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# Lagoons Reefs of Alacranes Reef and Chinchorro Bank: Ocean Reef of Mexican Atlantic

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## Abstract

Coral reef lagoons are one of the parts of the reef with the largest biotopes, making it an area with great inequalities. Under this perspective we try to compare the lagoons of the biggest ocean reefs in Mexico, which despite belonging to the Mexican Atlantic depend on two different systems: Alacranes Reef of the Gulf of Mexico and Banco Chinchorro of the Mexican Caribbean. From the results the proportion of living substrate is higher were obtained in Banco Chinchorro; however, the richness of species and diversity is greater in Alacranes (58 versus 39 species and 4.44 versus 4.38 bits/ind., respectively). *Lobophora variegata* (algae) is the only species whose dominance was proportionately consistent in both reefs; the similarity of sites identifies specific zones of the lagoons in both reefs, in the space the species are distributed close to the center of the axes, but many remain solitary or assembled in pairs. Despite the differences between the reefs according to the community descriptors, the location of the sites and their position in relation to the wind are relevant to the understanding of the dynamics of the lagoons.

**Keywords:** lagoon reefs, macroalgae, invertebrate coral reef, Atlantic reef, natural protected areas

## 1. Introduction

Coral reefs are one of the most diverse communities on the planet and the most diverse in the marine environment; they occupy less than 1% of the bottom of the ocean but are inhabited by 25% of all the marine species currently present [1]. In the Caribbean, coral reefs emerged about 27–30 million years ago in the mid-Oligocene, reaching outstanding development during the Miocene and part of the Pliocene (23–2.5 million years) due to the enrichment of species from the Pacific Ocean to the closure of the Isthmus of Panama [2], which confers it to be one of the oldest environments of the Earth [3].

It is built by living beings of the Scleractinia group that are the main builders and that rise from the bottom to the surface and that by its dimensions and physical structure, influence the environment. Its inhabitants are very diverse and have specific adaptations to each part of this system; therefore, the system has high sensitivity to external agents and an enormous complexity. They are systems located between the tropics, with high temperatures of 18–28°C, surrounded by

clear oligotrophic waters, with high oxygenation, and a salinity of 35 parts per thousand [4].

In addition to the high diversity in which these ecosystems live and develop, they are very productive marine communities. They play a critical role as habitat and protection areas of approximately 10–20% of the world's fisheries [5, 6]. This great system consists of sections that confer zoning. These sections can or will not be presented according to the type of reef in question, providing a distinctive and unique trait to each one. In our case, we will focus on the description of one of these sections, the reef lagoon, and we will do this by confronting the two largest reefs in Mexico, Alacranes Reef and Chinchorro Bank, both of them belong to the Atlantic Ocean, but their structures, characteristics, and components are different.

Both reefs have been studied under different aspects ranging from shipwrecks, [5] ecology [6, 7], biology [8], sociology [9], and paleontology [10], which gives us an idea of the importance of these ocean reefs to the country in relation to the exploitation of its natural resources, conservation, and even its importance in the delimitation of the territorial sea and consequently its sovereignty.

One of the main questions, however, was: are these reefs subject to the same ecological-environmental pressures and controllers even though they belong to two different ocean systems? To get closer to this response, we try to put the reader in context by making a wide description of each reef highlighting its ecological, fishing, and tourist importance, showing the results obtained through two sampling periods in the lagoon in particular and discussing them in relation to the southern, central, and northern areas of each of them, the leeward and windward zones and above all their membership in one or another ocean system.

One of the objectives of this research is to determine whether there are differences in the processes that occur in a given area of the reef, and this will lead to different ideas about whether it is possible to propose conservation and management plan differentials; different surveillance efforts, in the case of protected areas; differences in the natural resources exploitation, etc. That is the importance of this study. In the biological-ecological sense, there are also a number of objectives such as identifying the most important species in the structure of the lagoon community, knowing the dominant species in each area, and determining whether there is a substitution of species in each time period and above all knowing how stability is in the broader sense of this area of the reefs, recognizing that corals can be under such pressure that they can suffer disease and even death when the ambient conditions change rapidly without giving time to acclimatization. Around the world there is concern about coral reef conditions, especially because of the multiple problems they face such as coastal development and alterations by human influence that lead to a higher rate than estimated. Solutions to this problem can only be given through a vigorous drive for scientific research, particularly ecological and necessarily multidisciplinary that proposes informed procedures with firm scientific foundations. Fortunately, there are national and international efforts to preserve the health of reefs by restraining their arguments and procedures in scientific discoveries; we are sure that our contribution will serve as a further support to the efforts of conservation of these reefs.

## **2. Material and methods**

In this section we will present the study areas, the general characteristics of each reef, as well as the methodology used to obtain the data and the subsequent numerical analysis.

## 2.1 Study area

Both reefs are oceanic and the largest in Mexico and are marine protected areas: Alacranes reef with the National Park status and Chinchorro Bank as a biosphere reserve.

The physiographic reef structure makes it possible to recognize two sections, windward and leeward, and at least four main areas, South Lagoon, Central Lagoon, North Lagoon, and reef crest that border each reef.

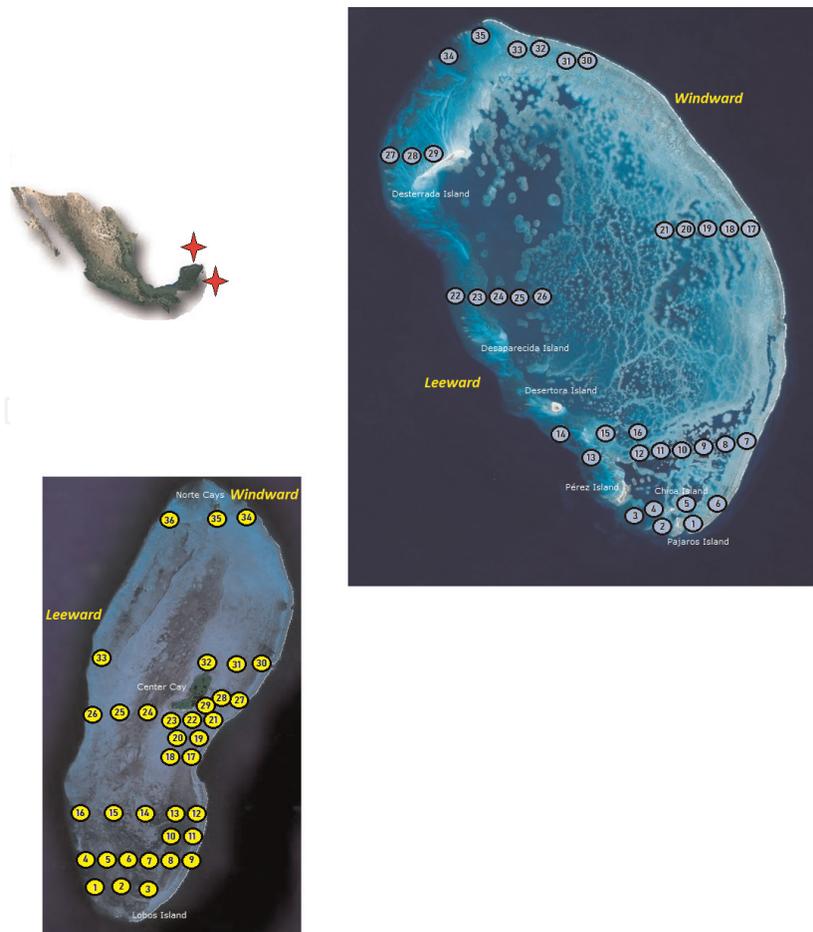
### 2.1.1 Alacranes reef

Their geographical location is 22°23'N, 89°41'W, and 135 km off coast of Port Progreso on the Yucatan Shelf. This reef is the largest and most complex of the series of reef lying along the edge of the Campeche Sound. The reef has the form of the atoll with northwest trend, due in part by winds and strong westerly currents. Its sub-oval pattern of outer reefs encloses shallow lagoon, and relationship to the Campeche Sound characterizes it as a shallow lagoon shelf atoll [11, 12]. The surrounding waters are 52 m deep. The lagoon reef maximum depth is 20 m in the north. We recognize a semicircular well-developed windward reef on the eastern side and leeward margin less sharply defined belt of reef growth. The windward reef forms a continuous barrier along the north, east, and southeast. The leeward side is characterized by small patch reefs and submerged sandbars. The lagoon is filled with microatolls giving a reticular pattern. There are five sand cays on the leeward rim of the reef: Bird or White Island, Isla Chica, Pérez Island, Dead Island, or Deserter and Banished Island. The total area recorded for the five islands is 530.407 m<sup>2</sup>, representing 1.7% of the area [13]. By virtue of the intense dynamics of the islands, their shape and dimensions can vary from the order of meters or tens of meters in short periods of time [11]. All cays are very low with maximum height of 3–4 m. A *Thalassia testudinum* seagrass bed and other algae are frequent in the lagoon reef. The cays are important site for nesting seabirds and nesting green turtles. Sharks are abundant in shallow waters; the management program [5] reported 116 bird species, 136 fishes, 24 species of shark, and 34 coral species. The reef is currently visited by fishermen who collect queen conch and other shells. Lobsters and grouper are also taken, mainly by skin diving and spear gun. The tourism is more and more frequent. The area has frequent climatological disturbance (winds of the north and hurricanes). The area has a forbidden period for the conch and lobster for the Fish Secretary decree.

### 2.1.2 Chinchorro Bank

Their geographical location is 18°47'–18°23'N, 87°14'–87°27'W, and 24 km off coast of southeastern Quintana Roo, México, between Xcalak and the Ubero and about 100 km north from Turneffe Island in Belize. This reef is part of the Great Atlantic Reef Belt (second world barrier). Chinchorro has an area of 53.379 ha. It is a kidney-shaped prominence and is separated from the mainland by a 1000-m-deep channel [14]. The current is very strong (often over two knots). There are four cays: Cayo Norte (two mangrove-covered islands with an area of 2645.2 ha, destined for the protection of the reef); Cayo Centro, the largest, is a mangrove island with few little inner lagoons with an area of 1263.76 ha, comprises the entire cay and adjacent waters; and Cayo Sur (or Lobos), the smallest (300 m long), is a sandy bank, the only close to the windward margin of the atoll, with 678.53 ha, destined mainly to the protection of the elkhorn corals; all the cays represent 5.82% of the total area of the reserve [15]. The reef has an area of 1443.6 km<sup>2</sup>; lagoon reef maximum depth is

21 m in the south, 3–4 m near Cayo Centro, and 2 m in the north. A *Thalassia testudinum* seagrass bed and garden eels, sometimes at high densities, are found in the reef lagoon. The reef lagoon extends for several tens of kilometers west of the bank and is extremely productive [13]. Under its waters the first thing we identify are sponges, fans and sea whips, and isolated colonies of stony corals and a huge diversity of multicolored reef fishes or small fish that are by hundreds hidden under the rocky cavities of where they come out and create a lively silver spot. However, the diversity and abundance of some groups (e.g., the management program [14] reports 95 species of Cnidaria, 35 sponges, 96 birds, 11 reptilian, 135 algae, and 104 species of mollusk), the main fauna inhabiting this tropical ecosystem is practically unknown (cichlid, crocodiles, etc.). Some of this species have never been described; maybe others are relict species, and others are a complex of subspecies interacting biologically and ecologically between them. Aggregation of the queen conch (*Strombus gigas*) and spiny lobsters (*Panulirus argus*) and abundance of large fish are frequent; turtles probably occur too. Cayo Centro is an important breeding site for frigate birds (*Fregata magnificens*) and olivaceous cormorant (*Phalacrocorax olivaceous*). The area is fished for queen conch (*Strombus gigas*) and lobster (*Panulirus argus*) by fishermen from Xcalac and Chetumal; there are three fishery cooperatives with 60–70 elements each one; the current disturbance for fishing is probably small, because of a forbidden period for the Fishery Secretary decree [14]. There are two lighthouses and many wrecks. The reef is gradually becoming popular with scuba divers who make 4- to 5-day trips from Cancún, Cozumel, and Quintana Roo coasts. The area has frequent climatological disturbance (winds of the north and south and hurricanes) (Figure 1).



**Figure 1.**  
Sampling sites in both oceanic reefs.

## 2.2 Methods

### 2.2.1 Sampling

The sampling was developed in two periods with a 2-year interval (2015–2017), for each reef. Each reef complex was divided into three main areas: north, central, and south. We established 35 sites for Alacranes reef and 36 stations for Chinchorro Bank, positioned with GPS (Garmin inReach Explorer+). The stations were distributed in the following ways: 16 sites in the southern zone of both reefs; 10 and 17 for Alacranes and Chinchorro, respectively, in the central zone and 9 and 3 for Alacranes and Chinchorro, respectively, in the north zone. The differences between the south and central areas with the northern area were mainly the difficulty and risks of navigating the low sand and shallow depths.

Two 20-m-long randomized photographic transects [16] for each site, transect consisted of 20 photographs that covered each one an area of  $(56 \times 34 \text{ cm})$   $1904 \text{ cm}^2$ , were used [17]. The photographs were taken with a Nikonos V camera, and the total number of photographs analyzed was 2802 ( $533.5 \text{ m}^2$ ); 38 photographs were disposed by out of focus. To obtain the coverage of the species, each photograph was superimposed on a grid with  $10 \text{ cm}^2$  divisions for the coverage calculation. In parallel with the photographic transects, a selective collection of species was carried out for their precise identification in the laboratory and to serve as a basis for photointerpretations. The bibliography used depended on the phylum [18–23].

### 2.2.2 Data analysis

The coralline coverage data matrix for each reef was used in different numerical analyses. A single matrix was formed by reef, where the most common community parameters were determined in the sites, with the purpose of obtaining a robust quantitative descriptive synthesis: the dominance was determined by the index of the importance value [24]; its formula is as follows:

$$IVI = A\% + F\% \quad (1)$$

where A—relative abundance, F—relative frequency and biological diversity was quantified with the Shannon-Wiener index [25] whose expression is

$$H' = - \sum_{i=1}^S p_i \log p_i \quad (2)$$

where  $p_i$  is the proportion of the abundance of the species  $i$ .

The sites were classified with the Bray-Curtis similarity index, using the flexible union criterion with a  $\beta = 0.25$  [26]; the coefficient has the following equation:

$$d_{i,k} = \frac{\sum_{i=1}^Z |X_{i,j} - X_{i,k}|}{\sum_{i=1}^Z (X_{i,j} + X_{i,k})} \quad (3)$$

where  $j, k$ —objects  $j$  and  $k$  that are evaluated,  $i$ — $i$ -ésimo descriptor,  $Z$ —number of descriptors,  $d_{j,k}$ —affinity value determined as geometric distance,  $X_{i,j}$ —descriptor value  $i$  in the entity  $j$ .

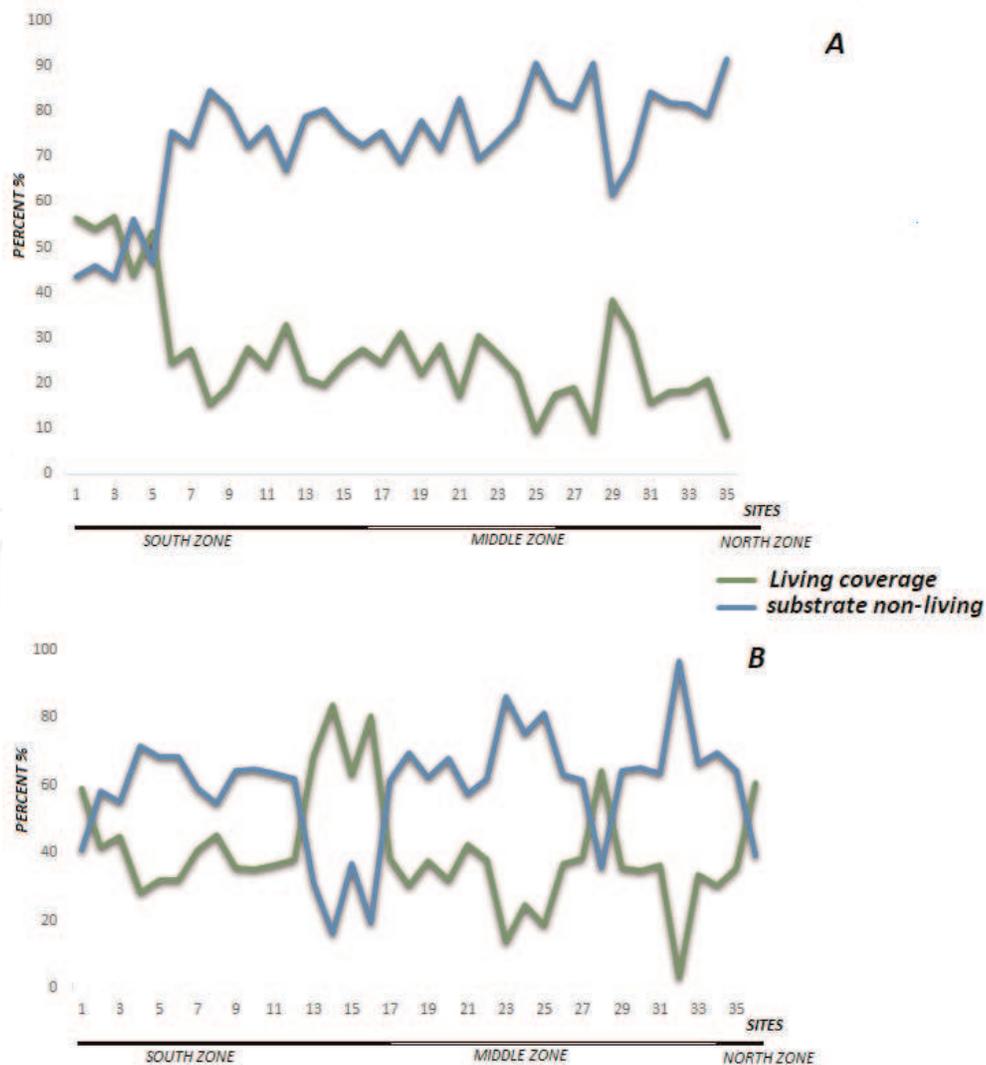
A main coordinate analysis was used for spatial distribution of the species [27].

### 3. Results

#### 3.1 Biodiversity

Biodiversity is a characteristic of nature and a property of living beings. It is a highly complex and nonlinear system, which is produced from a complex dynamic of interactions between living beings and their nonliving supports (physical, chemicals, etc.) through different contexts of time, geography, and cultures. The reef system is among the most biodiverse, equated with the tropical rain forest and linked to the ecological services provided by this interaction that finally integrates the environment and reflects the sensitivity of these services with concerning the depletion and disappearance of resources, communities, and populations. In this case we present the results obtained when investigating two lagoons of Atlantic Ocean reefs.

In both reefs the nonliving substrate generally has a higher percentage (Figure 2); however, in some places living coverage exceeds the substrate. On the other hand, on the Alacranes reef, only three sites are given this situation also in the southern part (Figure 2A). Some areas of the Chinchorro Bank, especially the southern part, show greater coverage than inert substrate (Figure 2B). Generally, the tendency for Alacranes reef is a decrease in living coverage from the south to the north, and consequently an increase of the substrate does not live in that



**Figure 2.** Live coverage and inert substrate percentages in the reef lagoons. (A) Alacranes reef, (B) Chinchorro Bank.

direction. Chinchorro Bank shows a similar tendency to Alacranes, where there is a descent from the south to the north, only that the trend slope is lower. The living substrate increases also from the south to the north with a similar slope.

In relation to the organisms collected in the reef lagoons, three phyla with 70 species were registered, the disposition of the groups in each reef is presented in **Table 1**, and in the annex the presence of the species in each lagoon is recorded.

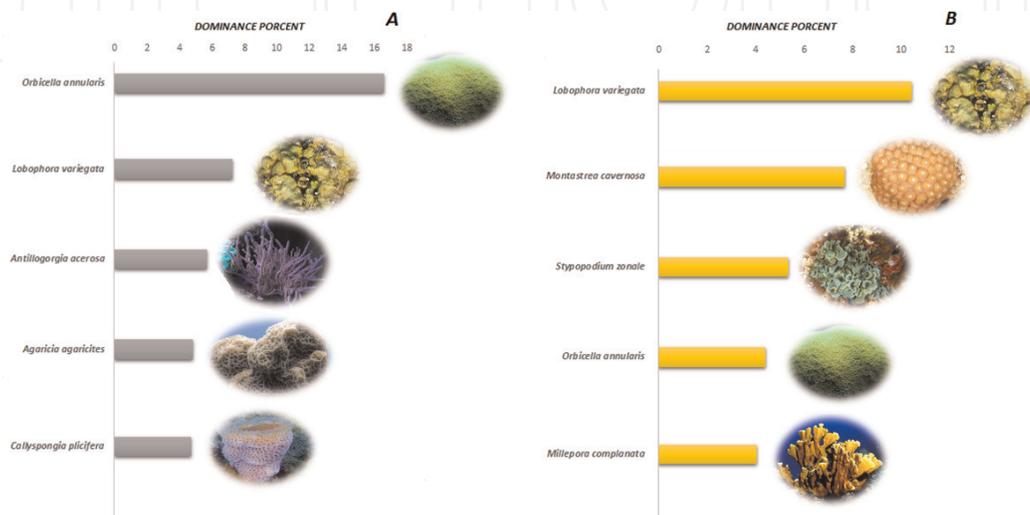
Even though some species are presented in both reefs, the dominance percentage of the five most representative species is shown in **Figure 3**; they show that the dominance percentage of *Orbicella annularis* for Chinchorro Bank is higher and that for Alacranes reef decreases until the fourth place. On the other hand, the alga *Lobophora variegata* is presented in the second place in Chinchorro Bank but rises to the first in Alacranes reef; however, the dominance percentage is similar.

The richness of species is lower in Chinchorro, since the sites that present the greatest richness reach only seven species, while in Alacranes most sites are between 15 and 20, reaching in the southern area up to 40 species (**Figure 4A, D**). Diversity in Chinchorro Bank goes from 0 (one species) to 2.4 bits/ind., while in the Alacranes reef, it goes from 1 to 4.3 bits/ind. (**Figure 4B, E**). Equitability has similar behavior to diversity in both reefs, reaching 0.9 as its maximum value (**Figure 4C, E**).

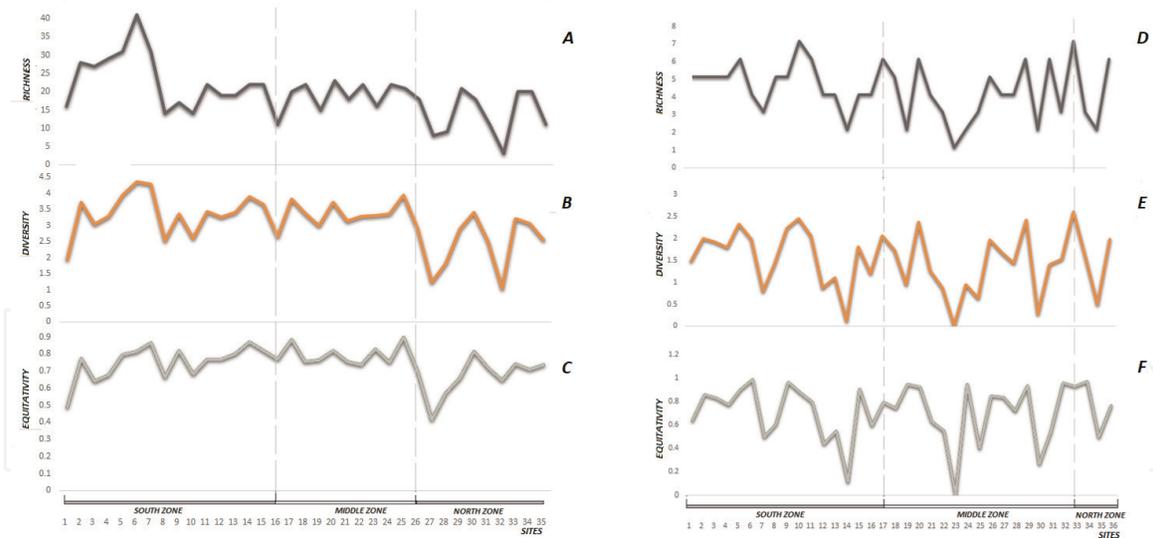
**Table 2** seeks to gather the general information of the two ocean reefs, their origin, presenting the totals in terms of their size, as well as the parameters of total diversity that are presented in both lagoons.

Groups	Alacranes reef	Chinchorro Bank
Algae	11	8
Sponges	18	4
Hydrozoa	2	2
Hard corals	18	16
Soft corals	9	9
Total	58	39

**Table 1.**  
 Species number per group registered in Alacranes reef and Chinchorro Bank lagoons.



**Figure 3.**  
 The five species with the highest percentage of dominance. (A) Alacranes reef, (B) Chinchorro Bank lagoons.



**Figure 4.** Richness (A, D), diversity (B, E), and equitability (C, F) in the lagoons of Alacranes (ABC) and Chinchorro (D,E,F) reefs. The three areas are south, central, and north.

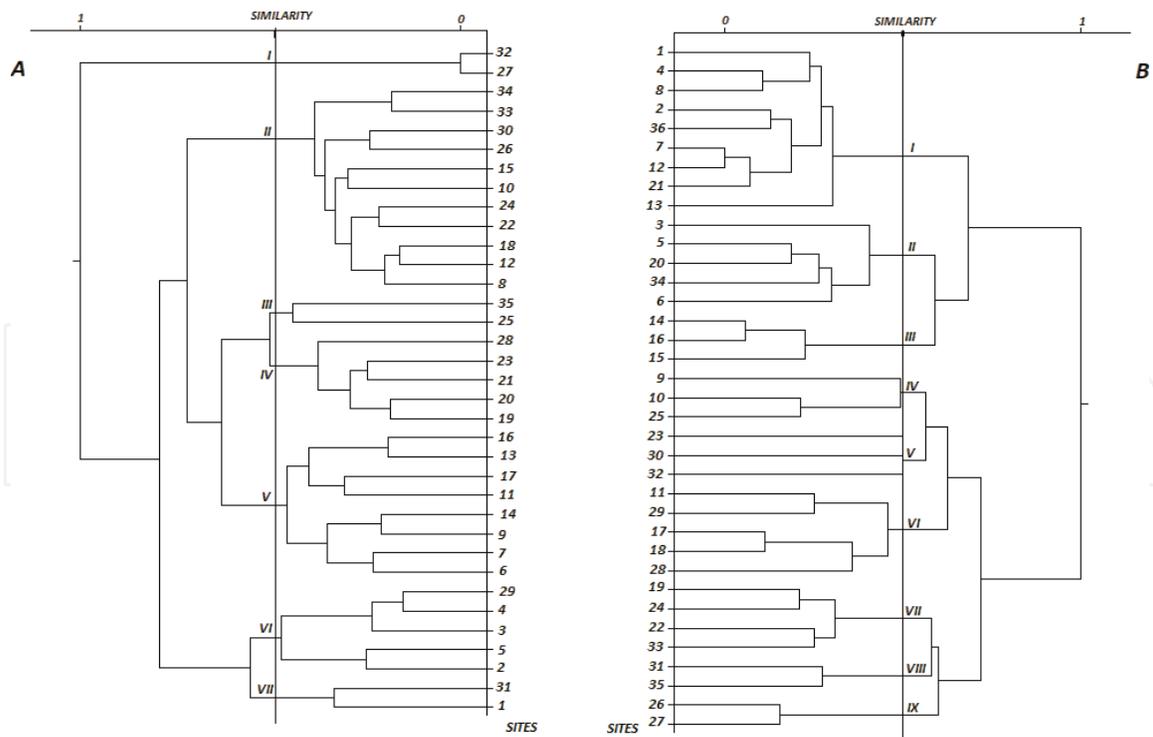
Attribute	Alacranes reef	Chinchorro Bank
Origin	Pleistocene-Cretaceous	Cenozoic: Pliocene-Pleistocene
Area (km <sup>2</sup> )	300	1443.6
Islands	5	4
Island area [km <sup>2</sup> ]	0.53	5.82
Insular percentage	1.7	0.40
Lagoon area [km <sup>2</sup> ]	299.755	533.79
Surrounding water depth (m)	52 m	+500 m
S (species no.)	58	39
H' (bits/ind.)	4.44	4.38
H' <sub>max</sub> (bits/ind.)	5.85	5.25
H' <sub>min</sub> (bits/ind.)	0.127	0.308
J'	0.759	0.834

**Table 2.** Alacranes reef and Chinchorro Bank characteristics.

### 3.2 Site affinity

The similarity given by the Bray-Curtis index, of the Alacranes Reef, forms seven groupings: The first is formed by two sites in the northern area. The second clusters more sites (11), which are distributed throughout the reef; however, at lower levels, sites of the same area or at least contiguous areas such as stations 8, 12, and 18 are associated. The third group joins two stations: one from the central zone and the other from the north.

The four clusters include five stations that although they identify some area, some site of another area is joined as is the case of sites 19, 20, 21, and 23, elements of the central zone to which site 28 of the north zone is joined. The fifth group relates eight sites, showing an association that completely identifies the area in the south. The sixth cluster has five sites, most of them from the south zone and only one from the north zone (site 29). The seventh group has only two sites: one of the south zone and one of the north (**Figure 5A**).



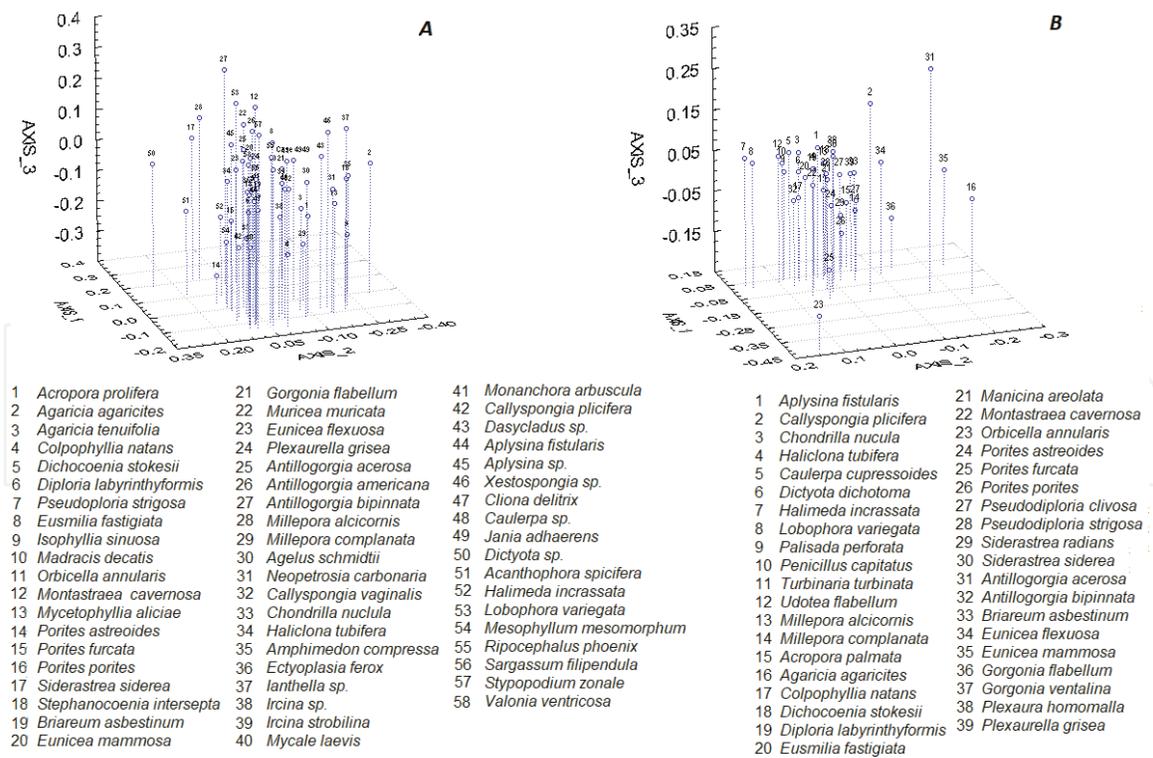
**Figure 5.** Sites similarity given by the Bray-Curtis index. (A) Alacranes reef, (B) Chinchorro Bank lagoons.

The Chinchorro Bank sampling sites form nine groups at a level of 50%. The largest of them includes eight stations, of which six belong to the south zone, one to the central part on windward, and one of the north zone in leeward. Group II gathers five sites of which three are in the south zone, one in the central part on windward, and one in the north area in leeward. The third cluster is exclusive to the southern zone. Cluster IV is made up of two sites in the south windward area and one in the center of the central area. Group V has three exclusive sites in the middle area, two of them close to the island of Cayo Centro and one of them on the windward edge. The sixth cluster has five stations, almost all of them from the middle area, except for a site located in the south area. Group VII has four locations, close to each other in the central area except for one of them located in the leeward area. The eighth cluster is formed by two stations in the central zone and the other in the north. The last group consists of two sites in the central area, one on the windward edge and the other in the leeward (**Figure 5B**).

### 3.3 Spatial species distribution

In relation to the spatial distribution of species of Alacranes reef, there were 58 species (flora and fauna) that also form, most of them, a large conglomerate close to the three axes of coordinates. There were paired associations as in the case of *Amphimedon compressa* with *Stephanocoenia intersepta*, *Siderastrea siderea*, and *Millepora alcicornis*, among others; *Antillologorgia bipinnata*, *Porites astreoides*, *Agaricia agaricites*, *Dictyota* sp., *Acanthophora spicifera*, and *Isophyllia sinuosa* move away from any grouping (**Figure 6A**).

In Chinchorro Bank, it has to be generally presented that for 39 species most of them cluster at the origin of the three axes, forming a large group. The species *Halimeda incrassata* and *Lobophora variegata* show a very close relationship, while the species *Callyspongia plicifera*, *Antillologorgia acerosa*, *Agaricia agaricites*, *Orbicella annularis*, *Eunicea mammosa*, *Eunicea flexuosa*, and *Gorgonia flabellum* are out of any conglomerate (**Figure 6B**).



**Figure 6.**

*Spatial ordination of the species found in the reef lagoons. (A) Alacranes reef, (B) Chinchorro Bank.*

## 4. Discussion

### 4.1 Biodiversity

The marine benthic communities have been evaluated from different points of view, which respond to their distribution, interests, or incidental events. The most common assessments are those focused on establishing the community structure and distribution patterns of temperate and boreal zones [28, 29], while in the tropical coastal zone are the evaluations focused on determining the response of these communities to changes caused by seasonal fluctuations and/or physico-chemical or structural modifications of the environment, by natural or anthropogenic sources [30–32]. Precisely, an indicator related to environmental services is biodiversity. It is essential to know the ecological characteristics of reefs and coral-line communities, because it allows to identify the stability of these ecosystems as well as the manifestations that these present in the face of natural and anthropogenic disturbances. The most obvious indication of the effect of natural and anthropogenic disturbances on coral systems is the death of corals. However, if the damage is not massive, sometimes there is a change of species, in which other types of coral species or various organisms in the bottom, such as carbonated or fleshy algae, arrive and occupy the position of the species that originally resided in the site, causing the so-called phase change [33, 34]. Consequently, the functions of the system are affected, since the corals that arrive are not always so efficient to produce carbonate, to generate sediments or sands, and above all, to give food or refuge to other species, so even if there is live coral, the environmental service is not the same.

Meanwhile, environmental variability is one of the two forms of environmental change, with alterations in the intensity or frequency of stochastic events [35, 36]. Its raise is associated with the increment in disturbances and variability of resources, imposing challenges that have a greater influence on biological communities, than those generated by changes in the average environmental condition

(the second form of environmental change). In turn, environmental variability has been conceptually used to frame all possible values that may exhibit the physical and chemical characteristics of a benthic habitat [37, 38].

Alacranes reef can be considered as the most studied coral complex of the Mexican seas due to its extraordinary characteristics, which place it within the most extensive and important coralline masses of the country [39]. The reef was described for more than a century [40] but, until the late 1950s, began to be studied more or less constantly, mainly by foreigners [41]. Alacranes has a vast history of shipwrecks and has been a point of attraction of visitors since colonial times [42].

The Yucatan Peninsula is a platform of sedimentary origin, constituted by a karstic Quaternary complex. It is the most recent emersion area in the country, and its growth is associated with sediment coastal transport processes and marine transgression and regression cycles. Therefore, Alacranes is of recent formation, originated by the biological action of the corals with the gradual deposit of calcareous material during the Pleistocene and Cretaceous, favored by the slow immersion of the Yucatan Peninsula [43]. Alacranes sits on a terrace of 51–64 m that is supposed to be carved during the descent eustatic sea level at the end of Wisconsin or at the beginning of the transgression Holocene (11,000 years ago), hence began the modern reef growth, arriving some 5000 years, both the reef and the sea level, to its current values [44]. The area is a platform reef of approximately 300 km<sup>2</sup>, which rises 50 m from the seabed. According to several investigations [45], it is known that the pattern of currents and the contribution of nutrients for the Alacranes reef come from the upwelling process that originates in the eastern end of the Yucatecan platform. The current of the Caribbean, as it passes through the Yucatán Strait and ascends on the platform, contributes high values of nutrients and therefore a high productivity [46]. Thanks to this contribution, there are commercial fisheries of lobster (*Panulirus argus*) and the groupers (*Epinephelus* sp.) [47]. The general state of conservation of the reef can be considered good [48].

Alacranes is a resting area for migratory birds that cross the Gulf of Mexico; particularly one of the islands of the Alacranes reef is considered one of the most important breeding areas in the world for the bird *Sula dactylatra*. Thus, it is considered an important area for the conservation of birds of the country [49], especially with a record of 110 species between accidental and permanent residents in the reef. In the reef environment, the management program has registered 34 species of corals, some of which are considered species under special protection [50]—in this assessment we report 28. According to the Alacranes bathymetric characterization, the slope of windward descends to an average of 55 m of depth; in the north part there is a marked inflection of the profile in comparison of the areas center and south, where the slope descends gently. The windward slope is the only site on the Alacranes reef where the stony corals of the genus *Orbicella/Montastraea* are not dominant. The dominance corresponds to *Siderastrea radians*. One of the characteristics of this area is the high density of soft corals or octocorals; the dominant genus is *Pseudopterogorgia*, although *Gorgonia flabellum* is also frequent and reaches large size. In addition to these, the genera *Eunicia*, *Plexaura*, and *Plexaurella* are represented in this part, like the one reported by other studies [42, 51]. The barrier reef is physiographically one of the most conspicuous elements of the system, and like any barrier reef, in turn is divided into outer barrier, west in the case of Alacranes, reef crest, and inner barrier [52]. The outside is the one that is exposed to the prevailing winds and the persistent swell train. Along the barrier at different points, it reaches the surface. The notorious dominance of the *Palythoa caribbeaerum* colonial anemone extends to the areas of the crest and the inner barrier. In the shallow part, between three and four meters of depth, the Hydrozoa *Millepora alcicornis* is frequent, like *Gorgonia flabellum*. In this area, the hard corals

are represented by *Porites asteroides*, *Pseudodiploria strigosa*, *Acropora palmata*, and *A. cervicornis*, mainly. In the southern part of the barrier, *Acropora prolifera*, a rare species in the Caribbean reefs, is located. The reef crest reaches up to 400 m wide and marks the maximum growth of the reef and is only interrupted by two channels of flow and reflux tidal in the area known as the flooded. The boundary between the crest and the inner barrier is not clearly defined, but it can be said that it starts in the area where the swell train begins to disappear. In the inner barrier, in the closest part to the crest, *Acropora palmata*, *A. cervicornis*, *Porites porites*, *P. astreoides*, and *Millepora alcicornis* are the corals competing with *Palythoa*. To the west the inner barrier comprises the meadows of seagrass and the canals near the barrier. Of these components, the seagrass meadows play an important role in the system [53]. They are presented in shallows of sandy bottoms covered by meadows of *Thalassia testudinum*, *Cymodocea manatorum*, and *Diplanthera wrightii* whose roots and rhizomes form a dense plot that functions as a sediment trap and stabilizes the substrate. Associated with the meadows are presented corals *Manicina areolata*, *Oculina diffusa*, and *Porites porites*. The reef plateau is the most complex area of reef lagoon and includes shallow seagrass meadows, pinnacular reefs, and microatolls, as well as an intricate network of canals, the result of these morphological structures that rise abruptly from 12 to 15 m deep, until almost reaching the surface. *Orbicella annularis* is dominant and accompanies *M. cavernosa*, *Pseudodiploria strigosa*, *Colpophylia natans*, *Porites porites*, *P. astreoides*, and *Stephanocoenia intersepta*.

For its biological characteristics, the reserve of Chinchorro Bank is a natural laboratory, practically unaltered, partially known, and even unknown in many of its aspects, to develop innovative scientific research and quality focused both on the execution of floristic and faunal inventories that enrich and update existing ones, as well as to understand in detail the biological and ecological relationships and processes that develop there. Due to Chinchorro Bank's geographical isolation and its position in the hurricanes and tropical storms route, it is important to establish mechanisms to facilitate the knowledge of the prevailing meteorological conditions to increase the safety degree of visitors and fishermen. Unlike other Mexican reefs, Banco Chinchorro does not develop on a continental or insular shelf but on a deep underwater crest (more than 400 m deep about 30 km out coast), which rises like a pinnacle [54, 55]. Little is known of its origin; we have the theory that in the past, the reef complex was formed by separation and derives from a portion of the continental coastal area, possibly in the Cenozoic era in the late Tertiary period or early Quaternary (in the Pliocene-Pleistocene age). The separate fraction of the coastline contained a fringe or marginal reef and coastal lagoons with typical fauna. The detachment of part of the coast was possibly of a single plate, which took with it a large reservoir of ancient water which possessed characteristics of a continental mass of water, which has maintained its characteristics with the contribution of the rains. Due to its geographical position in the Western Caribbean and their influence in the Gulf Stream, it is an intermediate point compared to other reef systems located downstream in the Lesser Antilles, which allows it to receive larvae of these distant places and in turn export larvae of different organisms generated in Chinchorro to systems located upstream, like Cozumel, Alacranes reef, and the keys of Florida, among others [56].

The Chinchorro Bank is of great ecological importance due to the high diversity of organisms that are there. By remaining practically isolated for a long time, some areas are unchanged, allowing for a comparable study with other similar ecosystems. Banco Chinchorro is nominated by UNESCO as a World Heritage Site and as a Ramsar site for the protection of migratory birds and wetlands. It was recently designated as the Man and Biosphere (MAB) site [50]. The fauna inventoried by the management program [14] is dominated by local and migratory birds that use the keys permanently or during the time of migration to rest and feed. Ninety-six

species of birds are registered. Several of them registered in NOM-059-ECOL-1994 as subject to special protection, for example, the blue-winged teal (*Anas discors*) and the roadside hawk (*Buteo magnirostris*). The brown heron (*Ardea herodias*) is considered rare. For example, the blue-winged teal (*Anas discors*) and the road hawk (*Buteo magnirostris*), the brown heron (*Ardea herodias*) is considered rare, the stork (*Mycteria americana*) and the rabies or rabihorcado (*Fregata magnificens*) as it is known in the locality where, according to fishermen's reports, this bird reached great abundance they have the category of threatened. Within the reptiles, the American crocodile (*Crocodylus acutus*) is listed as endangered, although apparently in the bank, this species is abundant.

The known composition of the coral taxa is represented by hexacorals, octacorals, and hidrozoarios with 95 species reported [14]; in this assessment we report 31. Among the Scleractinian *Orbicella annularis*, *M. cavernosa*, *Porites astreoides*, *Agaricia tenuifolia*, *A. agaricites*, *Acropora palmata*, and *A. cervicornis* dominate, while of the gorgonian the dominant ones correspond to *Eunicea mammosa*, *Gorgonia flabellum*, *P. americana*, *Briareum asbestinum*, and *Plexaura flexuosa*. The hidrozoarios are represented by *Millepora complanata* and *M. alcicornis* like the report by other investigation [57]. The macroinvertebrates are conspicuous elements of the coral reef; they are even organisms of great scientific, tourist, and commercial interest, but little is known of those that are presented in the reserve. The available records, which are not exhaustive, correspond to 35 species of sponges, 78 gastropods, 26 bivalves, and 6 crustaceans [14]. For Chinchorro Bank, faunal and floristic inventories with which it is counted in the reserve are partial. It is not known the composition of zooplankton, phytoplankton, microzoobenthos, and microphytobenthos, among others, as well as taxonomic groups of which there are no records such as the case of echinoderms, jellyfish, anemones, crustacean by marine fauna, and arachnids, insects, and mammals for terrestrial fauna is not known.

With the high values of diversity in Alacranes reef, one would think that it is the most diverse and most conserved reef; however, the high coverage values in Chinchorro Bank belie that assumption. It is very important to mention that the coverage composition of benthic organisms is a variable that determines total biodiversity or specific group biodiversity, such as benthic organisms, invertebrates, or reef fish [58]. Both lagoons have hard and soft corals in different proportions, but abundance has a high variation in soft corals. This may be related to the high colonization capacity of soft corals which adhere to different types of substrate.

The south part of Chinchorro Bank recorded the highest diversity of benthic groups, but Alacranes reef was in the north. Density and percentage of live coral coverage, particularly reef building corals in these areas, are slightly over the average recorded in coral reefs from the Mesoamerican Reef [59]. It is possible that these corals enhance considerably the growth of new colonies, which will make possible the persistence of reefs and the habitat they provide to other species. In the north of Chinchorro and the south of Alacranes, it is highly probable that sedimentation condition will affect and reduce the live coral coverage, since this condition persists for a period; about 7% of coral coverage in this area could be lost because it is well known that sediments damage coral polyp tissues by abrasion and asphyxia.

## 4.2 Site affinity

There are distinct morphological variations between leeward and windward sectors. A shallow and extensive reef flat is a common feature in most of leeward part of these reefs. Coralline algae are quite abundant in these flats, and rubble of coral skeletons in ample dead beds of hard corals is evident. With both data sets, the classification

analysis leads to effectively recognizing the quantitative differences between the different zones. It extracts subjective considerations and discovers the importance of the ecological attributes identified in the field. However, in some cases the factors that originate the distribution patterns are not clearly discovered, since the analysis conducted suggests that significant changes with the depth occurs in the populations and shows that the different parts of the same reef system can be subjected to different pressures and combinations in the selection process, even in physiographical areas related to the frequency and intensity of disturbance by the wave.

The affinities between the sites showed strong identities toward identifying areas with particular characteristics such as windward, leeward, and the reef ridge; however, the inclusion of some site of the reef plain in these groups can be caused by the depth and the type of biotope that develops there (availability of free substrate, coral fragments, etc.) as happens in other reef sites [60]. Chinchorro Bank presented a greater number of groupings, showing particular areas with strong characterization, where slight changes in some parameters is sufficient for the index to detect and separate them; Alacranes gathers more sites in its clusters, which would allow to think that their affinities are maintained in a larger area.

### 4.3 Spatial species distribution

In stable ecological systems, it is possible to recognize the dynamic state in which all the interactions and variations of a community are centered and nullified at a point of equilibrium to which all the components of the community are directed after a disturbance, allowing the community to be recognized as an entity based on its attributes [61–63], which are the total abundance of species, the total abundance of the dominant species, the biomass of the community, and the composition of species [64, 65]. With the analysis of Main Coordinates, it's possible to identify a community for the species that most influence its community spatial structure [66]; however, this community could present different points of stability, in which the dominance of different species is present, which they present specific equilibrium points, providing different levels of resistance to disturbances, as could create the differences between windward and leeward levels. In both reefs and analysis strategies, the species that takes advantage of the largest amount of resources for its benefit and consequently is the most dominant is *Orbicella annularis*, which is similar to that reported for the Netherlands Antilles [67], on both reefs was a species that separates from any grouping, being more evident in Chinchorro Bank. However, in areas with a certain degree of disturbance, the scheme changes dramatically, and other species replace *O. annularis* in its dominance. In the first case, when solid substrate is available, the gorgonians are those that have more aggressiveness and in the second when missing a solid substrate, the group of sponges has some advantage. In fact, these data confirm what was partially found by other research [68–70] who defined areas or biotopes with strong ecological differences. Coral reefs in the Caribbean and Gulf of Mexico have a similar coral biota. Nevertheless, there is a reduction in the number of common Scleractinian coral species from the Alacranes reef to Chinchorro Bank. Coral species richness, however, does not seem to decrease drastically as it does with gorgonians [71].

## 5. Conclusions

The conclusions of this research are as follows:

- The two lagoons have different dynamics.

- The proportion of live coverage in Chinchorro Bank is higher than in the Alacranes reef.
- While the richness is greater in the lagoon of the Alacranes reef, the magnitude of the Chinchorro Bank lagoon may result in an undervaluation due to insufficient sampling.
- The abundance-rich ratio of species given by diversity is similar in both lagoons.
- *Orbicella annularis* is the coral that is among the five most dominant species in both lagoons.
- In the lagoons there were site affinities, especially at the edges, that faithfully identify windward and leeward areas, which allow to infer the importance of this element and what originates in relation to wave force, oxygenation, etc.
- The analyses show areas with large ecological differences in the lagoons.

By virtue of its insular nature and the scarcity of freshwater, both reefs have remained safe from major alterations. Alacranes reef and Chinchorro Bank are a distant paradise that still have abundant fishing resources and diverse underwater life to marvel, as well as the possibility of discovering hidden secrets kept by the sea and time. However, we must consider and not forget that the overexploitation of resources can deplete the productivity of this place, which until now is one of the last places where coral reefs and memories of other times remain intact. The knowledge obtained from these systems must serve to conserve their natural resources, with special emphasis on endemic species, threatened, endangered, special protection, and those of current and potential economic importance, as well as preserving the reef landscape and its natural elements, for the enjoyment, recreation, exploitation, and elevation of the quality of life of social groups and visitors and for future generations. It should also encourage the conduct of research and studies that broaden and deepen this knowledge and contribute to the development of methods and alternatives for the sustainable use of resources.

The benchmarks of reefs in Mexico are changing, and they need to be redefined frequently to update them, in order for the management tools to be more effective and accurate; we hope that this contribution will go in that direction of conservation and maintenance of these magnificent ecosystems.

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## Appendix

			Alacranes reef lagoon																																			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
Species																																						
Algae	1	<i>Acanthophora spicifera</i> (M.Vahl) Borgesen, 1910	†	†		†	†	†	†			†			†			†			†			†			†			†	†	†		†	†			
	2	<i>Caulerpa</i> sp. J.V. Lamouroux, 1809					†					†										†					†		†		†					†		
	3	<i>Dictyota</i> sp. J.V. Lamouroux, 1809	†	†	†	†	†	†	†	†		†		†			†				†			†			†			†	†	†		†	†	†		
	4	<i>Halimeda incrassata</i> (J.Ellis) J.V. Lamouroux, 1816	†	†	†			†	†			†		†			†				†	†			†	†			†	†	†			†	†	†	†	
	5	<i>Jania adhaerens</i> J.V.Lamouroux, 1816		†			†	†	†	†		†		†			†			†	†			†			†	†							†		†	
	6	<i>Lobophora variegata</i> (J.V.Lamouroux) Womersley ex E.C.Oliveira, 1977	†	†	†	†	†	†	†	†	†		†			†					†			†			†		†		†	†	†			†	†	
	7	<i>Mesophyllum mesomorphum</i> (Foslie) W. H. Adey, 1970	†		†	†			†			†				†				†		†			†								†		†	†	†	
	8	<i>Rhipocephalus phoenix</i> (J.Ellis & Solander) Kützing, 1843					†	†	†							†						†															†	
	9	<i>Sargassum filipendula</i> C. Agardh, 1824		†				†	†			†															†						†					†
	10	<i>Styopodium zonale</i> (J.V.Lamouroux) Papenfuss, 1940		†			†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†					†	†	†
	11	<i>Valonia ventricosa</i> J. Agardh, 1887					†	†		†																			†		†						†	
Sponge	12	<i>Agelus schmidtii</i> Wilson, 1902								†						†					†							†		†								
	13	<i>Aplysina fistularis</i> (Pallas, 1766)				†	†		†	†																									†		†	
	14	<i>Aplysina</i> sp. Nardo 1834			†	†	†	†		†						†							†				†										†	
	15	<i>Amphimedon compressa</i> Duchassaing & Michelotti, 1864			†	†					†		†				†					†				†	†											
	16	<i>Callyspongia plicifera</i> (Lamarck, 1814)	†			†	†														†			†			†										†	
	17	<i>Callyspongia vaginalis</i> (Lamarck, 1814)				†	†															†																









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