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PHYSICAL CHARACTERIZATION OF THE REEF LAGOON AT BANCO CHINCHORRO, MEXICO: AN OVERVIEW

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ABSTRACT

In order to obtain data on the physical characteristics of the reef lagoon, temperature, salinity, dissolved oxygen, current velocity, and content pigments in the water column were measured in Banco Chinchorro from August 1997 to July 1998. Sediment samples were collected to determine grain size and organic matter content. The rainy season had the highest mean temperature (29.18 ± 0.41°C); whereas, the dry season and the cold season had 28.05 ± 1.22°C and 26.70 ± 0.71°C, respectively. There was no thermal or density stratification within the reef lagoon. Salinity varied from 36.90 ± 0.17‰ in the dry season to 36.05 ± 0.34‰ in the rainy season; dissolved oxygen was over 5.6 mg L^{-1} during the sample period. Velocity current was 2.06 ± 1.35 m s^{-1} in the rainy season and 1.95 ± 2.01 m s^{-1} in the dry season. Chlorophyll *a* concentration varied from 1.145 ± 0.942 μg L^{-1} to 0.954 ± 0.300 μg L^{-1} in rainy season and from 2.035 ± 0.198 μg L^{-1} to 1.249 ± 0.273 μg L^{-1} in the dry season. Chlorophyll *b* concentration varied from 1.4501 ± 0.208 μg L^{-1} to 1.2044 ± 0.3854 μg L^{-1} to in the rainy season and from 1.2602 ± 1.508 μg L^{-1} to 0.862 ± 1.010 μg L^{-1} in dry season. Sediment was very coarse sand in the southern part of the reef lagoon, whereas in the northern part was the sand medium and fine, with a maximum of 9.18% of organic matter. The reef lagoon is a shallow and stable environment, surrounded by oligotrophic oceanic waters, with a narrow variation of environmental parameters that promotes the presence of diverse and abundant communities.

Coral reef ecosystems are established in stable tropical environments leading to the development of diverse and complex communities dominated by scleractinian corals. These systems are very common in the Indo-Pacific, but also can be found in the eastern Pacific and western Atlantic Oceans (Goreau et al., 1979).

Mexico is distinguished by the presence of three very different areas with coral reefs: the Pacific coast, where reefs are small and poor in species, the coast of Veracruz and the Yucatán Peninsula, mainly the Campeche Bank and the Caribbean Sea reef formations (UNEP/IUCN, 1988).

On the east coast of Yucatán Peninsula, there is an important reef system 600 km long that includes the Belize barrier reef, the fringing reefs off Quintana Roo, the reef-fringed elevated island of Cozumel and Arrowsmith Bank, a drowned platform, and the isolated platforms Glovers Reef, Lighthouse, Turneffe Islands, and Banco Chinchorro (Lang et al., 1998). Banco Chinchorro is considered the only atoll in Mexico. It is an important fishery site and recently has become a tourist attraction (de Jesús-Navarrete and Oliva-Rivera, 1997).

The first investigations carried out in Banco Chinchorro dealt with the distribution of algae (Huerta and Garza, 1980). Miller (1982) described conch and lobster fishing activities; whereas, Chávez and Hidalgo (1984) studied benthic communities. In 1985, Chávez et al. compared Chinchorro characteristics with other reefs off the Yucatán Peninsula. New contributions on the marine flora were done by Huerta et al. (1987) and Jordán and Martin (1987) carried out a description of the geomorphology of Banco Chinchorro. The abundance and distribution of the queen conch, *Strombus gigas*, was studied by de Jesús-Navarrete et al. (1994) and Domínguez et al. (1994) and coral distribution was described by Torruco (this volume). In spite of all this information, there are few mentions in environmental data related to the physical characteristics of reef lagoon: temperature, salinity, dissolved oxygen, pigment contents, current velocity, organic matter content, and sediment type. The objective of this paper is to describe some environmental characteristics of the reef lagoon off Banco Chinchorro and to give information for future comparisons and analysis.

MATERIALS AND METHODS

STUDY AREA.—Banco Chinchorro is located within the Mexican Exclusive Economic Zone (18° 23′–18°47′N, 87°14′– 87°27′W). Chinchorro is 46 km long and 19 km in the widest part, with a reef lagoon area of 550 km^2. Depth varies from 12 m in the south region to 2 m in the north, and 3–7 m in the central part. The bottom is covered with sea grasses, mainly *Thalassia testudinum*, *Syringodium filiforme* and macroalgae. The dry season extends from March–June; the rainy season extends from July–October; and the cold season, characterized by strong winds locally denominated *nortes*, extends from November–February.

From August 1997 to July 1998, samples were collected bimonthly from six sites related to the fishing of queen conch and representative of the reef lagoon: Cayo Lobos (18°23′45.0″N, 87°21′ 20.9″W), Isla Che (18°30′12.3″N, 87°26′13.1″W), Cayo Centro (18°33′32.7″N, 87°18′24.5″W), Cayo Centro Oeste (18°33′24.1″N, 87°24′56.6″W), Penélope (18°42′47.6″N, 87°14′55.5″W), and Cayo Norte (18°45′28.1″N, 87°47′01.1″W) (Fig. 1). Cayo Lobos, Cayo Centro, Penélope, and Cayo Norte were located near the windward sides, whereas Isla Che and Cayo Centro Oeste were on the leeward sides.

During the work period, surface temperature, salinity and dissolved oxygen were measured at these six sites, using a YSI oxygen meter model 58 for temperature and oxygen and an OHAUS model 50 conductivity meter for salinity.

To measure bottom temperature, salinity, and dissolved oxygen, a calibrated oceanographic data sound was set over a concrete base separated 0.30 m from the bottom at four selected sites: Cayo Lobos, Isla Che, Cayo Centro, and Cayo Norte. The data sound recorded the physical parameters each hour by 24 hrs. These data were processed and the arithmetic mean of each parameter by climatic season was reported.

A General Oceanics flow meter was tied to the oceanographic sound frame to record current velocity. After observing the current flow, the sound was oriented in that direction; the initial and final registers of the flowmeter as well as the initial and final time were annotated.

To determine the concentration of chlorophyll *a*, 4–10 L of seawater were collected using a van Dohrn bottle and filtered with a 45 µm Millipore membrane. Filters were wrapped with aluminium foil and placed in glass tubes with identification; tubes were put into a cool box until their analysis. Pigments were extracted using 90% acetone according to Parsons et al. (1984). Chlorophyll *a* and chlorophyll *b* content (μg L^{-1}) were determined using a Spectronic 1001 spectrophotometer.

At each site approximately 500 g of sediment were collected in duplicate by driving a PVC pipe (5 cm diam) into the seabed to a depth of 10 cm. Sediment was dried at 60°C for 24 hrs. Organic matter content was determined by ignition loss in triplicate subsamples of 50 g each. Dry samples were heated to 550°C for 1 hr. After cooling to room temperature in a desiccator, samples were weighed; the difference between dry weight and ignited weight is the amount of organic carbon in the sample (Dean, 1974). Sediments free of organic matter were analyzed to grain size using a standard sieve series. Mean grain size (ϕ) and standard deviation (STD) was calculated following Buchanan (1984).

Surface and bottom values of temperature, salinity, and dissolved oxygen of the three seasons—rainy, cold and dry—were compared using one-way ANOVA ($P < 0.05$).

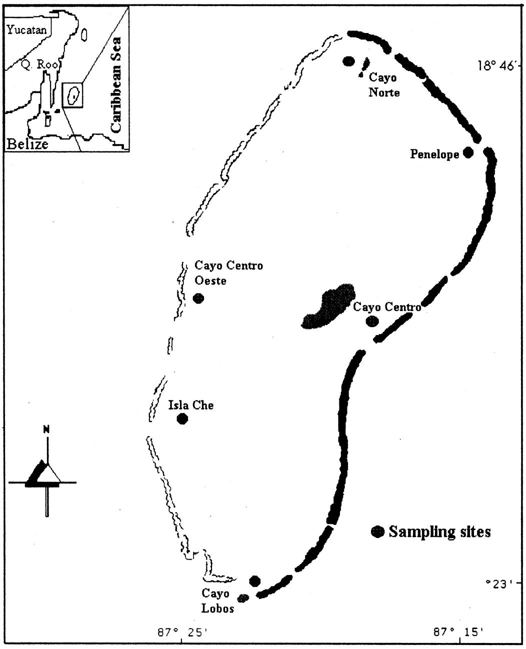

Figure 1. Location of Banco Chinchorro and sampling sites.

RESULTS

Rainy season (August 1997 and July 1998) had the highest mean surface temperature (29.18 ± 0.20°C). Cayo Centro Oeste had the highest temperature (29.80 ± 0.63°C) and Cayo Lobos had the lowest (28.65 ± 0.58°C). Cold season (October 1997 to December 1997) had a mean temperature of 27.83 ± 0.53°C, with the lowest temperature occurring at Cayo Centro Oeste (26.95 ± 0.82°C). In the dry season (March 1998 to May 1998), the mean temperature was 27.36 ± 0.49°C, with the highest temperature (27.75 ± 0.60°C) at Cayo Centro and the lowest (26.75 ± 0.60°C) at Cayo Lobos (Fig. 2A).

Bottom temperature showed daily variations from 0.55–4.1°C. Rainy season had the highest mean temperature (29.31 ± 0.10°C). The lowest mean temperature was measured in cold season (27.25 ± 0.51°C). In the dry season mean temperature was 27.47 ± 0.16°C. There were no significant differences between surface temperature values and bottom values (one way ANOVA, $P > 0.05$; Fig. 2B).

Salinity varied 1.41psu during the sampling period. The highest mean salinity corresponded to dry season (36.90 ± 0.17 psu), with a maximum salinity at Penélope (37.5 ± 0.01). In the rainy season, mean salinity was 36.05 ± 0.34 psu and the lowest mean salinity was measured in cold season (35.99 ± 0.91 psu), with a maximum at Isla Che (36.05 ± 0.05 psu; Fig. 2C). Salinity changes at bottom level were less than 1psu with a maximum of 36.09 ± 0.11psu in the rainy season and a minimum of 35.56 ± 0.12 psu in the cold season, both at Cayo Norte. There were no significant differences between surface and bottom salinity values (Fig. 2D).

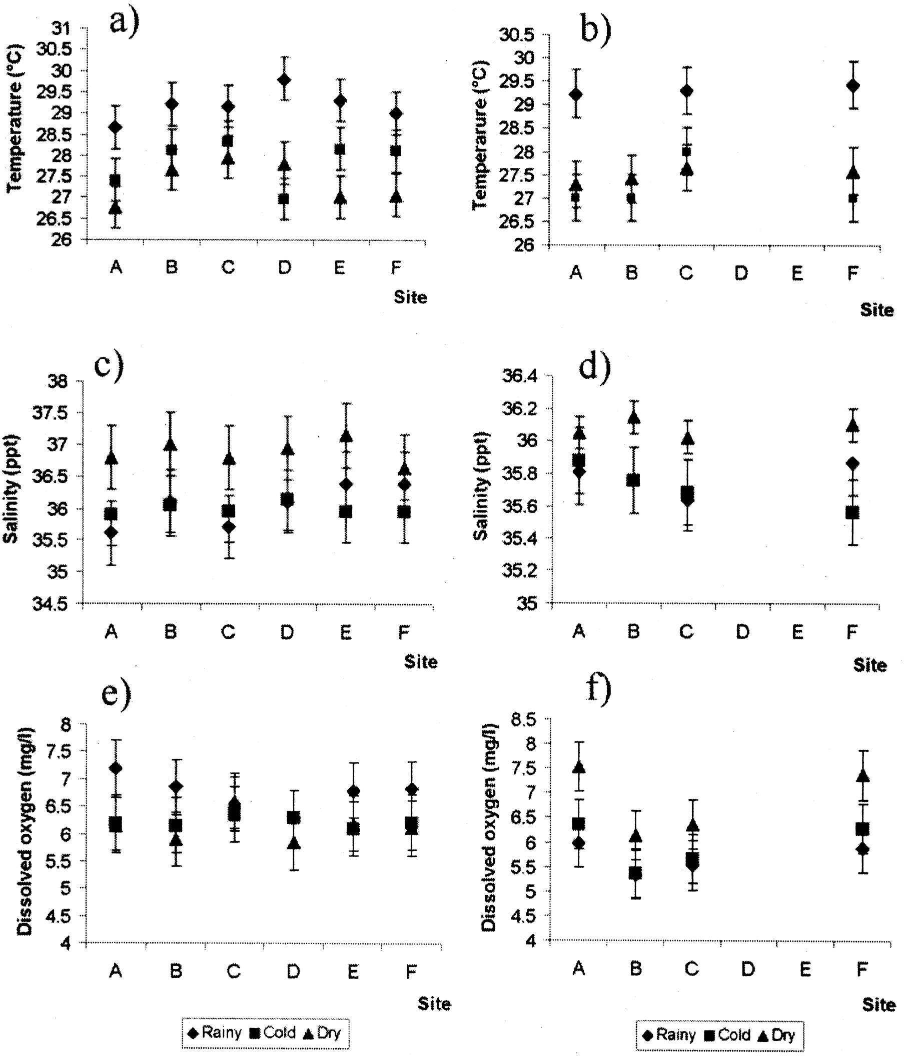

Figure 2. Mean surface temperature (a), bottom temperature (b), surface salinity (c), bottom salinity (d), surface dissolved oxygen (e) and bottom dissolved oxygen (f), within reef lagoon at Banco Chinchorro, (A) Cayo Lobos, (B) Isla Che, (C) Cayo Centro, (D) Cayo Centro Oeste, (E) Penélope, (F) Cayo Norte, bars represent one standard deviation

The highest surface oxygen concentration occurred in the rainy season (6.75 ± 0.30 mg L^{-1}). Cold season had a mean oxygen concentration of 6.22 ± 0.09 mg L^{-1} and in the dry season oxygen concentration was 6.13 ± 0.26 mg L^{-1}, the lowest seasonal value (Fig. 2E). Bottom dissolved oxygen varied from 4.45 ± 0.73 mg L^{-1} at Cayo Centro in March to 8.96 ± 2.77 mg L^{-1} at Cayo Lobos in May (Fig. 2F). However, there were no significant differences between surface and bottom dissolved oxygen concentration (one-way ANOVA, $P > 0.05$).

In rainy season mean current velocity was 2.06 ± 1.35 m s^{-1}. Maximum current velocity occurred to Cayo Lobos (3.61 m s^{-1}) and minimum to Cayo Norte (0.82 m s^{-1}). In

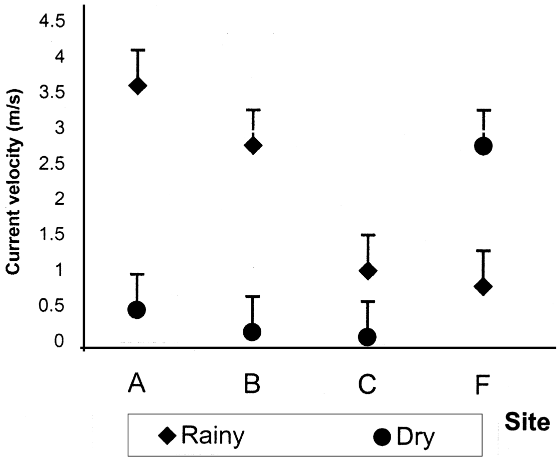

Figure 3. Mean current velocity at Banco Chinchorro, (A) Cayo Lobos, (B) Isla Che, (C) Cayo Centro, (D) Cayo Norte, bars represent one standard deviation

the dry season mean current velocity was 1.95 ± 2.01 m s^{-1}. Highest values were recorded at Cayo Centro (8.71 m s^{-1}) and to Cayo Norte (5.55 m s^{-1}; Fig. 3). No data were measured in *nortes* season (October and December) due to logistics problems.

Chlorophyll *a* concentration varied from 0.95 ± 0.300 µg L^{-1} to 1.15 ± 0.942 µg L^{-1} in rainy season. In the dry season a higher mean chlorophyll *a* concentration was measured at Cayo Norte (2.04 ± 0.198 µg L^{-1}) and the lowest was measured at Isla Che (1.25 ± 0.273 µg L^{-1}; Fig. 4).

The mean chlorophyll *b* concentration varied from 1.20 ± 0.395 µg L^{-1} in rainy season at Cayo Norte to 1.45 ± 0.208 µg L^{-1} at Isla Che. In the dry season, higher concentration of chlorophyll *b* occurred at Cayo Centro (1.26 ± 1.508 µg L^{-1}) and the lowest was recorded at Isla Che (0.86 ± 1.010 µg L^{-1}) (Fig. 4).

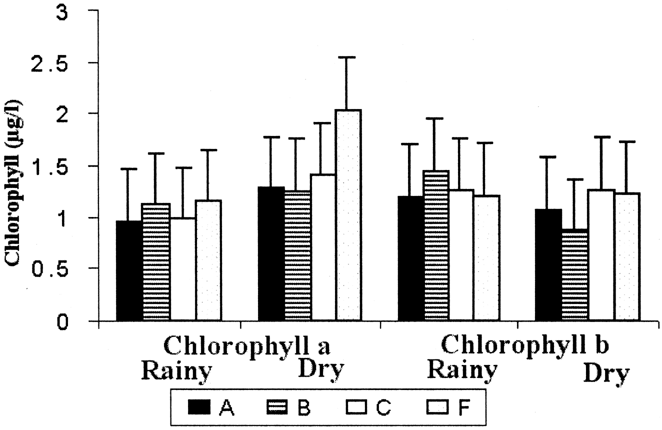

Figure 4. Chlorophyll *a* and Chlorophyll *b* content at Banco Chinchorro, (A) Cayo Lobos, (B) Isla Che, (C) Cayo Centro, (D) Cayo Norte, bars represent one standard deviation.

Table 1. Mean sediment grain size (ϕ), classification, standard deviation (STD) and organic matter percentage by season and sites of sample in Banco Chinchorro, Mexico.

	C. Lobos (ϕ), Clasif.	Isla Ché (ϕ), Clasif.	C. Centro (ϕ), Clasif.	C. C. Oeste (ϕ), Clasif.	Penélope (ϕ), Clasif.	C. Norte (ϕ), Clasif.
Rainy	0.55 Coarse sand	1.54 Medium sand	1.15 Coarse sand	0.81 Coarse sand	0.80 Coarse sand	1.16 Coarse sand
Cold	–0.31 Very coarse sand	–0.25 Very coarse sand	1.18 Coarse sand	1.49 Medium sand	1.7 Coarse sand	1.57 Medium sand
Dry	0.58 Coarse sand	1.47 Medium sand	1.82 Medium sand	1.20 Coarse sand	1.05 Coarse sand	1.13 Coarse sand
STD						
Rainy	0.85 Mod	0.77 Good	0.93 Mod	0.71 Good	0.86 Mod	1.12 Poorly
Cold	–0.06 Vgs	0.15 Vgs	1.37 Vgs	0.75 Good	1.05 Poorly	0.77 Good
Dry	0.84 Mod	0.79 Good	0.88 Good	1.12 Poorly	1.38 Poorly	1.12 Poorly
%OM						
Rainy	2.30 ± 0.15	1.93 ± 0.11	2.06 ± 0.19	1.85 ± 0.14	2.23 ± 0.07	2.79 ± 0.14
Cold	2.55 ± 0.16	2.15 ± 0.09	5.88 ± 0.11	2.08 ± 0.09	2.47 ± 0.12	2.20 ± 0.16
Dry	2.47 ± 0.22	1.99 ± 0.13	2.61 ± 0.18	3.95 ± 0.17	2.13 ± 0.22	9.18 ± 0.24

Very good sorted (Vgs), Good sorted (Good), Moderately sorted (Mod), Poorly sorted (Poorly).

Sediments within in the southern part of the reef lagoon were very coarse sands. Cayo Lobos and Isla Che had a mean grain size of 0.25 ϕ; whereas, Cayo Centro and Cayo Norte had medium sand (1.98 ϕ) (Table 1). In the cold season, a mean grain size of 1.57 ϕ was found in Cayo Norte, which corresponds to medium sand. In the dry season, the mean grain size found at Cayo Centro was medium sand (1.97 ϕ). The same distribution pattern was observed in the rainy season. Highest grain size sands were found at Isla Che, 1.40 ϕ (medium sand), and at Cayo Lobos (–0.30 ϕ, very coarse sand). Considering all sites and seasons, the mean percentage of organic matter was 2.93 ± 1.83%. The highest percentage was measured in dry season (9.18%) at Cayo Norte and minimum corresponded to rainy season (1.85%; Table 1).

DISCUSSION

Coral reef distribution is restricted to tropical seas where the temperature is never below 20°C. These environments are very stable systems, and this promotes a high diversity and ecological efficiency (Goreau et al., 1979). Extreme low and high temperatures have deleterious effects on the health of coral reefs. A temperature of 24°C in the cold season caused mortality of corals in Florida (Porter et al., 1982; Roberts et al., 1982; Odgen et al., 1994); whereas, an 18°C temperature resulting in a low coral diversity (Brigth, et al., 1984). On the other hand, seawater temperatures over 31°C are generally acknowledged to stress stony corals and have been associated with bleaching (Glynn and D´Croz, 1990; Brown and Ogden, 1993). At Banco Chinchorro the highest temperature was 30.43°C in rainy season, and this could be causing some isolated coral bleaching events (de Jesús-Navarrete, pers. obs.). Even when cold fronts were intense from November–March, apparently there were no negative effects caused by low temperature at Banco Chinchorro. Although there were no statistical differences between surface and bottom temperatures, bottom temperatures were slightly higher (< 1°C) than surface temperatures. This could be due to the shallowness of the reef lagoon, or to the effect of wind over the surface water, but there is no definitive temperature stratification within the reef lagoon. The presence of a wide mixed layer within reef lagoons has been observed in other atolls, and this is mainly due to wind effect (Andrews and Gentien, 1982). The temperature at Banco Chinchorro is high most of the year, which could favor reproductive events like those of *Strombus gigas* and other species, as well as a fast growth of larvae within the reef lagoon (Stoner et al., 1992; de Jesús-Navarrete and Aldana-Aranda, 2000).

Changes in salinity are more obvious in coral reefs closer to the coastline. Eventually modifications in the hydrologic pattern of a region can produce changes in the reef conditions, causing direct injury to corals. This has been reported at Florida Bay, where *Montastrea annularis* had a stress response to elevated temperature and hyper-salinity (Porter, et al., 1999). In atolls, the hydrological balance is governed mainly by rainfall that forms a freshwater lens on the surface (Underwood and Peterson, 1992). This phenomena has been observed at Cayo Norte at Banco Chinchorro. Even when rainfall produced no significant changes in the seawater salinity, a seasonal decrease in surface salinity was observed by Wüst (1964) in the Caribbean basin, and this fact is corroborated by our rainy season data (35.6 psu). Chávez et al. (1985) reported a salinity of 36.5 psu within the reef lagoon, but our mean salinity value (37.07 psu) measured in the dry season was higher due mainly to higher evaporation and lower precipitation.

Well-oxygenated waters characterize reefs. Dissolved oxygen values at our sites are higher than other data collected in the region (Wüst, 1964). Dissolved oxygen is a result of the balance between primary production and respiration within the lagoon and apparently is not a limiting factor to the distribution of communities in Banco Chinchorro.

Surface currents in the western Caribbean are directed northward, with variable velocities throughout the year (0.80–1.2 m s^{-1}; Wüst, 1964). Even though marine currents have been studied widely in the Caribbean, data are lacking in this area. A mean current velocity from 0.70–2.72 m s^{-1} increasing in the Yucatán Channel was reported by Merino-Ibarra (1986). These values are very similar to those measured in the reef lagoon. In Banco Chinchorro there is not enough information to define the surface circulation pattern within the reef lagoon. Our data showed a variation of current velocity as function of wind velocity and direction. This same effect has been observed in other Caribbean reefs, where wind velocity, tidal amplitude and waves caused circulation patterns within the reef system at Grand Cayman and Belize, generating currents between 0.30–0.40 m s^{-1} (Roberts et al., 1975; Greer and Kjerfve, 1982). Stoner et al. (1994) found a surface current velocity of 0.05–0.10 m s^{-1} in Bahamas. It must be considered that our measuring device was not as precise and this may have overestimated the velocity current. Additional data are needed in Banco Chinchorro to understand local surface circulations and their implications within the reef lagoon.

Generally, oceanic waters adjacent to coral reefs are transparent oligotrophic waters where picoplankton are the dominant primary producers (Legendre et al., 1988). In the Great Barrier Reef, Furnas et al. (1990) reported chlorophyll *a* concentrations that varied from 0.55–0.70 μg L^{-1}; although in French Polynesia chlorophyll *a* varied from 0.100 μg L^{-1} at adjacent oceanic surface waters to 0.025 μg L^{-1} at 100 m depth, and 0.120 μg L^{-1}

within the reef lagoon (Legendre et al., 1988). Our results are similar to that of Gilbes et al. (1996) who reported a chlorophyll *a* concentration varying from 0.4–1.8 μg L^{-1} at Mayagüez Bay and from 0.02–2.2 μg L^{-1} at Bahía de Añasco, Puerto Rico. Reef lagoon is a richer environment than the oceanic adjacent waters and this contributes to a higher abundance and diversity of meroplanktic forms within the reef lagoon (Emery, 1968).

The Caribbean Current represents the main water transport in the area; it flows northward. Banco Chinchorro receives the influence of this current in its southern region, and this water flow determines sediment transport within the reef lagoon. Sediment distribution is governed by the flow with coarse sands at Cayo Lobos and it is representative of a high energy environment (Gischler and Lomando, 1999). Medium and fine sediments at Cayo Centro and Cayo Norte have less wave energy. Chávez and Hidalgo (1984) hypothesized that reef lagoon in Banco Chinchorro is filling with calcareous sediments, and that this effect in the geologic time has produced an accumulation at Cayo Norte, a shallow environment with low abundance of corals and presence of fine sediments. Cayo Norte represents the older part in the corals' evolution at Banco Chinchorro whereas Cayo Lobos and Isla Che represent the newer area, characterized by deep bottoms, abundant coral patches, clear waters, and coarse sediments.

Overall, marine carbonate sand sediments contain between 0.2 and 2.5% organic matter (Emerson, 1985). Mean percentage of organic matter at Banco Chinchorro is slightly above this value (2.93 ± 1.82%), the high organic matter found at Cayo Norte (9.18%) could be due to the deposition of sea grasses and algae debris, mainly *T. testudinum* and *Halimeda* fragments abundant in the reef lagoon. A high content of total organic carbon (15.41%) was reported in lagoon sediments at Turneffe Islands. This was related to constant sources such as mangrove and macroalgae debris (Gischler and Lomando, 1999).

Environmental characteristics define the properties of an ecosystem. Banco Chinchorro reef lagoon represents a shallow, stable and rich environment surrounded by oligotrophic oceanic waters. Even when the data were collected at only six points, these could be considered as representative of the reef lagoon, with environmental parameters varying in a narrow interval, particularly temperature and salinity, and this promotes the presence of diverse and abundant communities in a stable ecosystem. Banco Chinchorro could be considered as a reef ecosystem with low anthropogenic impact.

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Literature Cited

Andrews, J. C. and P. Gentien. 1982. Upwelling as a source of nutrients for the Great Barrier Reef ecosystems: A solution to Darwin's question? Mar. Ecol. Progr. Ser. 8: 257–269.

Brigth, T. J., G. P. Kraemer, G. A. Minnery and S. T. Viada. 1984. Hermatypes of the Flower Garden Banks, Nortwestern Gulf of Mexico: A comparison to other western Atlantic reefs. Bull. Mar. Sci. 34: 461–476.

Brown, B. E. and J. C. Odgen. 1993. Coral bleaching. Sci. Am. 268: 64–70.

Buchanan, J. B. 1984. Measurement of physical and chemical environment. Pages 38–50 *in* N.A. Holme and A.D. MacIntyre, eds. Methods for the study of marine benthos. IBP Handbook No. 16. Blackwell, London.

Chávez, E. A. and E. Hidalgo. 1984. Spatial structure of benthic communities of Banco Chinchorro, Mexico. *In* Advances in reef science. Joint Meeting ISRS and Atoll Reef Comm. University of Miami, 26–28.

________________________. 1988. Los arrecifes coralinos del Caribe noroccidental y Golfo de México en el contexto socioeconómico. An. Inst. Cienc. del Mar. y Limnol. Univ. Nal. Auton. Mexico 15: 167–176.

________________________ and M. A. Izaguirre. 1985. A comparative analysis of Yucatán coral reefs. Proc. 5th Int. Coral Reef Cong., Tahiti. 6: 355–361.

Dean, W. E. Jr. 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparisons with other methods. J. Sedim. Petrol 14: 242–248.

de Jesús-Navarrete, A., J. Oliva-Rivera, A. Pelayo, M. Góngora, A. Medina and M. Domínguez-Viveros. 1994. Desarrollo científico y tecnológico para el cultivo del caracol. Boletín informativo, SEPESCA/CIQRO. 45 p.

____________________ and D. Aldana-Aranda. 2000. Distribution and abundance of *Strombus gigas* veligers at six fishing sites on Banco Chinchorro, Quintana Roo, Mexico. J. Shellfish Res., 19(2): 891–896.

_____________________ and J. J. Oliva-Rivera. 1997. Densidad, crecimiento y reclutamiento del caracol rosado *Strombus gigas* L. en Punta Gavilán, Quintana Roo, Mexico. Rev. Biol. Trop. 45: 797–801.

Domínguez, V. M., A. Medina Quej and A. de Jesús Navarrete. 1994. Sobrevivencia del caracol *Strombus gigas* en la región sur de Quintana Roo, Mexico. Proc. Gulf Carib. Fish. Inst. 47th Annual Meeting, Margarita, Venezuela, 1–8 p.

Emerson, S. 1985. Organic carbon preservation in marine sediments. Am. Geophys. Union. Geophys. Monogr. 32: 78–87.

Emery, A. R. 1968. A preliminary observation on coral reef plankton. Limnol. Oceanogr. 13: 293–303.

Furnas, M. J., A.W. Mitchell, M. Gilmartin and N. Revelante. 1990. Phytoplankton biomass and primary production in semi-enclosed reefs lagoons of the central Great Barrier Reef, Australia. Coral Reefs 9: 1–10.

Gischler, E. and A. J. Lomando. 1999. Recent sedimentary facies of isolated carbonate platforms, Belize-Yucatán System, Central America. J. Sed. Res. 69: 747–763.

Gilbes, F. J., M. López and P. M. Yoshioka. 1996. Spatial and temporal variations of phytoplankton chlorophyll *a* and suspended particulate matter in Mayagüez Bay, Puerto Rico. J. Plank. Res. 18: 29–43.

Glynn, P. W. and L. D´Croz. 1990. Experimental evidence for high temperature stress as the cause of El Niño-coincident coral mortality. Coral Reefs 8: 181–192.

Goreau, T. F., N. I. Goreau, and T. J. Goreau. 1979. Corales y arrecifes coralinos. Invest. Ciencia 37: 48–60.

Greer, J. E. and B. Kjerfve. 1982. Water currents adjacent to Carrie Bow cay, Belize. Pages 53–58 *in* K. Rützler and I. G. Macintyre, eds. The Atlantic barrier reef ecosystem at Carrie Bow Cay, Belize, I. Structure and communities. Smithsonian Contributions to the Marine Sciences 12.

Huerta, L. and A. Garza. 1980. Contribución al conocimiento de la flora marina de la zona sur del litoral de Quintana Roo, México. An. Esc. Nal. Cienc. Biol. 23: 25–44.

Huerta, M. L., A. C. Mendoza-González, L. E. Mateo-Cid. 1987. Avance sobre un estudio de las algas marinas de la Península de Yucatán. Phytologia 62: 23–53.

Jordán, E. and E. Martin. 1987. Chinchorro: Morphology and composition of a Caribbean atoll. Atoll. Res. 310: 1–20.

Lang, J., P. Alcolado, J. P. Carricart-Ganivet, M. Chiappone, A. Curran, P. Dustan, G. Gaudian, F. Geraldes, S. Gittings, R. Smith, W. Tunnel and J. Wiener. 1998. Status of coral reefs in the northern areas of the wider Caribbean. Pages 123–134 *in* C. Wilkinson, ed. Status of the coral reefs of the world. Australian Institute of Marine Science, Melbourne, Australia.

Legendre, L. S. Demers, B. Delesalle and C. Harnois. 1988. Biomass and photosyntethic activity of phototrophic picoplancton in coral reefs waters (Moorea Island, French Polynesia). Mar. Ecol. Prog. Ser. 47: 153–160.

Merino-Ibarra, M. 1986. Aspectos de la circulación costera superficial del Caribe Mexicano, con base en observaciones utilizando tarjetas de deriva. An. Cienc. del Mar y Limnol. UNAM. 13: 31–46.

Miller, D. 1982. Mexico's Caribbean fishery: Recent change and current issues. Ph.D. Diss., Univ. of Wisconsin, Milwaukee. 251 p.

Odgen, J. C., J. W. Porter, N. P Smith, A. M. Szmant, W. C. Jaap and D. Fortucci. 1994. A long term interdisciplinary study of the Florida Keys seascape. Bull. Mar. Sci. 54: 1059–1071.

Parsons, T. R., Y. Maita and C. M. Lalli. 1984. A manual of chemical and biological methods for seawater analysis. Pergamon Press. New York, 174 p.

Porter, J. W., J. F. Battey and G. J. Smith. 1982. Perturbation and change in coral reef communities. Proc. Nat. Acad. Sci. USA 79: 1678–1681.

__________, S. K. Lewis and K. G. Porter. 1999. The effect of multiple stressors on the Florida Keys coral reef ecosystem: A landscape hypothesis and physiological test. Limnol. Oceanogr. 44: 941–949.

Roberts, H. H., S. P. Murray and N. J. Suhayda. 1975. Physical processes in a fringing reef system. J. Mar. Res. 33: 233–260.

____________, L. J. Rouse, Jr., N. D. Walker and J. H. Hudson. 1982. Cold-water stress in Florida Bay and northern Bahamas a product of winter cold air outbreaks. J. Sed. Petrol. 52: 145–155.

Stoner, A. W., V. J. Sandt and I. F. Boidron-Metairon. 1992. Seasonality in reproductive activity and larval abundance of queen conch *Strombus gigas*. Fish. Bull. 90: 161–170.

Stoner, A. W., M. D. Hanisak, N. P. Smith and R. A. Armstrong. 1994. Large Scale distribution of queen conch nursery habitats: implications for stock enhancement. Pages 169–189 *in* R.S. Appeldoorn and Q. Rodriguez, eds. Queen conch biology, fisheries and mariculture. Fundación Científica los Roques, Caracas.

Underwood, M. R. and F. L. Peterson. 1992. Groundwater lens dynamics of atoll islands. Water Res. Res. 28: 2889–2902.

UNEP/IUCN. 1988. Coral reefs of the world. Vol. 1. Atlantic and eastern Pacific. UNEP-IUCN, Nairobi, Kenya, 373 p.

Wüst, G. 1964. Stratification and circulation in the Antillean-Caribbean Basins. Part one. Columbia University Press, New York. 201 p.

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