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The distribution of marine algae in a coastal lagoon, northern Yucatan Peninsula, Mexico

Distribuição espaço-temporal das algas marinhas de uma laguna costeira do norte da Península de Yucatán, México

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Abstract

This paper presents the first phycofloristic study carried out on the coastal lagoon of Chelem, Yucatan, Mexico. Eight sampling sites at three different seasons (dry, rainy and Nortes) allowed us to record 54 taxa of marine algae (35 species of Rhodophyceae, 18 Chlorophyceae and one Phaeophyceae), registered for the first time in this area. Rhodomelaceae is the best represented family, with 19 species. An analysis of PCA of environmental factors and species distribution showed that the Chelem Lagoon may be divided into three zones: inner, middle and outer zones. Temporally, the highest algal diversity (38 spp.) was found in the dry season and the lowest during the "Nortes" (winter) season (28 spp.). Spatially, the highest diversity was found at the outer zone of the lagoon (25 spp.), while the lowest was at the middle zone (13 spp.). The outer zone experiences a major influence of the sea, whereas both the inner and middle zones have brackish waters. The bottom had more species than the mangrove. Jaccard analyses were used to compare sites and seasons and show no similarity between zones and seasons. The distribution pattern in space and time was primarily determined by the salinity because this was the environmental factor that presented the highest variations between zones. The class Rhodophyceae has the largest number of species and dominate over Chlorophyceae and Phaeophyceae in time and space, this is because of the high number of epiphyte algae.
Regardless of the distribution and occurrence, the most common species over time was *Cladophoropsis macromeres.* At least two species [*Ceramium brevizonatum* var. *caraibicum* H.E. Petersen and Børgesen and *Chondria capillaris* (Hudson) M.J. Wynne] represent new records for the State of Yucatan.

Key words: marine algae, distribution, seasonality, coastal lagoon, Yucatan Peninsula, Mexico.

Resumo

Resumo: Este trabalho apresenta o primeiro estudo ficoflorístico efetuado na laguna costeira de Chelem, Yucatán, México. Foram coletadas amostras em oito sítios ao longo da laguna, em três estações do ano (estação de seca, de chuva e "Nortes"). Analisaram-se, espacial e temporalmente, a distribuição das espécies e os fatores ambientais, mediante uma análise dos componentes principais e determinou-se a similitude das estações e das

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épocas do ano mediante uma análise de conglomerados, usando o índice de Jaccard. Registrou-se um total de 54 espécies (35 da classe Rhodophyceae, 18 Chlorophyceae e uma Phaeophyceae). A família melhor representada foi Rhodomelaceae, com 19 espécies, sendo a maioria epífita. Com base na análise de componentes principais, a laguna foi dividida em três zonas, para fins de estudo: zona interna, zona média e zona externa. A maior riqueza de espécies (38 spp.) foi registrada na época de seca e a menor na época de "Nortes" (28 spp.). Espacialmente, a menor riqueza ocorreu na zona média (com características estuarinas) e a maior na zona externa, que corresponde à zona de desembocadura da laguna junto ao mar. A riqueza de algas foi maior no fundo da laguna que no mangue. O padrão de distribuição espaço-temporal muito provavelmente se deva à salinidade, já que é um dos fatores que apresenta maior variação entre as zonas. *Cladophoropsis macromeres* ocorreu em todas as épocas e em todas as zonas. Ainda que todas as espécies sejam novos registros para a laguna, duas [*Ceramium brevizonatum* var. *caraibicum* H.E. Petersen e Børgesen e *Chondria capillaris* (Hudson) M.J. Wynne] caracterizam novos registros para o Estado de Yucatán.

Palavras-chave: algas marinhas, distribuição, estacionalidade, laguna costeira, Península de Yucatán, México.

Introduction

This is the first phycofloristic study that was carried out on in Chelem Lagoon. No seasonal floristic studies on algae have been done before at this lagoon; the types of studies that have been done on this lagoon were mainly of primary productivity, trophic and nutrients status (Valdes and Real, 1994; Herrera-Silveira *et al*., 1995, 2002; Herrera-Silveira, 1994, 2006). In these studies, the aquatic vegetation that was reported for the lagoon was *Halodule wrightii*, *Thalassia testudinum,* and macroalgae, mainly rhodophytes and chlorophytes (Herrera-Silveira, 2006), but the names of the species were not specified.

The most part of the research on floristic and distribution studies of macroalgae have been carried out on the seashore (Huerta *et al.,* 1987; Robledo and Freile-Pelegrín, 1997, 1998; Robledo, 1998; among others) or other lagoons like Celestún (Taylor, 1939, 1941; Ortegón-Aznar and González-González, 2000) and Ría Lagartos (Ortegón-Aznar and González-González, 2000; Ortegón-Aznar *et al.,* 2001), all of them are part of protected national areas, due the great importance of the lagoons as a tourism zones and the wide variety of fauna, including the protected flamingo (*Phoenicopterus ruber ruber*), and commercially important species. Chelem is the only lagoon in Yucatan State that it is not part of a natural protected area. It is used as the State's largest port, which harbors 90% of the fishing Fleet. As a consequence, it is a highly disturbed zone, which makes of the Chelem Lagoon an important zone to do extensive research on its flora and fauna, in order to determine the impact of human activity on the biodiversity of this area.

In this study, we examined the occurrence and seasonal distribution of marine algae in the coastal Chelem Lagoon, Yucatan. A list of species is also presented.

Material and methods

Study site

The Chelem Lagoon is a shallow lagoon (1.4 m average depth), measuring 14.7 km long by 1.8 km maximum width, with an overall surface area of 15 km^2, located on the northern coast of the Yucatan State at the Gulf of Mexico (21º14'-21º16' N; 89º39'-89º48' W) (Figure 1). It is connected to the sea

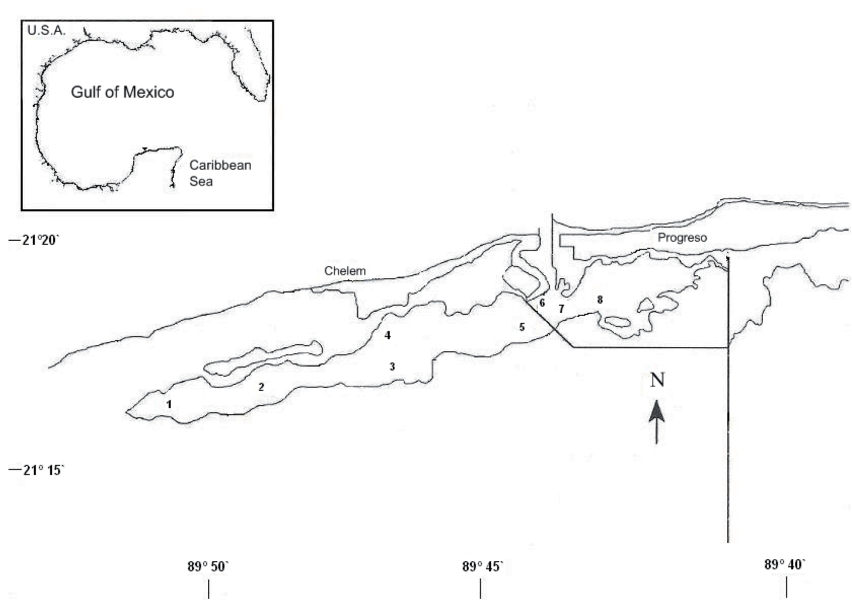

Figure 1. Coastal lagoon of Chelem and the study sites.

by a 225 m wide artificial opening which serves as a harbor with access to the Port of Yucalpeten (Herrera-Silveira *et al.,* 2002). Marine algae were collected from eight sites. These sites were selected based on a previous trophic and nutrients study that shows salinities differences between sites (Valdez and Real, 1994).

The collections were made in November of 2001, April and September of 2002. These months correspond to three seasons of the year with different weather conditions: "Nortes" season (cold winter winds that come from the North with much rain), the dry season, and the rainy season, respectively. A remarkable environmental aspect of the Yucatan is the lack of rivers but with a well-developed network of underground water flowing towards the open sea carrying with it inorganic nutrients such as NO_3 and SRSi, and showing a hydrological variability strongly associated with the discharge from fractures in the freatic mantle as springs (Herrera-Silveira and Comin, 1995). In general, all the sites of the study area comprised of red mangrove (*Rhizophora mangle* L.) with a deposit of limestone-clay at the bottom, and a few sandy and rocky zones near the sea.

Algae were preserved according to the techniques established by Abbott and Dawson (1978). Algal material was analyzed, and species were determined using Taylor (1960) and Littler and Littler (2000). The classification adopted was the one from Silva *et al*. (1996), Sentíes-Granados and Fujii (2002), Fujii and Sentíes-Granados (2005), Wynne (2005) and Nam (2007).

The collections were made from the roots of the mangroves and from the bottom (benthos) from eight sites and three seasons (dry, rainy and Nortes). At each site temperature and salinity were measure. We compared absence-presence of species using a Jaccard Index to determine similarity between sites and seasons and substrate. A PCA analysis was used to evaluate environmental and floristic differences between sites and seasons in space and time. All the analyses were done using the statistical program MVSP 3.1.

A reference collection was placed at the University Autonomous of Yucatan (Universidad Autónoma de Yucatán) Herbarium "Alfredo Barrera" (823-877 FICYUC).

Results

Floristic

Fifty-four species were determined, comprised of 18 Chlorophyceae, 35 Rhodophyceae, and one Phaeophyceae. (Table 1) The best represented class was the Rhodophyceae (67%), and the best represented family was the Rhodomelaceae with 19 species. All these represent new records for Chelem Lagoon. *Ceramium brevizonatum* var. *caraibicum* and *Chondria capillaris* represent new records for the State of Yucatan.

Spatial and temporal distribution

Based on the PCA analysis the species composition, distribution and the environmental factors divided the lagoon into three sections: the Inner Zone (I.Z) comprises sites 1-4, the Middle Zone (M.Z) comprises the site 5, and the Outer Zone (O.Z) comprises sites 6- 8 (Figure 2).

The most important species to distinguish the zone in the axis 1 were *Acetabularia crenulata, Batophora oerstedii, Chondria capillaris* and *Palisada poiteaui,* and for the axis 2 were *Bostrychia tenella, Polysiphonia subtilissima* and *Centroceras clavulatum.*

The highest diversity was found at the outer zone of the lagoon with 34 species, and the lowest diversity was in the middle zone with 13 (Figure 3). The outer zone has more influence of the sea, and the inner and middle zones have brackish water.

At the inner zone, 25 species were present, the bottom presenting more species than the mangrove, most of them Rhodophyceae and Chlorophyceae. At the middle zone 13 species were present, the epiphytes dominating over the mangrove and the bottom. At the outer zone, 34, species were present, the bottom having Rhodophyceae and Chlorophyceae while in mangrove, only Rhodophyceae (Figure 3).

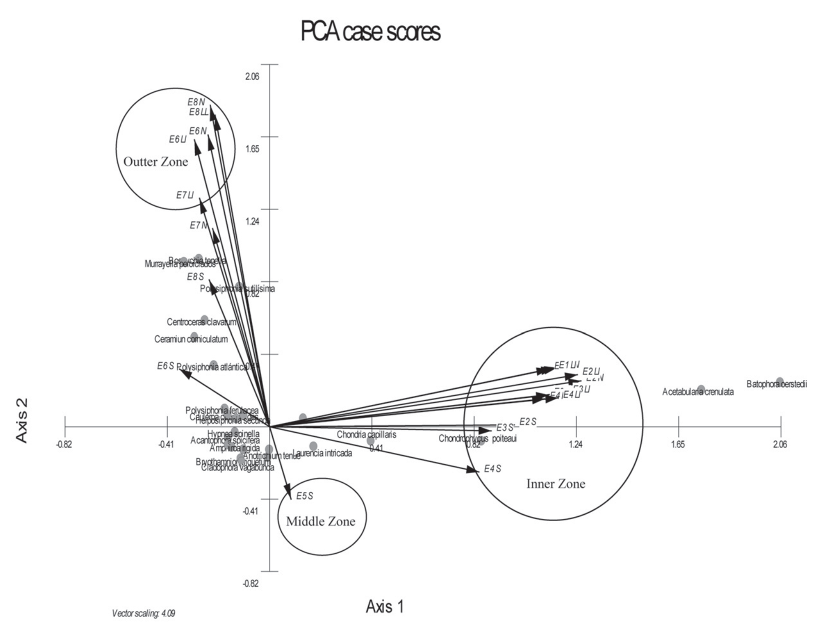

Figure 2. Sections of the lagoon determined by PCA analysis.

Only two species occurred in all three zones: *Cladophoropsis macromeres* and *Hypnea musciformis*.

The bottom had more species at the inner zone (16 spp.) than at the outer zone, but the inner zone had more Chlorophyceae than Rhodophyceae while at the outer zone, Rhodophyceae dominated over the Chlorophyeceae. The highest richness occurred during the dry season (21 spp.).

The mangrove had 11 species and four of these were found only at this substrate (*Champia parvula, Bostrychia tenella*, *Murrayella periclados* and *Chondria polyrhiza)*. The association at the inner and the middle zone were *Batophora* with *Acetabularia* while at the outer zone the Rodophyceae dominated the mangrove roots (*Champia parvula, Bostrychia tenella*, with *polysiphonia* spp.) and no Chlorophyceae were found. The highest richness (10 spp.) occurred during the dry season and the lowest occurred during the "Nortes" season (5 spp.). The common species regardless of distribution and occurrence over time was *Cladophoropsis macromeres.*

In the study area, 28 epiphytic species were identified as growing on seagrasses and other algae, of which 20 were Rhodophyceae and 8 were Chlorophyceae (Figure 3; Table 1).

The highest diversity was found in the dry season with 38 species, and the lowest in the "Nortes" season with 28, which was the only time when the Phaeophycean specie was found (Table 1). Twelve species were shared among the different seasons, but the Jaccard coefficient showed no similarity among seasons (Figure 4), zones or substrate.

Discussion

Floristic

The proportion of species reported by algal classes is similar to those found at other lagoons of the Yucatan Peninsula and even the number of species could differ from lagoon to lagoon. The number of species reported from lagoons with influence from the Gulf of Mexico is lower than those with influence of the Caribbean (Ortega, 1995; Collado-Vides *et al.,* 1995; Díaz-Martín *et al.,* 1998; Ortegón-Aznar and González-González, 2000; Ortegón-Aznar *et al.,* 2001).

The richness of benthic macroalgae reported to the Gulf of Mexico and the Caribbean is about 651 species; of them, two species, *Ceramium brevizonatum* var. *caraibicum* and *Chondria capillaris* have been previously reported from beaches and islands of the Mexican Caribbean (Mateo-Cid and Mendoza-González, 1991; Mendoza-González and Mateo-Cid, 1992; Collado-Vides *et al.,* 1994) and coastal lagoons (Collado-Vides *et al.,* 1995; Ortega, 1995). However, it is the first time that these two species are reported in the State of Yucatan. The algae at this region are tropical (Cheney index, 1977) with affinities with the Caribbean flora, like all the flora of the Gulf of Mexico (Ortega *et al*., 2001).

Spatial and temporal distribution

The higher diversity was found at the outer zone of the lagoon, which has more marine influence than the inner zone. The inner zone receives nutrients and freshwater from the watertable, producing a salinity gradient, that is reflected in the number and composition of the species in the different habitats, especially during the "Nortes" and rainy seasons. At the lagoon the main freshwater input comes from precipitation and from a few springs (Herrera-Silveira *et al.,* 2002), most of them separated from the main body of water by road construction, promoting an increase in salinity (Valdes and Real, 1994).

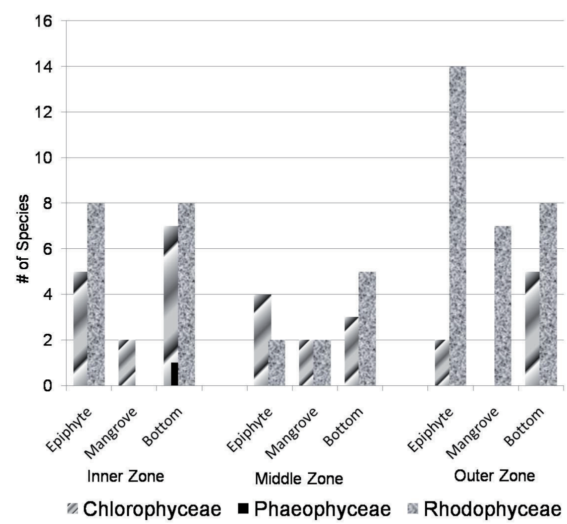

Figure 3. Distribution of algae in different substrates at the Chelem Lagoon.

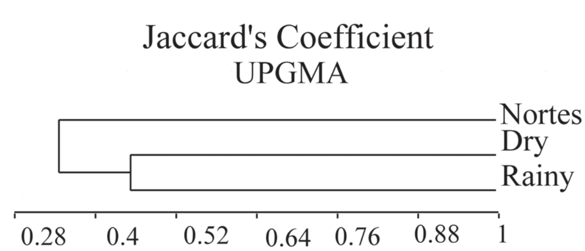

Figure 4. Similarity between seasons in the study area.

Table 1. Marine algae from coastal lagoon of Chelem, Yucatan, Mexico.

	Inner Zone			**Middle Zone**			**Outer Zone**		
Species/ Seasons	**Nortes**	**Dry**	**Rainy**	**Nortes**	**Dry**	**Rainy**	**Nortes**	**Dry**	**Rainy**
Chlorophyceae									
Acetabularia crenulata Lamouroux.	E, M, B	E, M, B	E, M, B	E, M, B	E, M, B	E, M, B			
Batophora occidentalis (Harvey) S.Berger & Keaver ex M.J. Wynne.					B			B	
Batophora oerstedii J. Agardh.	E, M, B	E, M, B	E, M, B	E, M, B		E, M, B			
Caulerpa cupressoides (West in Vahl) C. Agardh.							B		B
Caulerpa prolifera (Forsskål) Lamouroux.	B		B						
Caulerpa sertulariodes (S.G.Gmelin) M. Howe.		B							
Caulerpa verticillata J. Agardh.								B	
Chaetomorpha aerea (Dillwyn) Kützing.		B							
Cladophora catenata (Linneus) Kützing.		E							
Cladophora laetevirens (Dillwyn) Kützing.								E	
Cladophora vagabunda (Linneus) van den Hoek.					E				
Cladophoropsis macromeres W.R. Taylor.	E		E		E		E	E	E
Codium decorticatum (Woodward) M. Howe.								B	
Halimeda incrassata (J. Ellis) Lamouroux.	B	B	B						
Penicillus capitatus Lamarck.		B							
Rhizoclonium riparium (Roth) Kützing ex Harvey.		E							
Ulva intestinalis Linnaeus.								B	
Ulva rigida C. Agardh.								B	
Rhodophyceae									
Acanthophora spicifera (Vahl) Børgesen.								M	
Aglaothamnion cordatum (Børgesen) Feldmann-Mazoyer.								E	
Amphiroa rigida Lamouroux.		E						E	
Anotrichium tenue (C. Agardh) Nägeli.		E			E				
Bostrychia tenella (Lamouroux) J. Agardh.							M		M
Bryothamnion triquetum (Gmelin) M. Howe.		B						B	
Centroceras clavulatum (C. Agardh in Kunth) Mont. in Durieu de Maisonneuve.							E	E	E
Ceramiun brevizonatum var. *caraibicum* H.E. Petersen & Børgesen.								E	
Ceramiun corniculatum Montagne.							E	E	E
Ceramiun cruciatum Collins & Harvey.								M	
Champia parvula (C. Agardh) Harvey.					M				
Chondria capillaris (Hudson) M.J. Wynne.	B	B	B						
Chondria dasyphylla (Woodward) C. Agardh.	B		B		B				
Chondria littoralis Harvey.					B				
Chondria polyrhiza Collins & Harvey.								M	
Digenia simplex (Wulfen) C. Agardh.								B	
Gayliella flaccida (Harvey ex Kützing) T.O. Cho & L.J. McIvor								E	

Table 1. Marine algae from coastal lagoon of Chelem, Yucatan, Mexico.

	Inner Zone			Middle Zone			Outer Zone		
Species/ Seasons	**Nortes**	**Dry**	**Rainy**	**Nortes**	**Dry**	**Rainy**	**Nortes**	**Dry**	**Rainy**
Chlorophyceae									
Haliptilon cubense (Mont ex Kützing.) Garbary & H.W. Johans.								B	
Herposiphonia secunda (C.Agardh) Ambronn.		E					E	E	E
Heterosiphonia crispella (C. Agardh) M.J. Wynne.		E						E	
Hypnea musciformis (Wulfen in Jacquin) Lamouroux.		B			B			B	
Hypnea spinella (C. Agardh) Kützing.		E, B						E, B	
Jania adherens Lamouroux.	E	E	E						
Laurencia intricata Lamouroux.	E, B	E, B	E, B						
Laurencia microcladia Kützing.	B	B	B						
Murrayella periclados (C. Agardh) Schmitz.							M	M	M
Neosiphonia ferulacea (Suhr ex J.Agardh) S.M. Guimaraes & M.T. Fujii.							E	E	E
Neosiphonia sphaerocarpa (Børgesen) M.S. Kim & I.K. Lee.				E, M		E, M		E, M	
Palisada poiteaui (Lamouroux) K.W. Nam.	B	B	B		B				
Palisada papillosa (C. Agardh) K.W. Nam.							B		B
Polysiphonia atlantica Kapraun & .J.N. Norris.							E	E	E
Polysiphonia howei Hollenberg in W.R. Taylor.							E, M	E, M	E, M
Polysiphonia subtilissima Montagne.	E		E				E	E	E
Spyridia filamentosa (Wulfen) Harvey in Hook.					B			B	
Spyridia hypnoides (Bory in Belanger) Papenfus.							B		B
Phaeophyceae									
Dictyota menstrualis (Hoyt) Schnetter, Hörning & Weber-Peukert.		B							

E = Epiphyte, M = Mangrove, B = Bottom.

The Chlorophyceae dominated in the inner zone and decreased gradually towards the outer zone, while the reverse was true for the Rhodophyceae, with a lower proportion in the inner zone increasing towards the outer zone.

The zone with less species was the middle zone that acts as a mixing zone containing species of the inner and the outer zone, which explains the low similarity values. Also, the middle zone is the most disturbed zone, where all ships pass across it.

Species tend to increase in number from freshwater to marine zones in estuarine ecosystems (Barnes, 1974). Even salinity has been reported as a restrictive factor in the distribution and diversity of estuarine lagoons (Britton and Morton, 1989) and it could be one of the most important factors in species composition and distribution, we considered that the fact that inner zone is the most far from disturbances of ships activities let it had more species than the middle zone.

The most common species regardless of the distribution and occurrence over time was *Cladophoropsis macromeres*, maybe because Chlorophyceae species tends to tolerate higher or lower salinities than the species of Rhodophyceae and Phaeophyceae (Remane and Schlieper, 1971; Britton and Morton, 1989).

The class Rhodophyceae has the largest number of species and dominates over Chlorophyceae and Phaeophyceae in time and space, due the high number of epiphyte algae, especially those of the genus of *Polysiphonia* and *Ceramium.* The Jaccard analysis shows no similarities between substrate, each one had species that are typical for each substrate.

In both mangrove and bottom the Rhodophyceae dominated. The habitat with the highest richness was the bottom. In mangrove and bottom habitats the specific richness was higher in the outer zone than in the inner, due to the low salinity of the latter. For the former habitat, 46% of the species was found at in the outer zone and 35% in the inner (Figure 3). The highest diversity was found in the dry season and the lowest in the "Nortes" season. This pattern is similar to that of other lagoons of Yucatan (Ortegón-Aznar and González-González, 2000; Ortegón-Aznar *et al.,* 2001). The association known as "Bostrychietum" (Post, 1968) is a typical association for mangrove communities, but it was found exclusively in the outer zone, due the differences in salinity between the zones.

The results of the Jaccard index show no similarities between seasons. The species' composition changes considerably in time and space. For the duration of one season there was no similarity between zones, so it is more accurate to consider gradients.

The data shows that the ficoflora changes in time and space depending on the environmental factors in this case salinity and substratum, and the capacity of the species to tolerate the outer changes.

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