Tropical and Subtropical Agroecosystems

HYDROLOGICAL ASPECTS OF THE LAGOONS OF ATASTA AND POM, MEXICO

[ASPECTOS HIDROLOGICOS DE LAS LAGUNAS DE ATASTA Y POM, MEXICO]

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SUMMARY

The Lagoons of Pom and Atasta are part of a natural protected area of flora and fauna lagoon of Terminos in the region of Campeche, Mexico. This is an important ecological area since it is a habitat of many native and migratory species. These lagoons have been affected by industrial activities and sewage water discharge. Monitoring of nitrogen, phosphorus and faecal coliform in surface waters were carried out along the length of both lagoons during the dry, rainy and north winds seasons during one year. The highest temperatures in the summer (31°C) and minimum in the north winds (25°C) were associated with values of dissolved oxygen (5.1 and 6.3 mg l^{-1}, respectively) indicating also a probably relation of the phytoplankton activity. The pH (8.0-8.2) and the salinity (0.32 – 3.48 SPU) did not show any significant variation amongst the three climatic seasons. The level of ammonium did not surpass the suggested value to the eutrophication control (0.1 mg l^{-1}), while the levels of phosphorus were of higher concentrations (2.0-3.5 mg l^{-1}) to those considered safe (0.01-0.125 mg l^{-1}) to the environmental. The highest concentration of N and P near the inhabitant areas suggest an important contribution of nutrients stemming from the sewage waters, associated with the decomposition of organic materials. The concentration of faecal coliform during the rains and the north wind season (8.0–26.0 MPN 100 ml^{-1}) was greater than during the dry period (1.3–3.5 MPN 100 ml^{-1}) suggesting an important access for the infiltration of rain water and sewage waters not treated coming from the nearest inhabited areas. The deforestation of the mangroves and uncontrolled agricultural activity would affect the quality of the water in both lagoons in the future.

Key words*:* Eutrophication, faecal coliforms, nutrients, sewage waters, Pom and Atasta lagoons.

RESUMEN

Las lagunas de Pom y Atasta forman parte del área natural protegida de flora y fauna laguna de Términos en la región de Campeche, México. Esta es una importante área ecológica ya que es el habitat de muchas especies nativas y migratorias. Estas lagunas han sido afectadas por actividades industriales y por descargas de aguas residuales. Monitoreo de nitrógeno, fósforo y coliformes fecales en agua superficial fueron realizados a lo largo de ambas lagunas durante las temporadas de seca, lluvia y nortes durante un año. Las altas temperaturas en verano (31 ºC) y mínimas en nortes (25ºC) fueron asociadas con valores de oxigeno disuelto (5.1 y 6.3 mg l^{-1}, respectivamente) indicando también una probable relación con la actividad fitoplanctonica. El pH (8.0-8.2) y la salinidad (0.32 – 3.48 UPS) no mostraron variación significativa entre las tres temporadas climáticas. El nivel de amonio no fue mayor a los valores sugeridos para el control de eutroficación (0.1 mg l^{-1}), mientras que los niveles de fósforo fueron de mayor concentración (2.0-3.5 mg l^{-1}) que aquellos considerados seguros (0.01-0.125 mg l^{-1}) para el medio ambiente. Las más altas concentraciones de N y P cerca de las áreas habitadas sugiere un importante contribución de nutrientes provenientes de aguas de desecho, asociado con la descomposición de material orgánico. La concentración de coliformes fecales durante la temporada de lluvias y nortes (8.0–26.0 MPN 100 ml^{-1}) fue mayor que durante la temporada de seca (1.3–3.5 MPN 100 ml^{-1}) sugiriendo un importante acceso por escurrimiento pluvial y aguas residuales no tratadas proveniente de las áreas cercanas al lago habitadas. La deforestación de manglares y la descontrolada actividad de agricultura afectaran la calidad del agua en ambos lagos en el futuro.

Palabras claves*:* Eutroficación, coliformes fecales, nutrientes, aguas residuales, lagunas de Pom y Atasta.

INTRODUCTION

The coastal lagoons are productive aquatic systems with a great amount of energetic supply reason why they frequently show high concentrations of nutrients (Mee 1978); many of these therefore are considered to be eutrophics. Annually, the continuous changes are provoked by the movements and the re-suspension of sediments within the column of water, adding nutrients through the biogeochemical cycle and the transformation of materials which are found in such sediments (Morán-Silva et al., 2004). These nutrients could represent a large number of temporary variations, generally found in the rainy season (Ruiz-Marin and Canedo-Lopez 2002). Moreover, minimal concentrations are found later of the spring phytoplankton bloom (De la Lanza and Arenas 1986).

Interesting is to mention that in the costal plain of the Gulf of Mexico, The lagoon of Terminus and the pluvial-delta systems (that drain the waters into the lagoon) are recognized for their dimensions and importance. The lagoons Pom-Atasta under research in this study are located in this system. These systems are the main cause of the flooding of the low lands between The Terminos lagoon and The Campeche Sonda (Ayala-Pérez et al., 1993).

The lagoons of Pom and Atasta that form parts of the system Pom-Atasta are subject to environmental impacts such as: the construction of the petroleum infrastructure, the dredging of the Pom lagoon to install pipes that transport crude oil and gasoline, removal of the mangroves in order to use the land for agricultural purposes and the installation of drilling platforms, the incipient aquaculture activities as well as human settlement. All these factors together with the lack of maintenance of the drainage system and the deficient treatment of sewage waters in the near by inhabited areas could alter the physical, chemistry and biological characteristics of the Lagoons Pom and Atasta.

Therefore the great part of the biological processes that occur in the Pom and Atasta lagoons are affected by the physical-chemical characteristics of the water. At the same time many chemical parameters of the water, are the results of the biological processes that are happening to it (Barreiro-Güemes and Aguirre-León 1999). Because of the insufficient information about the Physical-Chemical variations and the nutrients in these two lagoons, the main goal of this study is to determine the magnitude of such temporal physical-chemical variations, nutrients concentration and faecal coliform in the lagoons of Pom and Atasta in an annual period in the column of water. This information will permit us to evaluate if natural processes or anthropogenic are changing the conditions in both lagoons.

MATERIALS AND METHODS

Study area

The area under research is situated in the occidental part of the Términos lagoon between 18°30´and 18°35´ N and 91° 50´ and 92°20´W into the costal plains in the state of Campeche. The lagoons of Atasta and Pom are communicated to each other by a narrow channel, and cover an approximate area of 80 km², of which 50 km² correspond to the Pom lagoon. The Atasta lagoon is elongated, with a main axis 9 km long oriented to the NE-SW; The Pom lagoon has an ellipsoidal form with a major diameter of approximately 10 km in length.

The average depth of these lagoons is 1.50 m; the level of their waters is variable, depending upon the diurnal and seasonal changes. The bottom of the lagoon is quite flat, with the exception of the areas covered by organic banks and by the remains of the old ridges of the beach. The tidal flow inputs into the lagoon of Atasta through a meandric marsh that links it up with the Lagoon of Términos. The lagoonal currents are related to NE winds and minor tide influence. Both lagoons Pom and Atasta present a low salinity of 0.32 a 3.167 UPS and it is conditioned to the temporal variations of the region (Sastre-Conde et al., 2003).

The waters are dominated by the muddy-clay sediments (Gutiérrez-Estrada et al., 1982). The submerged grassland type vegetation is very rare. There are extensive woods and mangroves surrounding the lagoons (De la Lanza-Espino et al., 1993). During the year there are three climatic periods in this region: (1) the dry season, from February to May; (2) the rainy season, from June to September and (3) the north winds, from October to February (Yañez-Arancibia and Day 1998).

Physical-Chemical Analysis and Nutrients

In order to carry out the hydrological study, for the collection of samples we established a net of 12 stations along the two lagoons (Figure 1). The measurements and the samples collected were carried out during the months of: February, March, April, July, September and December of 2001. All of the samples were collected at two levels: surface and the bottom of the water, with the purpose of testing the complete column of water, since the system has low depth. At the same time we tried to detect possible vertical variation, collecting a total of 24 samples considering surface and bottom of the water for the 12 station.

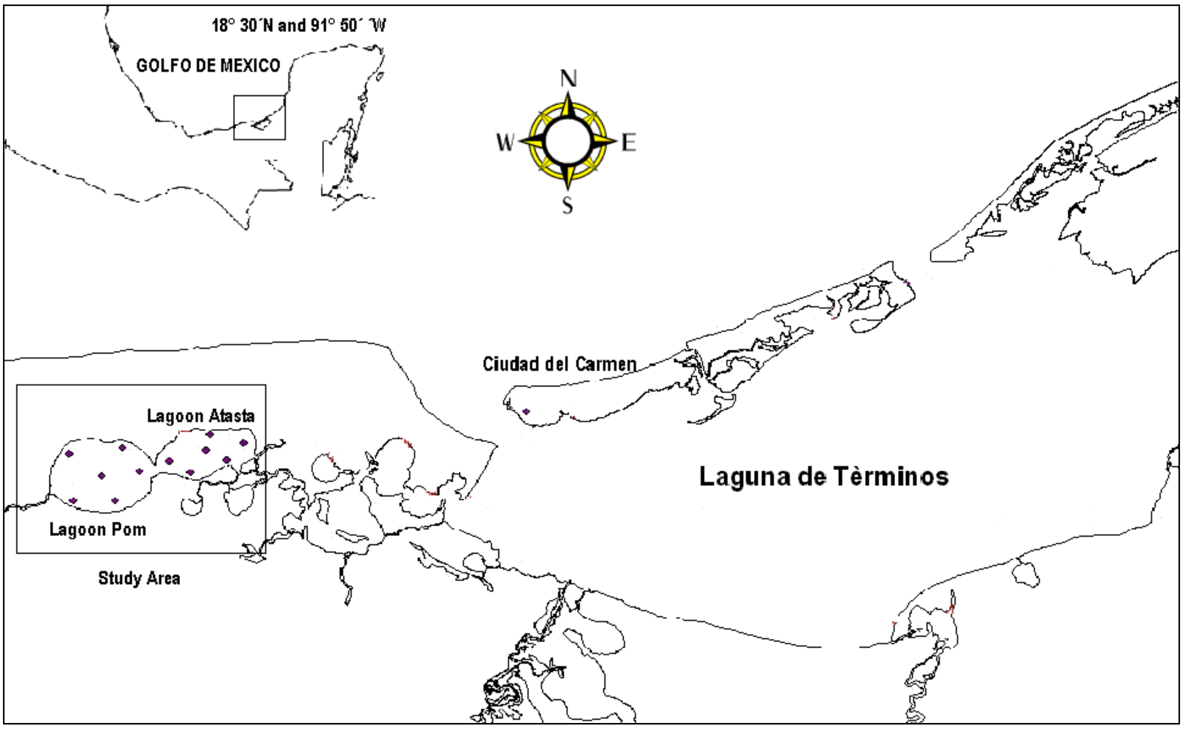

Figure 1. Location of the lagoons Pom and Atasta and the stations for recollecting samples.

The measurements for the temperature, salinity, pH and dissolved oxygen were in situ with a Sonda Hydrolab Data 4 on the surface and bottom of the water in each one of the stations that were collecting the samples. At the same time, samples of water from the surface and the bottom were collected by using a Van-Dorn bottle.

The samples were preserved at 4 °C and transported on the same day to the Environmental Science laboratory at the Autonomous University of Carmen, in order to determine the nitrates, ammonium, and phosphate levels, with regard to the recommended methods standards (NMX-AA-079-SCFI-2001; NMX-AA-026-SCFI-2001; NMX-AA-029-SCFI-2001). These analyses were carried out during a 24 hours period (AWWA-APHA-WPCF 1995).

Bacteriological Analysis

For determining the faecal coliforms (FC), the samples of water were transported in sterilized glass bottle and preserved at 4°C in order to be analyzed the same day. The quantification of FC was analyzed according to the Most Probable Number (MPN 100 ml^{-1}) technique, with a series of five tubes for analyses, by using both probabilistic and confirmative tests (AWWA-APHA-WPCF 1995). Results of the analysis of faecal coliforms was reported as values average monthly of 12 samples of water in surface and bottom for each lagoons.

RESULTS AND DISCUSSION

Physical-chemical variables

The temperature of water in both Lagoons Pom and Atasta; show moderate fluctuations during almost all the year, which goes according to the dynamic of the bodies of superfitial tropical water. The minimum values apply to the period of December to February (25 ºC), and the maximum values apply to the month of September (31 ºC) (Figure 2). These moderate fluctuations of temperature in these tropical ecosystems cause a favorable environment to be colonized by a great variety of organisms compared by environments of cold water (Day 1967).

Figure 2 show that the levels of dissolved oxygen in the column of water did not have any significant changes (ANOVA, P = 0.849) during the period of the study. However, a maximum concentration of oxygen was registered in the months of March and April (spring) from 6.0-6.2 mg l^{-1}. Meanwhile in the month of september low concentrations of oxygen were recorded at 5.0 mg l^{-1} (Figure 2).

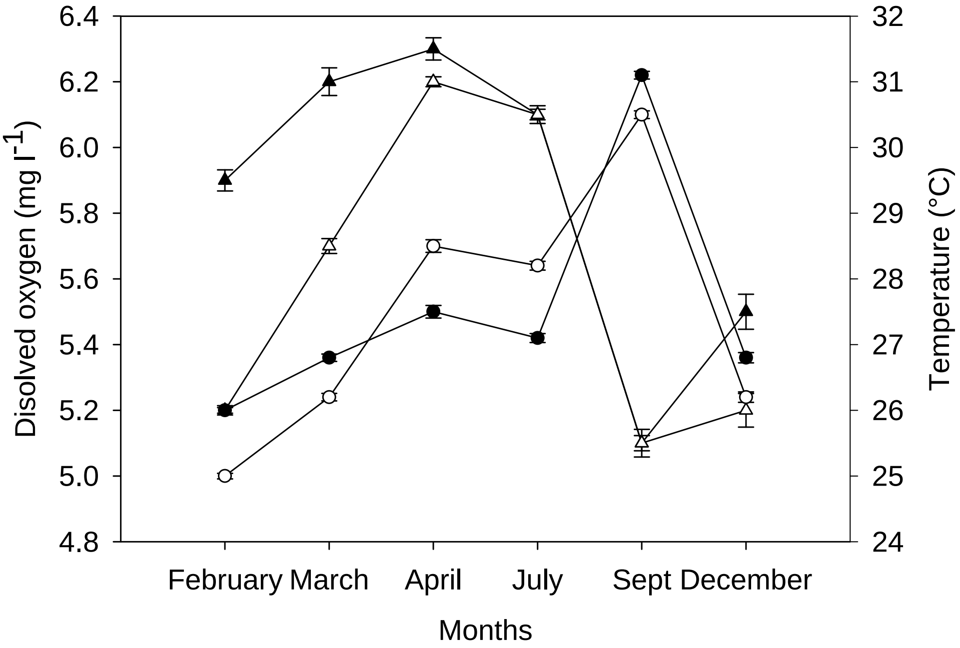

Figure 2. Seasonal variations average of dissolved oxygen (mg l^{-1}) and temperature (ºC) of superficial and bottom of water column from the Pom and Atasta lagoons. Black circles: temperature in Atasta lagoon; white circles: temperature in Pom lagoon; black triangles: dissolved oxygen in Atasta lagoon; white triangles: dissolved oxygen in Pom lagoon.

This low concentration of oxygen corresponds to the end of the rainy season, probably attributed to an increase of suspend organic material, as observed by Rivera-Monroy et al. (1988) for the Terminos lagoon. Kennish (1986) suggested than when the organic material increases, the microorganisms decompose such organic material removing the oxygen from the column of water. On the other hand, the higher concentrations of oxygen in the dry season are probably associated with the phytoplanktonic or seagrass activity, similar to Contreras and Gutiérrez (1990) findings for the systems of water in the state of Veracruz.

There was not found any stratification of salinity in the waters of both lagoons because of the low depth that exists (2.5 m) and the swell caused by the wind as it is shown in figure 3. As a result of the low salinity levels recorded in the samples, the system was considered as a body of fresh water. Moreover during the period of the dry season (April), high values of salinity were detected in the superficial water, which fluctuated from 3.0 – 4.0 SPU. This is because of low or no rainfall, and the high rate of evaporation that occurs during that period.

From the period of July- September, the salinity of the water diminished from 0.5 – 2.0 SPU (Figure 3), probably because of the effect of the dilution caused by the rainfalls during this period. These two lagoons show little influence of the tides or in other words saline intrusion, which is the reason why during the whole year it represents a limnetic pattern of salinity with scarcely any variation (Barreiro-Güemes and Aguirre-León 1999).

The values of pH (data not provided in this study) did not show significant differences during the three climatic seasons (ANOVA, P = 0.865). The values of pH fluctuated amongst 7.6 to 8.8 in both lagoons during the entire period when the samples were collected. These results are very close to those findings in other coastal lagoons in Mexico (Mee 1978; Contreras 1983). These results suggest that this variable is being subdued by the CO_2- carbonates system (Broecker 1974), this is the reason why, the acid or alkaline conditions (above 9 pH) are almost impossible to find in such lagoons.

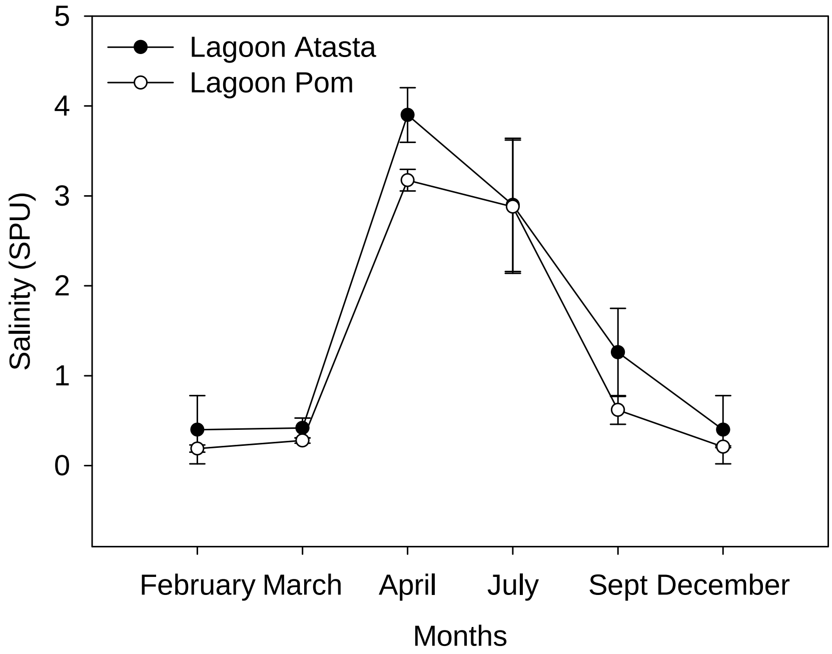

Figure 3. Seasonal variations average of the salinity (SPU) of superficial and bottom of water column from the Pom and Atasta lagoons.

Distribution of nutrients

As it is known the content of ammonia that is the chemical structure of the nitrogen that is used by the bacterias, phytoplankton, seagrass and epibentic algae in both light and dark periods of the day (Nixon 1981) maintaining the balance of the nitrogen level. In our study, of the lagoons Pom and Atasta the concentrations of ammonia recorded started with 0.14 mg l^{-1} during the months of march and april (Spring) until concentration values of 0.06 mg l^{-1} were recorded during the month of september (rainy season). As for the months corresponding to the north winds (December-February), the concentration of ammonia increased gradually reaching the values of 0.07 – 0.09 mg l^{-1} (Figure 4). These variations of ammonia did not present any significant difference (ANOVA, P = 0.0867) and were observed in both of the lagoons during the annual period of this study.

The low concentration of ammonia during the rainy season probably is caused by the processes of dilution. However, in this season the lagoons receive a high contribution of the organic material transported by infiltration. In this sense, the bacterial decomposition of organic matter possibly provides an enrichment of ammonia that was observed at the beginning of the north winds season (Figure 4). On the other hand, the high values of 0.14 mg l^{-1} were observed in the stations nearest to the inhabited areas. We assume that this is due to the contribution of the organic disposal and sewage waters which are carried to the system of lagoons. These inhabited areas do not have any drainage systems neither do they have any treatment for their sewage waters, thus changing their lower areas of land and channels, creating a higher risk zone for human health.

The results suggest that, the high contribution of ammonia from the north wind season, prepared the conditions for the availability of nitrogen for the phytoplankton during the spring. Figure 5 shows the distribution of ammonia in the dry season, with a gradient of major concentration of ammonium from lagoon of Atasta towards lagoon of Pom. Due to the low movement of water in this season, the results show a major concentration principally from within the interior of the lagoon of Atasta.

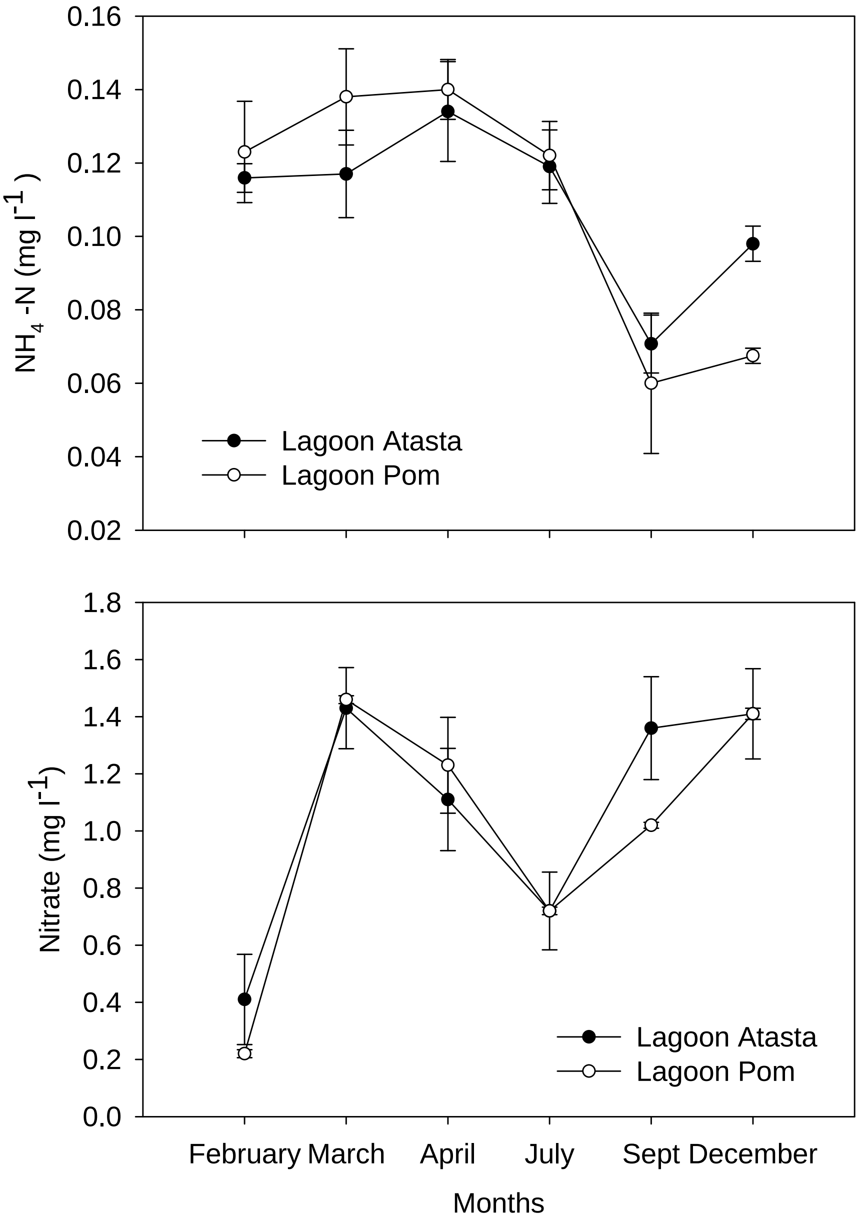

Figure 4. Average values of ammonia and nitrate of superficial and bottom of water column from the Pom and Atasta lagoons

It is probable that the ammonia would originate from within the interior of the lagoon of Atasta as it has been reported in other bodies of water (Valiela et al., 1978; Contreras 1983) where the sediments play an important role, seeing that the ammonia is the main form of nitrogen interchange through the interphase between the sediment and the water (Nixon 1981).

The high amount of ammonia produced in the lagoon of Atasta in the dry season is probably exported towards the lagoon Pom and it is the result of the mixture of contributions of the discharges of organic disposals, infiltrations and those originated from the decomposition of organic matter produced by the contributions of the detritus from the mangroves, the sea grass as well as the fauna communities. Barreiro-Güemes and Aguirre-León (1999) suggest that the maximum concentration of ammonium causes the occasional flourishing of phytoplankton in the system of Pom-Atasta since this community is distributed in little zones of different dimensions, which adds an element of high variability in the concentrations of pigments (Harris 1987).

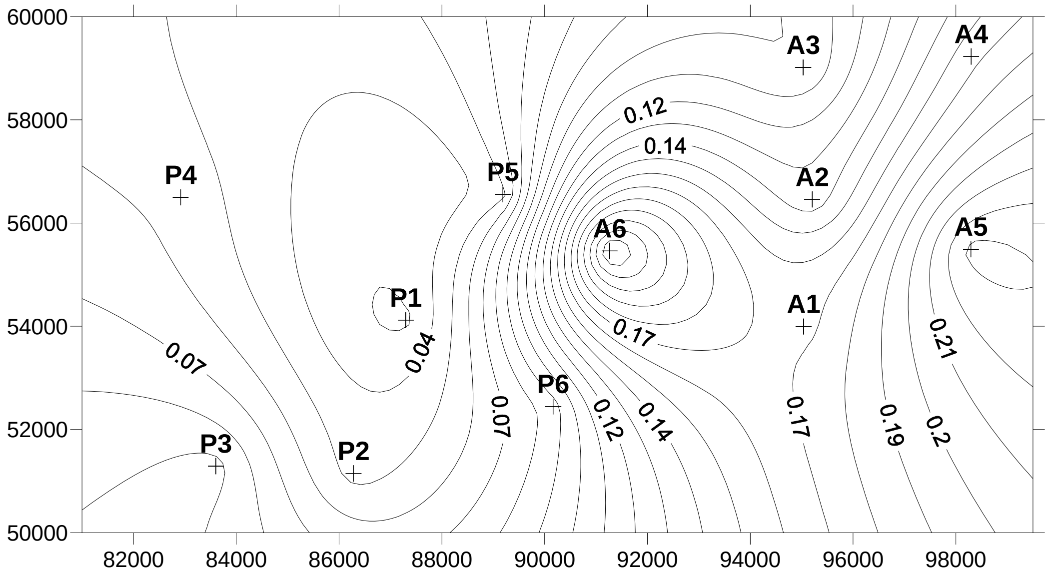

Figure 5. Distribution of ammonium (mg l^{-1}) in the lagoons of Pom and Atasta during the dry season. Letters A and P represent Atasta and Pom lagoons, respectively.

The temporary variation of nitrates show significant differences (ANOVA P = 0.0120) during the moths that this study was carried out. A high concentration of nitrates of 1.43 mg l^{-1} was observed in the rainy season and minimum concentrations of 0.41 y 0.22 mg l^{-1} in the dry season (Figure 4). The high content of nitrates is produced in both lagoons during the rainy season; this is commonly related to maximum agricultural activity. However, other processes can interfere as the processes of nitrifications if these are not inhibited by the absence of oxygen.

Oxygen is one of the parameters that regulate the nitrification and in order to carry out this nitrification, the level should not be lower than 2 mg O_2 l^{-1} (Metcalf and Eddy 1991). Ødegaard (2000) suggested that the critical amount of concentration of oxygen should be from 2 to 3 mg l^{-1} in order that the nitrification process could be carried out. In short, in this study, both lagoons maintained a range of oxygen of 5 – 6 mg l^{-1} in the column of water creating favourable conditions to perform the conversion of nitrates of ammonium.

However, we should not overlook the processes of removal of nitrates by the denitrification processes, carried out in the anoxic areas of the mangroves. Rivera-Monroy et al. (1995) suggested that the zones near to the mangroves regularly are depositing nitrates, showing that < 10% of the removal of nitrates in sediments of those mangrove zones can be lost by denitrification and the rest by immobilization processes in the sediment. Because of this, it is important to preserve the population of the mangroves in the region; in order to regulate the flow of nitrogen that gets into the system

Barreiro-Güemes and Aguirre-Leon (1999) find out that there exists an increase of nitrates during the rainy season, which is necessary to start a phytoplankton bloom during the dry season. Our data show an increase of nitrates during the months of september and december, similar to the findings of Morán-Silva et al. (2005) in the lagoon system of Alvarado Veracruz; who observed a high concentration of nitrates in the months of November and December, which was related also to the subsequent increase in chlorophyll in February.

With respect to the phosphorus, the maximum concentration was obtained in the north winds season at 3.0 – 3.5 mg l^{-1}, we attribute this increase to the re-suspension of sediments caused by strong winds and the filtrations from the nearby inhabited areas. The minimum concentration of P was obtained in the dry season at 2.0 mg l^{-1} (Figure 6), agreeing with Barreiro-Güemes and Aguirre-Leon (1999) with respect to the reports of increment of the nitrogen forms and the phytoplankton biomass concentration in this season for the lagoons of Pom-Atasta.

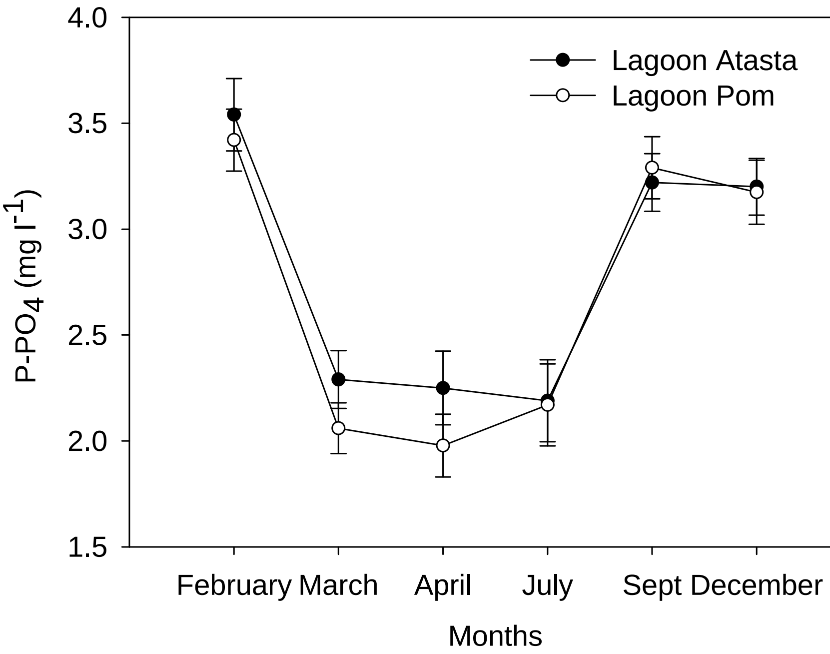

Figure 6. Mean values of phosphorous of superficial and bottom of water column from the Pom and Atasta lagoons

The average values of phosphorus in the column of water show significant temporary variations (ANOVA, P = 0.002). Nonetheless, the content of phosphorus was distributed homogeneously along both lagoons Atasta and Pom in each one of the climatic seasons. Some researchers report that the coastal lagoons export this element towards the marine zone or adjacent lagoons (Valiela 1978, Nixon 1981, Contreras 1983) mention that the high quantity of organic material that comes from the marsh, mangroves and grass that are deposited in the sediments of the lagoons create an environmental reductor and low in pH where trapped phosphorus is dissolved in the interstitial anoxic waters and placed in the main layers by diffusion. Although in this study we did not measure the flow of this nutrient, it is probably that the lagoon of Atasta is an exporter of phosphorus to the Pom lagoon. In both lagoons, the maximum and minimum contents of phosphorus suggest that this element is not limited in the lagoons and it diminishes in the spring season, suggesting elimination by the phytoplankton biomass (Contreras and Castañeda 1992).

On the other hand, it is estimated that the concentration of nitrogen and phosphorus for the control of eutrophication in bodies of clear water should be maintained between 0.1 mg l^{-1} and 0.01 mg l^{-1}, respectively (Shelef et al., 1980). The content of nitrogen for both lagoons (0.06 – 0.14 mg N l^{-1}) was similar to those reported by Shelef et al. (1980); meanwhile the concentration of phosphorus (2.0–3.5 mg P l^{-1}) was high, thus suggesting, some kind of contribution of this element from the flow of sewage waters or agricultural activities.

According to Ketchum (1969) the concentrations of phosphorus in bodies of water under 0.125 mg 1^{-1} are considered as not affected by the anthropogenic activities, this confirms the contribution of P by such activities. The Mexican environmental regulation (AWWA-APHA-WPCF 1995), however, permits flows that contain 5 mg l^{-1} of total phosphorus to bodies of water, which is considered a high value compared to international standards in order to reduce or prevent the euthrofication.

Distribution of faecal coliforms

The maximum concentration of faecal coli forms obtained in the lagoons of Pom and Atasta was in the north winds and rainy seasons (193 MPN 100 ml^{-1} and 40 MPN 100 ml^{-1}, respectively), in contrast to the one obtained in the low dry period (1.5- 4.5 MPN 100 ml^{-1}), these results suggest a strong influence in the seasonal variations (Figure 7). Similarly to those findings reported by Lizarraga–Partida et al. (1986) in the lagoon of Términos, where most concentration of micro organisms heterotrophic was in the months of september and october, concluding that the strong winds and the re-suspension of sediment increased the concentration of faecal coliforms significantly (10000 MPN ml^{-1}) whereas in the low dry season it was only (5200 MPN ml^{-1}).

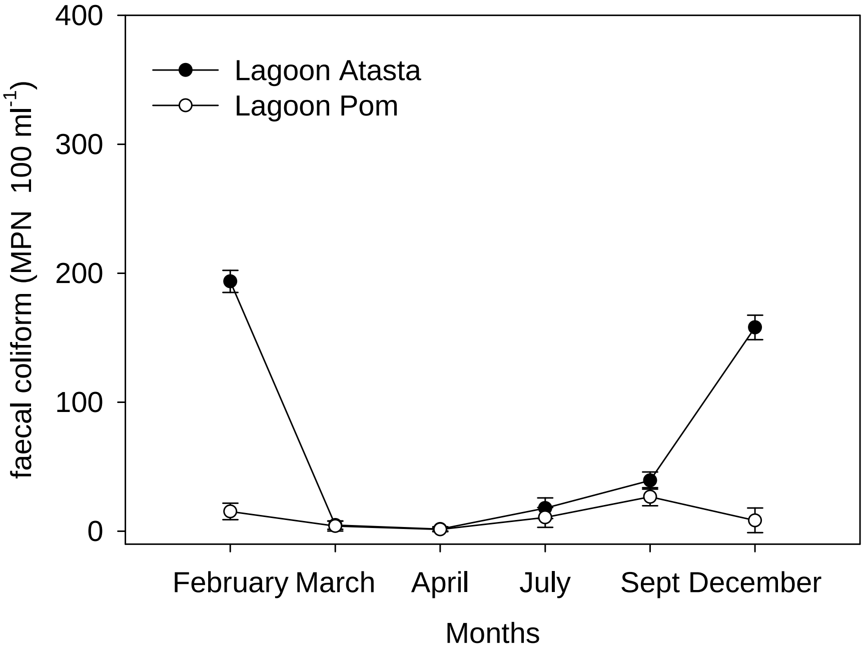

Figure 7. Average monthly variation of the content of faecal coliform in the lagoons of Pom and Atasta of superficial and bottom of water column.

A number of studies have confirmed that the presence of faecal coliforms in the bodies of water is due mainly to the ingress of sewage waters. The faecal coli forms present in high concentrations in lagoon or estuary systems represent a potential risk for the health of people such as swimmers and also for those who consume the bivalves molluscs obtained from the polluted waters which are contaminated with the sewage waters (Orozco-Borbon and Sañudo-Wilhelmy 1988; Barrera-Escorcia and Namihira-Santillán 2004;).

Based on the environmental regulations, the minor concentrations of 14 and 70 total coliforms 100 ml^{-1} in bodies of water can be considered as adequate to exploit and cultivate bivalve molluscs for direct consumption and aquaculture (Wong and Barrera-Escorcia, 1996); whereas concerning recreation activities should be less than 200 total faecal coliforms 100 ml^{-1} and less than 1000 total coliforms 100 ml^{-1} for marine waters (SEDUE 1989). In this sense the values of faecal coliform obtained in this work suggest that both lagoons are recommended for recreational use but can also be considered to be used for the aquaculture of bivalves.

It is observed in figure 8 that for the dry season there was a high contribution of faecal coli forms coming from the inhabitant area of Atasta. This contribution is caused by the lack of drainage and lixiviates. This situation is worse in the rainy season, increasing the concentration of faecal coliforms provoked by the infiltrations from the inhabited zones. Although the environmental conditions that affect the presence of faecal coliforms are the solar radiation, turbulence, temperature and salinity (Kocasoy 1989), it is worth too mention that in the present work the temperature and the salinity did not affect the population of bacteria.

CONCLUSIONS

Our results suggest that the lagoons of Pom and Atasta received a contribution of important nutrients and faecal coliforms in the rainy season through filtrations and the flow of sewage waters. We cannot conclude that both lagoons are in an eutrophication state, nevertheless, the nearest channels to the inhabitant area of Atasta and San Antonio have shown a high concentration of nutrients and bacteria. The deforestation and use of the land for the installation of infrastructure of the petroleum industry are putting the ecosystem at risk. These should be regulated for the preservation of the bodies of water.

This study did not involve economic and political recommendation, however, we did provide scientific information that must be used in order to detect any increase in contaminant concentrations by anthropogenic inputs and, therefore, appropriate actions could be taken.

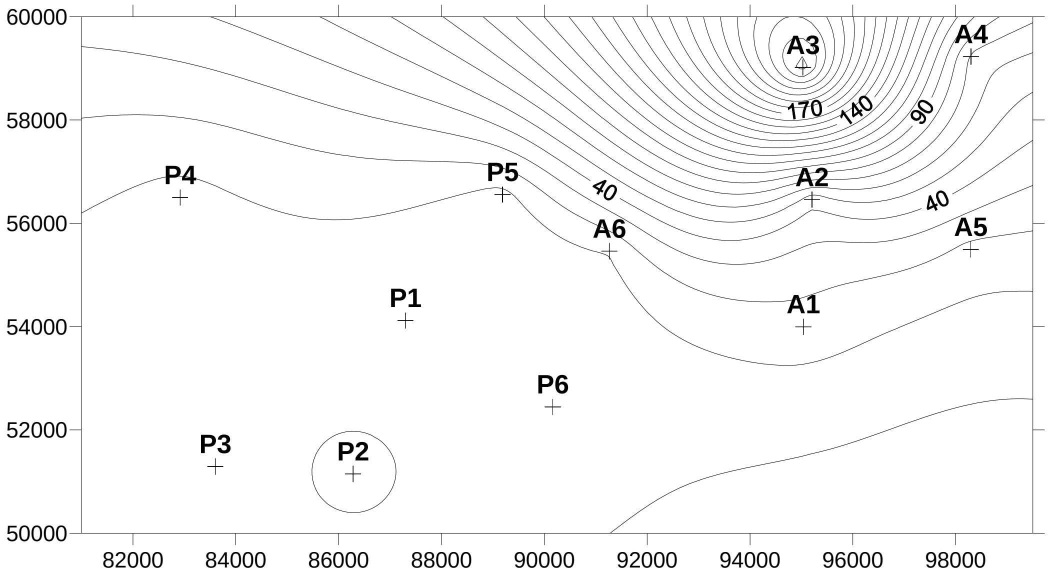

Figure 8. Distribution of faecal coliform in the lagoons of Pom and Atasta during the dry season. . Letters A and P represent Atasta and Pom lagoons, respectively.

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