A. & Comín, F.A., An Introductory account of the types of aquatic ecosystems of Yucatan Peninsula (SE Mexico) (Chapter 17). *Aquatic Ecosystems of Mexico: Status & Scope,* ed. M. Munawar, Lawrence, S.G., Munawar, I.F., & Malley, D.F., Ecovision World Monographs Series: Backhuys Pub. Leiden, Netherlands, pp 213-227, 2000.

[3] Strickland, J., &Parsons, T., A practical handbook of seawater analysis. J. Fish. Res. Bd. Canada Bull. 167, pp.310, 1972.

[4] Karydis M., Ignatiades, L., & Moschopoulou, N., A Index associated with Nutrient Eutrophication in the Marine Environment. *Estuarine, Coastal and Shelf Science,* **16**, pp. 339-344, 1983.

[5] Herrera-Silveira, J.A., Spatial and temporal patterns in a tropical coastal lagoon with groundwater discharges. *Journal of Coastal Research,* **10(3)**, pp. 738-746, 1994.

[6] Herrera-Silveira, J.A., Ramírez, J., & Zaldivar, A., Overview and Characterization of the Hydrology and Primary Producers Communities of Selected Coastal Lagoons of Yucatan, Mexico. *Aquatic Ecosystem Health & Management,* **1(3-4)**: pp. 353-372, 1998.

[7] Pennock, J. R., Boyer, J.N., Herrera-Silveira, J.A., Iverson, R.L., Whitledge, T.E., Mortazavi, B., & Comin, F.A., Nutrient behavior and phytoplankton production in Gulf of Mexico estuaries (Chapter 5). *Biogeochemistry of Gulf of Mexico Estuaries*, eds. T. S. Bianchi, Pennock, J.R., & Twilley R.R., John Wiley & Sons, Inc: New York, pp.109-162, 1999.