Submerged and Insular Vegetation in the Reefs of Campeche, Mexico

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ABSTRACT

In this research, we analyzed the coverage of the submerged vegetation in six reef systems and the insular vegetation in four sandy keys in Campeche, Mexico. The topographic relief of the islands is in average 1.6 m. We registered a total of 28 species of the submerged and insular vegetation. To define the similarities in vegetation, an affinity analysis was used under The Content of Information criteria ($C.I._2$). The detected levels were very low for both vegetation: 31.67 beles in insular flora and 41.82 beles in the submerged one. *Suriana maritima* L. was the specie responsible for the main information fall in the insular flora and *Padina santae-crucis* Böergesen in the submerged one. The analysis outcome between the islands = topography and vegetation resulted in a direct correlation between the island height and the coverage of the insular vegetation. The ecological structure of the submerged vegetation presents a consistent pattern in relation with other related researches to the zone, with a reduction in the ecological diversity however. On the other hand, in the insular flora, the size of these changes has been more important, since some important meteorological events have removed completely the vegetation along the sandy carpet that covered some of the islands.

KEY WORDS: Vegetation, coral reef, Campeche Mexico.

Vegetación Sumergida e Insular de los Arrecifes de Campeche, Mexico

En el presente estudio se analiza la cobertura de la vegetación sumergida en seis sistemas arrecifales y la vegetación insular en cuatro cayos arenosos del estado de Campeche, México. El relieve topográfico de las islas es de 1.6 m en promedio. Se registró un total de 28 especies de la vegetación sumergida e insular. Para definir las similitudes de la vegetación, se utilizó un análisis de afinidades bajo el criterio del Contenido de Información ($C.I._2$). Los niveles detectados fueron muy bajos para ambas vegetaciones: 31.67 beles en la flora insular y 41.82 beles en la sumergida. *Suriana maritima* L. fue la especie responsable de la principal caída de información en la flora insular y *Padina santae-crucis* Böergesen en la sumergida. El análisis entre la topografía de las islas y la vegetación proporcionó una correlación directa entre la altura de la isla y la cobertura de la vegetación insular. La estructura ecológica de la vegetación sumergida presenta un patrón consistente con respecto a otros trabajos relacionados con la zona, aunque con un decremento en la diversidad ecológica. En contraste, en la flora insular, la magnitud de estos cambios ha sido mayor, ya que algunos eventos meteorológicos importantes han llegado a eliminar totalmente la vegetación junto con el tapete arenoso que cubría algunas de las islas.

PALABRAS CLAVES: Vegetación, sumergida, insular, arrecifes, Campeche

INTRODUCTION

Research made on most of the reefs of the country has been very punctual, with very specific goals and objectives, this makes knowledge about reef areas = attributions, not only the ecological features but also social-economic, be poor and uneven in space and time (Torruco and González 1997). The thirty eight emerging reefs in the Gulf of Mexico, have been impacted in bigger or lesser extend by natural events (Tunnell 1988), as well as inappropriate use related to the coastal development itself. This lack of scientific knowledge and the standards of a biological criteria have caused a lack of elements of judgment in conservation policies and use of reefs, which has originated a number of undesired consequences both biological and social as well as economical (habitats destruction, fishing resources loss, etc.). In most of the cases, an inventory of these coral reefs has not been compiled. In this context we present a description of the relief of the main islands that this zone presents, and vegetation they have and submarine flora of the reefs as well as a contribution to the knowledge of vegetal biodiversity and fisiography of the keys, which so far had been unknown.

MATERIALS AND METHODS

Study Field

The reefs in Campeche are located on a wide carbonated platform in an interval between 130 and 200 km out of the coast (Figure 1), forming banks with tops and furrows that expand from the shore up to 30 m. depth. All the reefs form a reef mountain range in form of an arch that starts in Alacranes and ends in Cayo Arcas (Antoine and Gilmore 1970). Topographically there are variations in the width of the platform with important elevations in the sandy keys = surroundings. The floor of the islands, presents concentrations rich in calcium and phosphor due to its calcareous origin of shells and corals remnants (Torruco and González 2001). Rebolledo (1983), mentions that for this reason, the pH is predominantly basic in all the keys and therefore it does not interfere in the nutrients availability of the soil nor in the distribution of the insular vegetation of this zone

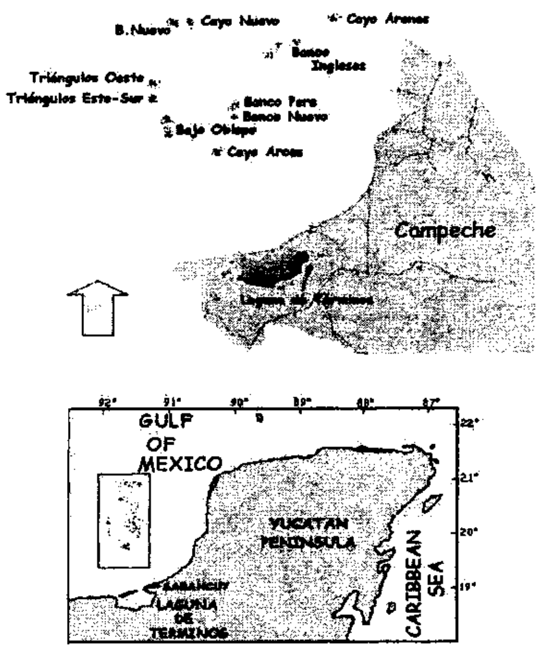

Figure 1. Study area

Methodology

One of the aspects that the job covered was the determination of the islands and the relief they present. For this, standard topographic methods were used. Data was processed by the computer program Surfer v.7. in order to get the surface of the contours that each key presents.

Insular Vegetation

In the islands where insular vegetation was present, a covering of all present species was registered. Data was obtained by photographs of every patch of vegetation and their later digitalization and analysis by the analysis package of images Erdas imagine v. 8.3.1; every photograph was taken 1 m from the floor using a camera Minolta Dinax 9000, the registered area per every photograph is 2 400 cm2 (60 x 40 cm). The obtained area was an estimated of the covering of every species. In order to corroborate the area given by the program, different line measuring of every patch (a long 6 axes) and every polygon area was gotten, reaching an error level on either method of +- 1.73 cm^2. At the same time, samples were collected for their later taxonomic double checking.

Submarine Vegetation

The analyzed algae corresponded to the first 40 m. depth on the littoral and superior infralittoral floor. Triangulos Este location was the only place where submarine sampling was not performed. Submarine photography as a method of registration was used by covering and interval from 1 to 40 m with SCUBA diving method. Data was gotten by two phototransect lines of 20 m of length by 10 m of depth, along with a collection of different species found in every line. The photographs were taken at 80 cm from the floor using a Nikonus V camera, therefore the registered area of every photo is 1 904 cm^2 (56 x 34 cm). The analyzed photographs total was 2500 (476 m^2). From every photograph, 35 points were sub-sampled randomly, to get the relative abundance of every species. Works done before in other reef areas (González 1995, Torruco 1995) mention that in a graphic of area-species with 18 points, 80 % of the species present in the photography is gotten.

For the analysis of both communities, the dominance of every species and the diversity of the locations involved were used. The analysis of the dominance was performed by the index of importance value (Orlocí 1978), where with relative contribution of frequency and covering of every descriptor, the algorithm ponders the frequency in which a species appears within an order of abundance **n** and it orders them according to their total contribution; once the descriptor with the highest contribution is found, it is subtracted from the total and the following descriptor is looked with the highest contribution in the remnant variation and so on. The ecological diversity was gotten through Shannon-Wiener method (Pielou 1984).

Comparing and finding out changes in communities were performed with statistical methods of a multivaried analysis. The study is based on an analysis of conglomerates under a divisive criteria of the second order Information Content ($C.I._2$), coded by abundance quantitative data (Torruco 1995). In the process of dropping the total information until its minimum values, the analysis provides a feature (species or site) that excludes every portion, the algorithm used is the following:

$$I2 = 2sn \log n \quad n\sum_{i=1}^{s} \log \sum_{k=1}^{m} a_{ki}^{2}$$

Where:

Aki - indicates the number of times the attribute **i** is found in the status **k**.
n - Number of elements to classify.
S - Attributes that characterizes it.
m - Maximum number of present status in any attribute.

Finally, Trying to define the relationships that exists between the topographic relief and the presence of species on its covering, the analysis of regression was performed with these variables (Daniel 1974).

RESULTS

Relief

The description of relief is presented in seven keys. The topography of Cayo Arenas was not possible to get due to failures in the topographic tool, while in Bajo Obispo, it is only presented a small oval islet of approximately $9m^2$, that disappears with high tides. With order purposes the description is done from north to south and every image presents area and relief scale.

Cayo Nuevo — The relief of two keys was gotten here. Both islands are formed by coral remnants and they almost do not present any sandy portion. The first one is located towards the eastern portion of the reef, it is 30 m long and 5 m wide(150 m^2 of area approximately); its maximum height is 1.3, no vegetation was present (Figure 2a). The second key, located towards the western extreme of the reef, is the biggest (651 m^2 approximately); its gradients are soft and its mayor elevation (1.3 m) is located also at its center (Figure 2b), this islet only presents the *Tournefortia gnaphaloides* (L) R. Br.

Arrecife Triángulos — It presents four emerging areas: Triangulos West, this has an area of 192,000 m^2, with steep gradients and a strong central depression. The maximum height is 2.5 m s.n.m; it is also formed by coral fragments (almost without sand) and by remnants or other reef organisms (Figure 2c) Triangulos South, this one has in average 485 m^2, its relief shows a gradual progression that gets higher up to its maximum which is 1.2 m.s.n.m. (Figure 2d). Triangulos East External, this is a long-shaped key (Its length is 122.5 m) with an area of 3 528 m^2, the eastern part presents a depression up to 0.5 m, its height reaches 1.5 m, and its relief is heterogeneous since it presents some peaks and pronounced valleys (Figure 2e). Triangulos East internal, this is a slope with coral fragments with a height of 1.8 m that softens towards the extremes, its area is 29 250 m^2 being wider than longer. The depressions are less steep (up to 0.5m in one of the extremes) and no pronounced peaks are shown (Figure 2f).

Arrecife Arcas — This is the biggest of all the islands of the zone both in extension as well as width (234,900 m^2); it presents the most diverse flora including plants introduced as cassuarines, coconut palm etc. It has an average height of 3.8 m, its topography shows two slopes with two depressions. The gradients are variable with a prominent basin in the center. Towards the edge it presents a peak and a very pronounced valley (Figure 2g).

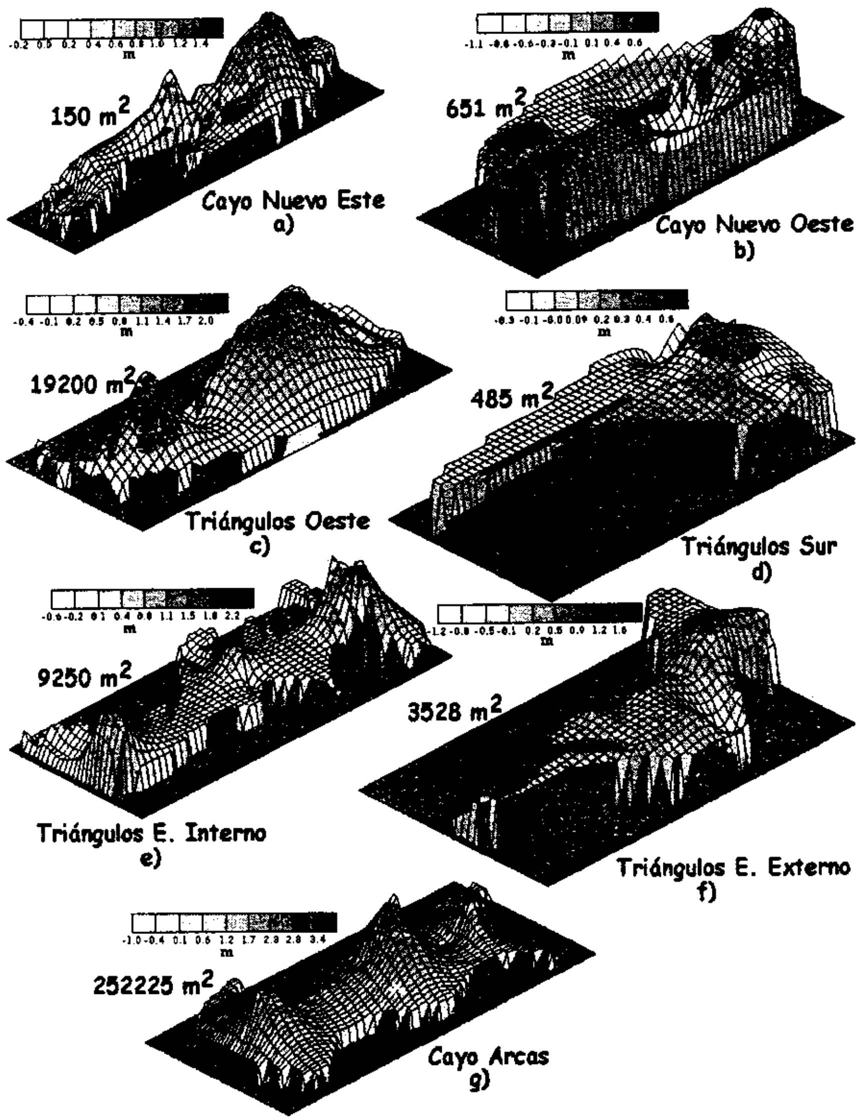

Figure 2. Campeche reef sandy Keys relief. The estimated area is presented.

Insular Vegetation.

A total of 14 species of vascular plants was registered. Some of the other sandy keys of this zone have very little vegetation represented by two or three species. Other do not present any vegetation at all as the case of the Keys Triángulos Oeste, Triángulos Sur and Bajo Obispo. The species with the greatest dominance in these reefs according to the Importance Value Index with a 35 % is *Sesuvium portulacastrum* L. (Table 1).

Table 1. Dominance Percent of the reef and sand key flora in Campeche, México

Insular Species	Dominance (Percent)	Algae Species	Dominance (Percent)
Sesuvium portulacastrum	35.009	*Cladophoropsis membranacea*	23.747
Cenchrus insularis	14.375	*Lobophora variegata*	20.053
Suriana maritima	13.455	*Stypopodium zonale*	17.678
Opuntia stricta var. dilleni	11.757	*Dictyota divaricata*	8.179
Amaranthus greggii	10.883	*Alga incrustante purpura*	7.916
Ipomea pes-caprae	7.456	*Dictyota bartayresii*	6.332
Tournefortia gnaphaloides	3.159	*Mesophyllum mesomorphum*	5.541
Salicornia virginica	1.744	*Padina santae crucis*	3.694
Portulaca oleraceae	1.514	*Sporolithon episporum*	2.639
Capraria biflora	0.230	*Dictiosphaeria cavernosa*	1.847
Echites umbellata	0.150	*Halimeda incrassata*	1.055
Hymenocallis littoralis	0.12	*Amphiroa rigida*	0.792
		Halimeda opuntia	0.264
		Valonia ventricosa	0.264

The richness of species expressed with the simplest diversity index presents Cayo Arcas as the most diverse island (13 species), while the least diverse is Cayo Nuevo (1 species), the diversity obtained follows the same pattern. Taking the evenness as an approximate of the distribution of resources (space, soil, nutriments, etc.), the highest and the lowest values correspond to the islands mentioned before. (Table 2).

The disposition of the groups shown in the cluster analysis of the reef group, only links with bigger similarities Cayo Nuevo with Triángulos Este; However, this union is represented more for their lack of species than for their vegetation similarities. While calculating the total information of the community and later eliminating each of them sequentially to the species that provide the most information about the system, we got *Suriana maritima* L as the species responsible for the highest drop of the total information. The assembly of the species forms three groups of corotypes up to intermediate information levels, the biggest gathers most of the species and the other associations have few species (two and four respectively). The location that impacts the most in the information of these associations is Cayo Arenas. The total content of information is very low; however, it is convenient to consider that it is a total census (Figure 3a).

Table 2. Diversity index in the Campeche reef vegetation. We show the richness and eveness of this community in each site.

Sites	Richness (S)	Diversity index (H = bits/ind.)	Eveness
	Insular Flora		
Cayo Arcas	13	2.664	0.72
Cayo Arenas	3	1.071	0.675
Triángulos Este	3	0.561	0.354
Cayo Nuevo	1	0	0
Total	14	2.723	0.736
	Algal Flora		
Cayo Arcas	2	0.722	0.722
Cayo Arenas	6	2.05	0.793
Triángulos Sur	4	1.135	0.567
Triángulos Oeste	11	3.069	0.887
Bajo Obispo	2	0.946	0.946
Cayo Nuevo	7	2.381	0.848
Total	14	3.058	0.7

The vegetation in the different islands was presented in uni-specific patches, characteristic in halophilous groups and by its spatial disposition, it seems that it is presented a beginning zoning originated by small changes in the elevation of the land.

While relating height of the islands with covering and number of species, it is found that in the moment to increase the average height, the covering of vegetation also rises as well as species present in them, this is so because there is a direct correlation not very close though since only a small fraction of the total variation is explained by the regression equation ($R^2 = 0.30$); the correlation coefficient ($r = 0.555$) does not permit to accept a non-lineal between both variables, since the reason between both variances is much higher than the value of $F(8.04 > 0.010)$) (Figure 4).

Submarine Vegetation

The number of species in the six analyzed locations was 14. The algae with the highest dominance were: *Cladophoropsis membranacea* (C. Agardh) (23.74 %) and *Lobophora variegata* (Lamouroux) (20.05 %) (Table 1). The richness of species with this fraction of the vegetation was the highest in Triángulos Oeste (11 species), and the lowest richness in Cayo Arcas and Bajo Obispo (2). The highest diversity was in Triangulos Oeste and the lowest in Cayo Arcas (Table 2). The highest eveness in terms of reparation of resources was reported for Bajo Obispo and the lowest for Triángulos Sur.

The dendrograms show the following results: two groups are presented; the first links one of the reefs of Arcas, Obispo, Arenas and Triángulos Sur and the Second links equally Triangulos Oeste with Cayo Nuevo, the species responsible for the highest information fall is *Padina santae-crucis* Bõergesen.

The assembly of the species show very heterogeneous associations, to media similarities values, two groups are presented with a similar number of species (8 and 6 species respectively), the first one defines species that are presented in an occasionally way in some of the islands, while the second group is formed by species with more extended distribution. It is evident that the location that discriminates more strongly these associations is like the case before, Cayo Arenas (Figure 3b).

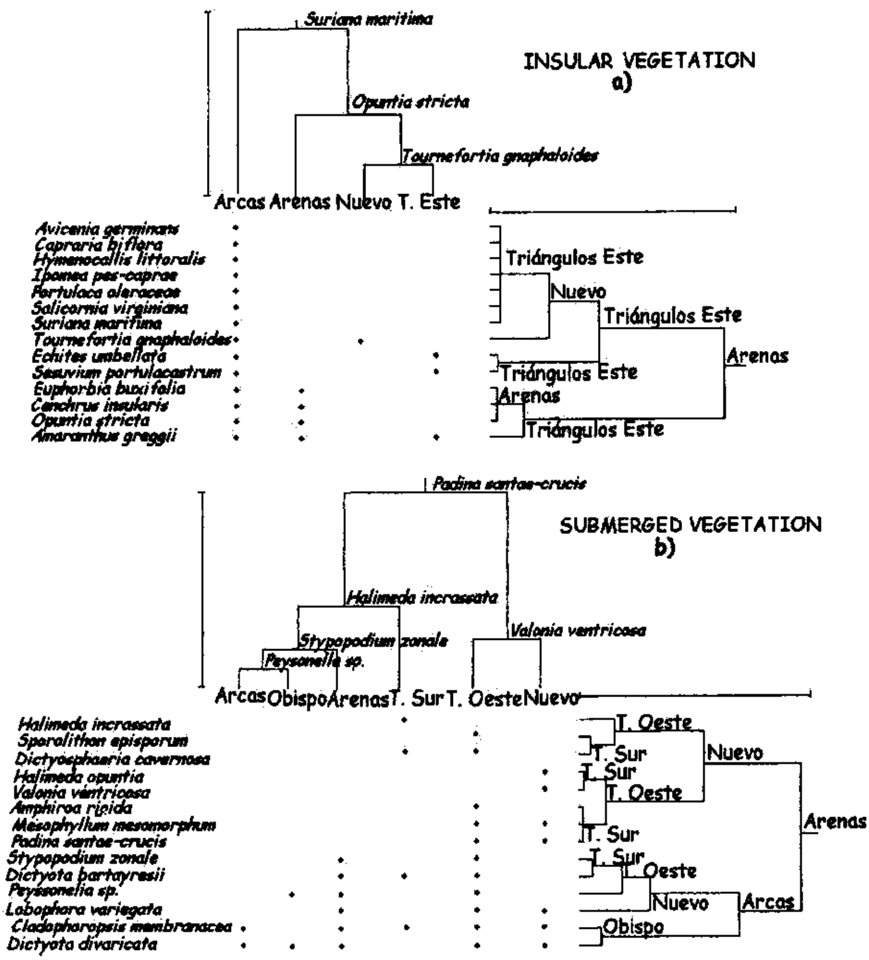

Figure 3. Dendrogram (Q and R) in species and sites of the Campeche Reef vegetation. The especis and places discriminants are shown

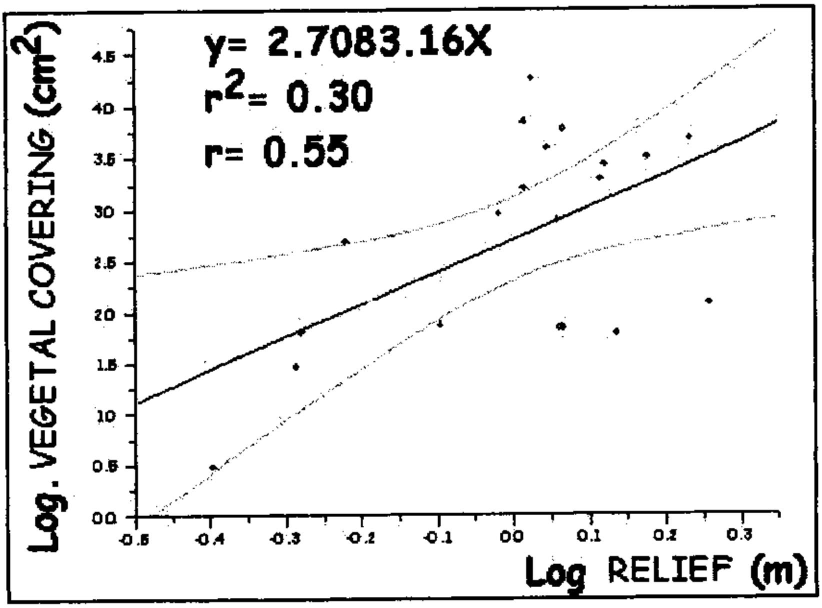

Figure 4. Correlation between vegetal covering and relief.

DISCUSSION

The insular vegetation is more diverse, is better developed and more structured in Cayo Arcas, where there is an assembly of species very particular; the 57 % of the registered species are exclusively from this key. Two situations favored this development: the size of the islands (emerged area) and the proximity to the continent (Carleton 1988). Considering the obtained values of diversity, the diversity of Cayo Arcas could represent all the system (Table 2). The maximum diversity of the system, calculated as if all species had the same covering, do not differ too much from the values obtained in this location, which indicates that the habitats available are being used in an optimal way.

The strong identity that is present in the locations could be originated by effects of meteorological events (tropical storms and hurricanes) which represent a great influence in the emerged part both by strong precipitation or winds and by effect of the alluvium of coral remnants and garbage from other areas. Despite all islands have suffered some impact, some have resulted with greater or lesser damage, depending on the trajectory and origin of the event. In keys which have been impacted greatly, insular flora has disappeared, such as Cayo Nuevo and Triangulos Oeste, the first one only with a pioneer species, while the second has been left totally without vegetation, not even in substrate, since the sand that covered the coral remains forming the island has also disappeared as a result of strong winds.

Previous records (Flores-Guido 1983), show a higher and different distribution and diversity to the one currently found. However, the vegetal community more developed is still the coastal dune, as a matter of fact *Suriana maritima* and *Tournefortia gnaphaloides* could be considered in a more advanced seral stage in forming dune bushes. While delimiting to a restricted area, there is not an environmental mosaic as such. It is possible that microdifferences be present that make the organisms respond in a differential way to the environmental stimuli, specially on the halophilous species. It is probable that the excessive accumulation of soluble salts and lack of nutrients specially on the edges, could be the cause of the poor growth of most of the plants (Toussenbroek 1995). Even when this situation favors some of them such as the case of *Sesuvium portulacastrum*, *Opuntia stricta* var. *dilleni*, *Salicornia virginiana*, etc., the capacity of some species to keep salts and hold moisture is variable (Bear 1964) and encourages the establishment of different species in function of the tolerance the present to these factors such as Espejel (1987) mentions. In the keys of Campeche there is not a vegetal succession defined. Despite the relationship between the relief and the distribution of the covering; the lack of vegetation does not allow strong conclusions that permit to issue any causal or prediction hypothesis, above all considering the great percentage of unexplained variation. It is possible that the environmental dynamic and the sizes of the islands do not permit the consolidation and maturity of any vegetal community, keeping itself always in young seral stages.

With algae, the hydrologic effect of the strong currents originated by meteorological events in the surroundings of sandy keys, originated a different pattern, related to availability and high instability of substrate (Bellantine 1978, Sousa 1984). The observed distribution can be caused by both direct effects such as intense waves, since the area presents a very homogeneous topography (Torruco and González 1997) without great valleys and reef crest, and indirect such as the increase of suspension sediments that eventually were deposited over the flora such as it has happened in other close reef areas (Carpenter and Lodge 1986, Boem 1988) where some species have successfully survived to abrasion of sediment, species with capacity to colonize cryptic habitats (Hanisak et al. 1988, Steneck and Dethier 1994).

The species of *Halimeda* that are characterized by having a rhizoid system and a compacted morphology (Mata 1981) are scarcely represented; this means that almost all calcium carbonate precipitated is due to the hermatypical corals and there is no an important presence of calcareous algae (Ohlhorst and Liddell 1988). An aspect that is worth to mention is that no previous study (Ferre-D'Amare 1995, Jordan et al. 1997) made in Arcas and Triángulos Este, report species of *Halimeda*; However, in this work two species were detected in Triángulos Sur and Cayo Nuevo with minimum coverings though.

It is important to mention the absence of *Thalassia testudinum* as a difference between Campeche's reefs and the ones in the Mexican Caribbean (Ferré-D'Amare 1995), this species is used to forming extended submarine prairies specially in protected environments and reef lagoons and it has an important roll in the accumulation of sediment, its absence originates a lack of typical lagoon communities, rich in sediment and fauna related to softer basins. Therefore, while interrupting the coral growth, the degradation of these structures is very fast (Gallegos et al. 1993). Due to the carsick characteristics of the platform, the detritus are easily eroded by the mechanic action of the waters over the reef zones that are found in shallow waters, where there are only coral remnants and mollusks shells. The litic fraction is very important in this area, the classification of the sediment biogene-litic a relation of 6:4 (Secretaria de Marina 1981, Novak et al. 1992). This little representation of the detritus, makes this coral environment not be appropriate for a wide proliferation of bentonic macroalgae, even in conditions without disturbances the ficologic flora in the coral reef present associations due to some main characteristics such as: the floor, the sediments, and the waves (Gonzalez and Torruco 1996). These same attributions could be the ones that originate the main losses of information and therefore the responsible for the inter specific associations that exists in the algae communities of the reefs of Campeche, an evidence of these suppositions is the small size and the presence of most of the species in reef areas that possess a certain protection to waves (González and Torruco 2001).

Despite Jordan et al. (1997), mentions a high mass mortality of acroporidae before the storm events in 1995, and therefore, a high proliferation of crustose coralline algae *Sproroliton, Poirilithon* and *Titanoderma* that cover partially the skeletons of the acroporidae in areas on low depth, our research did not record those conditions, maybe because the studied interval of depth was not extensive only to the zone. From the medium to deep levels the typical constructing species keep dominating and therefore there is a decrease of the covering of macroalgae, normal condition in most of the reefs of the Golf and the Caribbean (Gonzalez and Torruco 1996). Nor did we find in this research extended formations of acroporidae in excellent status mentioned by Logan (1969) and by Farrel et al. (1983) 34 and 20 years ago. In these areas there are now a proliferation of zoanthids and some crust algae and fleshy. It is possible that this disappearance be the answer for the mass mortality mentioned by Jordan (1997) or by a pollution by hydrocarbons as Ferre-D'Amare (1995).

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