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Topography and coral community of the Sisal Reefs, Campeche Bank, Yucatán, México

Topografía y comunidad coralina de los arrecifes de Sisal, Banco de Campeche, Yucatán, México

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ABSTRACT

The Campeche Bank, Gulf of Mexico, is a region with abundant coral reef ecosystems that haven't been studied despite providing goods and services to some human communities. This work presents the topography, coral community and conspicuous reef associated fauna of three reefs of this region: Sisal, Madagascar and Serpiente. Three-D models of reef topography were derived using a GPS-echo-sounder coupled with geostatistical methods. The coral community was assessed through composition, richness, density and size of the colonies. The size of the Sisal Reefs was bigger than other Gulf of Mexico reefs. Hard coral colonies presented an average diameter of 9 cm and an average density of 9 colonies/m^2, whereas octocoral colonies averaged 11 cm in height and presented an average density of 24 colonies/m^2. We found 18 hard coral and 14 octocoral species, all of them distributed in the Atlantic Ocean; however, this work is the first to report *Carijoa riseii* and *Phyllangia americana* for the Mexican reefs of the Gulf of Mexico. The conspicuous fauna consisted in species with aquaculture potential (*e.g. Octopus maya, Panulirus argus, Periclimenes pedersoni)* and conservation priority (*i.e. Eretmochelys imbricata*). This study shows that these reefs are important centers of marine life and provides a baseline for future research.

Key words: Conservation, corals, geostatistics, Gulf of Mexico, octocorals.

RESUMEN

El Banco de Campeche (Golfo de México) es una región con múltiples arrecifes de coral que proveen bienes y servicios a las comunidades humanas y varios de ellos aún no han sido estudiados todavía. Este trabajo presenta información preliminar ó pionera sobre la topografía, la comunidad coralina y la fauna conspicua, asociada de tres arrecifes de esta región: Sisal, Madagascar y Serpiente. La topografía se obtuvo realizando muestreos batimétricos y métodos geoestadísticos. La comunidad coralina se evaluó a través de la composición, riqueza, densidad y tamaño de las colonias de corales pétreos y octocorales. Los arrecifes estudiados presentaron tamaños superiores a otros arrecifes del Golfo de México. Las colonias de corales duros presentaron diametros de 9 cm en promedio y una densidad de 9 colonias/m^2, mientras que las colonias de octocorales promediaron 11 cm de altura y una densidad de 24 colonias/m^2. Se registraron 18 especies de corales duros y 14 de octocorales. Entre estas *Carijoa riseii* y *Phyllangia americana* no habían sido registradas en arrecifes mexicanos del Golfo de México. Algunas de las especies conspicuas presentan potencial en acuicultura (*e.g. Octopus maya*, *Panulirus argus* y *Periclimenes pedersoni*) o prioridad para su conservación (*i.e. Eretmochelys imbricata*). El estudio muestra que estos arrecifes son importantes centros de vida marina y provee la base para futuras investigaciones.

Palabras clave: Conservación, corales, geoestadística, Golfo de México, octocorales.

INTRODUCTION

Coral reefs are important marine ecosystems that need to be protected. Coral reefs have one of the highest levels of biodiversity in the world and supply multiple resources to human populations (Paulay, 1997). The 9-12% ($\sim 9 \times 10^6$ tons yr^{-1}) of the overall global fishery biomass is extracted from coral reefs (Salvat, 1992). However, the excessive use of their resources and other environmental disturbances (*e.g.* global warming) are causing a fast global degradation of these ecosystems (Hughes *et al.*, 2003; Mora, 2008). Twenty per cent of the world's coral reefs has been already lost (MEA, 2005), causing an important decrease in fishery resources (Jackson *et al.,* 2001; Pauly *et al.*, 2002). This urges to plan and implement conservation measures to avoid further degradation and enhance the recovery of coral reefs (Hughes *et al.*, 2003).

The collection of baseline information is imperative to understand the dynamics of the abundance and distribution of the resources to be protected. Biological and environmental data gathered initially supports the development of further studies and helps to assess the effectiveness of the conservation efforts by comparing the changes of the community through time (Edgar *et al.*, 2004). Pioneer studies for coral reefs must aim to gather bathymetric information because it is fundamental to determine the limits of the reefs, the distribution of habitats and species and thus the planning of scientific and conservation activities. Coral species are the main builders of the structure of coral reefs (Montaggioni & Braithwaite, 2009) and they contribute greatly to maintain the high biodiversity of the ecosystem (Done, 1997). Thus, the species abundance, composition and richness of the coral community are key variables for the assessment of coral reefs ecosystems (Alvarado *et al.,* 2011).

The Campeche Bank (Gulf of Mexico) is an example of a region with abundant coral reef ecosystems with important gaps of information. The region presents some reefs localized well offshore (>100 km), such as Alacranes reef, Cayo Arenas and Cayo Arcas, that have been subject of different studies already (Jordán-Dahlgren, 2003; Tunnell, 2007). About 40 species of scleractinean corals and 31 octocorals species have been found (Whithers & Tunnell, 2007). However, there are an undetermined number of reefs closer to the shore of the Yucatan state that haven't been studied. These unstudied reefs may be important biodiversity hotspots, since they receive waters from the Caribbean Sea that may transport diverse taxa (Cowen *et al.,* 2006), and may present different coral communities from the other Campeche Bank reefs because of their close proximity to the coast, which implies different environmental conditions from natural and anthropogenic sources (Burke & Maidens, 2004; SEMAR, 2006) (Fig. 1).

The present work focuses on three reefs near the coastline of the Yucatan state: Sisal, Madagascar and Serpiente (Sisal Reefs) (Fig. 1). These reefs serve as fishing grounds for the nearby human communities, such as the ports of Celestun and Sisal, which operate fishing fleets of >100 boats (Martínez-Portilla, 2008), but no studies about their physical features and sessile community exist, as other similar reefs in the region. This work presents the first description of the physical structure and benthic biological composition of the Sisal Reefs. In particular, the objectives of this study are (i) to describe their topography through the creation of high-resolution digital bathymetric models and (ii) to describe the reef communities through the composition, richness and abundance of the coral communities, and the presence of other conspicuous reef species with ecologic and economic importance.

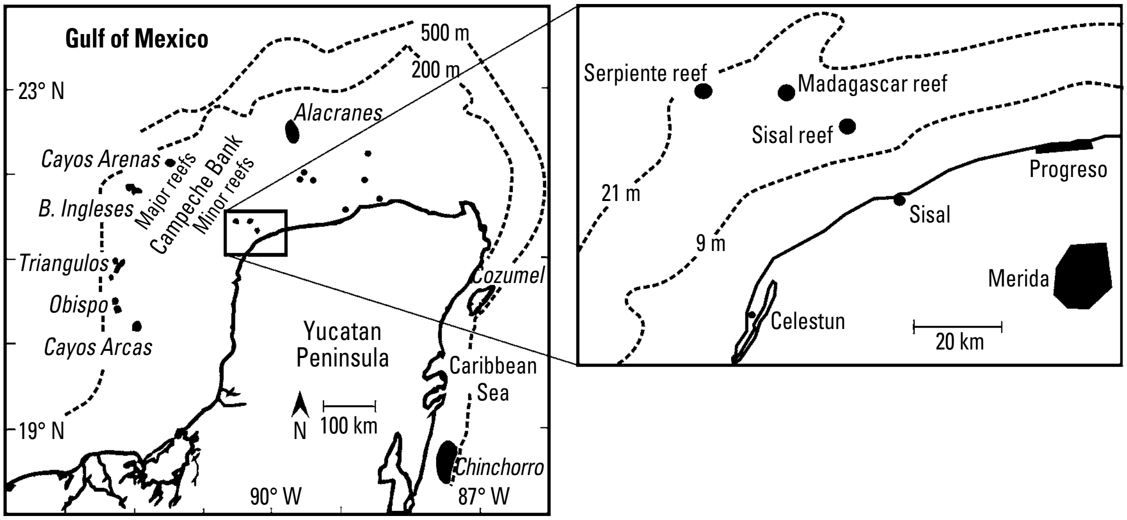

Figure 1. Location of the coral reefs of the Campeche Bank (Modified from Jordán-Dahlgren (2002) and Burke & Maidens (2004)). The magnifier glass shows the area of the Sisal Reefs: Sisal, Madagascar and Serpiente and their proximity to some important fishing ports: Celestún, Sisal and Progreso, plus the capital of the Yucatan state: Merida, (Modified from the Mexican Navy Nautical Chart S. M. 800).

MATERIALS AND METHODS

The geomorphology of the Sisal reefs was characterized using a method proposed by Heyman *et al.* (2007), but instead of applying triangular irregular network (TIN) as the interpolation method for the generation of the digital bathymetric models we used kriging. The bathymetric information was obtained using a depth-sounder (Lowrance LCx111c HD) with integrated GPS and dual transducer (50/200 kHz) following a sampling design of three stages from March to August 2007.

Stage 1: Recognition. A nautical chart (SEMAR, 2006) was used to obtain the approximate locations of the reefs and to define the initial exploration quadrats. The bathymetric data obtained was loaded into the software SonarViewer (Lowrance Electronics Inc.) and exported as a spreadsheet (*.csv). Depth data were converted from feet to meters and the system's native echo sounder geographical coordinates (Lowrance Mercator) were transformed to WGS84 (decimal degrees), using the following formulas respectively (Heyman *et al.*, 2007):

$$Dm = -Dp \cdot 0.3048$$

$$X = \frac{180}{\pi} \cdot \frac{LME}{6356752.3142}$$

$$y = \frac{180}{\pi} \cdot (2 \tan^{-1} e^{LMN/6356752.3142}) \frac{\pi}{2}$$

Where:

Dm is depth in meters and *Dp* depth in feet;

X is easting coordinate in WGS84 and

LME Lowrance Mercator Eastings;

Y is the northing coordinate in WGS84 and

LMN Lowrance Mercator Northings

After the transformation, data were projected to the UTM 15N coordinate system using the software ArcGIS 9.2 (ESRI corp.) and a TIN interpolation was done to eliminate measurement errors from the database.

Stage 2*:* Focus. In the second stage, the depth surveys were focused over each reef following a 200 × 200 m grid pattern. The depth data obtained during this phase was added to the database and processed as the previous phase.

Stage 3*:* Refinement. In the last stage, the depth surveys were concentrated on zones of higher topographic variability in each reef, following a grid of 50 to 20 m. The new data was also processed as the previous phases and added to the previous datasets before the geostatistical analysis, obtaining a final matrix of 281,562 depth-position points (74,234 for Serpiente; 75,554 for Madagascar and 131,774 for Sisal).

Geostatistical Analysis. To obtain the final digital elevation models, an overall kriging interpolation including all three reefs was done to locate each reef at the general bathymetric field. Subsequently, an independent ordinary kriging interpolation was performed for each reef (Fig. 2). The best model for each reef was chosen based on the results of the cross validation and regression between field and predicted data statistics. The physiographic characteristics of interest for each reef were calculated from these maps (Table 1).

Reef Community. After obtaining the digital bathymetric models, a preliminary fast visual assessment of the coral communities of the reefs was done (Torres, 2001). The observations indicated that the reefscapes of the Sisal Reefs were dominated by macroalgae and that most of the colonies of hard coral and octocorals presented small sizes (<10 cm in diameter and ~20 cm tall respectively). Thus, the methodology to estimate coral density consisted in the count of individual colonies in quadrates of 25 × 25 cm (0.0625 m^2) (Ruiz-Zárate & Arias-Gonzáles, 2004). The quadrates were placed every meter along six transects (10 m long) placed between 7 m and 16 m deep in each reef (*i.e.* 60 quadrates per reef), between April and July 2007. Fragments of coral colonies seen during the preliminary and the transect surveys were collected for species identification (Veron & Stafford-Smith, 2002; Bayer, 1961) Thus, not all species identified in the Sisal Reefs were present in the quadrates. Size of the colonies of hard corals (diameter) and octocorals (height) were estimated on field using marks in the quadrate and a ruler; however, it was not possible to identify taxonomically all individuals in the field. Additionally, the occurrence of other conspicuous fauna that were observed during the surveys was registered (Humman, 1992).

Differences in coral densities and sizes between reefs were tested with the non-parametric Kruskal-Wallis and Mann-Whitney U *post hoc* comparison with Bonferroni correction (alfa of 0.5 corrected = 0.5/3 = 0.017) since data lacked normality (Shapiro-Wilk tests).

RESULTS

Physiography. The resulting general bathymetric map showed a moderate and homogeneous downward slope of the seafloor pointing to the northwest (Fig. 2A), presenting a depth increment of just 25 m from the Sisal harbor to the farthest reef (58.5 km).

Sisal reef, the closest to shore (23 km), presented the shallower reef structures and the biggest area. The reef went from 2 m on a small reef area to 10 m deep, where the landscape became dominated by sandy plain areas. It had several segregated reef structures extended over 0.67 km^2, which together form a reef front of 3.3 km long with a NW-SE orientation. Additionally, this reef presented a distance of 1.2 km from the reef front to the back slope in its widest zone (Fig. 2C).

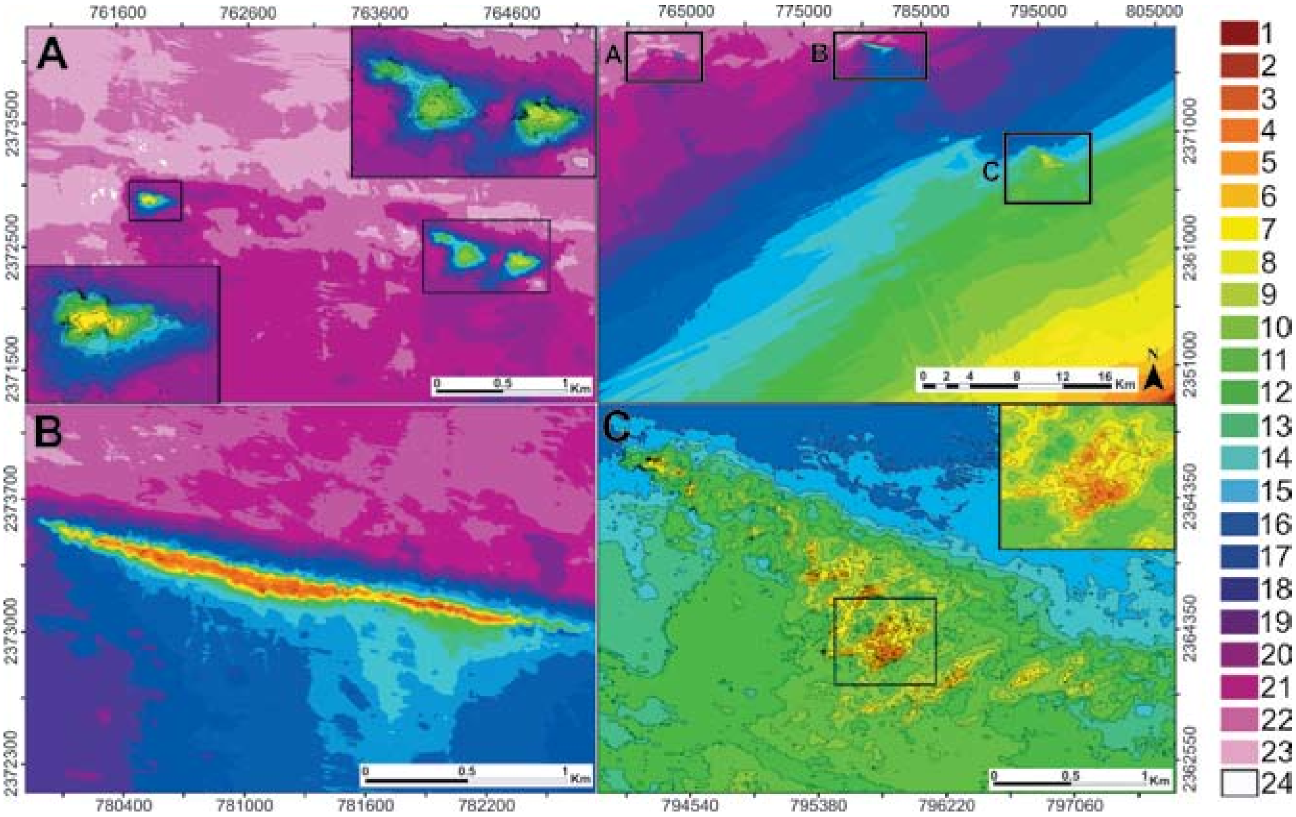

Figure 2. Bathymetric models of the overall area (upper right-corner) and Sisal Reefs: Serpiente reefs (A), Madagascar reef (B) and Sisal reef (C). The color bar represents depth in meters. Geographic coordinate system: WGS84 projected to UTM 15N.

Table 1. Physiographic characteristics of the Sisal Reefs: Sisal, Madagascar and Serpiente West (WS) and Serpiente East (ES) reef units.

Reef	Distance to the Coast (km)	Range depth (m)	Area (km^2)	Front reef orientation	Length (m)	Width (m)
Sisal	23	3-10	0.67	119°	3,330	1,140
Madagascar	40	4-13	0.21	98°	2,550	130
WS	55	7-18	0.04	107°	320	200
ES	53	8-18	0.17	106°	900	280

Madagascar reef was found 40 km away from the coast, presented a depth of 4 m in the reef platform and 13 m deep at the end of the front slope (Fig. 2B). The reef was 2.55 km long and 130 m wide at the central zone. It presented a single large reef unit covering 0.2164 km^2 with an NW-SE extension. Moreover, the middle and widest section of the reef presented extensive crevices of ~2 m deep running longitudinally to the reef.

Serpiente reef was located ~54 km away from the coast and was composed by two reef structures separated by 2.5 km, one in the West (WS) and the other in the East (ES), contrasting with the SEMAR nautical chart that shows only one structure (Fig. 2A). The reefs were poorly developed horizontally, presenting the smallest area and a roughly elliptical shape (WS: 320 × 200 m; ES: 900 m × 280 m long) (Table 1). However, they were more developed vertically, rising from a depth of 18 to 7 m in its shallowest area.

Coral richness. A total of 14 species of octocorals and 19 of hard corals were identified on the Sisal Reefs (Table 2). With the exception of the family Milleporiidae, belonging to the class Hydrozoa, all other species belong to the class Anthozoa. Families Briareidae, Anthothelidae, Clavulariidae and Plexauriidae belong to the subclass Octocorallia, and the remaining families to the subclass Hexacorallia, order Scleractinia. Sisal reef presented 8 octocorals and 11 hard coral species, while Madagascar had 13 octocorals and 17 hard coral species and Serpiente reefs 11 octocorals and 16 hard coral species.

Table 2. List of octocoral and hard coral species found on the Sisal Reefs: Sisal, Madagascar and Serpiente Yucatan, Mexico and its comparison with other Mexican reefs. SW Gulf of Mexico (Tunnell *et al.* 2007): VRS: Veracruz Reef System, TRS: Tuxpan Reef System, E: Enmedio reef, L: Isla Lobos, B: La Blanquilla reef. Campeche Bank (BC) (Tunnell *et al.* 2007): AL: Alacranes reef, AC: Arcas reef, AR: Arenas reef, TR: Triangulo reef; S: Sisal reef, M: Madagascar reef, Se: Serpiente reef.

Species	SW Gulf of Mexico	Campeche Bank	
		Major Reefs	Sisal Reefs
Octocorals			
Briareum asbestinum (Pallas, 1766)	L	AL, AC, AR, TR	S, M, Se
Erythropodium caribaeorum (Duchassaing & Michelotti, 1860)	E	AL, AC, AR, TR	S, M, Se
Iciligorgia schrammi Duchassaing, 1870		TR	
Carijoa riisei (Duchassaing & Michelotti, 1860)			M
Eunicea asperula Milne Edwards & Haime, 1857	E	AL, AC, AR, TR	
Eunicea calyculata (Ellis & Solander, 1786)	L, VRS	AL, AC, AR, TR	M, Se
Eunicea laciniata Duchassaing & Michelotti, 1860	E, L	AL, AC, AR, TR	M, Se
Eunicea clavigera Bayer, 1961	VRS	AL	
Eunicea fusca Duchassaing & Michelotti, 1860			
Eunicea laxispica (Lamarck, 1815)	VRS	AL, AC, AR, TR	
Eunicea mammosa Lamouroux, 1816		AL, AC, AR, TR	M, Se
Eunicea succinea (Pallas, 1766)		AL, AC, TR	
Eunicea tourneforti Milne Edwards & Haime, 1857	VRS, TRS	AL, AC, TR	
Muricea atlántica (Riess, 1919)	E, L	AL, AC	
Muricea elongata Lamouroux, 1821		TR	
Muricea muricata (Pallas, 1766)	E, L	AL, AC	M, Se
Muriceopsis flavida (Lamarck, 1815)		AC, AR, TR	
Plexaura flexuosa Lamouroux, 1821	B, L	AL, AC, AR, TR	S, M
Plexaura homomalla (Esper, 1792)	L, VRS	AL, AC, AR, TR	
Plexaurella dichotoma (Esper, 1791)	B, L	AL, AC, AR, TR	S, M, Se
Plexaurella fusifera Kunze, 1916	E	AL	
Plexaurella grisea Kunze, 1916		AL	
Plexaurella nutans (Duchassaing & Michelotti, 1860)	VRS	AL, AC, AR	
Pseudoplexaura flagellosa (Houttuyn, 1772)		AC, AR, TR	
Pseudoplexaura porosa (Houttuyn, 1772)	VRS, TRS	AL, AC, AR, TR	S, M, Se
Gorgonia ventalina Linnaeus, 1758		AL, AC, AR, TR	
Gorgonia flabellum Linnaeus, 1758		AL, AC, AR, TR	
Filigorgia sanguinolenta (Pallas, 1766)		AR	
Pterogorgia anceps (Pallas, 1766)		AL	S
Pterogorgia citrina (Esper, 1792)		AL, AC, AR	M, Se
Pterogorgia guadalupensis Duchassaing & Michelin, 1846		AL, AC, AR	S, M, Se
Pseudopterogorgia americana (Gmelin, 1791)	L, VRS	AL, AC, AR, TR	S, M, Se
Pseudopterogorgia kallos (Bielchowsky, 1918)		AL, AC, TR	
Pseudopterogorgia rigida (Bielschowsky, 1929)		AL	
Pseudopterogorgia acerosa (Pallas, 1766)	B, E, L	AL, AC, AR, TR	
Hard Corals			
Acropora cervicornis (Lamarck, 1816)	VRS, TRS	AL, AC, AR, TR	
Acropora palmata (Lamarck, 1816)	VRS, TRS	AL, AC, AR, TR	
Acropora prolifera (Lamarck, 1816)	VRS, TRS	AL, AC, AR, TR	
Agaricia agaricites (Linnaeus, 1758)	VRS	AL, AC, AR, TR	M, Se

Table 2. Continue.

Species	SW Gulf of Mexico	Campeche Bank	
		Major Reefs	Sisal Reefs
Agaricia fragilis Dana, 1846	VRS, TRS	AL, TR	
Agaricia lamarcki Milne Edwards & Haime 1851	VRS	TR	
Leptoseris cucullata (Ellis & Solander 1786)	VRS, TRS	BC	
Madracis decactis (Lyman, 1859)	VRS, TRS	AL, AC, AR, TR	S, M, Se
Stephanocoenia intercepta (Lamarck, 1816)	VRS	AL, AC, AR, TR	S
Phyllangia Americana Milne Edwards & Haime, 1849			S, M, Se
Eusmilia fastigiata (Pallas, 1766)	VRS	AL, AC, AR, TR	
Cladocora arbuscula (Lesueur, 1820)		AL, AC	S, M, Se
Diploria clivosa (Ellis & Solander, 1786)	VRS, TRS	AL, AC, AR, TR	M, Se
Diploria strigosa (Dana, 1846)	VRS, TRS	AL, AC, AR, TR	M, Se
Diploria labyrinthiformis (Linnaeus, 1758)	VRS, TRS	AL, AC, AR, TR	
Montastraea faveolata (Ellis & Solander, 1786)	VRS, TRS	AL, AC, AR, TR	
Montastraea franksi (Gregory, 1895)	VRS, TRS	AL, AC, AR, TR	
Montastraea annularis (Ellis & Solander, 1786)	VRS, TRS	AL, AC, AR, TR	
Montastraea cavernosa (Linnaeus, 1767)	VRS, TRS	AL, AC, AR, TR	M, Se
Colpophyllia natans (Houttuyn, 1772)	VRS, TRS	AL, AC, AR, TR	
Favites favosa Ellis & Solander 1786	VRS	AL	
Favia fragum (Esper, 1793)	VRS	AL, AC, AR, TR	
Manicina areolata (Linnaeus, 1758)	VRS, TRS	AL, AC, TR	M
Dichocoenia stokesi Milne Edwards & Haime, 1848	VRS, TRS	AL, AC, TR	M
Meandrina meandrites (Linnaeus, 1758)	TRS	AC, TR	
Mussa angulosa (Pallas, 1766)	VRS, TRS	AL, AC, TR	M, Se
Scolymia cubensis Milne Edwards & Haime, 1849	VRS	TR	Se
Scolymia lacera (Pallas, 1766)	VRS, TRS	AL, TR	
Isophyllia sinuosa (Ellis & Solander, 1786)	VRS	AL	
Mycetophyllia aliciae Wells, 1973		AC, TR	
Mycetophyllia daniana Milne Edwards & Haime, 1849	VRS, TRS	AL, AC, AR, TR	
Mycetophyllia ferox Wells, 1973	VRS, TRS	AL, AC, AR, TR	
Mycetophyllia lamarckiana Milne Edwards & Haime, 1848	VRS, TRS	AL, AC, AR, TR	
Oculina valenciennesi Milne Edwards & Haime, 1845	VRS		
Oculina diffusa Lamarck, 1816	VRS, TRS		S, M, Se
Porites astreoides Lamarck, 1816	VRS, TRS	AL, AC, AR, TR	S, M, Se
Porites branneri Rathbun, 1888	VRS, TRS	AL, TR	S, M, Se
Porites divaricata Lesueur, 1820	VRS	AL, AC, AR	S, M, Se
Porites furcata Lamarck, 1816	VRS	AL	
Porites porites (Pallas, 1766)	VRS, TRS	AL, AC, AR, TR	S, M, Se
Siderastrea radians (Pallas, 1766)	VRS, TRS	AL, AC, AR, TR	
Siderastrea sidérea (Ellis & Solander, 1786)	VRS, TRS	AL, AC, AR, TR	S, M, Se
Millepora alcicornis Linnaeus, 1758	B, E, L	AL, AC, AR, TR	S, M, Se
Stylaster roseus (Pallas, 1766)	E	AL	
Octocoral Species	18	34	14
Hard Coral Species	41	41	19
Total species	59	75	33

Coral abundance. Sisal reef presented less octocoral colonies (33%) than hard corals (66%). Madagascar and Serpiente reefs presented the opposite pattern; the colonies of hard corals only represented 17.8% in Madagascar and 20.8% in Serpiente reef, while octocorals were 82.2% and 79.2% respectively (Table 3).

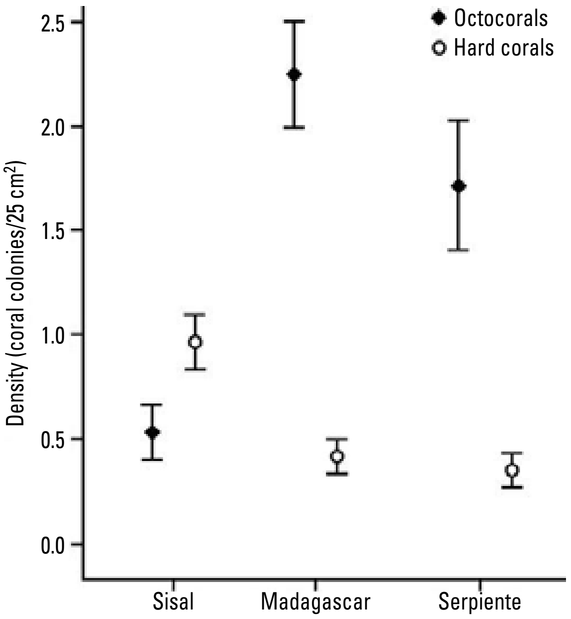

Figure 3.Density (mean ± standard error) of colonies of hard corals and octocorals found in the Sisal Reefs: Sisal, Madagascar and Serpiente reefs.

The densities of hard corals in the reefs were 0.97 ± 0.13/25 cm^2 (Mean ± Standard Error) in Sisal, 0.4 ± 2.2/25 cm^2 in Madagascar, and 0.35 ± 0.08/25 cm^2 in Serpiente reef, while octocoral densities resulted in 0.53 ± 0.1/25 cm^2 in Sisal, 2.25 ± 0.25/25 cm^2 in Madagascar and 1.7 ± 0.3/25 cm^2 in Serpiente reef (Fig. 3). The differences in densities of hard corals among reefs were statistically significant (H = 18, d.f. = 2, $p < 0.001$). Sisal presented a significantly higher density of hard corals than Madagascar (U = 1237, Z = –3.2, $p = 0.001$) and Serpiente reefs (U = 1149, Z = –3.8, $p < 0.001$), which in turn had similar values (U = 1690, Z = –0.7, $p = 0.473$) (Fig. 3). The differences in densities of octocorals between reefs was significant as well (H = 36.4, d.f. = 2, $p < 0.001$). Sisal presented the lowest densities and differed significantly from Madagascar (U = 715, Z = –5.9, $p < 0.001$) and Serpiente (U = 1097, Z = –3.9, $p < 0.001$), which in turn again didn't differ significantly (U = 1410, Z = –2, $p < 0.037$), although Madagascar presented the higher values (Fig. 3).

The relative abundance of coral species varied among reefs. The more common hard coral species in Sisal reef were *Siderastrea siderea* (36.5%), *Oculina diffusa* (14%), *Cladocora arbuscula* (14%), *Millepora alcicornis* (14%) and *Phylangia americana* (9%). Madagascar reef presented a similar pattern but the species ranked differently: *Millepora alcicornis* (23.5%), *Cladocora arbuscula* (20.5%) *Siderastrea siderea* (12%), *Oculina diffusa* (6%) and *Phylangia americana* (6%), whereas Serpiente reef was dominated by *Oculina diffusa* (14%), *Montastrea cavernosa* (11%) and *Porites porites* (7%) (Fig. 4). Among the identified octocoral species the most abundant in Sisal were *Erythropodium caribeorum* (45%), *Briareum asbestinum* (30%) and *Pseudopterogorgia*

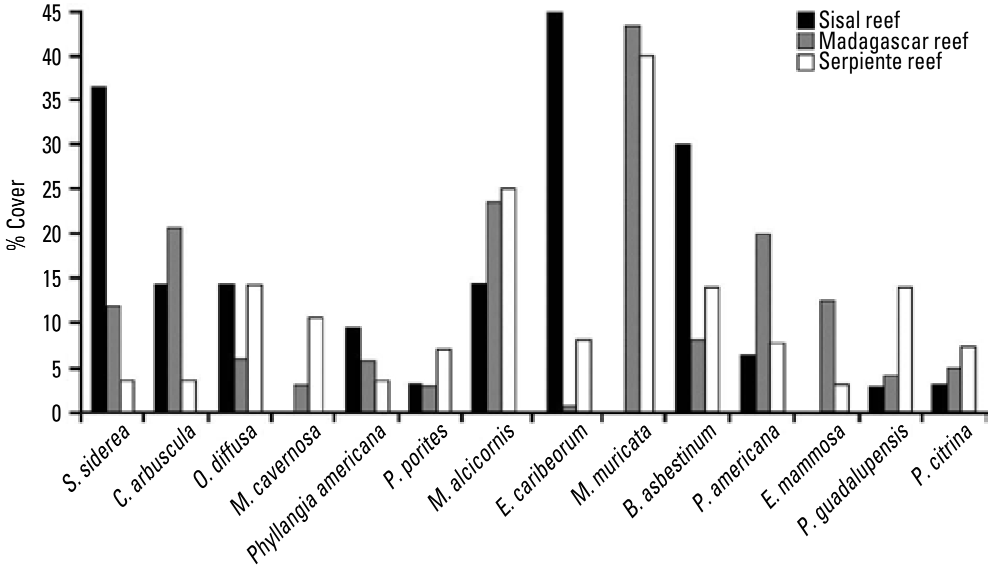

Figure 4. Relative abundance of the most common hard coral (*Siderastrea siderea, Cladocora arbuscula, Oculina diffusa, Montastrea cavernosa, Phyllangia americana, Porites porites and Millepora alcicornis*) and octocoral species (*Erythropodium caribeorum, Muricea muricata, Briareum asbestinum, Pseudopterogorgia americana, Eunicea mammosa, Pterogorgia guadalupensis, Pterogorgia citrina*) in the Sisal Reefs: Sisal, Madagascar and Serpiente reefs, Yucatán, Mexico.

Table 3. Relative abundance and number of colonies and size (mean ± standard error) of hard corals (diameter) and octocorals (height) species in the Sisal Reefs Yucatan, Mexico. Species collected during the preliminary rapid visual assessment don't present size information. Octocorals that couldn't be identified in the field sampling were grouped as Unidentified.

	Sisal	Madagascar	Serpiente
Octocorals			
Relative abundance	32.7%	82.2%	79.2%
Average size (cm)	16 ± 3	8 ± 0.9	14 ± 1.7
Briareum asbestinum (cm^2)	10 (12 ± 2)	8 (10 ± 2)	9 (80 ± 35)
Erythropodium caribaeorum (cm^2)	15 (18 ± 2)	1 (49)	5 (142 ± 65)
Carijoa riisei		1	
Eunicea calyculata		1	1
Eunicea laciniata		1	1
Eunicea mammosa		13 (11 ± 1.6)	2 (10 ± 2)
Muricea muricata		45 (3 ± .4)	26 (13 ± 2)
Plexaura flexuosa	1	1	
Plexaurella dichotoma	1	1	1
Pseudoplexaura porosa	1	1	1
Pterogorgia anceps	1		
Pterogorgia citrina		5 (2 ± 0.2)	5 (8 ± 2.3)
Pterogorgia guadalupensis	1 (23)	4 (5 ± 1.6)	9 (18.5 ± 2.5)
Pseudopterogorgia americana	2 (17 ± 5)	21 (23.2 ± 4)	5 (35 ± 19)
Unidentified	10 (14 ± 3.5)	54 (10 ± 1)	42 (12 ± 2)
Hard corals			
Relative abundance	67.3%	17.8%	20.8%
Average size (cm)	5 ± 3.5	10 ± 6.5	15 ± 7
Agaricia agaricites		1(12.5)	1(20)
Cladocora arbuscula	9 (3 ± 0.7)	7 (2.5 ± 1)	1 (17)
Diploria clivosa		1	1 (18)
Diploria stokesi		1	
Diploria strigosa		1	1
Montastrea cavernosa		1	3 (17.6 ± 9.5)
Manicina areolata		1	
Mussa angulosa		1	1
Madracis decactis	1	1	1
Oculina diffusa	9 (3 ± 1.2)	2 (2.5 ± 1)	4 (3 ± 1)
Phyllangia americana	6 (2.2 ± 0.8)	2 (3.6 ± 1.2)	1 (2.5)
Porites astreoides	1	1	1
Porites branneri	1	1	1
Porites divaricata	1	1	1
Porites porites	2 (3.6 ± 17.5)	1	2 (15.3 ± 8.8)
Scolymia cubensis			1
Stephanocoenia intersepta	1		
Siderastrea sidérea	23 (3 ± 0.7)	4 (3 ± 1.8)	1
Millepora alcicornis	9 (8.3 ± 6)	8 (16.4 ± 10.3)	7 (16 ± 9.8)

americana (6%). Madagascar reef presented higher abundances of *Muricea muricata* (43%), *Pseudopterogorgia americana* (20%), *Eunicea mammosa* (12%), *Briareum asbestinum* (7%) and *Pterogorgia citrina* (5%), while the most abundant octocorals in Serpiente reef were *Muricea muricata* (40%), *Briareum asbestinum* (14%), *Pterogorgia guadalupensis* (14%), *Pterogorgia citrina* (7%) and *Pseudopterogorgia americana* (7%) (Fig. 4).

Colonies sizes. Octocorals with branching forms differed in their sizes among reefs (H = 35, d.f. = 2, $p < 0.001$) (Fig. 5). Octocorals in Sisal reef averaged 16 ± 3 cm (mean ± standard error) and were similar to colonies in Serpiente reef (U = 469, $p = 0.274$) that averaged 14 ± 1.7 cm tall, whereas the colonies in Madagascar averaged 8 ± 1 cm and were significantly smaller than octocoral colonies in Sisal (U = 421, $p = 0.001$) and Serpiente (U = 3640, $p < 0.001$) (Table 3). The colonies of the encrusting octocorals *Briareum asbestinum* and *Erythropodium caribeorum* in Serpiente reef had sizes of 80 ± 35 cm^2 and 142 ± 65 cm^2 respectively. Colonies in Madagascar and Sisal reef were smaller (Table 3). *B. asbestinum* averaged 12 ± 2 cm^2 in Sisal and 10 ± 2 cm^2 in Madagascar reef, whereas *E. caribeorum* averaged 18 ± 2 cm^2 in Sisal and the only colony found in Madagascar covered 49 cm^2.

The sizes of hard corals differed significantly among reefs (H = 33, d.f. = 2, $p < 0.001$) (Fig. 5). Hardcoral colonies in Sisal reef averaged 5 ± 3.5 cm (mean ± standard error) in size and were smaller than colonies in Madagascar (10 ± 6.5 cm) (U = 1199, $p = 0.001$) and Serpiente (15 ± 7 cm) (U = 554, $p < 0.001$), which in turn presented significant differences in the sizes of their colonies (U = 314, $p < 0.001$) (Table 3). *M. alcinornis* was the species with the biggest sizes in average among the hardcorals: 8.3 ± 6 cm (mean ± standard error) in Sisal reef, 16.4 ± 10.3 cm in Madagascar reef and 16 ± 9.8 cm in Serpiente reef (Table 3). Other species presenting big sizes were: *Porites porites* colonies measuring 15.3 cm in average in Serpiente reef and 25 cm in Sisal reef (one colony); *Montastrea cavernosa* colonies were as large as 21.2 cm^2 in average in Serpiente reef; *Diploria clivosa* presented a colony with 18 cm in diameter as well in Serpiente reef and *Agaricia agaricites* measured 25 cm in Serpiente (one colony) and 13 cm in Madagascar reef (one colony) (Table 3).

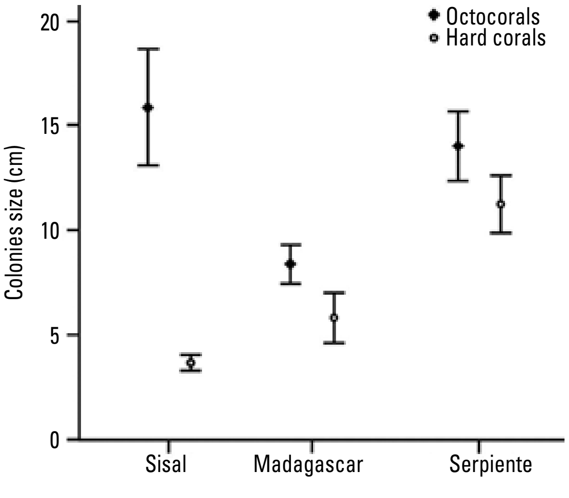

Figure 5. Colony sizes (mean ± standard error) of hard corals (diameter) and octocorals (height) present in the Sisal Reefs: Sisal, Madagascar and Serpiente reefs, Mexico.

Reef associated fauna. The conspicuous reef associated fauna found during the coral community sampling included zoanthids: *Zoanthus* sp.; anemones: *Bartholomea annulata* (Lesueur, 1817) and *Condylactis gigantea* (Weinland, 1860); cleaner shrimps: *Periclimenes pedersoni* (Chace, 1958) in astonishing high densities of >10 individuals per *C. gigantea*; crabs: *Stenorhynchus seticornis* (Herbst, 1778) and *Petrolisthes galathinus* (Bosc, 1802) in colonies of *Millepora alcicornis* (Linnaeus, 1758); sea cucumbers: *Astichopus multifidus* (Sluiter, 1910); sea stars: *Oreaster reticulatus* (Linnaeus, 1758) and *Echinaster* (*Othilia*) *echinophorus* (Lamarck, 1816); brittle stars: *Ophiothrix suensoni* (Lütken, 1856); sea snails: *Cyphoma gibbosum* (Linnaeus, 1758) and *Strombus* sp.; octopus: *Octopus maya* (Voss & Solis, 1966); lobsters: *Panulirus argus* (Latreille, 1804) and elder and young hawksbill turtles (*Eretmochelys imbricata* (Linnaeus, 1766).

DISCUSSION

Reef Topography. The Sisal Reefs presented extensive reef frameworks that may support abundant marine life. The maximum longitudes of the reefs were 0.9 km for Serpiente East, 2.5 km for Madagascar and 3.3 km for Sisal. These are similar dimensions to the better known Campeche Bank reefs, such as Triangulo Oeste (~600 m), Triangulo Este (1 km in two blocks), Cayo Arenas (~2.4 km) and Cayo del Centro (2.6 km) (Tunnell, 2007). Moreover, the Sisal Reefs are bigger than other reefs in the Southwest Gulf of Mexico, such as the reefs Blanquilla (~700 m), Tanguillo (<500 m), Enmedio (<500 m) and Tuxpan (<500 m) in the Tuxpan Reef System, and the reefs Galleguilla (1 km), Blanquilla (~600 m), Santiaguillo (~400 m), Anegadilla (~600 m) and Verde (~1.1 km) in the Veracruz Reef System (Tunnell, 2007). Since the area of natural ecosystems have been positively correlated with their levels of biodiversity (Cornell & Karlson, 2000) and because the Sisal Reefs are larger than some reefs that have already been recognized as biologically diverse (Withers & Tunnell, 2007), the Sisal Reefs may also have the capacity to host diverse marine life.

Coral Community. Our findings suggest that the coral communities of the Sisal Reefs are under stress. The density of hard coral colonies varied from 0.96 colonies/25 cm^2 in Sisal to 0.35 colonies/25 cm^2 in Serpiente reef (Fig. 3). These density values are similar to coral communities under stress. Coral communities under sedimentation and eutrophication stress have presented densities as low as 0.6 colonies/25 cm^2 (Wittenberg & Hunte, 1992). Similarly, coral communities under the impact of hurricanes have presented coral densities as low as 0.84 colonies/25 cm^2 (Connell *et al.*, 1997), whereas reefs under less stressful conditions had presented more than 5 colonies/25 cm^2 (Edmunds, 2000). The percentage of hard coral cover was not determined in our study but according to the observations during the preliminary and the quantitative surveys, the macroalgae were evidently occupying most of the substratum. The stress in the coral community may be also reflected in the size of the colonies found. Scleractinean corals in Sisal and Madagascar reef presented sizes of juvenile colonies <5 cm (diameter), with the exception of *P. porites* (21 cm) in Sisal and *A. agaricites* (12 cm) in Madagascar reef. The biggest colonies were present in Serpiente reef but these weren't bigger than 20 cm (Table 3). This could mean that the growth of coral colonies is being limited and/or that there is a high rate of mortality because of adverse environmental factors (Szmant, 1986).

The composition of hard coral species found in the Sisal Reefs is similar to the composition of other reefs that have been highly perturbed. For example, the Castle Harbour reefs in Bermuda that present high sedimentation rates and contamination levels (Flood *et al.*, 2005) share 7 out of 14 species (*Montastrea cavernosa, Diploria strigosa, Madracis decactis, Stephanocoenia intercepta, Oculina diffusa, Porites astreoides, Porites porites, Dichocoenia stokesi, Millepora alcicornis*) and 9 out of 11 genera (*Madracis, Montastrea, Diploria, Siderastrea, Stephanocoenia, Porites, Dichocoenia, Oculina* and *Millepora*) of hard corals with the Sisal Reefs (Flood *et al.*, 2005). Moreover, the species more common on the Sisal Reefs have been reported to tolerate environments with poor water quality. *M. alcicornis* is generally recognized as a characteristic species of stressed reef ecosytems (*e.g.* Wittenberg & Hunte, 1992, Dutra *et al.,* 2004) and *M. cavernosa* (Acevedo, 1989), *S. siderea* (Acevedo 1989), *P. porites* (Tomascik & Sander, 1985), *P. americana* (Rice & Hunter, 1992), *C. arbuscula* (Rice & Hunter 1992) and *O. diffusa* (Krone, 1980) are sediment-tolerant species. Regarding octocorals, Sisal reef presented 8.5 colonies/ m^2 which is a moderate density according to the criteria of Alcolado (in Olivera-Espinosa *et al.,* 2010); however, Madagascar and Serpiente reefs presented very high densities with 36 colonies/m^2 and 27 colonies/m^2 respectively. From all the colonies identified as species, 70% belonged to octocorals recognized as tolerant to hydrodynamic stress, contamination and sedimentation (*Eunicea mammosa*, *E. muricata*, *Pterogorgia citrina*, *P. guadalupensis* and *Pseudopterogorgia americana*) (Alcolado *et al.,* 2008; Olivera-Espinosa *et al.,* 2010), in agreement with the observations made about the hard coral community.

The present study didn't measure environmental variables; however, we found poor visibility in the field and sand deposition in horizontal surfaces of the reefs. The Sisal Reefs are surrounded by sandy plains and the sediments can be resuspended because of the turbulence caused by winter northern winds, storms and hurricanes common in the region (Carrillo *et al.*, 2007), as found in other studies that support this hypothesis (Segal *et al.*, 2008; Torres *et al.*, 2001). Additionally, the upwelling in the northeast of the Yucatan Shelf (Cape Catoche) is a source of nutrient rich cold water to the Campeche Bank (Merino, 1997) and has been suggested as the main reason of the low coral reef development in the east region of the Yucatan Shelf (Lidell, 2007). As in Castle Harbor these factors may not impede the survival of the coral community in the Sisal Reefs but may be affecting the composition, abundance and growth of the coral colonies.

The Sisal Reefs presented differences in their coral communities. This can be caused by differences in the kind, frequency and intensity of disturbances affecting them according to their morphologic and geographic characteristics. Sisal presented the lowest species richness (Table 2), the highest density of scleractinean corals and the smaller coral colonies (Table 3). The largest area of Sisal reef would suggest that it has higher opportunities to host different species (Cornell & Karlson, 2000); nevertheless, because it is the closest reef to the shore it may suffer a higher frequency and intensity of natural (*e.g.* higher sedimentation and stronger waves and currents) and anthropogenic disturbances (fishing, anchoring and diving) than Madagascar and Serpiente reefs. If this is true, it would have a higher species' extinction rate that can explain its lower diversity (Cornell & Karlson, 2000). This could as well explain the smaller and more abundant coral colonies found in Sisal reef. Organisms living in environments with a high frequency of disturbances, and thus a high rate of mortality, try to reproduce sexually as soon as possible and invest their energy in reproduction early in life instead of growth, resulting in a community composed of abundant small individuals (Szmant, 1986). This hypothesis is speculative at the moment because our study is the first in the Sisal Reefs and effect of disturbances among the Sisal Reefs was not in our goals, but this hypothesis highlights that these reefs provide good opportunities to test ecological theories and future research may find exiting insights about coral ecology and biology.

Regional Importance. The Sisal Reefs present coral species that haven't been found in other Mexican reefs of the Gulf of Mexico. Among the 33 coral species found at the Sisal Reefs, all the species had been registered in the Caribbean and the Gulf of Mexico. However, *Pterogorgia citrina, P. guadalupensis, Eunicea mamosa* and *Cladocora arbuscula* are absent in the Veracruz region (Tunnell *et al.*, 2007) and *Pterogorgia anceps* has only been found in Alacranes reef (Tunnell *et al.*, 2007). Furthermore, *Carijoa riisei* and *Phyllangia americana* haven't been found in neither Veracruz reefs or the Campeche Bank reefs and thus our records are the first for the Mexican reefs of the Gulf of Mexico (Table 2). This result expands the distribution of *C. riisei* from the Caribbean to the Campeche Bank (Tunnell *et al.,* 2007). *P. americana* has been found nearby the region of the Sisal Reefs by Cairns (2000) and thus its geographic distribution is not modified, nevertheless, the exact location and habitat of the species was not specified by Cairns (2000). There are 14 coral species present in Veracruz that are absent in the Sisal Reefs which are mostly hard corals (Table 2). Regarding octocorals, only *Plexaura homomalla* and *Pseudopterogorgia acerosa* are absent from the Sisal Reefs and present in Veracruz (Table 2). This, along with the presence of *C. riisei* in the Sisal Reefs, may support the hypothesis of a sporadic connectivity of octocorals between the Caribbean and Gulf of Mexico reefs (Jordán-Dhalgren, 2002). The Sisal Reefs could be receiving larvae directly from the Caribbean or from some of the other unstudied reefs near the coast of the Yucatan state that may work as stepping stones. More biodiversity and connectivity research in the region is needed to get more insight about this.

The coral community of the Sisal Reefs is more similar to other Campeche Bank reefs than the reefs in Veracruz and the Caribbean. Accounting for reefs individually, coral reefs in the Campeche Bank present similar species richness to the Sisal Reefs. For example, Cayo Arenas had registered 25 hard coral species while 18 species were registered for the Sisal Reefs (Tunnell *et al.,* 2007) (Fig. 6). Nevertheless, reefs located farther away such as Puerto Morelos in the Caribbean (>40 species) and the reefs systems of Veracruz (35 species) and Tuxpan (30 species) present considerably more species of hard corals than the Sisal Reefs (Fig. 6). However, regarding octocorals, although the Sisal Reefs presented less species (14 species) than the Caribbean (*e.g.* Puerto Morelos has ~40 species) they had similar numbers compared to the Veracruz Reefs System (17 species) and even more species than the Tuxpan Reef System (12 species) (Jordán-Dhalgren, 2002) (Fig. 6). This is significant since Veracruz and Tuxpan reef systems are composed of many reefs (~23), and comprise much more area than the Sisal Reefs.

The Sisal Reefs provide habitats for diverse species that would otherwise be absent from the near-shore region group of the Campeche Bank. The reef associated fauna resulted in a diverse live forms, including primary and secondary consumers, which is a sign of a good ecosystem functioning. Sessile organisms such as the ones found in our study: octocorals, *Millepora alcicornis* and sea anemones, are organisms that need reefal substrata to live. These in turn provide the necessary habitat for other species, such as *Cyphoma gibbosum, Stenorhyncus seticornis, Petrolisthes galathinus* and *Periclimenes pedersonni* respectively. The abundance of macroalgae may help to sustain both vertebrate (*e.g. Eretmochelys imbricata*) and invertebrate (*e.g. Strombus* sp.*)* herbivores, which in turn support higher trophic levels of consumers (*e.g. Octopus maya* and *Oreaster reticulatus*). The presence of Hawksbill turtles (*Eretmochelys imbricata*) is important, since it is classified as highly threatened by the International Union for Conservation of Nature and the Sisal Reefs may work as feeding points before travelling to beaches in the Yucatán Peninsula to spawn (Cuevas *et al.*, 2008).

Apart from the biological importance of certain species, some of the registered benthic fauna have economic importance. Octopus (*O. maya*), lobster (*P. argus*) and sea cucumbers (*A. multifidus*) are highly valued in the aquaculture market. Additionally, anemones (*B. annulata* and *C. gigantea*), cleaner shrimps (*P. pedersoni*), crabs (*S. seticornis* and *P. galathinus*) and zoanthids (*Zoanthus* sp.) are highly valued in the ornamental aquarium business. These species are suitable candidates for promoting alternative economic activities and may provide benefits for the nearby local economies (Pomeroy *et al.,* 2006). However, the implementation of such activities needs further multidisciplinary work to avoid undesired detrimental results to the society and the environment (Tlusty, 2002).

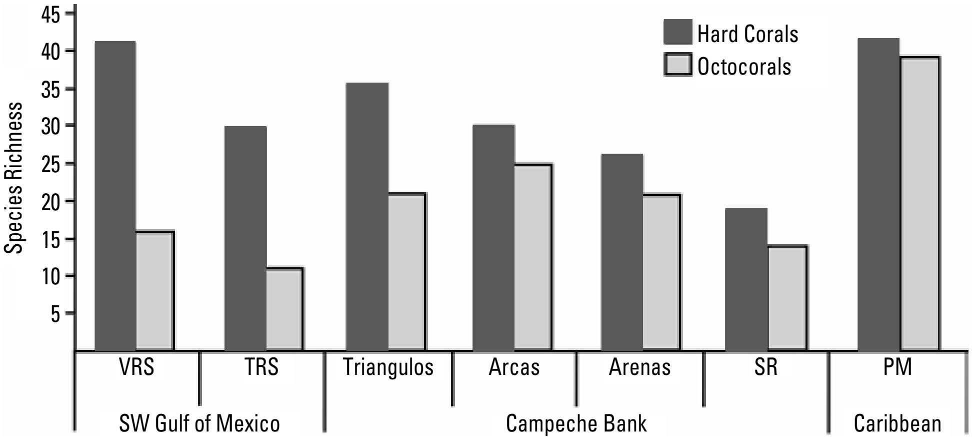

Figure 6. Hard coral and octocoral species richness of different coral reefs of the Mexican Atlantic Ocean (SAV: Veracruz Reef System; SAT: Tuxpan Reef System; PM: Puerto Morelos) (Tunnell *et al.,* 2007) and its comparison with the Sisal Reefs (SR): Sisal, Madagascar and Serpiente reefs, Mexico.

The present investigation represents the ecosystem baseline of the Sisal Reefs and future studies are necessary to know the trajectory that their communities are following. We may expect a continuous variation of the reef community because of the constant occurrence of hurricanes and storms in the area (Carrillo *et al.*, 2007) and the seasonal changes in macroalgae cover reported in other areas of the Campeche Bank, with peak abundance during summer (June to August) and mass mortality at the beginning of the cold season (November to May) (Orduña-Rojas & Robledo, 2002). A monitoring plan of the environmental features that constantly affect the reef community, such as water quality, temperature, irradiance and pH, must be implemented to detect the driver factors of the reef community and be able to predict future changes of the ecosystem. Nevertheless, nowadays the reef framework provides shelter for a wide range of life as evidenced by the diverse reef associated fauna found, despite the small size of the hard coral colonies, and thus these reefs could be an interesting system of study in the face of the future expectations of coral reef phase shifts from coral to alternative sessile taxa due to climate change (Norström *et al.,* 2009).

The present study presents significant improvements on the biophysical information of the Sisal, Madagascar and Serpiente reefs, and represents the first study of the topography and benthic community of the numerous reefs closer to shore of the Campeche Bank. Previous data had only represented the approximate reef´s location without physical or biological features of the reefs. The detailed reef topography presented here showed that the Sisal Reefs resulted equal or larger than many other reefs in the Gulf of Mexico. The composition, size and density of the coral colonies suggest that the reefs are under high stress; however, we found two species (*Phyllangia americana* and *Carijoa riisei*) not registered previously in the Mexican coral reefs of the Gulf of Mexico and given the generalized sandy bottoms with low topographic complexity in the Yucatán Shelf, the Sisal Reefs are important centers of marine resources and biodiversity. Furthermore, the presence of reef organisms belonging to all trophic levels, some of these being economically and ecologically important, is a sign of a complex and diverse ecosystem. Similar studies to this one, monitoring programs and experimental work should be undertaken in these reefs and the rest of the near-shore reefs of the Campeche Bank. These studies may increase the value of these reefs and provide additional opportunities for research and regional economic development.

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