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MARINE BIOLOGY

Marine Benthos



Biology, Ecosystem Functions
and Environmental Impact

RAFAEL RIOSMENA-RODRÍGUEZ
EDITOR

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MARINE BIOLOGY

MARINE BENTHOS

BIOLOGY, ECOSYSTEM FUNCTIONS AND ENVIRONMENTAL IMPACT

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RAFAEL RIOSMENA-RODRÍGUEZ

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PREFACE

Marine Benthos: Biology, Ecosystem Functions and Environmental Impact is a book dedicated to show a series of case studies about how benthic habitats are organized and how they function as a tool for any environmental impact studies. The present book documents how the natural condition of these communities is and aims to expand the authors' present knowledge about their organization. The human population growth is driving a very strong pressure over coastal areas, and now more than ever the author urgently need elements to evaluate environmental impacts. One of the most striking situations is the loss of biodiversity and the increase of invasive species who modify the trophic networks as well as the community structure. Many endangered species and species related to fisheries depend on the benthic habitat for their basic life cycle stages (reproduction, recruitment, nursery and feeding grounds) who might be impacted by natural and human induced causes. Ranging from species richness studies to population and community structure chapters, this book will bring the reader many options on how to measure environmental impacts. In particular, an analysis of how these environmental studies are made in Mexico provided a good example of how the present report base model is overdue and expresses the need for another approach. Keep in mind the present model does not take into account any statistical approach and is not mandatory in terms of the synergic and accumulative impacts; the lack of this consistency makes evaluation impossible to tell if the impacts are really happening.

Chapter 1 - The Gulf of California comprises a great diversity of benthic ecosystems. The western coast in particular is dominated by rocky and coral reefs that shelter a wide diversity and abundance of species. Despite the importance of benthic ecosystems for the structure and organization of associated communities, few studies have focused on the importance of benthos in the trophic organization of the fish community. In this chapter the fish communities of four areas of the Los Frailes rocky reef differing in benthic structural complexity (BSC) were evaluated through visual censuses. According to the BSC two low benthic structural complexity (LBSC) areas and two high complexity (HBSC) areas were identified. The HBSC areas had a higher number of cavities, greater depth and greater substrate heterogeneity. However, despite differences in structural complexity, the trophic organization of the ichthyofauna did not show significant changes in terms of formation of functional trophic groups (FTG) between the HBSC (21 FTG) and LBSC (19 FTG) locations. The biomass flow diagram of the different prey species of carnivorous, omnivorous and herbivorous fish present in the reef showed variable connections and biomass flow, with

dominance of benthic prey species, which highlights the importance of benthic invertebrates as a source of energy for the reef ichthyofauna.

Chapter 2 - The Mexican Caribbean and the Atlantic coast of Mexico have 3,294 km of coastline with diverse habitats and rich biota. Coastal ecosystems, unfortunately, are experiencing wide range of pressures due to siltation, eutrophication, coastal development and climate change. Those species that adapt to these pressures will expand their living boundaries while others may fade away. Accordingly, the study of coastal biodiversity is of great concern globally and constitutes an important element of global change research. Peninsula of Yucatan has 1,940 km of coastline, reportedly with rich diversity of seaweeds. Previously published accounts on seaweed biodiversity were mainly in the form of checklists. The present study is a timely publication based wholly on primary data. Data were collected through extensive and systematic field studies conducted by the authors during different seasons over an eleven years period since 2004 to 2014, also the authors checked herbarium's specimens that are housed in the herbarium ENCB. Analysis of the information showed that Rhodophyta has the greatest diversity with 317 species; Chlorophyta has 180; Phaeophyceae 70 and finally Cyanobacteria with 38 species. One of the groups best represented in the study area is the Order Corallinales with two families and 43 species, these organisms are of major ecological importance in the reefs of the Peninsula. Three species are new records from Mexican Caribbean, *Centroceras hyalacanthum*, *Metapeyssonnelia tangerina* and *Sarcodiotheca divaricate*, and sixteen species are new records for the study area. The importance of epiphytic algae in the study area is discussed as well as the use of molecular markers in order to solve taxonomic problems of selected genera of algae. The floristic list includes data on distribution, tidal level and habitat. On the other hand Quintana Roo is the state that has the greatest diversity of marine algae in the Gulf of Mexico and Mexican Caribbean's shores with 551 species. Topics on economic importance and extraction of bioactive substances are discussed, as well as suggestions on conservation of seaweeds from Yucatan Peninsula. Finally, several coastal towns in the Yucatan Peninsula are being impacted by natural events such as hurricanes as well as urban; tourism and industrial development, so it is important continue studies that allow us to characterize the changes that populations of seaweeds are undergoing.

Chapter 3 - Rocky shores are areas of high diversity and productivity providing goods and services. Since humans are altering nature at an unprecedented rate, producing shifts in important parameters for life such as temperature, habitat availability, water quality, among others, it is expected that species will respond by changing their natural distributions and/or abundances. To understand how species will respond to such changes, it is necessary to learn the processes that determine these patterns. The South American Research Group on Coastal Ecosystems was established to assess marine diversity and biomass along both coasts of South America through an international collaboration. The main goals of SARCE are to: (1) Test hypotheses about latitudinal gradients and patterns of local and regional biodiversity, (2) Identify the relationship between biodiversity and ecosystem functioning, (3) Assess the effect of environmental gradients and anthropogenic stressors, (4) Carry out capacity building and training activities aimed to solve environmental problems for the benefit of society. The SARCE network has sampled the coasts of nine countries around South America with a standardized protocol in more than 150 sites (2010-2014), ranging from 11° North to 55° South. This chapter provides a description of the biodiversity of the sites sampled by SARCE,

along with a review of the uses and services that these ecosystems provide to human populations and the main threats and impacts these uses have caused.

Chapter 4 - *Acanthophora spicifera* is a red algae, native to the Caribbean, was introduced to the Hawaiian Islands in the early 1950's, where he Invasive catalog. His success as an invader is attributed to having the ability to reproduce both sexually and vegetatively by fragmentation or by spores. Their growth is accelerated and invades Pacific coral reefs. Prevents nutrients and sunlight to penetrate these ecosystems producing that reduce populations of resident seaweeds and corals. In Punta Roca Caimancito, BCS, a blanket of *A. spicifera*, which formerly dominated the brown algae of the genus Sargassum found. The temperature at which develops in Punta Roca Caimancito was 20-29. It can be found growing on a variety of substrates epilithic hard rock, dead coral or shells, even as an epiphyte on other species of macroalgae or epizoica invertebrates. They have a simpodial and apical growth, presents secondary branches, has a rough or rough texture, has a disk-shaped, in its main axis no thorns. It is characterized by a highly branched and bushy, leafy thallus. Apical meristem, spines of 3 mm, which may vary morphologically. In cross-section was observed that pericentral cells are dense. Commonly axial cells in the center. In the study area this invasive algae reproduces asexually (fragmentation). The extension of the mantle in Punta Roca Caimancito of has continued to increase since 2006 in which you registered for the first time. The current extension (2009) is 31536.93m² or 3.16 Hectares. The maximum average biomass dry weight was 8.12 t/ha and 3.16 minimum 1.18 Ton/3.16 h. The color varies from brown to red. The average length of the thalli was 163 mm and 108 mm maximum minimum in the period October 2008 to October 2009. The annual average was 154 mm. The ANOVA showed differences between different months being October others to present longer than season. The maximum number of branches value was 7 and at least 5 branches per thallus. ANOVA performed for the numbers of branches not show significant differences. The average monthly number of spines has a maximum value of 5.4 mm² and a minimum of 3.9 mm². The ANOVA shows differences per month, October being the one with the highest number of spines. The biomass is higher in the autumn season. And in winter drastically reduces the population. The average of the highest biomass is 0.26 kg/m² and was presented in November; the minimum dry weight biomass was presented in February 0.0375 kg/m². The average annual biomass dry weight is 0.29 kg/m². The flora and fauna that was associated with *A. spicifera* goes from epiphytic algae molluscs, echinoderms, sponges to fish. The maximum monthly average was 0.20 kg/m² and a minimum of 0.031 kg/m². The result of the correlation indicates no relationship between biomass and plant-fauna ($r = -0.1892$). The authors conclude that *A. spicifera* its development at temperatures ranging from 20-29°C. Morphological characters posing *A. spicifera* of Punta Roca Caimancito are similar to those reported by other authors. The main mode of reproduction of *A. spicifera* is asexually by fragmentation and occurs all year round (perennial). Sexual reproduction was limited in spring-summer, only empty conceptáculos were observed. Presents greater lengths during autumn and lower in winter. The number of spines is not related to the length of the branch. The maximum number of branches was 7 in autumn and winter and minimum of 4 branches per talo in summer. The maximum number of thorns thorns was 5.4 mm⁻² and the minimum was 3.9 mm⁻² spines. The percentage of wet weight biomass of *A. spicifera* is greater in autumn with 3.50 kg/m² and the lowest was in winter with 0.59 kg/m². The percentage of biomass dry weight of *A. spicifera* is greater in autumn with 0.86 kg/m² and the lowest was in winter with 0.0375 kg/m². The impact of *A. spicifera* in Punta Roca Caimancito is negative

for coral reefs because high densities of this algae can affect the uptake of light and nutrients and thus affect their growth.

Chapter 5 - The twin island state of Trinidad and Tobago is the Caribbean's southern-most island state located between 10° to 11° North latitude and 60° to 61° West longitude. Like most of the Caribbean small-island states, Trinidad and Tobago's coastal waters are an economically important natural resource and at the same time, a vulnerable one. Trinidad and Tobago is a producer of oil and natural gas with the energy sector being by far, the most important contributor to the country's GDP, Government revenues and foreign exchange. Crude oil production averaged 122,902 barrels per day (bbl/d) in 2004, while natural gas production averaged 2,938 million standard cubic feet per day (Ministry of Planning and Development Central Statistical Office, 2007). The petrochemical sector (at Point Lisas Industrial Estate, west coast of Trinidad) has continued to expand in line with natural gas production producing methanol, ammonia, urea, and natural gas liquids. In this respect, Trinidad and Tobago is the 5th largest exporter of liquid nitrogen gas (LNG) in the world, and the single largest supplier of LNG to the U.S.A. (between 70-75% of all LNG imported into the U.S.A, Ministry of Planning and Development Central Statistical Office, 2007). Coupled with this, La Brea on the south-west coast of Trinidad is home to the world famous Asphalt or Pitch Lake. This coastal area in Trinidad has one of the highest known natural seepage rates on earth - an estimated 100 barrels per dy per 2560 km².

Chapter 6 – The authors examined the possibility of using the length of the outermost sheath (OSL) to predict values of different variables of *Zostera marina* (eelgrass), as the authors' previous observations indicated a strong correspondence between eelgrass length structures (leaves and sheaths) and its biological and morphometric variables, i.e., growth, production, and leaf area. The authors first determined leaf growth and production by means of the Ibarra-Obando and Boudouresque (1994) technique, and then used correlation matrixes to explore the relationship between length of shoot leaves and sheaths, and the following variables: shoot growth (SG), leaf production (LP), shoot weight (SW = sum of weights of all leaves and sheaths in a shoot), and shoot leaf area (SLA) in order to predict them, based on a single shoot structure easy to measure in the field. The authors' results indicate that the OSL is a reliable and easy technique to measure a variable that can be used to predict the variables mentioned above on two-week and monthly periods. Then the authors must emphasize the importance to developing predictive equations for each study region as the only way to prevent over or underestimation of the variables of interest.

Chapter 7 - The geographic and bathymetric patterns of distribution of *Nephropsis occidentalis*, the only marine decapod crustacean of the infraorden Astacidea known from the eastern Pacific Ocean, were studied on the continental slope off the Mexican Pacific, and environmental drivers of those patterns were investigated. Samplings were performed using an Agassiz dredge and a benthic sledge in three main areas: the Gulf of California, the west coast of the Baja California Peninsula and the southern Mexican Pacific. Twelve sampling cruises were performed from 1991 to 2014, by which 171 hauls were obtained between 522 and 2309 m. Temperature, oxygen, salinity and total organic matter from sediments were sampled simultaneously, and data of surface production were recorded. The relationship between the patterns in abundance of *N. occidentalis* and potential environmental drivers was explored through generalised linear models. In addition, all previously published and unpublished records of the species were compiled and bathymetric patterns of distribution along latitude were explored. Within Mexico, 85 specimens of *N. occidentalis* were captured

over a narrow bathymetric range, mainly between 1000 and 1300 m, at oxygen concentrations above hypoxia. Because of its high level of activity, this species is likely excluded from hypoxic waters. Males and females were of similar size and larger individuals were restricted to depths greater than 1100 m. The bathymetric patterns of distribution of *N. occidentalis* were associated with oxygen and temperature, probably because of the interdependence between aerobic capacity and temperature tolerance in ectothermic animals. In addition, surface production enhanced aggregations of *N. occidentalis* four months later. In the Mexican Pacific, *N. occidentalis* occurs in environmental conditions with 0.22-0.87 ml O₂ l⁻¹ and 3.4-4.4°C. Including unpublished records, a total of 61 localities where the species occurs were compiled and a continuous distribution of *N. occidentalis* along the continental slope of the Eastern Pacific from Mexico (ca. 27°N) to Chile (ca. 33°S) was confirmed. The first depth of appearance of *N. occidentalis* slightly decreased southwards and somehow followed the bathymetric distribution of the OMZ, thus confirming the effects of such structure on the distribution of the species. Finally, fishery potential of the species is briefly addressed and compared to what is known about similar deep-water species worldwide.

Chapter 8 - Sea turtles are migratory vertebrates that are linked to many coastal and marine habitats in different parts of the world depending on the stage of their life cycle. These agencies have given them a higher value as a sentinel species by characteristics such as longevity, size, resilience to environmental changes of the seas, and even changes induced by humans as environmental pollution. One of the main risks to sea turtles is drowning in gill nets or trawl fisheries used in flake or shrimp; it has been extensively analyzed in different regions of the country and the world. However, the effects of environmental pollution on the health of sea turtles is the least studied. The environment has been altered dramatically in recent years by rising temperatures, increased severity, and frequency of storms and rising sea level, where most human settlements have been deforested and changed land use for urban, port and tourist developments. In the case of turtles, these changes affect species differentially throughout his life. For example, climate change and temperature variations can affect the sex ratio of the hatchlings and nesting patterns since they depend on healthy beaches to lay eggs, so the migration patterns of females could be affected significantly by climate change. The dependence of sea turtles of seagrass meadows, mangrove forest, rhodolith beds, Sargassum forest, coral reefs and deep ocean to live, give them the importance of indicators of the environmental health of these ecosystems. Understanding how pollution and climate change may affect these ecosystems not only benefit conservation programs of populations of sea turtles, but also the diversity associated with them. On which they depend on millions of people living along the shores of the world using marine resources and ecosystem services for their economic activities and food safety.

Chapter 9 - Mollusks mesograzers are an important ecological factor in subtidal environments. The authors analyzed conspicuous habitats from Gulf of California and Mexican Pacific littoral in northwest to answer: 1) How are formed the associated mollusks assemblages? 2) Is taxocenosis structure maintained over time and space inside habitats? 3) How does biodiversity change between habitats? Mollusks were found in critical habitats *Zostera marina*, rhodoliths and *Sargassum* forest, and invasive red seaweed *Acanthophora spicifera*. The authors made clusters about their presence in different geographical sectors and surveys using qualitative and quantitative data. 75 small species were recorded. Rhodoliths was the habitat with higher richness (25) and diversity, as well eelgrass beds (24). The grouping shows one assemblage that contains localities with eelgrass, the second rhodoliths,

and the third seaweeds. Small gastropods *Acteocina*, *Alabama*, and *Barleeia* were essential components in all hosts. The structure changed over time and between habitats. Results suggest similar assemblages in eelgrasses and distant regards brown/red seaweeds as well rhodolith beds. This study highlights the importance of *Zostera marina* beds by evidence of similarity even localities inside and outside gulf; coralline beds by preserving atypical diversity and brown/red seaweeds as transitional microhabitats and temporary corridors subject to further change. These interactions are more complex than estimated, but this contribution helps to understand these critical habitats as biological corridors and implications on mollusk distribution.

Chapter 10 - By means of behavioral studies it has been determined for the first time in Mexico the critical habitat of a semi-resident group of coastal dolphin *Tursiops truncatus* (bottlenose dolphin) in Ensenada de La Paz and the south-southeast of Bahía de La Paz. In this zone it is more frequent to observe small groups of mothers with calves and juvenile dolphins. Through the years it has been recorded a habitat shift of these cetaceans induced by environmental and anthropogenic factors: loss of southwest basin in Ensenada de La Paz due to silting, dredging and tropical cyclones; similarly a reduction of the feeding activity has been observed in the northwest basin due to fisheries and the increase of nautical traffic which overlaps with the main transit route of bottlenose dolphins near El Mogote, thus affecting their conduct. The disturbance could increase because of dredging realized in 2012 by the touristic development Paraiso del Mar to build a dock for a marina in El Mogote, affecting particularly zones where females teach juvenile dolphins to feed next to mangroves. Unfortunately, the ecological, social and economic importance of these coastal wetlands it is not considered, subject to a stress and risk increase in the last decades due to non-regulated deforestation and dredging, as a consequence of the mentioned touristic development for the construction of a golf course, and affecting the mangrove zone. It is imperative a decree by SEMARNAT stating Ensenada de La Paz and south of Bahía de La Paz as a critical habitat for dolphins, based on the scientific information available; given the current threats on this Ramsar site and its communities, the lack of acknowledgement as a critical zone, and the need to be included in the environmental impact evaluation for coastal developments. By including them as part of the environmental policy other species will be protected too, establishing general management plans for its conservation, building agreements with environmental authorities, researchers, government agencies, society organizations, fishermen, and general public.

Chapter 1

**IMPORTANCE OF BENTHOS IN THE TROPHIC
STRUCTURE OF THE ICHTHYOFaUNA
OF LOS FRAILES REEF,
GULF OF CALIFORNIA, MEXICO**

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ABSTRACT

The Gulf of California comprises a great diversity of benthic ecosystems. The western coast in particular is dominated by rocky and coral reefs that shelter a wide diversity and abundance of species. Despite the importance of benthic ecosystems for the structure and organization of associated communities, few studies have focused on the importance of benthos in the trophic organization of the fish community. In this chapter the fish communities of four areas of the Los Frailes rocky reef differing in benthic structural complexity (BSC) were evaluated through visual censuses. According to the BSC two low benthic structural complexity (LBSC) areas and two high complexity (HBSC) areas were identified. The HBSC areas had a higher number of cavities, greater depth and greater substrate heterogeneity. However, despite differences in structural complexity, the trophic organization of the ichthyofauna did not show significant changes

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in terms of formation of functional trophic groups (FTG) between the HBSC (21 FTG) and LBSC (19 FTG) locations. The biomass flow diagram of the different prey species of carnivorous, omnivorous and herbivorous fish present in the reef showed variable connections and biomass flow, with dominance of benthic prey species, which highlights the importance of benthic invertebrates as a source of energy for the reef ichthyofauna.

INTRODUCTION

Reef systems represent the interdependence between the physical environment and organic activity. Physical factors are decisive in reef formation and in the specific composition of the benthic community that lives there (Jones and Endean, 1977). It has been shown that the factors that determine the benthic community structure of reef systems are caused by physical parameters that dictate the structure in shallow areas, and by biological parameters that are decisive in deeper areas, where competition for food and space is an important factor in this type of community (Glynn et al., 1972; Liddell and Ohlhorst, 1987; Borges-Souza, 2003).

The composition of the fish species assemblage associated to rocky and coral reef systems is the result of the interaction of several processes, including biotic factors associated with recruitment, predation and competition, and abiotic factors such as habitat structure (Ebeling and Hixon, 1991). Reef fish can respond to several aspects of habitat structure (substrate type, size and shape of cavities, crevices, rocks, algal growth, coral growth, etc.) that influence their distribution, abundance, specific richness and diversity (Álvarez-Philip, 2004). Several studies have examined the effect of different habitat characteristics and different attributes of the community (Luckhurst and Luckhurst, 1978; Roberts and Ormond, 1987; Öhman and Rajasuriya, 1998). Some of these studies reported a positive relationship between structural habitat complexity and ecological community indices such as fish diversity and rugosity (Risk, 1972; Roberts and Ormond, 1987). However, other studies report no such relationship (Sale and Dybdahl, 1975; Luckhurst and Luckhurst, 1978).

These differing results could be due to not all structural characteristics of the habitat having the same influence on each attribute of the fish community and influencing differently each of the species that comprise it (Roberts and Ormond, 1987; Grigg, 1994; McClanahan, 1994; Gratwicke and Speight, 2005). Depending on the structural complexity of the habitat, a greater or smaller number of microhabitats can be established that impact the degree of competition among species and individuals, as well as the persistence of the predators and their prey, which in turn impacts directly the different attributes of the community (abundance, species richness and diversity) (Crowder and Cooper, 1982; Wooton, 1990; Gerking, 1994).

To analyze jointly the functioning and feeding organization of the ichthyofauna within a community context it is necessary to investigate the effect of the habitat structural complexity and existing trophic relationships (functional groups) (Elliott et al., 2007). In this chapter we analyzed the effect of the habitat complexity on the structure and trophic organization of the conspicuous ichthyofauna of the Los Frailes reef, B.C.S., in order to determine the ecological role of the habitat structural complexity (as one of the main factors) in the variability of benthic fish associations in this area of the mouth of the Gulf of California (GC).

The Los Frailes reef is located at 23°25'N and 109°30'W (Figure 1). It is part of Cabo Pulmo National Park, at the entrance to the GC (Robinson and Thomson, 1992; Reyes Bonilla, 1997). The Los Frailes Bay is located in a transition zone between the Eastern Tropical Pacific and the Temperate Eastern Pacific, where three water masses converge: (1) cold low-salinity water (34.6 PSU; practical salinity units) of the California Current; (2) warmer medium-salinity water (34.65-34.85 PSU) from the southeast, carried by the Costa Rica coastal current; and (3) warm high-salinity water (>34.9 PSU) from the GC (Álvarez-Borrego and Lara-Lara, 1991).

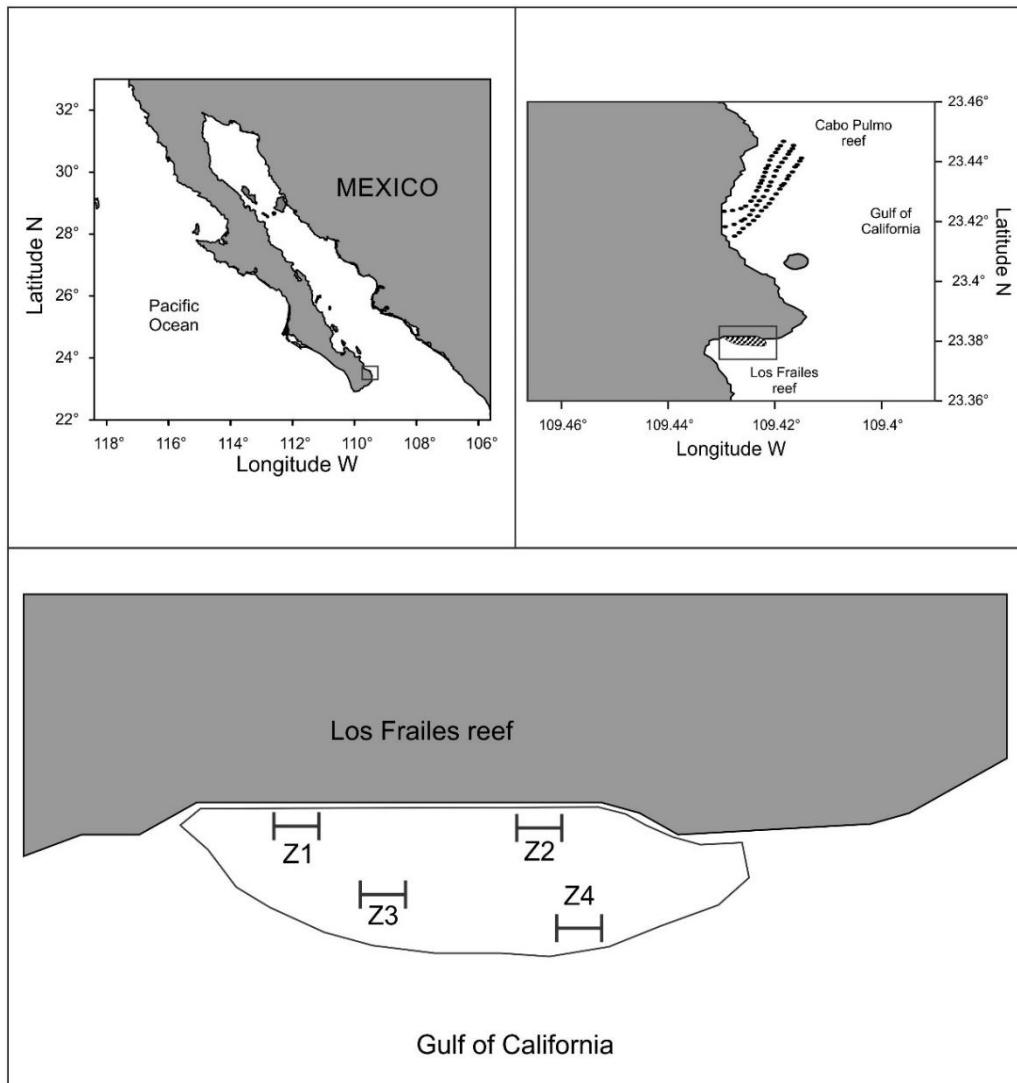


Figure 1. Los Frailes reef. Locations Z1 and Z2 have low benthic structural complexity (LBSC) and locations Z3 and Z4 have high benthic structural complexity (HBSC).

There are no studies to date on oceanographic variables at Los Frailes reef, only isolated measurements of some variables taken in Cabo Pulmo reef (Trasviña-Castro et al., 2013). The

mean temperature on the reef is 24.9°C, but there are temperature records of 17°C in February 1988 and of 32°C in August 1997 (Anaya-Reyna, 1993). Salinity remains relatively constant at 35 PSU year-round. Water in the area has low turbidity and precipitation is low at 200 mm year⁻¹, although two creeks flow into the Los Frailes area and provide an important volume of fresh water and terrestrial sediment. The rainy season ranges from July to September (Anaya-Reyna, 1993). Large structures and rocks can be observed in this area from the intertidal zone to 15 m depth, with presence of sandy patches (Moreno-Sánchez, 2009). Four sampling areas were chosen at locations Z1 and Z2, found at a shallow depth of between 1 and 3 m. These two locations are characterized by high energy waves, by rocky material that ranges in size from pebbles (20 to 30 cm) to blocks over 3 m in diameter, and by a not very steep beach slope. Both locations had 80 percent rock cover and presence of coral heads.

The Z3 and Z4 locations were situated at an intermediate depth of 7 to 10 m. At these locations there were fewer pebbles, the slope was steeper, there was 70% percent cover of rocky material, with up to 20% sand cover. These two locations were at the transition between the rocky part of the reef and the sandy ocean bottom (Figure 1). The submarine Los Frailes canyon, with a depth of over 1000 m, is located near the reef. This bathymetric feature enables the presence of pelagic species and of local events such as upwelling (Fiedler, 1992; Reyes Bonilla, 2001). To characterize the benthic structural complexity (BSC) the following characteristics were taken into account at each location:

Characteristic	Measurement
Depth	Depth was measured at 3 points along the transect using a standard scuba depth gauge, and a mean depth was calculated for each sampling area.
Substrate type cover	Substrate cover (rock, coral and sand) was calculated from 250 1m ² photographs taken at each transect, using the program Coral Point (V3.4)
Number of cavities	All cavities were counted at each location
Rugosity index (RI)	The method of contour distance to linear distance was used (McCormick, 1994). This was calculated as the proportion between the final length of a chain (10 m long; 0.5 cm links) placed over the substrate topography and the total linear distance (10m).
Rock size	The size of rocks at each location was categorized according to diameter (\emptyset), in the following way: A = (\emptyset) < 30 cm (pebble; B = 30 cm < (\emptyset) > 1m; C = 1m < (\emptyset) < 3m; D = L (\emptyset) 3m (Aburto-Oropeza, 1999).

Sampling trips were carried out monthly from November 2004 to October 2006 at four locations (Z1 and Z2 at shallow depths, Z3 and Z4 at intermediate depths), within the Los Frailes reef, B.C.S. The method of visual censuses by scuba and free diving was used, which is a method commonly used in fish ecology studies of this type of community (Bortone et al., 1991). Censuses were carried out along transects. This technique is recommended when a quantitative estimate of abundance is needed.

In this chapter transects 50 m long by 5 m wide were used (Elorduy-Garay and Jiménez-Gutiérrez, 2000). Censuses were carried out during daylight hours between 10:00 and 16:00, which is when illumination is best. Transects started from a fixed point along the shore where coordinates were taken using a global positioning system (GPS). All fish species and abundances were recorded on acrylic sheets using graphite pencils. Photographs and videos

were also taken for later reference, comparing with specialized bibliography (e.g., Fischer et al., 1995; Thomson et al., 2000; Gotshall, 2001; Robertson and Allen, 2008).

With the recorded information a systematic list of conspicuous fish at the Los Frailes reef was assembled. The composition was evaluated counting the number of species present in each sample at each location (Brower and Zar, 1977).

In order to obtain a hierarchical location of species within the community, species were grouped into four categories according to their frequency and relative abundance at each location in the following manner (Villegas-Sánchez et al., 2009):

- Rare species: relative abundance under 0.1%
- Common species: relative abundance under 1% and over 0.1%
- Frequent species: relative abundance over 1% and under 10%
- Abundant species: relative abundance over 10%

To evaluate the diversity of functional trophic groups defined as a set of permanent or temporal polyphyletic species sharing morphological characteristics and carrying out equivalent functions in the ecosystem (Naeem and Li, 1997; Blondel, 2003), a search of ecological attributes and morphological characteristics was carried out. The ecological attributes taken into account were diet, trophic level, species residency (frequency and abundance), and position in the water column, whereas the morphological characteristics taken into account were length (cm), average weight, form of the caudal fin, position and type of mouth. These attributes and characteristics were selected based on studies by several authors who selected them as key characteristics associated to the function of a species within an ecosystem (Sánchez-Gil and Yáñez-Arancibia, 1997; Mathieson et al., 2000; Dumay et al., 2004; Álvarez-Filip and Reyes-Bonilla, 2006). The information was obtained from books, scientific articles and the FISHBASE data base (Froese and Pauly, 2006; <http://www.fishbase.org>).

Excepting diets, all data were standardized using the square root transformation. Diet was recorded as the percent weight of each prey species. A cluster analysis was carried out starting from a similarity matrix (calculated using the Bray-Curtis similarity index with complete linkage). The samples were successively joined in groups according to the highest similarity value. This process ended when one unit containing all samples was obtained (Clarke and Warwick, 2001). Results were represented in a dendrogram, where the "y" axis represented all groups and the "x" axis defined the similarity level at which all groups or samples were deemed to be joined. The trophic categories (TC) were obtained using the program PRIMER 6.1.6. The selection of the cut-off point in the dendrogram was arbitrary, selecting a similarity level that would produce a manageable number of groups and would at the same time maximize the biological coherence among the members of each TC (Simberloff and Dayan, 1991; Petchey and Gaston, 2002).

To determine the importance of benthos in the trophic organization of the fish community the differences between the number of species and the functional trophic groups (FTG) were evaluated. The biological consistency of the functional groups was analyzed using the species that integrated a FTG in particular and presented similar characteristics in habitat use. We also determined whether several species carried out the same ecological role within the community (ecological redundancy). To estimate the importance of the benthos in the trophic

organization of the fish community of the Los Frailes reef the FTG were integrated into three feeding categories: herbivores (diet composed of over 70% algae), omnivores (diet composed of 30% algae and 70% animals), and carnivores. On this basis a biomass flow diagram was designed. This type of analysis allows the visualization of how the different prey and predator species are connected, as well as the number of connections within the reef.

The Z3 and Z4 locations were deeper (mean = 8 meters; Figure 2a). There was a high percentage of rock substrate at all locations; the Z3 location had more sand cover, and the Z1 location had more coral cover (Figure 2b). The Z3 and Z4 locations had more cavities and higher rugosity (Figure 2c and d). The Z3 location had small-sized rocks, while the Z1 and Z4 locations had larger rocks (Figure 2e). The descriptors of BSC allowed the separation of locations in two groups with different levels of complexity: the shallow Z1 and Z2 stations made up the low BSC group (LBSC), while the Z3 and Z4 stations made up the high BSC group (HBSC) (Figure 2f).

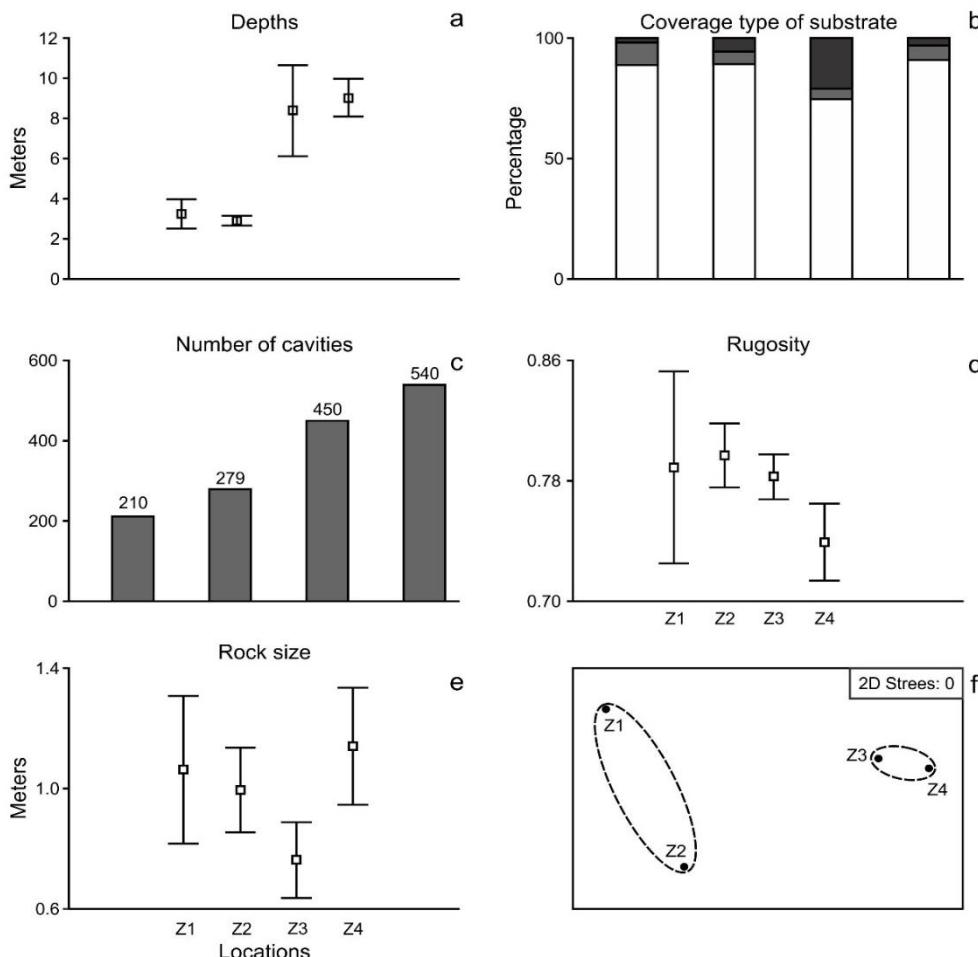


Figure 2. Habitat characteristics at each location. Z1 northwest, Z2 northeast, Z3 southwest, Z4 southeast. (a) average depth (□) and standard deviation (T); substrate cover, (b) white: rock cover, grey: coral cover, black: area cover, (c) number of cavities; (d) rugosity – average (□) and standard deviation (T); (e) rock size, average (□) and standard deviation (T).

Composition of the Fish Community

A total of 88 monthly sampling trips were conducted in 2005 and 2006. A total of 34,887 fish were counted, belonging to 31 families, 61 genera and 89 species (Table 1). The total richness was 89 species. In the HBSC locations species richness was 89 species with an average of 25 species, while at LBSC locations species richness was 77 species, with average values of 17.36 species at Z1 and 16.36 species at Z2 (Figure 3a).

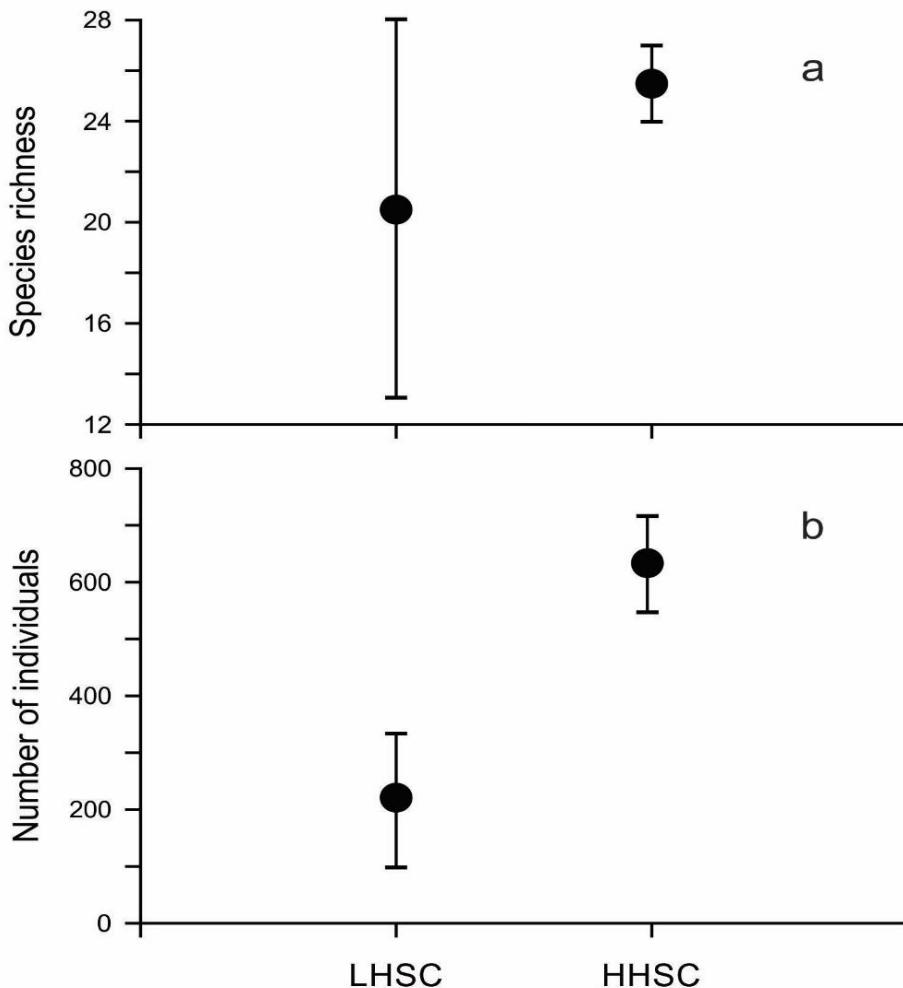


Figure 3. Species richness and total abundance, average and standard deviation (T) at low benthic structural complexity (LBSC) and high benthic structural complexity (HBSC) locations.

Table 1. Systematic list of reef fish species in Los Frailes, including scientific name, abundance, frequency, classification according to abundance and frequency, presence in HBSC or LBSC, warm or cool season. O = species present, X = species absent

Species	relative abundance (n = 34 887)	% occurrence (n = 88)	Classification	HBSC	LBSC	functional trophic group	cold season
CLASS CHONDRICHTHYES							
ORDER MYLIOBATIFORMES							
FAMILY MYLIOBATIDAE							
<i>Rhinoptera steindachneri</i> Evermann and Jenkins, 1892	0.02	1.1	Rare	O	X	18	+
CLASS ACTINOPTERYGII							
ORDER ELOPIFORMES							
FAMILY ELOPIDAE							
<i>Elops affinis</i> Regan, 1909	0.13	4.5	Common	O	O	1	+
ORDER ANGUILLIFORMES							
FAMILY MURAENIDAE							
<i>Gymnothorax castaneus</i> (Jordan and Gilbert, 1883)	0.06	14.8	Rare	O	O	2	+
<i>Muraena lentiginosa</i> Jenyns, 1842	0.01	4.5	Rare	O	X	2	X
ORDER AULOPIFORMES							
FAMILY SYNODONTIDAE							
<i>Synodus lacertinus</i> Gilbert, 1890	0.01	3.4	Rare	O	X	3	O
ORDER BERYCIFORMES							
FAMILY HOLOCENTRIDAE							
<i>Myripristis leiognathos</i> Valenciennes, 1846	0.05	9.1	Rare	O	O	20	O
<i>Sargocentron suborbitalis</i> (Gill, 1863)	0.18	17.0	Common	O	O	20	O
ORDER GASTEROSTEIFOMES							
FAMILY FISTULARIIDAE							
<i>Fistularia commersonii</i> Rüppell, 1838	0.46	35.2	Common	O	O	1	O
ORDER SCORPAENIFORMES							
FAMILY SCORPAENIDAE							
<i>Scorpaena mystes</i> Jordan and Starks, 1895	0.07	9.1	Rare	O	O	3	O
FAMILY SERRANIDAE							
<i>Alphestes multiguttatus</i> (Günther, 1867)	0.03	5.7	Rare	O	O	12	O
<i>Cephalopholis panamensis</i> (Steindachner, 1877)	0.23	27.3	Common	O	X	2	X
<i>Epinephelus labriformis</i> (Jenyns, 1840)	0.12	29.5	Common	O	O	3	O

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Species	Relative abundance (n = 34 887)	% occurrence (n = 88)	Classification	HBSC	LBSC	functional trophic group	cold season
<i>Mycteroperca rosacea</i> (Streets, 1877)	0.24	26.1	Common	O	O	3	O
<i>Paranthias colonus</i> (Valenciennes, 1846)	0.45	26.1	Common	O	O	21	O
<i>Rypticus nigripinnis</i> Gill, 1861	0.02	4.5	Rare	O	O	3	O
<i>Serranus psittacinus</i> Valenciennes, 1846	0.44	34.1	Common	O	O	3	O
<i>Serranus</i> sp.	0.00	1.1	Rare	O	O	3	O
FAMILY APOGONIDAE							
<i>Apogon retrosellus</i> (Gill, 1862)	0.66	15.9	Common	O	O	7	O
FAMILY NEMATISTIIDAE							
<i>Nematistius pectoralis</i> Gill, 1862	0.01	1.1	Rare	O	X	1	X
FAMILY CARANGIDAE							
<i>Caranx caballus</i> Günther, 1868	0.27	12.5	Common	O	O	1	O
<i>Caranx caninus</i> Günther, 1867	0.50	3.4	Common	O	O	1	X
<i>Caranx melampygus</i> Cuvier, 1833	0.17	10.2	Common	O	O	1	O
<i>Gnathanodon speciosus</i> (Forsskål, 1775)	0.16	9.1	Common	O	O	1	O
<i>Trachinotus rhodopus</i> Gill, 1863	0.31	14.8	Common	O	O	18	O
FAMILY LUTJANIDAE							
<i>Hoplopagrus guentherii</i> Gill, 1862	0.06	10.2	Rare	O	O	9	O
<i>Lutjanus viridis</i> (Valenciennes, 1846)	1.20	38.6	Frequent	O	O	3	O
FAMILY GERREIDAE							
<i>Gerres simillimus</i> Reagan, 1907	0.01	2.3	Rare	O	O	20	O
FAMILY HAEMULIDAE							
<i>Haemulon flaviguttatum</i> Gill, 1862	1.63	6.8	Rare	O	O	20	O
<i>Haemulon maculicauda</i> (Gill, 1862)	0.58	11.4	Common	O	O	7	O
<i>Haemulon sexfasciatum</i> Gill, 1862	0.15	9.1	Common	O	O	21	O
<i>Microlepidotus inornatus</i> Gill, 1862	1.05	17.0	Frequent	O	O	21	O
FAMILY MULLIDAE							
<i>Mulloidichthys dentatus</i> (Gill, 1862)	1.26	34.1	Frequent	O	O	21	O
FAMILY KYPHOSIDAE							
<i>Kyphosus elegans</i> (Peters, 1869)	0.10	9.1	Rare	O	O	13	O
<i>Kyphosus vaigensis</i> (Quoy and Gaimard 1825)	0.01	3.4	Rare	O	O	13	O

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Table 1. (Continued)

Species	Relative abundance (n = 34 887)	% occurrence (n = 88)	Classification	HBSC	LBSC	functional trophic group	Cold season
FAMILY CHAETODONTIDAE							
<i>Chaetodon humeralis</i> Günther, 1860	0.21	19.3	Common	O	O	14	O
<i>Johnrandallia nigrirostris</i> (Gill, 1862)	0.25	27.3	Common	O	O	6	O
FAMILY POMACANTHIDAE							
<i>Holacanthus clarionensis</i> Gilbert, 1891	0.30	22.7	Common	O	O	6	O
<i>Holacanthus passer</i> Valenciennes, 1846	1.95	81.8	Frequent	O	O	8	O
FAMILY CIRRHIRIDAE							
<i>Cirrhitichthys oxycephalus</i> (Bleeker, 1855)	1.35	58.0	Frequent	O	O	8	O
<i>Cirrhitus rivulatus</i> Valenciennes, 1846	0.04	6.8	Rare	O	O	3	O
FAMILY POMACENTRIDAE							
<i>Abudefduf troschelii</i> (Gill, 1862)	3.84	63.6	Frequent	O	O	16	O
<i>Chromis atrilobata</i> Gill, 1862	12.74	70.5	Abundant	O	O	17	O
<i>Chromis limbaughi</i> Greenfield and Woods, 1980	0.73	15.9	Common	O	O	17	O
<i>Microspathodon bairdii</i> (Gill, 1862)	0.02	2.3	Rare	O	O	13	O
<i>Microspathodon dorsalis</i> (Gill, 1862)	2.05	55.7	Frequent	O	O	5	O
<i>Stegastes acapulcoensis</i> (Fowler, 1944)	0.19	10.2	Common	O	O	21	O
<i>Stegastes flavilatus</i> (Gill, 1862)	0.60	48.9	Common	O	O	21	O
<i>Stegastes rectifraenum</i> (Gill, 1862)	3.39	63.6	Frequent	O	O	21	O
FAMILY LABRIDAE							
<i>Bodianus diplotaenia</i> (Gill, 1862)	1.63	60.2	Frequent	O	O	8	O
<i>Halichoeres chierchiae</i> di Caporiacco, 1947	0.07	10.2	Rare	O	O	9	O
<i>Halichoeres dispilus</i> (Günther, 1864)	1.49	33.0	Frequent	O	O	8	O
<i>Halichoeres melanotis</i> (Gilbert, 1890)	0.11	4.5	Common	O	O	9	O
<i>Halichoeres nicholsi</i> (Jordan and Gilbert, 1882)	0.17	19.3	Rare	O	O	15	O
<i>Halichoeres notospilus</i> (Günther, 1864)	0.56	12.5	Common	O	O	9	O
<i>Halichoeres semicinctus</i> (Ayres, 1859)	0.70	3.4	Common	O	O	9	O
<i>Novaculichthys taeniourus</i> (Lacepède, 1801)	0.03	4.5	Rare	O	O	19	O
<i>Thalassoma grammaticum</i> Gilbert, 1890	2.98	70.5	Frequent	O	O	21	O

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Species	Relative abundance (n = 34 887)	% occurrence (n = 88)	Classification	HBSC	LBSC	Functional trophic group	Cold season
<i>Thalassoma lucasanum</i> (Gill, 1862)	35.36	100.0	Abundant	O	O	21	O
<i>Xyrichtys pavo</i> Valenciennes, 1840	0.04	5.7	Rare	O	O	19	O
FAMILY SCARIDAE							
<i>Nicholsina denticulata</i> (Evermann and Radcliffe, 1917)	0.34	11.4	Common	O	O	4	O
<i>Scarus compressus</i> (Osburn and Nichols, 1916)	0.47	25.0	Common	O	O	4	O
<i>Scarus ghobban</i> Forsskål, 1775	0.72	54.5	Common	O	O	4	O
<i>Scarus perrico</i> Jordan and Gilbert, 1882	0.65	52.3	Common	O	O	4	O
<i>Scarus rubroviolaceus</i> Bleeker, 1847	0.32	25.0	Common	O	O	4	O
<i>Scarus</i> sp.	0.10	6.8	Common	O	O	4	O
FAMILY TRIPTERYGIIDAE							
<i>Crocodilichthys gracilis</i> Allen and Robertson, 1991	0.01	2.3	Rare	O	O	8	X
FAMILY BLENNIIDAE							O
<i>Ophioblennius steindachneri</i> Jordan and Evermann, 1898	0.16	19.3	Common	O	O	5	O
<i>Plagiotremus azaleus</i> (Jordan and Bollman, 1890)	1.08	37.5	Frequent	O	O	8	O
FAMILY LABRISOMIDAE							
<i>Labrisomus multiporosus</i> Hubbs, 1953	0.12	6.8	Common	O	O	9	O
<i>Labrisomus xanti</i> Gill, 1860	0.01	3.4	Rare	O	O	12	O
<i>Malacoctenus hubbsi</i> Springer, 1959	0.00	1.1	Rare	O	X	11	X
<i>Malacoctenus margaritae</i> (Fowler, 1944)	0.01	2.3	Rare	O	X	12	X
FAMILY ZANCLIDAE							
<i>Zanclus cornutus</i> (Linnaeus, 1758)	0.23	22.7	Common	O	O	6	O
FAMILY ACANTHURIDAE							
<i>Acanthurus nigricans</i> (Linnaeus, 1758)	0.01	2.3	Rare	O	O	13	O
<i>Acanthurus triostegus</i> (Linnaeus, 1758)	0.88	19.3	Common	O	O	4	O
<i>Acanthurus xanthopterus</i> Valenciennes, 1835	0.57	28.4	Common	O	O	21	O
<i>Prionurus laticlavius</i> (Valenciennes, 1846)	0.40	10.2	Frequent	O	O	4	O

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Table 1. (Continued)

Species	Relative abundance (n = 34 887)	% occurrence (n = 88)	Classification	HBSC	LBSC	Functional trophic group	Cold season
<i>Prionurus punctatus</i> Gill, 1862	7.61	85.2	Common	O	O	4	O
FAMILY SCOMBRIDAE							
<i>Euthynnus lineatus</i> Kishinouye, 1920	0.01	2.3	Rare	O	X	1	O
ORDER TETRAODONTIFORMES							
FAMILY BALISTIDAE							
<i>Balistes polylepis</i> Steindachner, 1876	0.12	9.1	Common	O	O	9	O
<i>Pseudobalistes naufragium</i> (Jordan and Starks, 1895)	0.30	22.7	Common	O	O	10	O
<i>Sufflamen verres</i> (Gilbert and Starks, 1904)	1.03	68.2	Frequent	O	O	8	O
FAMILY TETRAODONTIDAE							
<i>Arothron hispidus</i> (Linnaeus, 1758)	0.04	8.0	Rare	O	O	10	O
<i>Arothron meleagris</i> (Lacèpede, 1798)	1.51	86.4	Frequent	O	O	8	O
<i>Canthigaster punctatissima</i> (Günther, 1870)	1.06	52.3	Frequent	O	O	5	O
<i>Sphoeroides lobatus</i> (Steindachner, 1870)	0.01	3.4	Rare	O	X	15	O
FAMILY DIODONTIDAE							
<i>Chilomycterus reticulatus</i> Linnaeus, 1758	0.12	3.4	Common	O	X	19	O
<i>Diodon holocanthus</i> Linnaeus, 1758	0.36	50.0	Common	O	O	19	O
<i>Diodon hystrix</i> Linnaeus, 1758	0.28	13.6	Common	O	X	10	O

Abundance

A total of 34,887 individuals were counted. The highest abundances occurred at the HBSC locations, where 18,284 individuals were recorded, with an average of 415.54 individuals. At LBSC locations 16,603 individuals were counted, with an average of 377.34 individuals (Figure 3b).

Classification of Species According to Their Relative Abundance

Of the 89 recorded species two (*Thalassoma lucasanum* and *Chromis atrilobata*) were categorized as abundant. A total of 16 species were categorized as frequent, including *Prionurus punctatus*, *Abudefduf troschelii*, *Stegastes rectifraenum*, *Arothron meleagris*, and *Plagiotremus azaleus*. A total of 42 species were categorized as common, among which were included *Acanthurus triostegus*, *Halichoeres semicincta*, *Scarus ghobban* and *Apogon retrosellus*. There were a total of 29 rare species, present at one or two locations with a low number of individuals; among these were: *H. chierchiai*, *H. nicholsi*, *Scorpaena plumieri*, *Crocodilichthys gracilis* and *Synodus lacertinus* (Figure 4). The HBSC locations had a higher number of abundant (4.9%) and rare species (76.5%), as well as higher species richness, while LBSC locations had higher values of frequent (43.7%) and common (76.5%) species (Figure 4).

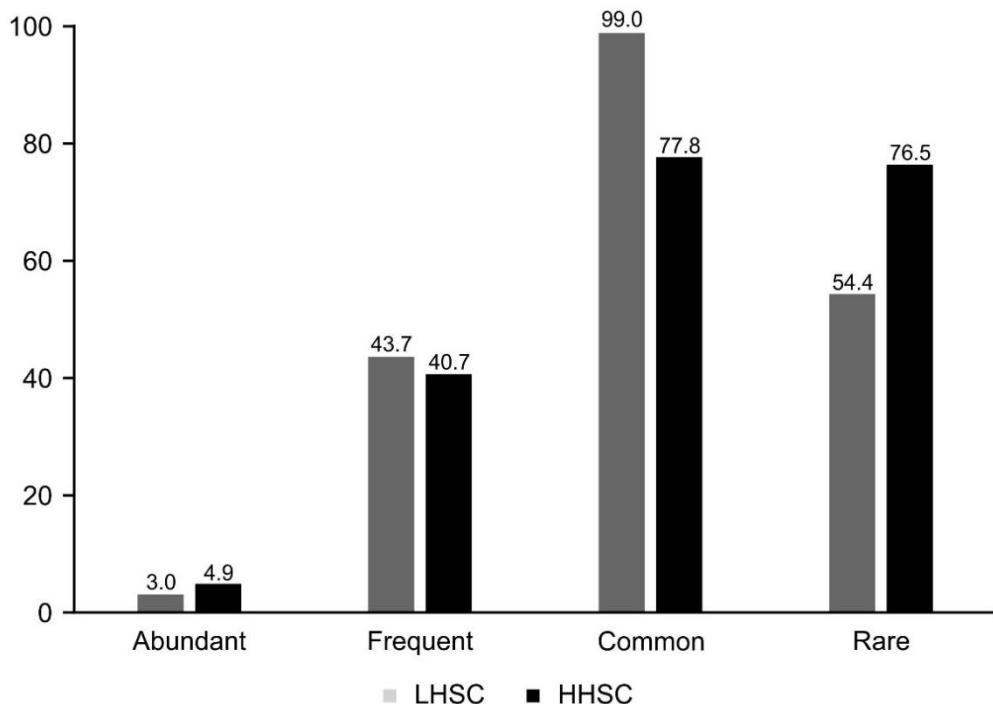


Figure 4. Classification of species according to their frequency and abundance in low benthic structural complexity (black bars) and high benthic structural complexity (grey bars) habitats.

Functional Trophic Groups (FTG)

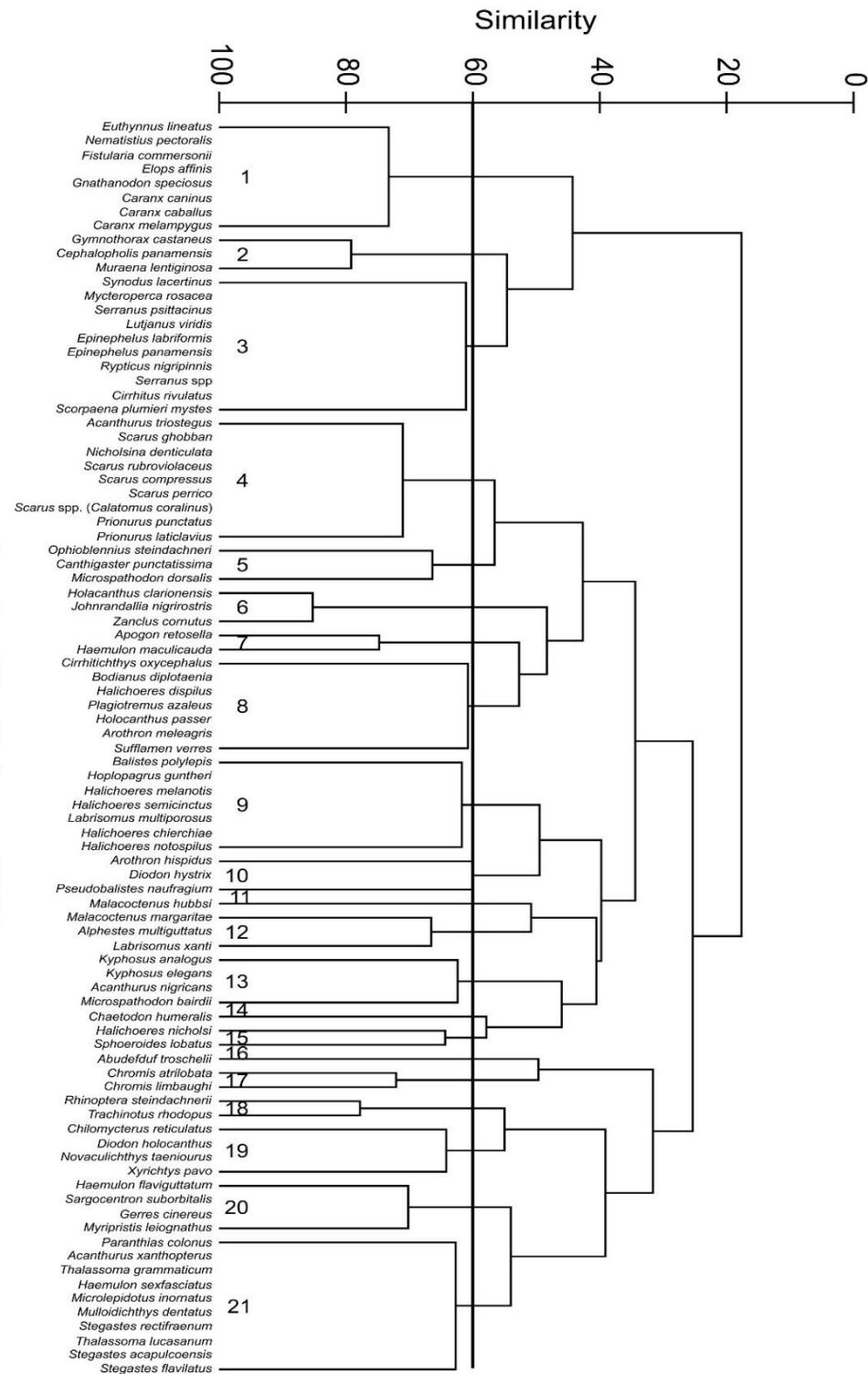


Figure 5. Functional groups in HBSC locations. Numbers represent each functional group and the species that comprise it.

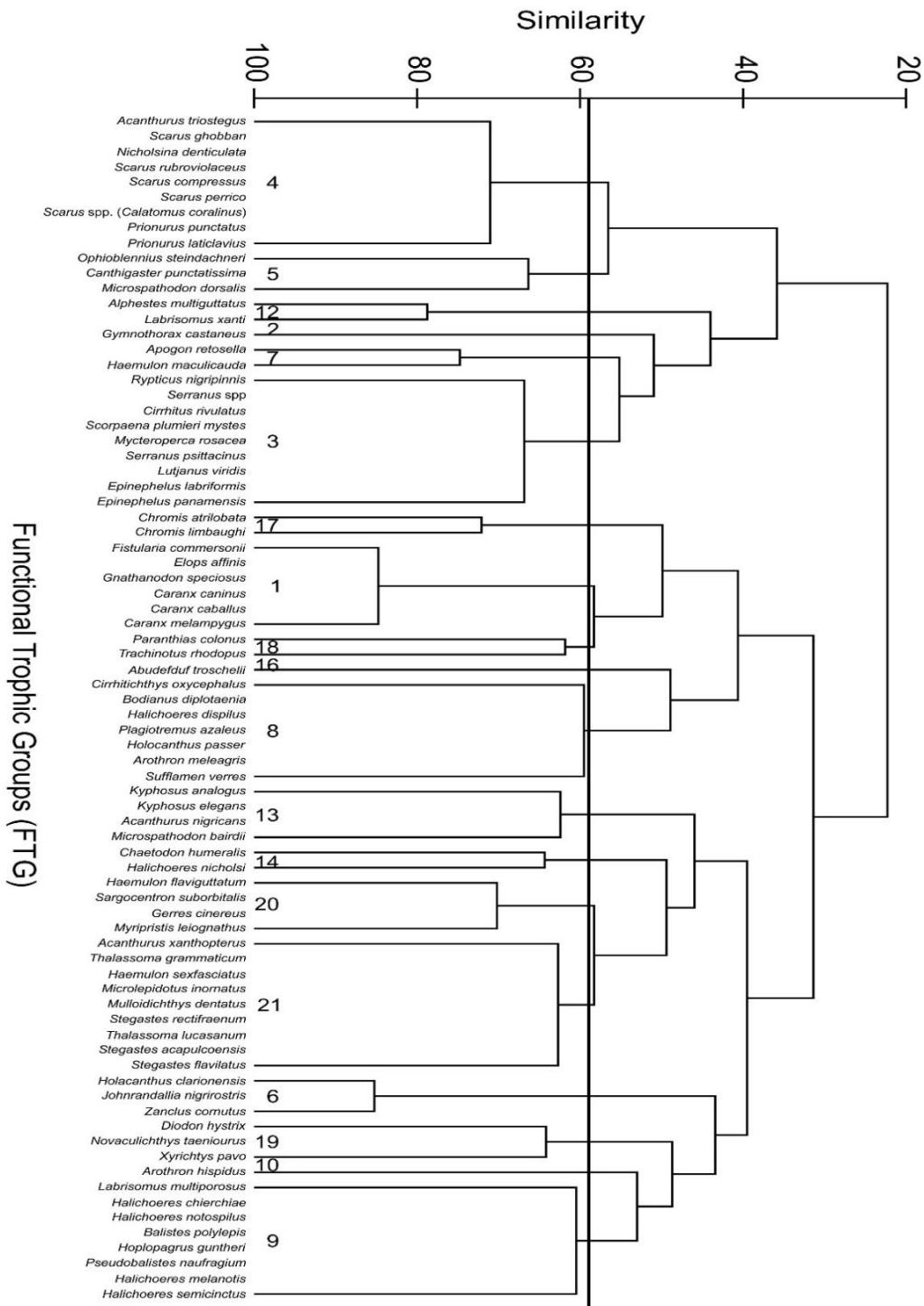


Figure 6. Functional groups in LBSC locations. Numbers represent each functional group and the species that comprise it.

Trophic Organization

Of the 89 species making up the fish fauna of the Los Frailes reef, 32% were at a trophic level between 3 and 3.5; only 21% were level 4 predators, while 12% belonged to low trophic levels (2 – 2.5). A total of 58% of fish species were associated to the bottom, 3% were species associated to the surface, and of the total of recorded species only five were territorial. There was a dominance of small-sized fish (67%), while there were few medium and large fish (25% and 8%, respectively). The type of fin of most species was emarginate (43%), followed by the lunate type (25%) and forked (10%).

Functional Trophic Groups

In HBSC areas a total of 89 species were recorded and a total of 21 functional trophic groups (FTG) were integrated (Figure 5). In the LBSC areas a total of 78 species were recorded, which were grouped into 19 FTG (Figure 6).

There were differences in the number of species contained in the functional trophic groups between the areas. The FTG in the HSBC locations are denoted as 1, 2, 3, 4..., and FTG in the LSBC locations are denoted as 1^a, 2^a, 3^a, 4^a...

1. This group was made up by mainly piscivorous species, most of which were pelagic and some demerso-pelagic. They were catalogued as common and rare.

1^a. This group comprised the same species as group 1, excepting *E. lineatus* and *N. pectoralis* which did not occur in LBSC areas.

2. This group comprised carnivorous species, which were not abundant and inhabited the reef bottom among rocks and cavities.

2^a. This was a mono-specific group (*Gymnothorax castaneus*).

3. This group was made up by piscivorous species, although some invertebrates were also included (crab, shrimp, polychaetes) in their diet. All these species had a high trophic level (>3.95); they inhabited the bottom and mid-water over the reef, and were common and rare species.

3^a. This group comprised nine species that had the same trophic function in LSBC as in HSBC locations.

4. This group was made up by herbivorous species (70-90% of the diet) and corallivorous species (20-10% of diet). The trophic level of this group was less than 2.5. Species occurred on the reef bottom and in mid-water.

4^a. This group comprised the same nine herbivorous species and had the same trophic relationships in HBSC as in LBSC locations.

5. This group was made up by three herbivorous species (40–60% of diet), although echinoderms, fish remains, sponges and bivalves were also included in their diet. Their trophic level was between 2.75 and 2.85. These were frequent and common species, associated to the bottom and territorial.

5^a. This group included the same species in LBSC locations.

6. In HBSC locations the group was comprised of species that fed on sponges (80 to 85% of diet), algae (5 to 10%), and invertebrates (less than 5% of diet). These were common species associated to the substrate and mid-water, with slow swimming speeds.

6^a. This group of species remained the same in LBSC locations.

7. This group included two species that fed mainly on shrimp and on a lower proportion of crab and other fish. These species were considered common and were associated with the bottom and mid-water.

7^a. This group did not change with the benthic structural complexity; the same members and trophic functions were maintained.

8. This group included species that fed on shrimp, sea urchins, crab, brown algae and sponges. The species were considered common and were found on the bottom and mid-water.

8^a. This group remained the same in LBSC locations.

9. Nine species comprised this group. They fed on echinoderms, pellecipods and gastropods. They were considered common and rare species related to the bottom.

9^a. This group comprised 10 species, also including *Pseudobalistes naufragium*.

10. This group was made up of three species that fed on echinoderms, sipunculids and tunicates. They had low abundance and frequency on the reef and were associated to the bottom.

10^a. This group was made up only by *Arothron hispidus*, since *D. hystrix* was not recorded in LBSC locations and *P. naufragium* was included in group 9 due to its trophic characteristics.

11. This group included only one species that fed mainly on ophiurids (sea stars). It had low frequency and abundance and was associated to the bottom.

11^a. The species that conformed this group in HBSC locations was not recorded in LBSC locations, so that this group did not occur there.

12. This group was made up of three species that fed on crab and complemented their diet with echinoderms and gastropods. They had a trophic level of 3.5 and were considered rare species on the reef.

12^a. This group was made up of only two species: *Alpheus multiguttatus* and *Labrisomus multixanti*, since *Malacoctenus margaritae* was not recorded in LBSC locations.

13. This group was made up of four species that fed on a high percentage of algae (over 90%) and a lower proportion of detritus (10%). In general these organisms had low presence on the reef and were found in mid-water.

13^a. This group did not show changes in the number of members and trophic functions in LBSC locations.

14. The only species in this group was *Chaetodon humeralis*. It fed on copepods, green algae, polychaetes, amphipods and shrimp. It was considered frequent on the reef.

14^a. This group did not occur in LBSC locations.

15. Two species made up this group. They fed on the same organisms (copepods, polychaetes, amphipods, bivalves and gastropods) mainly on the benthos. They had a high trophic level (>3.5) and were considered rare.

15^a. This group did not occur in LBSC locations.

16. The only species in this group was *Abudefduf troschelii*. It fed on anthozoans, copepods, tunicates, polychaetes and fish eggs. Its position was on the reef surface.

16^a. This mono-specific group did not show changes in LBSC locations.

17. This group was made up by two species of the Pomacentridae family, which fed on copepods, fish eggs and shrimp. They were found in the water column and only associated with the substrate to lay eggs.

17^a. This group remained constant in LBSC locations.

18. This group was made up of two species that fed on bivalves and gastropods, and that were considered rare.

18^a. This group was made up by *Trachinotus rhodopus* and *Paranthis colonus*, which consumed bivalves and gastropods. *Rhinoptera steindachneri* was not recorded in LBSC locations.

19. This group was made up by three species (*Diodon holocanthus*, *Novaculichthys taeniourus* and *Chilomycterus reticulatus*) that fed on gastropods and bivalves. Their trophic level was similar. These species were considered common to rare and were associated to the bottom and mid-water.

19^a. This group was made up by three of the four species, since *Chilomycterus reticulatus* was not recorded in LBSC locations.

20. This group was made up by four species that fed on polychaetes, shrimp, crab, gastropods and other benthic components. They were rare species associated to the benthos and demerso-pelagic.

20^a. This group did not change as to the number of species or trophic organization in the two types of location.

21. This group was heterogeneous, and included 10 species that fed on ostracods, copepods, polychaetes, chaetognaths, crabs, echinoderms, gastropods, bivalves, sipunculids, algae (brown and green), isopods, fish eggs (associated to the benthos), and sponges. They were considered abundant and common.

21^a. This group remained constant, excepting *Paranthis colonus*, which was included in group 18. The nine remaining species maintained their trophic functionality in LBSC locations.

Diagram of Biomass Flow in the Reef

In order to estimate the importance of the benthos in the trophic organization of the fish community of the Los Frailes rocky reef, a diagram of biomass flow was created of the different prey species and the fish community, categorizing it according to feeding components as herbivorous, omnivorous or carnivorous.

In the diagram of biomass flow the herbivore category comprised 13 species, which were assigned to trophic guilds 4 and 13. The omnivorous category comprised 17 species assigned to trophic guilds 5, 6, 14 and 21, while carnivores comprised 59 species assigned to the remaining 15 guilds.

Omnivores and carnivores shared 20 food components belonging to the benthos and 2 components from the pelagic zone. The chaetognaths were the only components that were exclusive to omnivores, while cephalopods from the pelagic zone, and prosobranchs, asteroids and opistobranchs from the benthic zone were exclusive to carnivores.

In general, the connections and biomass flow within the reef were varied, but there was great dominance of benthic species, which confirms the importance of invertebrates as a food source for reef fish (Figure 7).

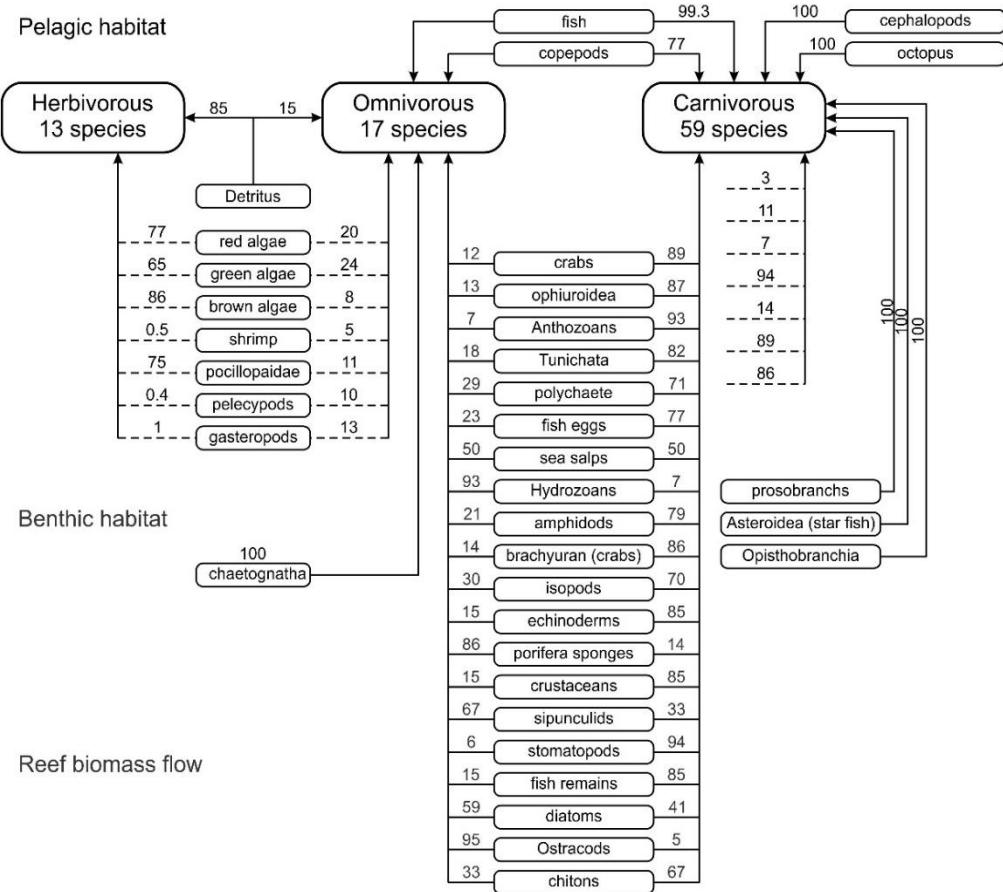


Figure 7. Diagram of biomass flow in Los Frailes reef. Feeding categories (large black rectangles), food components (small black rectangles), connections (arrows), and biomass percentage of each food component.

DISCUSSION

Habitat Structural Complexity

The objective of the present chapter was to analyze the effect of benthic structural complexity (BSC) on the trophic organization of the conspicuous ichthyofauna of the Los Frailes reef. The first step was to evaluate some habitat characteristics such as number of cavities, substrate heterogeneity, rugosity, number of rocks, and depth. These attributes were considered ideal to measure the degree of BSC because they are conceptually descriptive, easily measured and allow comparisons at different spatial scales (McCormick, 1994).

According to results of the grouping analysis, zones one (Z1) and two (Z2) were categorized as low benthic structural complexity (LBSC) areas, while zones three (Z3) and four (Z4) were categorized as high benthic structural complexity areas (HBSC). McCormick (1994) and Bartholomew et al. (2000) reported that locations with high values of these

attributes are not only more complex from the architectural point of view, but also from the biological point of view, so that it can be inferred that benthic complexity has an effect and is reflected on the trophic organization of the reef (Ángel and Ojeda, 2001).

LBSC locations were found in the shallow zone (between one and three meters depth), while HBSC locations were found at intermediate depths (between eight and nine meters depth). It should be mentioned that the grouping analysis did not take into account depth values because they affect grouping *per se*, and given the shallow depth of the Los Frailes reef (10m) it was considered that the effect of depth on community structure was limited, due to the variability of other factors such as temperature, hydrodynamic processes, water pressure, light intensity, and space available in the water column (Bayle-Sempere et al., 1994; Chabanet and Letourneur, 1995; García-Charton and Pérez-Ruzafa, 2001).

Substrate heterogeneity is an important part of HSC and has a differential effect on the ichthyofauna (Roberts and Ormond, 1987) because depending on its characteristics specific election preferences are created that influence directly the distribution and abundance of fish, and therefore, the community structure (Ruitton et al., 2000).

HBSC locations were characterized by a higher number of cavities than LBSC locations. Hixon and Beets (1989) reported that habitats with these characteristics offer a higher number of potential refuges, which promotes recruitment by juveniles and increases the number of species (predators and prey) and their density (Shulman, 1984; Kellison and Sedberry, 1998).

HBSC locations were located between the rocky reef and sandy areas of the ocean bottom. This “edge effect” promoted higher abundance and diversity due to the convergence of different species that inhabit both habitat types. In other parts of the world this same pattern has been observed, and the presence of rare species associated only to these transition zones has been detected (Acosta and Robertson, 2002; Friedlander and Parrish, 2002).

Rugosity is defined as the ratio of substrate contour to linear distance (Luckhurst and Luckhurst, 1978), that is, how sinuous the bottom contour is. This characteristic provides refuge and space for new recruits, and settlement areas for algae and invertebrates, in an indirect manner. Martin-Smith (1993) reported that epifaunal settlement is dictated by high substrate rugosity, because substrate is proportional to the contact area of organisms. Rugosity was also different among locations, being lower for LBSC areas.

Each HSC has an effect on the structure of the fish community to a greater or lesser degree and therefore on trophic organization, so that it is important to determine the relationship between the habitat (benthos) and the species, since each modification to HSC will have an effect on the fish community structure.

Fish Community Composition

The list of fish species in the Los Frailes reef during the two year study period comprised 89 species (Table 1). The reef contained approximately $0.8 \text{ species m}^{-2}$, which makes it more diverse than other nearby areas within the Gulf of California. The Los Frailes reef shelters the equivalent of 31% of reef fish species recorded for the entire Gulf of California (281 species; Thomson et al., 2000), and 38% of species reported for the Cabo Pulmo reef (236 species recorded over a 12 year period; Villareal-Cavazos et al., 2000).

It should be mentioned that this chapter focused mainly on conspicuous species, underestimating cryptic and nocturnal species (Sale, 1997; Villareal-Cavazos et al., 2000;

Romero-Ponce, 2002). Other contributions of this chapter lay in the systematic sampling and methods used, which, although they did not take into account cryptic species, were relevant for comparative analyses of seasons and habitats with different degrees of structural complexity.

Studies carried out in several areas within the Gulf of California are not easily comparable among each other due to differences in structure, depth, number of refuges and latitude of the reefs, and in some cases, due to the existing variation in the census method used. In other Gulf of California locations fish studies have been carried out using visual censuses. Pérez-España et al. (1996) recorded 75 species in four areas within the Bahía de La Paz; Sánchez-Ortíz et al. (1997) recorded 101 species in 11 locations ranging from north to south from Isla San Dieguito to Isla Cerralvo; Arreola-Robles and Elorduy-Garay (2002) recorded 80 species during censuses carried out in five islets and one wreck in the Espíritu Santo archipelago; Aburto-Oropeza (1999) counted 102 species, of which only 72 were identified using visual censuses (Aburto-Oropeza and Balart, 2001); and Villegas-Sánchez et al. (2009) recorded 84 species at five locations of Isla San José. Species richness in Los Frailes reef (with a lower number of sampling areas) was similar or even higher than the species richness reported in those studies.

Trophic Organization of the Fish Community

The highest abundance of recorded species (89) in the Los Frailes reef corresponded to carnivorous fish, followed by omnivores and a low percentage of herbivores. This type of trophic structure is commonly found in tropical and subtropical areas of the eastern Pacific (Roberson et al., 2004), including Cabo Pulmo (Álvarez-Filip and Reyes-Bonilla, 2006), Bahía de La Paz, Loreto, Bahía de Los Ángeles (Viesca-Lobaton et al., 2007), Bahía de Acapulco (Palacios-Salgado, 2005) and the Clipperton Atoll (Allen and Robertson, 1997).

It should be mentioned that despite there being fewer herbivorous than carnivorous species in these systems, their relative abundance in tropical areas is much higher than in temperate areas, with a gradual decrease from the equator towards the poles. This could be due to fish having more efficient digestive processes in warm waters (Floeter et al., 2004).

Among the most abundant carnivorous species in the Los Frailes reef are *Lutjanus viridis*, *Mycteroperca rosacea*, *Serranus psittacinus* and *Cephalopholis panamensis*. All these species feed mainly on fish, and according to their size and swimming capabilities, can complement their diet with invertebrates from the reef itself or from nearby sandy areas (Hobson, 1968; Thomson et al., 2000). Among low abundance carnivorous species are *Muraena lentiginosa*, *Synodus lacertinus* and *Alphestes multiguttatus*, which are associated to edge areas of the reef; they are ichthyofagous and have a stalking tactic to hunt their prey (personal observation). Carangids such as *Caranx caninus* and *Caranx melampygus* are visual, active predators that spend a great part of their time on the reef searching for prey (Hobson, 1968; Cervigón, 1972).

One of the main herbivorous species on the reef was *Prionorus punctatus*, which is one of the most characteristic fish species in Baja California Sur reefs (Montgomery et al., 1980). It feeds on filamentous and crustose algae, and forms schools that move about the reef stopping briefly to feed (Moreno-Sánchez et al., 2014). Species that feed on coral include the

scarids *Scarus ghobban*, *S. compressus*, *S. perrico*, and *S. rubroviolaceus*. These species were abundant probably because of the great quantity of coral present (Álvarez-Filip, 2004).

Plagiotremus azaleas was categorized as a parasitic species, since it fed on the mucus and skin of other fish (Hobson, 1968; Fischer et al., 1995). Omnivores were the second representative group on the reef, of which the species *T. lucasanum*, *S. rectifraenum*, *M. dorsalis*, *H. passer* and *A. meleagris* were most abundant. These species fed on invertebrates and algae, and are considered key in the trophic webs of reef systems (Acero and Rivera, 1992), because detritus enters the food chain of fish mainly through benthic invertebrates that are preyed on by these species (Lieske and Myers, 1996).

Effect of Benthic Structural Complexity on the Trophic Organization of the Ichthyofauna of the Los Frailes Reef

It was determined that the benthic structural complexity had little effect on the trophic organization of the fish community at Los Frailes reef. A total of 21 functional trophic groups (FTG) were defined at LBSC locations, and 19 FTG were identified at LBSC locations. These results contrast with what was reported by Ángel and Ojeda (2001), who compared two macroalgal areas with different HSC levels in the northern Chile coast. These authors found that complex habitats (benthos with different algae species, variation in density, size and shape of fronds) provided higher spatial heterogeneity for the settlement of a greater quantity and variety of invertebrates and fish. The FTG were more interconnected due to the manner in which prey were shared.

This pattern has also been reported for fish communities in rivers. Pouilly et al. (2006) documented a change in the trophic structure of rivers in Bolivia due to the habitat structural complexity, and recorded changes in conductivity, pH, temperature, slope, speed and width of the river. These factors had a favorable effect on primary productivity.

Willis et al. (2005) detected a positive correlation between benthic structural complexity and functional diversity in the fish associations present in the Cinaruco River in Venezuela. The relationship was based on leaf litter mounds, logs and other substrate providing more area for higher benthic production and resulting in greater density of fish that used these sites for feeding and protection.

The abundance and diversity of resources in this type of habitat allow fish to exploit resources in different ways. For example, fish enter into cavities and crevices of logs to feed and seek protection. Larger omnivores with protractile mandibles can also feed on the organisms found in crevices (Angermeier and Karr, 1984), promoting in this way an increase in the presence of different species and therefore of fish diversity.

Friedlander and Parrish (1998) reported that in several locations in Hawaii the spatial relief of the reef bottom, equivalent to the number and size of cavities, depth, bottom configuration and location of reef patches, was the main promoter of biomass and abundance of the fish community.

The discrepancy between the results presented in this chapter with what was found by the previously-mentioned authors is probably related to the fact that we did not analyze the diets of all species at each location, and that diet was assigned independently of the sampling area. This was decisive in not finding significant differences in the number of FTG. Ángel and Ojeda (2001) stated that richness and abundance of species were not critical in the

conformation of the number of FTG. A clear example of this is *Isacia conceptionis*, a species recorded at both location types. In high complexity locations, this species functions as an omnivore feeding on the benthos (on 5 main food components), while in low complexity areas it functions as a pelagic carnivore (with 3 main food components).

It was determined that *Arothron meleagris* was an omnivorous species, since it fed on a great variety of benthic species (sponges, sea urchins *Echinometra vanbrunti*, corals *Pocillopora* spp., *Porites* spp., bryozoans and *Crepidula arenata*). Reyes-Bonilla and Calderón-Aguilera (1999) reported that this same species in a nearby zone of Cabo Pulmo fed on coral, which could be indicative of its trophic plasticity.

The diagram of the fish community biomass flow showed high flow among the different categories. This same pattern was documented in Cape Hatteras, North Carolina, by Garrison and Link (2000), who did not find differences in the trophic structure of 40 species that integrated 14 trophic guilds. In that study a wide spatial scale was covered with 400 sampling stations, a depth range of 8 to 400 m, and diets that were sampled over 25 years. The authors reported that ontogenetic diet changes were the main factors that determined the differences found between trophic guilds, and that these changes were produced by morphological and habitat changes. Although that study was not focused on determining the effect of habitat complexity, the authors mentioned that a more detailed analysis could have found differences related to those factors.

Aburto-Oropeza and Balart (2001) reported that in Bahía de La Paz the structural complexity of the benthos (rugosity, size of cavities, cover of the different substrate types) could have a different effect on the behavior of individuals that chose sites for protection, feeding, reproduction and recruitment. The authors determined that several species were generalists with a wide distribution over different habitats. They also reported that empty spaces can be important for larvae and juveniles, and that survival depends in great part on the characteristics of the location.

Viesca-Lobaton et al. (2007) compared the functional groups formed in Bahía de La Paz, Loreto and Bahía de Los Ángeles. They reported that although the presence of functional groups was maintained in the entire area, there was an ecological substitution of species among regions due to the latitudinal change. This was possibly associated to the different physiological adaptation of species to cold water conditions, and secondarily, to a change in the feeding habits of the species due to resource availability.

It should be pointed out that this same effect occurred in the functional trophic groups (FTG) formed in Los Frailes reef. Although almost the same FTG were maintained, within each FTG some species and their abundance varied slightly depending on the structural characteristics of the habitat. For example, FTG number one was comprised of coastal pelagic species with ichthyofagous habits (*Euthynnus lineatus*, *Nematriustius pectoralis*, *Fistularia commersoni*, *Elops affinis*, *Gnathanodon speciosus*, *Caranx caninus*, *C. caballus* and *C. melampygus*) (Hobson, 1968; Sierra et al., 1990; Fischer et al., 1995; Thomson et al., 2000). The first two species did not occur in the LBSC locations because they are mainly oceanic. The presence of FTG one in the reef is related to feeding, because during sampling this FTG was observed feeding on *Harengula thrissina*, an abundant prey species during the summer months, when the presence and frequency of predators was also higher. This same behavior has been reported in several locations of the Gulf of California and Bahía Magdalena (Thomson et al., 2000; Moreno-Sánchez, 2004).

Fistularia commersoni shares few morphological characteristics with the remaining species, but was integrated into FTG one due to its trophic level. It occupies the same space in the water column as the other members of this group, feeding on recently settled fish (mostly in LBSC locations), using a stalking tactic. Hobson (1968) reported that this species feeds on reef fish smaller than 5 cm at any time of day.

The species from the Carangidae family (*Gnathanodon speciosus*, *Caranx caninus*, *C. caballus* and *C. melampygus*) feed on fish but also consume components of the benthos to complement their diets. They are active and visual predators that feed mainly during the day (Daneman, 1993; Cruz-Escalona and Abitia-Cárdenas, 2004).

The second trophic functional group included *Gymnothorax castaneus*, *Muraena lentiginosa* and *Cephalopholis panamensis* at HBSC locations, while *Gymnothorax castaneus* only occurred at LBSC locations. These three species have similar feeding habits, consuming a high percentage of fish and a lower proportion of shrimp and crab (Randall, 1967; Raymundo-Huizar, 2000; Thomson et al., 2000). They are ambush predators associated to rocky bottoms that can be found among cavities and crevices from where they attack their prey; they have no specific feeding time (Hobson, 1968). The HSC could have an important effect on their presence and feeding.

In HBSC areas species usually employ stalking or ambush tactics because there are more places to hide (Coen et al., 1981). In fact, the coexistence of ecologically similar species could be possible due to resource sharing along one or more niche edges (Gladfelter and Johnson, 1983), which in this case would be the number and size diversity of cavities as well as consumption of prey species, since despite feeding on the same items, the proportion of each species was different. In this scenario *Gymnothorax castaneus* could occur over the whole reef, independently of benthic complexity. This species' morphology, aggressiveness, voracity and trophic plasticity give it a competitive advantage over the other two species (Werner and Hall, 1988).

The third FTG included species catalogued as roaming species that are distributed near the bottom without depending on it (demersal). They have a wide trophic spectrum comprised of fish, crab, shrimp, and polychaetes (Randall, 1967; Hobson, 1968; Fischer et al., 1995; Raymundo-Huizar, 2000; Thomson et al., 2000).

This FTG included the same members at both locations, except for *Synodus lacertinus*, which was not recorded at LBSC locations because its main prey occur at the edges of rocky reefs and sandy areas. It is a stalking predator, a voracious carnivore that propels itself from the bottom upwards to capture prey, usually small fish (Fischer et al., 1995; Raymundo-Huizar, 2000), and tends therefore to be located in deep areas. The characteristics that could favor this behavior can be observed mainly in HBSC locations. The occurrence of this FTG at both locations suggests efficiency in sharing of feeding resources.

FTG number four was made up by herbivorous species that occurred in both types of benthic complexity, although the abundance and frequency at each location was different. In general these species feed on three types of algae (Chlorophyta, Phaeophyta and Rhodophyta) and coral (Randall, 1967; Montgomery et al., 1980., Thomson et al., 2000). Anaya-Reyna and Riosmena-Rodríguez (1996) reported that 61 species made up the systematic list of macroalgae present in the coral reef of Cabo Pulmo-Los Frailes, highlighting the algal diversity in both areas.

The analysis of the feeding habits of the herbivores *Acanthurus nigricans* and *Prionorus punctatus* indicated that they have different diets (Abitia-Cárdenas et al., 2011; Moreno-

Sánchez et al., 2014). *A. nigricans* feeds mainly on *Ulva linza* (50% relative importance) and *P. punctatus* feeds on *Gracilaria* spp., *Jania Mexicana* and *Hypnea musciformis*. Montgomery et al. (1980a, b) compared the diet of two herbivorous species (*Stegastes rectifraenum* and *Microspathodon dorsalis*) that differed considerably in their feeding behavior in this same reef: the first is selective and the second is not. In both cases the sharing of resources among herbivores was manifest.

The presence of species from the Scaridae family (*Scarus ghobban*, *Nicholsina denticulata*, *S. rubroviolaceus*, *S. compressus*, *S. perrico* and *Calatomus* spp.) could be explained by the nearness of Los Frailes reef to Cabo Pulmo, where they are common, implying that they could move from one reef to the other. These species feed on live coral, which in Los Frailes reef comprises up to 10% of cover. Their presence could also be due to the need to find refuge at night, as these organisms rest among cavities and crevices of rocky areas and segregate a mucus that presumably prevents predators from smelling them (Thomson et al., 2000; Viesca-Lobatón, 2003).

There was temporal segregation between *Acanthurus nigricans* and *Prionurus punctatus* in FTG four. *A. nigricans* occurs in higher abundance during the cold season and in lower abundance during the warm season. *P. punctatus* is common all year long. This FTG was not affected by the HSC, because these species feed on algae with a high turnover rate (Abitia-Cárdenas et al., 2011; Moreno-Sánchez et al., 2014).

FTG five was made up of species that feed mainly on algae and also consume invertebrates (Randall, 1967; Hobson, 1974; Montgomery, 1980; Thomson et al., 2000). These species are morphologically similar; they feed on the same prey and occur in the same position on the reef. Although this functional group was integrated in the two HSC types, the abundances of *O. steindachneri* and *C. punctatissima* were higher at HBSC locations, probably because these species need refuges to get protection from predators (Thomson et al., 2000). However, their dependence on the substrate was markedly higher than that of *M. dorsalis*, which is an herbivorous species that moves near the substrate but only depends on it to lay eggs (Hernández-Olalde, 2008). In general this FTG is little affected by the HSC and occupies both areas.

The sixth FTG occurred at both locations. The species that made up this group fed on algae, invertebrates and a high percentage of sponges (Hobson, 1974). These species had moderate abundance and frequency (common species). The presence of the group at both HSC locations could be related to spacing within the reef because none of these species depends strictly on the substrate (Thomson et al., 2000).

The seventh FTG group was made up by *Apogon retrosellus* and *Haemulon maculicauda*, which were present at both HSC locations. Their diet was composed of shrimp, crab and fish. They are considered common species that occupy the space from the bottom to mid-water; they are nocturnal species.

The eighth FTG was one of the most diverse in trophic spectra, feeding behavior and morphology, and could be found at all locations. The diet of the species included this group was made up of algae and invertebrates (Randall, 1967; Hobson, 1968; Hobson, 1974; Pérez-España and Abitia-Cárdenas, 1996; Thomson et al., 2000). The abundances of each species varied among locations. For example, at HBSC locations, *C. oxycephalus*, *H. dispilus* and *P. azaleus* were numerous. These are small-sized species that measure between 5 and 15 cm and need to be close to their refugia to feed and hide (Hobson, 1976). *B. diplotaenia* and *H. passer* were considered roaming species in the reef: *B. diplotaenia* feeds on organisms on the

substrate, and *H. passer* is coprophagous, living in the water column, usually under schools of *C. atrilobata* (Reynolds and Reynolds, 1977; Pérez- España and Abitia-Cárdenas, 1996; Aburto-Oropeza et al., 2000; Thomson et al., 2000). *Arothron meleagris* and *Sufflamen verres* were more abundant at LBSC locations. These are generalist species, with great trophic plasticity (Reyes-Bonilla and Calderón-Aguilera 1999; Thomson et al., 2000; Moreno-Sánchez et al., 2009).

The ninth FTG included species that fed on echinoderms, pellecipods and gastropods (Hobson, 1968; Hobson, 1974). These species were not very abundant or frequent, and were affected by the HSC. These labrids are small and live among crevices to avoid being preyed on; they were abundant at HBSC locations (Thomson et al., 2000). Of the four recorded species, two were the most abundant (*H. notospilus* at LBSC locations and *H. semicinctus* at HBSC locations) so that despite this group occurring at both locations, there was spatial segregation.

Hoplopagrus guntheri and *L. multiporosus* are relatively small species that also occupy cavities and crevices for refuge. These are ichthyofagous reef-roaming species (Thomson et al, 2000).

Despite this functional group occurring in both areas, the abundance of its members changed according to the HSC. Most members use cavities and crevices to find refuge; therefore the species most dependent on the substrate were most abundant in HBSC areas. In a similar way to previous cases, there was sharing of resources that facilitates coexistence among species.

The tenth FTG included *Pseudobalistes naufragium*, *Diodon hystrix* and *Arothron hispidus* in HBSC locations. *A. hispidus* was recorded only in LBSC locations. The three species depend on substrate characteristics to feed and are catalogued as reef-roaming species. The most important food components were sea urchins, which can be consumed due to the characteristics of the mouth apparatus of these species. *Diodon hystrix* and *A. hispidus* have plate-shaped teeth and *P. naufragium* has eight prominent teeth (Fischer et al., 1995; Thomson et al., 2000). These species complement their diet with sipunculids and tunicates (Randall, 1967). This FTG was more abundant at HBSC locations where a greater quantity of echinoderms was recorded.

The eleventh FTG was monospecific, with only *Malacoctenus hubbsi* being recorded. This species requires specific habitat characteristics and is therefore sensitive to benthic complexity. Thomson et al., (2000) reported that this is an aggressive and abundant species that inhabits preferentially depths over 8 m and feeds mainly on sea stars. In the Los Frailes reef it was recorded at HBSC locations, where this type of habitat is commonly found.

The twelfth FTG group included *Alphestes multiguttatus*, *Labrisomus xanti* and *Malacoctenus margaritae*. These species were recorded at both locations, except *M. margaritae* which was not found at LBSC locations. This is probably related to this being a comparatively small species that also needs small cavities, which are more abundant and frequent at HBSC locations. *A. multiguttatus* and *L. xanti* are larger species that depend on the substrate for feeding but are not territorial. Although the abundances of the members of this group differed depending on the HSC, they could carry out their activities in both areas.

The thirteenth FTG group, which included the herbivorous species *Kyphosus analogus*, *K. elegans*, *Acanthurus nigricans* and *Microspathodon bairdii*, was sensitive to the HSC. These species feed on algae, diatoms and detritus (Hobson, 1974; Montgomery, 1980 a and b; Thomson et al., 2000). No effect of benthic characteristics could be identified, since algal

production is sufficient for all herbivorous species present in the area, although competition with more territorial or aggressive species could influence the presence of some of the members of this group, such as *S. rectifraenum* (Hobson, 1968, Moreno-Sánchez et al., 2011).

The fourteenth functional group included only *Chaetodon humeralis* at HBSC locations. This fish fed on copepods, green algae, polychaetes, amphipods, and shrimp, among other components (Randall, 1967; Hobson; 1974; Thomson et al., 2000). Due to its morphological characteristics this species could compete with FTG 15. There seems to be spatial segregation since this FTG did not occur at LBSC areas.

Despite *Halichoeres nicholsi* and *Sphoeroides lobatus* being different morphologically (Fischer et al., 1995), they made up the fifteenth functional group because they share food resources (copepods, polychaetes, amphipods, bivalves, gastropods). *H. nicholsi* needs cavities to find refuge from its predators and moves from the bottom to mid-water. *S. lobatus* inhabits preferentially the reef edges (rock-sand interface; Randall, 1967; Thomson et al., 2000). In this system this species was classified as rare. Due to its habitat requirements it was not recorded in LBSC locations. For this FTG the HSC did have an effect on *S. lobatus* due to its habitat requirements.

The sixteenth FTG was monospecific, it only included *Abudedefduf troschelii*. This species has characteristics that give it a competitive advantage over other species such as *C. atrilobata*. For example, it has a wide feeding spectrum (including anthozoans, copepods, tunicates, polychaets and fish eggs) and diverse feeding areas (water column and benthos). The dependence of this species on the substrate occurs during the reproductive period. When it nests its eggs need cavities with specific size and shape, with presence of algae (Hernández-Olalde, 2008). In general the species was well represented in both locations. There are reports of this species interacting with *C. atrilobata* in the pelagic zone and with *S. rectifraenum* on the benthos. *A. troschelli* occurs all year long and practically in all reef environments. It was classified as a frequent species.

The seventeenth FTG included two Pomacentrids, *Chromis atrilobata* and *C. limbaughi*. Both species were recorded in LBSC and HBSC locations, although the highest abundances and frequencies occurred in HBSC locations. At these locations depth is considerable, and in this type of habitat cavities are heterogeneous and are used as refuge areas during the night (Hobson, 1968; Hobson, 1974; Thomson et al., 2000). Strong interspecific competition could be detected in this functional group because both species use benthic resources in a similar way and feed practically on the same prey.

The eighteenth FTG included *Trachinotus rhodopus* and *Rhinoptera stendanchneri* in HBSC locations, while in LBSC locations *R. stendanchneri* was substituted by *Paranthias colonus*. The HSC had an important effect on this FTG, due to the habitat requirements of *R. steindanchneri*. This species needs sandy substrate near the reef edge, where it searches for food (bivalves and gastropods) at depths over 7 meters (Thomson et al., 2000).

Trachinotus rhodopus is a carangid with all the characteristics of a pelagic organism, but it feeds on a high percentage of benthic organisms (bivalves and gastropods; Randall, 1967; Moreno-Sánchez, 2004). *P. colonus* is a mainly planktوفagous species, although it also consumes a lower proportion of organisms from the benthos (Thomson et al. 2000). In general this group shares space and food resources, which probably allows them to coexist.

The nineteenth FTG included *Chilomycterus reticulatus*, *Diodon holocanthus*, *Novaculichthys taeniourus* and *Xyrichtys pavo*, of which only *C. reticulatus* did not occur in LBSC locations. These species feed on gastropods and bivalves (Randall, 1967; Hobson,

1974; Thomson et al., 2000) and are associated to the bottom and mid-water. Their abundances changed according to the HSC, being higher in HBSC areas, probably due to the greater quantity of invertebrates present at these locations.

The twentieth FTG was made up by *Haemulon flaviguttatum*, *Sargocentron suborbitale*, *Gerres cinereus* and *Myripristis leiognathus*, and occurred in both HSC locations. It should be mentioned that all these species are considered rare. They feed on a great variety of benthic organisms such as polychaetes, shrimp, crab and gastropods (Randall, 1967; Hobson, 1968; Thomson et al., 2000), which could explain their presence in both areas.

The twenty-first FTG was one of the most diverse in its feeding habits and was made up by three pomacentrids (*Stegastes rectifraenum*, *S. acapulcoensis* and *S. flavilatus*), two labrids (*Thalassoma lucasanum* and *T. grammaticum*), two haemulids (*Haemulon sexfasciatum* and *Microlepidotus inornatus*), an acanthurid (*Acanthurus xanthopterus*), a mullid (*Mulloidichthys dentatus*), and a serranid (*Paranthias colonus*).

The feeding requirements of *S. rectifraenum*, *S. acapulcoensis* and *S. flavilatus* are similar. They occupy a territory of approximately one meter in radius, which they defend constantly to reduce predation pressure (Wellington, 1982; Wellington and Víctor, 1988, Moreno-Sánchez et al., 2011). Pomacentrids occurred at both location types but their abundances were higher in HBSC areas, possibly because there is a greater number of cavities and refuges there. During the two years of sampling it was observed that despite these species sharing the same areas, there was a succession, with *S. flavilatus* being found first, then *S. rectifraenum*, and lastly *S. acapulcoensis*. It is possible that *S. rectifraenum*, being the dominant species, occupies the best sites.

The labrids *T. lucasanum* and *T. grammaticum* use the benthos in a similar way, with *T. lucasanum* being dominant because its abundance is ten times higher than that of *T. grammaticum*. Its trophic diversity, enormous fecundity, capacity to reproduce twice a year and to tolerate wide variations in temperature confer it a good competitive advantage (Fischer et al., 1995; Thomson et al., 2000; Robertson and Allen, 2002, Hernández-Olalde, 2008).

The serranid *Paranthias colonus* was included in this FTG due to the quantity of copepods that it consumes. This species does not compete with the other group members because it is distributed over the entire water column (Thomson et al., 2000; Robertson and Allen, 2002). *Acanthurus xanthopterus* feeds on benthic invertebrates (Hobson, 1968; Fischer et al., 1995; Thomson et al., 2000).

The haemulid *Haemulon sexfasciatum* fed on brachiurans, but contrary to other members of this FTG, it fed during the night, roaming around the edges of the reef during the day. It is possible that competition with this species is lower because of the wide heterogeneity of its diet (number and diversity of components). There was no change in this species' abundance with HSC (Hobson, 1968; Fischer et al., 1995; Thomson et al., 2000).

Microlepidotus inornatus fed mainly on sipunculids and other benthic invertebrates. The highest abundances of this species were recorded at HBSC locations. It is a nocturnal predator and during the day it forms schools that roam the reef (Hobson, 1968; Fischer et al., 1995; Thomson et al., 2000).

Mulloidichthys dentatus feeds on small bivalves and crabs in rocky and sandy areas. It is a nocturnal predator but the smaller individuals feed during the day. This could explain the higher abundances recorded at HBSC locations, where observed individuals were small (10 to 15 cm). Competition for food with the other members of the FTG was low because the total population size is small (Hobson, 1968; Fischer et al., 1995; Thomson et al., 2000).

The benthic structural characteristics did not have a significant effect on the trophic organization of the fish community, because although there were small changes in the number of FTGs and in the species that integrated them, these variations were not significant. This could be indicative of food not being a limiting factor in Los Frailes reef. It is known that upwelling occurs at the mouth of the Gulf of California all year, enriching superficial waters, favoring algal blooms and increasing the general system productivity (Álvarez-Borrego and Lara-Lara. 1991). Results could also be explained by the high redundancy of the functional groups present in the reef (Álvarez-Filip and Reyes-Bonilla, 2006).

CONCLUSION

Benthic heterogeneity, the number and size of cavities, the size of rocks, rugosity, and depth are robust variables that characterize adequately the benthic structural complexity (BSC) of the Los Frailes reef. Ecological indices of the fish community structure (species richness and abundance) were higher at HBSC locations than at LBSC locations. It is possible that this is due to an increase in BSC being related to a higher availability of benthic microhabitats. The BSC did not have a measurable effect on the trophic organization of the fish community in Los Frailes reef. It was observed that at both locations there was almost the same number and composition of trophic functional groups (high functional redundancy). Few species differed from this pattern. This is possibly due to the restricted effect that the benthic structural characteristics have on fish feeding habits.

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Chapter 2

MARINE SEAWEEDS OF THE YUCATAN PENINSULA: DIVERSITY, ECONOMIC IMPORTANCE AND CONSERVATION

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ABSTRACT

The Mexican Caribbean and the Atlantic coast of Mexico have 3,294 km of coastline with diverse habitats and rich biota. Coastal ecosystems, unfortunately, are experiencing wide range of pressures due to siltation, eutrophication, coastal development and climate change. Those species that adapt to these pressures will expand their living boundaries while others may fade away. Accordingly, the study of coastal biodiversity is of great concern globally and constitutes an important element of global change research. Peninsula of Yucatan has 1,940 km of coastline, reportedly with rich diversity of seaweeds. Previously published accounts on seaweed biodiversity were mainly in the form of checklists. The present study is a timely publication based wholly on primary data. Data were collected through extensive and systematic field studies conducted by the authors during different seasons over an eleven years period since 2004 to 2014, also we checked herbarium's specimens that are housed in the herbarium ENCB. Analysis of the information showed that Rhodophyta has the greatest diversity with 317 species; Chlorophyta has 180; Phaeophyceae 70 and finally Cyanobacteria with 38 species. One of the groups best represented in the study area is the Order Corallinales with two families and 43 species, these organisms are of major ecological importance in the reefs of the Peninsula. Three species are new records from Mexican Caribbean, *Centroceras*

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hyalacanthum, *Metapeyssonnelia tangerina* and *Sarcodiotheca divaricate*, and sixteen species are new records for the study area. The importance of epiphytic algae in the study area is discussed as well as the use of molecular markers in order to solve taxonomic problems of selected genera of algae. The floristic list includes data on distribution, tidal level and habitat. On the other hand Quintana Roo is the state that has the greatest diversity of marine algae in the Gulf of Mexico and Mexican Caribbean's shores with 551 species. Topics on economic importance and extraction of bioactive substances are discussed, as well as suggestions on conservation of seaweeds from Yucatan Peninsula. Finally, several coastal towns in the Yucatan Peninsula are being impacted by natural events such as hurricanes as well as urban; tourism and industrial development, so it is important continue studies that allow us to characterize the changes that populations of seaweeds are undergoing.

INTRODUCTION

Floristic studies on the marine algae growing in Yucatan Peninsula area were made by several workers [1, 2]. Huerta et al. [1] reported on a preliminary survey of shallow water marine algae of coastal and islands area of Yucatan Peninsula, although much pertinent new information has accumulated since its publication. Aguilar-Rosas et al. [3] and Collado-Vides et al. [4] studied the Chlorophyta of the Mexican Caribbean. Callejas-Jiménez et al. [5] reported the seaweeds of several localities of Campeche; Mateo-Cid et al. [6], publishes lists on subtidal Rhodophyta of Cozumel Island, Mendoza-González et al. [7] listed offshore seaweeds of Mujeres Island. Cetz-Navarro et al. [8] reported new records of seaweeds for the Mexican Atlantic coast as well as update data on the floristic richness of the Mexican Caribbean. Mateo-Cid et al. [9] presented the results of the study on benthic marine algae in eight localities from the coast of Campeche; these authors reported 30 new records of seaweeds for Campeche. Until now have been recorded 635 species of seaweed for the Yucatan Peninsula, in this sense, it is noted that the algal flora of this region is still not well known. On the other hand is obvious the lack of knowledge on ecology and conservation of marine algae in this region, in addition oil spills and pollution are a persistent danger for the significant risk involved for human lives and the health of shallow and deep marine habitats. Furthermore, it is remarkable the numbers of hurricanes that have affected the Yucatan Peninsula in the last ten years, the risks associated with hurricanes are: storm surge, high winds, heavy rains, landslides and flooding. It is expected that under these arguments is important to know the changes in the short and medium terms of marine algae in this region, which possible to assess the risks to which these organisms as well as their management and sustainable use.

The present chapter was undertaken with a view to know the composition of seaweed and its distribution in the study area, as well some effects of pollution and human. The data achieved for a period of ten years from July 2004 to June 2014 are presented in this chapter and would be very much useful to the seaweed industries about the occurrence of economically important agar and algin yielding seaweeds for commercial exploitation and for conservation.

Study Area

The Yucatan Peninsula is a biogeographical area comprising the entire territory of the Mexican states Campeche, Yucatan and Quintana Roo, adjacent small portions of Tabasco and Chiapas, The El Petén department in Guatemala, and the northern half of Belize (Figure 1). The coastal environment of the Yucatan Peninsula includes a wide variety of ecosystems ranging from mangroves to coral reefs, resulting in a heterogeneous landscape. Specifically, the marine system is characterized by environmental differences which respond to regional and local forcing functions such as marine currents and groundwater discharges. Yucatan Peninsula has 1,940 km of coastline, its coast has been characterized as low lying coastal area, where 57% is represented by coastal lagoons with barrier islands and 43% is ocean front, 85% of this ocean front is sandy coast. The tidal regime is mixed with a diurnal dominance, with a tidal variety of 0.1 m for neap tides and 0.8 m for spring tides. Reported grain size values are only available for the Progreso beach area ranging between 0.2 mm (at 0.5 m depth) to 0.5 mm (swash zone) with poorly sorted grains. Coastal ecosystems of the Yucatan Peninsula experience three well-defined seasons: dry (March to May), rainy (June to October), and “nortes” (November to February), which is dominated by cold fronts. Additionally, the hurricane season (from August to September) has a strong influence on coastal lagoon stability and disturbance regime. The Yucatan Peninsula has unique hydrogeological characteristics, including low relief, lack of rivers, highly permeable karst-derived soils, and substantial submarine groundwater discharge [10].

The Yucatan Peninsula is affected by extreme wind waves generated by two meteorological systems: (i) mid latitude anticyclonic meteorological systems which generate northerly cold fronts known as “nortes”; and (ii) cyclonic systems known as Tropical Cyclones including tropical depressions and hurricanes [11]. Along the Caribbean coast of the Yucatan Peninsula; brackish ground water (mixed fresh water and sea water) is channeled through upper Pleistocene limestone via fracture-controlled caverns. In caves, cenotes, and caletas at Xcaret, Yalku, and Tancah, this open-flow coastal mixing zone comprises three major layers: (1) an upper dilute zone of gradually increasing salinity with depth (slow mixing), (2) a thin intermediate zone of rapidly increasing salinity with depth (rapid mixing), and (3) a lower saline zone of gradually increasing salinity with depth. The intermediate layer occurs at different absolute salinities at different localities, and it generally corresponds to the level of a notch in the wall rock of the caverns [12].

Collections were made using SCUBA for subtidal; while, seaweeds in the intertidal zone were collected during low tide periods by hand picking in different habits such rocky and sandy. Collections at 40 locations were made during twenty five visits since 2004 to 2014. Algae were preserved in formalin/sea water at a 1:19 ratio. Semi-permanent slides were prepared using corn syrup/water 1:1 with a trace of phenol added to prevent fungal growth. Identification was made with specialized literature [13, 14, 15, 16, 17]. Voucher slides and specimens are deposited at the herbarium of the Escuela Nacional de Ciencias Biológicas (ENCB) at the Instituto Politécnico Nacional in Mexico City, D.F. Mexico. The taxa were identified with from the collections are listed following the order proposed by Wynne [18] and Guiry and Guiry [19]. Each species is presented with data regarding distribution in the study area, tidal level, habitat and observations (Table 1).

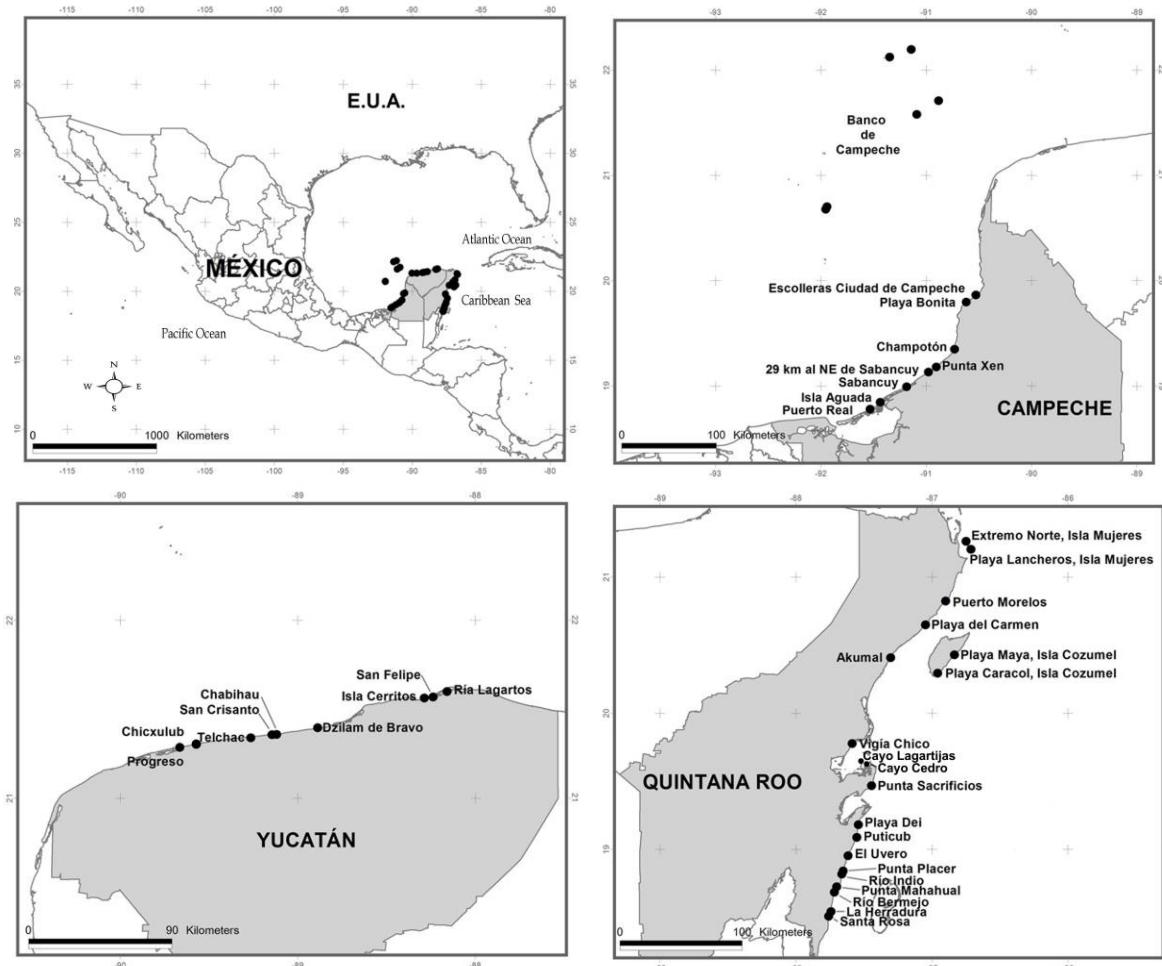


Figure 1. Study area and sample localities.

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Table 1. Marine algae of Yucatan Peninsula

Species	SYMBOLS STATES			Level/ Habitat	OBS		
	CAMP	YUC	QROO				
CYANOBACTERIA							
Cyanophyceae							
Oscillatoriaceae							
1. <i>Blennothrix lyngbyacea</i> (Kützing ex Gomont) Anagnostidis and Komárek	X	X	X	I, S /R, Ep			
2. <i>Lyngbya confervoides</i> C. Agardh ex Gomont	X	X		I /R			
3. <i>L. lutea</i> Gomont ex Gomont			X	I/Ep			
4. <i>L. majuscula</i> (Dillwyn) Harvey ex Gomont	X		X	I/Ep			
Phormidiaceae							
5. <i>Phormidium limosum</i> (Dillwyn) P. C. Silva	X			I/Ep			
6. <i>P. retzii</i> Kützing ex Gomont			X	I/Ep			
7. <i>P. submembranaceum</i> Gomont			X	I/Ep			
8. <i>Porphyrosiphon notarisii</i> Kützing ex Gomont			X	I/R, Ep			
Pseudanabaenales							
Schizotrichaceae							
9. <i>Schizothrix arenaria</i> Gomont			X	I/R			
10. <i>S. calcicola</i> Gomont		X	X	I/Ep			
11. <i>S. mexicana</i> Gomont		X	X	I/R			
12. <i>Trichocoleus tenerrimus</i> (Gomont) Anagnostidis	X			I/Ep	NRP		
Pseudanabaenaceae							
13. <i>Leptolyngbya marina</i> (Gardner) Anagnostidis	X	X		I/Ep			

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
14. <i>Pseudanabaena catenata</i> Lauterborn			X	S/Ep	
Sympyonemataceae	X		X	I/R, Ep	
15. <i>Brachytrichia quoyi</i> (C. Agardh) Bornet and Flahault					
Microcoleaceae		X	X	I, S/Ep	
16. <i>Microcoleus vaginatus</i> Gomont ex Gomont					
17. <i>Symplocastrum purpurascens</i> Gomont Anagnostidis			X	I, S/Ep	NRP
Nostocales		X	X	I, S/Ep	
Nostocaceae					
18. <i>Anabaena oscillariooides</i> Bory de Saint-Vincent ex Bornet and Flahault					
19. <i>Nodularia spumigena</i> Mertens			X	I, S/R, Ep	
Rivulariaceae		X		S/R	
20. <i>Rivularia atra</i> Roth ex Bornet and Flahault					
21. <i>Scytonematopsis crustacea</i> (Thuret ex Bornet and Flahault) Koválik and Komárek	X	X	X	I, S/R, Ep	
Scytonemataceae			X	I/R	
22. <i>Scytonema hofmannii</i> C. Agardh ex Bornet and Flahault					
Chroococcales			X	S/Ep	
Microcystaceae					
23. <i>Chroococcus turgidus</i> (Kützing) Nägeli					
Hydrooccocaceae		X		S/Ep	NRP
24. <i>Radaisia epiphytica</i> Setchell and N. L. Gardner					
25. <i>Microcystis zanardinii</i> (Hauck) P. C Silva	X		X	S/Ep	
Dermocarpellaceae	X				
26. <i>Dermocarpa acervata</i> (Setchell and Gardner) Pham-Hoàng Hô				S/Ep	NRP
27. <i>D. willei</i> (Gardner) P. C. Silva	X			S/Ep	
Xenococcaceae	X			S/Ep	
28. <i>Xenococcus gilkeyae</i> Setchell and N. L. Gardner					
29. <i>X. pyriformis</i> Setchell and N. L. Gardner	X	X		I, S/Ep	

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
Entophysalidaceae			X	S/En	NRP
30. <i>Chlorogloea endophytica</i> M. A. Howe					
31. <i>Entophysalis conferta</i> (Kützing) F. E. Drouet and W. A. Daily	X	X	X	I, S/Ep	
32. <i>E. deusta</i> F. E. Drouet and Daily			X	S/Ep	
33. <i>Placoma violacea</i> Setchell and N. L. Gardner		X		I/R	NRP
Cyanobacteriaceae		X			
34. <i>Aphanotece microscopica</i> Nageli				S/Ep	NRP
35. <i>A. stagnina</i> (Sprengel) A. Braun			X	I, S/Ep	
Gomphosphaeriaceae		X	X		
36. <i>Gomphosphaeria aponina</i> Kützing				S/Ep	
Spirulinaceae			X		
37. <i>Spirulina subsalsa</i> Oersted ex Gomont				S/Ep	
Synechococcales			X		
Merismopediaceae					
38. <i>Aphanocapsma marina</i> Hansgirg				I, S/Ep	
RHODOPHYTA	X	X	X	I, S/Ep	
Stylonematophyceae					
Stylonematales					
Stylonemataceae					
39. <i>Chroodactylon ornatum</i> (C. Agardh) Basson					
40. <i>Stylonema alsidii</i> (Zanardini) K.M. Drew	X	X	X	I, S/Ep.	
Compsopogonophyceae	X	X	X	I, S/Ep	
Erythropeltidales					
Erythrotrichiaceae					
41. <i>Erythrotrichia carnea</i> (Dillwyn) J. Agardh					
42. <i>E. vexillaris</i> (Montagne) G. Hamel	X			S/Ep	
43. <i>Sahlingia subintegra</i> (Rosenvinge) P. Kornmann	X	X	X	I, S/Ep	
Rhodochaetales			X	S/Ep	
Rhodochaetaceae					
44. <i>Rhodochaete pulchella</i> Thuret ex Bornet					

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
Bangiophyceae	X			I/R	
Bangiales					
Bangiaceae					
45. <i>Pyropia leucosticta</i> (Thuret) Neefus and J. Brodie					
Florideophyceae		X	X	I, S/Ep	
Acrochaetales					
Acrochaetiaceae					
46. <i>Acrochaetium flexuosum</i> Vickers					
47. <i>A. globosum</i> Borgesen			X	I, S/Ep	
48. <i>A. microscopicum</i> (Nägeli ex Kützing) Nägeli		X	X	I, S/Ep	
49. <i>A. savianum</i> (Meneghini) Nägeli		X	X	I, S/R, Ep	
Colaconematales	X	X	X	I, S/Ep	
Colaconemataceae					
50. <i>Colaconema daviesii</i> (Dillwyn) Stegenga					
51. <i>C. hallanicum</i> (Kylin) Afonso-Carrillo, Sansón, Sagil and Díaz-Villa	X		X	I, S/Ep	
52. <i>C. hypnea</i> (Børgesen) A. A. Santos and C. W. N. Moura		X	X	I, S/Ep	
Corallinales	X	X	X	S/Ro	
Hapalidiaceae					
53. <i>Lithothamnion occidentale</i> (Foslie) Foslie					
54. <i>L. sejunctum</i> Foslie			X	I/R	
55. <i>Melobesia membranacea</i> (Esper) J. V. Lamouroux	X	X	X	I, S/Ep	
56. <i>Mesophyllum mesomorphum</i> (Foslie) W. H. Adey	X		X	S/Ep	
Corallinaceae			X	I, S/R	
57. <i>Amphiroa beauvoisii</i> J. V. Lamouroux					
58. <i>A. fragilissima</i> (Linnaeus) J. V. Lamouroux	X	X	X	I, S/R	
59. <i>A. rigida</i> J. V. Lamouroux	X	X	X	I, S/R	
60. <i>A. tribulus</i> J. V. Lamouroux		X	X	I, S/R	
61. <i>A. valonioides</i> Yendo			X	I, S/R	
62. <i>A. vanbossea</i> Me. Lemoine			X	I, S/R	

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
63. <i>Goniolithon decutescens</i> (Heydrich) Foslie ex M. A. Howe			X	I/R	
64. <i>Hydrolithon boergesenii</i> (Foslie) Foslie	X		X	I/R	
65. <i>H. farinosum</i> (J. V. Lamouroux) D. Penrose and Y. M. Chamberlain	X	X	X	I, S/Ep	
66. <i>H. improcerum</i> (Foslie and M. Howe) Foslie			X	S/R	
67. <i>H. onkodes</i> (Foslie) D. Penrose and W.H. Woelkerling	X		X	S/R	
68. <i>H. pachydermum</i> (Foslie) J. C. Bailey, J. E. Gabel and D. W. Freshwater			X	S/R	
69. <i>H. reinboldii</i> (Weber-van Bosse and Foslie) Foslie			X	S/Ro	
70. <i>Jania adhaerens</i> J. V. Lamouroux	X	X	X	I, S /R, Ep	
71. <i>J. capillacea</i> Harvey	X	X	X	I, S /R, Ep	
72. <i>J. cubensis</i> Montagne ex Kützing	X	X	X	I, S /R, Ep	
73. <i>J. rubens</i> (Linnaeus) J.V. Lamouroux	X	X	X	I, S/R	
74. <i>J. subulata</i> (J. Ellis and Solander) H. W. Johansen			X	I, S/R	
75. <i>Lithoporella atlantica</i> (Foslie) Foslie			X	I, S /Ep	
76. <i>L. bermudensis</i> (Foslie) W. H. Adey		X	X	I, S /R	
77. <i>Lithophyllum incrustans</i> Philippi			X	S/R	NRP
78. <i>L. stictaeforme</i> (Areschoug) Hauck			X	S/R	
79. <i>Neogoniolithon accretum</i> (Foslie M. A. Howe) Setchell and L. R. Mason			X	I, S/R	
80. <i>N. acropetum</i> (Foslie and M. Howe) H. W. Adey		X	X	I, S/R	
81. <i>N. affine</i> (Foslie and M. Howe) Setchell and Mason			X	I, S/R	
82. <i>N. erosum</i> (Foslie) W. H. Adey			X	I, S /R, Ep	
83. <i>N. fosliei</i> (Heydrich) Setchell and L. R. Mason		X	X	I, S/R	
84. <i>N. mamillare</i> (Harvey) Setchell and L. R. Mason			X	I, S/R	
85. <i>N. propinquum</i> (Foslie) Me. Lemoine			X	I, S/R	
86. <i>N. rhizophorae</i> (Foslie) Setchell and L. R. Mason		X	X	I, S/R	
87. <i>N. siankanensis</i> Mateo-Cid, Mendoza-González and P. W. Gabrielson			X	I, S/R	
88. <i>N. spectabile</i> (Foslie) Setchell and L. R. Mason	X	X	X	S/Ro	
89. <i>N. strictum</i> (Foslie) Setchell and L. R. Mason		X	X	S/Ro	
90. <i>N. trichotomum</i> (Heydrich) Setchell and L. R. Mason			X	S/R	
91. <i>Pneophyllum confervicola</i> (Kützing) Y.M. Chamberlain	X	X	X	I,S/Ep	
92. <i>P. fragile</i> Kützing	X	X	X	I,S/Ep	

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
93. <i>Spongites yendoi</i> (Foslie) Y.M. Chamberlain	X			I, S/R	
94. <i>Titanoderma pustulatum</i> (J.V. Lamouroux) Nägeli	X		X	I, S /R, Ep	
Nemaliales		X	X	S/R	
Liagoraceae					
95. <i>Ganonema farinosum</i> (J.V. Lamouroux) K.C. Fan and Yung C. Wang	X				
96. <i>G. megagynum</i> (Børgesen) Huisman			X	S/R	
97. <i>G. pinnatum</i> (Harvey) Huisman			X	S/R	
98. <i>Gloiocallis dendroidea</i> (P.L. Crouan and H.M. Crouan) S.M. Lin, Huisman and D.L. Ballantine			X	S/R	
99. <i>Helminthocladia calvadosii</i> (J.V. Lamouroux ex Duby) Setchell			X	I/R	
100. <i>Liagora albicans</i> J.V. Lamouroux			X	S/R	
101. <i>L. ceranoides</i> J.V. Lamouroux			X	I, S/R	
102. <i>L. tsengii</i> Huisman and M. J. Wynne			X	S/R	
103. <i>Trichogloeopsis pedicellata</i> (M. A. Howe) I.A. Abbott and Doty			X	I, S/R	
104. <i>Titanophycus validus</i> (Harvey) Huisman, G. W. Saunders and A. R. Sherwood		X	X	I, S/R	
Galaxauraceae	X		X	S/R	
105. <i>Dichotomaria marginata</i> (J. Ellis and Solander) Lamarck					
106. <i>D. obtusata</i> (J. Ellis and Solander) Lamarck	X			S/R	
107. <i>Galaxaura comans</i> Kjellman			X	S/R	
108. <i>G. rugosa</i> (J. Ellis and Solander) J.V. Lamouroux			X	S/R	
109. <i>Tricleocarpa cylindrica</i> (J. Ellis and Solander) Huisman and Borowitzka			X	S/R	
110. <i>T. fragilis</i> (Linnaeus) Huisman and R. A. Townsend			X	S/R	
Scinaiaceae	X		X	S/R	
111. <i>Scinaia complanata</i> (F. S. Collins) A. D. Cotton					
Bonnemaisoniales	X	X	X	I, S/Ep	
Bonnemaisoniaceae					
112. <i>Asparagopsis taxiformis</i> (Delile) Trevisan de Saint-Léon					

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
Naccariaceae			X	S/Ep	
113. <i>Naccaria antillana</i> W. R. Taylor					
Ceramiales			X	I, S/Ep	
Callithamniaceae					
114. <i>Aglaothamnion boergesenii</i> (Aponte and D. L. Ballantine) L'Hardy-Halos and T. Rueness					
115. <i>A. cordatum</i> (Børgesen) Feldmann-Mazoyer			X	I, S/R, Ep, M	
116. <i>A. felliponei</i> (M. A. Howe) D. L. Ballantine, N. E. Aponte and J. N. Norris			X	I, S /R, Ep	
117. <i>A. herveyi</i> (M. A. Howe) N. E. Aponte, D. L. Ballantine and J. N. Norris	X	X		I, S/R, Ep	
118. <i>Callithamnion corymbosum</i> (Smith) Lyngbye			X	I, S/M, Ep	
119. <i>Crouania attenuata</i> (C. Agardh) J. Agardh			X	I, S /Ep	
120. <i>C. mayae</i> Mateo-Cid, Mendoza-González and Searles		X	X	S/R, Ep	
121. <i>C. pleonospora</i> W. R. Taylor			X	S/R, Ep	
122. <i>Crouanophycus latiaxis</i> (I. A. Abbott) A. Athanasiadis			X	S/Ep	
123. <i>Seirospora occidentalis</i> Børgesen			X	S/Ep	
Ceramiaceae			X	S/Ep	
124. <i>Antithamnion cruciatum</i> (C. Agardh) Nägeli					
125. <i>A. decipiens</i> (J. Agardh) Athanasiadis			X	S/Ep	
126. <i>Antithamnionella boergesenii</i> (Cormaci and G. Furnari) Athanasiadis			X	S/Ep	
127. <i>A. elegans</i> (Berthold) J. H. Price and D. M. John	X		X	S/Ep	
128. <i>Callithamniella tingitana</i> (Schousboe ex Bornet) Feldmann-Mazoyer	X		X	I,S/Ep	
129. <i>Centrocerocolax ubatubensis</i> A. B. Joly			X	S/Par	
130. <i>Centroceras hyalacanthum</i> Kützing	X	X	X	I, S /R, Ep	NRM
131. <i>C. micracanthum</i> Kützing	X	X	X	I, S /R, Ep	
132. <i>Ceramium brevizonatum</i> var. <i>caraibicum</i> H.E. Petersen and Børgesen	X	X	X	I, S/R, Ep	
133. <i>C. cimbricum</i> H. E. Petersen		X	X	I, S/R, Ep	
134. <i>C. codii</i> (H. Richards) Mazoyer	X	X		I, S/R, Ep	
135. <i>C. corniculatum</i> Montagne	X	X	X	I, S/R, Ep	
136. <i>C. cruciatum</i> F. S. Collins and Hervey	X			I, S/R, Ep	

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
137. <i>C. deslongchampii</i> Chauvin ex Duby			X	S/Ep	
138. <i>C. floridanum</i> J. Agardh			X	S/R	
139. <i>C. leptozonum</i> M. A. Howe	X	X	X	S/Ep	
140. <i>C. leutzburgii</i> Schmidt	X	X	X	I, S/R, Ep	
141. <i>C. nitens</i> (C. Agardh) J. Agardh			X	I, S/R, Ep	
142. <i>C. subtile</i> J. Agardh			X	I, S/R, Ep	
143. <i>C. tenerrinum</i> (G. Martens) Okamura			X	I, S/R, Ep	
144. <i>C. virgatum</i> Roth			X	S/R	
145. <i>Corallophila verongiae</i> (D. L. Ballantine and M. J. Wynne) R. E. Norris			X	S/R	
146. <i>Gayliella flaccida</i> (Harvey ex Kützing) T.O. Cho and L. J. McIvor	X	X	X	I, S/R, Ep	
147. <i>G. mazoyerae</i> T. O. Cho, Fredericq and Hommersand	X	X	X	I, S/R, Ep	NRP
148. <i>G. transversalis</i> (F. S. Collins and Hervey) T.O. Cho and Fredericq			X	I, S/R, Ep	
149. <i>Dohrnella antillana</i> (W. R. Taylor) Feldmann-Mazoyer			X	S/Ep	
Spyridiaceae	X	X	X	I, S/R	
150. <i>Spyridia filamentosa</i> (Wulfen) Harvey					
151. <i>S. hypnoides</i> (Bory de Saint-Vincent) Papenfuss	X	X	X	I, S/R, Ep	
Wrangeliaceae	X	X	X	I, S /Ep	
152. <i>Anotrichium tenue</i> (C. Agardh) Nägeli					
153. <i>Griffithsia globulifera</i> Harvey ex Kützing			X	S /Ep	
154. <i>G. heteromorpha</i> Kützing			X	S /Ep	
155. <i>G. radicans</i> Kützing			X	I, S /Ep	
156. <i>G. schousbei</i> Montagne			X	S /Ep	
157. <i>Gymnothamnion elegans</i> (Schosboe) J. Agardh			X	S /Ep	
158. <i>Grallatoria reptans</i> M. A. Howe			X	S /Ep	
159. <i>Haloplegma duperreyi</i> Montagne			X	S /Ep	
160. <i>Ptilothamnion speluncarum</i> (F. S. Collins and Hervey) D. L. Ballantine and M. J. Wynne			X	S/R	

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
161. <i>Spermothamnion gymnocapum</i> M. A. Howe			X	I, S/Ep	
162. <i>S. investiens</i> (P. Crouan and H. Crouan) Vickers			X	I, S/Ep	
163. <i>S. macromeres</i> Collins and Harvey			X	I, S/Ep	
164. <i>S. repens</i> (Dillwyn) Rosenvinge			X	I, S/Ep	
165. <i>Tiffaniella gorgonae</i> (Montagne) Doty and Meñez	X	X	X	I, S/Ep	
166. <i>Wrangelia argus</i> (Montagne) Montagne	X		X	I, S/R, Ep	
167. <i>W. bicuspidata</i> Borgesen			X	I, S/R, Ep	
168. <i>W. penicillata</i> (C. Agardh) C. Agardh			X	S/R	
Delesseriaceae	X	X	X	I/M	
169. <i>Caloglossa leprieurii</i> (Montagne) G. Martens					
170. <i>Hypoglossum hypoglossoides</i> (Stackhouse) Collins and Harvey			X	S/Ep	
171. <i>H. involvens</i> (Harvey) J. Agardh			X	S/Ep	
172. <i>H. simulans</i> M. J. Wynne, I. R. Price and D. L. Ballantine			X	S/Ep	
173. <i>H. subsimplex</i> M. J. Wynne			X	S/Ep	
174. <i>H. tenuifolium</i> (Harvey) J. Agardh			X	S/Ep	
175. <i>Martensia fragilis</i> Harvey			X	I, S/R, Ep	
176. <i>Nitophyllum adhaerens</i> M. J. Wynne			X	S/Ep	
177. <i>Taenioma nanum</i> (Kützing) Papenfuss			X	I, S/Ep, M	
Dasyaceae	X	X	X	I, S/R	
178. <i>Dasya baillouviana</i> (S. G. Gmelin) Montagne					
179. <i>D. caraibica</i> Børgesen	X		X		
180. <i>D. collinsiana</i> M. A. Howe	X	X	X	I, S/R, Ep	
181. <i>D. corymbifera</i> J. Agardh	X	X	X	I, S/R, Ep	
182. <i>D. crouaniana</i> J. Agardh	X	X	X	S/R	
183. <i>D. haitiana</i> S. Fredericq and J. N. Norris			X	S/R	
184. <i>D. hutchinsiae</i> Harvey			X	S/R	
185. <i>D. mollis</i> Harvey			X	S/R	
186. <i>D. ocellata</i> (Grateloup) Harvey	X	X	X	I, S /R, Ep	
187. <i>D. ramosissima</i> Harvey			X	S/R	
188. <i>D. rigidula</i> (Kützing) Ardissoni	X	X	X	I, S /R, Ep	
189. <i>Dictyurus occidentalis</i> J. Agardh			X	S/R	

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
190. <i>Halydictyon mirabile</i> Zanardini	X	X	X	S/R	
191. <i>Heterosiphonia crispella</i> (C. Agardh) J. M. Wynne	X	X	X	I, S /Ep	
192. <i>H. gibbesii</i> (Harvey) Falkenberg			X	I, S /R	
193. <i>Thuretia bornetii</i> Vickers			X	I,S/R	
Rhodomelaceae	X	X	X	I,S/R	
194. <i>Acanthophora muscoides</i> (Linnaeus) Bory de Saint-Vincent					
195. <i>A. spicifera</i> (M. Vahl) Børgesen	X	X	X	I,S/R	
196. <i>Amansia multifida</i> J. V. Lamouroux		X	X	I,S/R	
197. <i>Bostrychia montagnei</i> Harvey			X	I/M	
198. <i>B. moritziana</i> (Sonder ex Kützing) J. Agardh			X	I/M	NRP
200. <i>B. radicans</i> (Montagne) Montagne	X	X	X	I,S/R, M	
201. <i>B. tenella</i> (J.V. Lamouroux) J. Agardh	X	X	X	I,S/M	
202. <i>Bryothamnion seaforthii</i> (Turner) Kützing	X	X	X	I,S/R	
203. <i>B. triquetrum</i> (S. G. Gmelin) M. A. Howe	X	X	X	I,S/R	
204. <i>Chondria baileyana</i> (Montagne) Harvey	X	X	X	I,S/R	
205. <i>Ch. capillaris</i> (Hudson) M. J. Wynne			X	S/R	
206. <i>Ch. cnicophylla</i> (Melvill) De Toni	X	X	X	S/Ep	
207. <i>Ch. collinsiana</i> M. A. Howe	X	X	X	I,S/R, Ep	
208. <i>Ch. curvilineata</i> F. S. Collins and Hervey	X		X	I,S/R	
209. <i>Ch. dasyphylla</i> (Woodward) C. Agardh	X	X	X	I,S/R	
210. <i>Ch. floridiana</i> (F. S. Collins) M. A. Howe			X	S/R	
211. <i>Ch. leptacremon</i> (Melvill ex G. Murray) De Toni	X	X	X	I,S/R	
212. <i>Ch. littoralis</i> Harvey	X		X	I,S/R	
213. <i>Ch. platyramea</i> A. B. Joly and Ugadim	X		X	S/Ep	
214. <i>Ch. polyrhiza</i> F.S. Collins and Hervey	X	X	X	I,S/Ep	
215. <i>Digenea simplex</i> (Wulfen) C. Agardh	X	X	X	I,S/R	
216. <i>Dipterosiphonia dendritica</i> (C. Agardh) F. Schmitz			X	I/Ep	
217. <i>D. rigens</i> (Shousboe ex C. Agardh) Falkenberg			X	I/Ep	

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
218. <i>Herposiphonia bipinnata</i> M. A. Howe			X	I, S/R, Ep	
219. <i>H. pecten-veneris</i> (Harvey) Falkenberg	X	X	X	I, S/R, Ep	
220. <i>H. secunda</i> f. <i>tenella</i> (C. Agardh) M. J. Wynne	X	X	X	I, S/R, Ep	
221. <i>Heterodasya mucronata</i> (Harvey) M. J. Wynne		X	X	S/R	
222. <i>Laurencia brongniartii</i> J. Agardh			X	S/R	
223. <i>L. caraibica</i> P. C. Silva			X	I, S/R, Ep	
224. <i>L. filiformis</i> (C. Agardh) Montagne	X	X	X	S/R	
225. <i>L. intricata</i> J. V. Lamouroux	X	X	X	I, S/R, Ep	
226. <i>L. laurahuertana</i> Mateo-Cid, Mendoza-González, Senties and Díaz-Larrea			X	I/Ep	
227. <i>L. microcladia</i> Kützing	X		X	I, S/R, Ep	
228. <i>L. obtusa</i> (Hudson) J. V. Lamouroux	X		X	I, S/R, Ep	
229. <i>L. venusta</i> Yamada	X		X	S/R	
230. <i>Lophosiphonia cristata</i> Falkenberg	X		X	I, S/R, Ep	
231. <i>L. obscura</i> (C. Agardh) Falkenberg	X		X	I, S/R, Ep	
232. <i>Lophocladia trichoclados</i> (C. Agardh) F. Schmitz			X	I, S/R, Ep	
233. <i>Meridiocolax polysiphoniae</i> (E. C. Oliveira and Ugadim) J. Morrill			X	I/Par	
234. <i>Murrayella periclados</i> (C. Agardh) F. Schmitz	X	X	X	I, S/R, Ep	
235. <i>Neosiphonia echinata</i> (Harvey) N. Mamoozadeh and D. W. Freshwater		X	X	I, S/R, Ep	
236. <i>N. ferulacea</i> (Suhr ex J. Agardh) S.M. Guimarães and M. T. Fujii		X	X	I, S/R, Ep	
237. <i>N. gorgoniae</i> (Harvey) S. M. Guimarães and M. T. Fujii		X	X	I,S/Ep	
238. <i>N. harveyi</i> (J. Bailey) M.-S. Kim, H.-G. Choi, Guiry and G. W. Saunders			X	I, S/R, Ep	
239. <i>N. hawaiiensis</i> (Hollenberg) M.-S.Kim and I. A. Abbott	X	X	X	I, S/R, Ep	
240. <i>N. howei</i> (Hollenberg) Skelton and G.R. South		X	X	I, S/R, Ep	
241. <i>N. sertularioides</i> (Grateloup) K. W. Nam and P. J. Kan		X	X	I, S/R, Ep	
242. <i>N. sphaerocarpa</i> (Børgesen) M. S. Kim and I. K. Lee	X	X	X	I, S/R, Ep	
243. <i>Osmundaria obtusiloba</i> (C. Agardh) R. E. Norris			X	I/R	
244. <i>Palizada corallopis</i> (Montagne) Senties, Fujii and Díaz	X		X	S/R	
245. <i>P. flagellifera</i> (J. Agardh) K. W. Nam			X	S/R	

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
246. <i>P. perforata</i> (Bory de Saint-Vincent) K. W. Nam	X	X	X	I, S/R, Ep	
247. <i>Polysiphonia atlantica</i> Kapraun and J. N. Norris	X	X	X	I, S/R, Ep	
248. <i>P. binneyi</i> Harvey	X	X	X	I, S/R, Ep	
249. <i>P. denudata</i> (Dillwyn) Greville ex Harvey	X			I, S/R, Ep	
250. <i>P. exilis</i> Harvey			X	S/R	
251. <i>P. pseudovillum</i> Hollenberg			X	I, S/R, Ep	NRP
252. <i>P. scopolorum</i> var. <i>villum</i> (J. Agardh) Hollenberg			X	S/Ep	
253. <i>P. subtilissima</i> Montagne	X		X	I, S/R, Ep	
254. <i>P. ramentacea</i> Harvey			X	S/R	
255. <i>Yuzurua poiteaui</i> (J.V. Lamouroux) Martin-Lescanne	X		X	S/R	
256. <i>Y. poiteaui</i> var. <i>gemmifera</i> (Harvey) M.J. Wynne	X			S/R	
257. <i>Wrightiella tumanowiczii</i> (Gatty ex Harvey) F. Schmitz			X	S/R	
Sarcomeniaceae			X	S/R	
258. <i>Cottoniella sanguinea</i> M. A. Howe					
Gelidiales	X	X	X	I, S/R, Ep	
Gelidiaceae					
259. <i>Gelidium americanum</i> (W. R. Taylor) Santelices					
260. <i>G. corneum</i> (Hudson) J. V. Lamouroux			X	I, S/R	
261. <i>G. crinale</i> (Hare ex Turner) Gaillon	X	X	X	I,S/R	
262. <i>G. pusillum</i> (Stackhouse) Le Jolis	X	X	X	I, S/R, Ep	
263. <i>G. spinosum</i> (S. G. Gmelin) P. C. Silva			X	S/R	
Gelidiellaceae					
264. <i>Gelidiella acerosa</i> (Forsskål) Feldmann and G. Hamel	X		X	I,S/R	
265. <i>G. lubrica</i> (Kützing) Feldmann and G. Hamel			X	I,S/Ep	
266. <i>Parviphycus pannosus</i> (Feldmann) G.XFurnari			X	I,S/R, Ep	
267. <i>P. setaceus</i> (Feldmann) J. Afonso-Carrillo, M. Sanson, C. Sangil and T. Díaz-Villa	X	X		I,S/R	
268. <i>P. trinitatensis</i> (W. R. Taylor) M. J. Wynne			X	S/R	

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
Pterocladiaceae	X		X	S/R	
269. <i>Pterocladiella capillacea</i> (S. G. Gmelin) Santelices and Hommersand					
270. <i>P. sanctarum</i> (Feldmann and G. Hamel) Santelices	X	X		S/R	
271. <i>P. taylorii</i> (Joly) Santelices	X			I,S/R	
Gigartinales			X	S/R	
Gigartinaceae					
272. <i>Chondracanthus elegans</i> (Greville) Guiry					
273. <i>C. teedei</i> (Mertens ex Roth) Kützing			X	S/R	
Caulacanthaceae			X	I/Ep	
274. <i>Catenella caespitosa</i> (Withering) L. M. Irvine					
275. <i>C. impudica</i> (Montagne) J. Agardh	X	X	X	I/Ep	
Cystocloniaceae	X	X	X	I,S/R, Ep	
276. <i>Hypnea musciformis</i> (Wulfen) J. V. Lamouroux					
277. <i>H. spinella</i> (C. Agardh) Kützing	X	X	X	I,S/R, Ep	
278. <i>H. valentiae</i> (Turner) Montagne			X	I,S/R, Ep	NRP
279. <i>Hypneocolax stellaris</i> Børgesen	X			I/Par	
Sebdeniaceae	X		X	S/R	
280. <i>Sebdenia flabellata</i> (J. Agardh) P. G. Parkinson					
Kallymeniaceae			X	S/R	
281. <i>Kallymenia westii</i> Ganesan					
Solieriaceae	X		X	S/R	
282. <i>Agardhiella ramossissima</i> (Harvey) Kylin					
283. <i>A. subulata</i> (C. Agardh) Kraft and M. J. Wynne	X		X	S/R	
284. <i>Eucheuma isiforme</i> (C. Agardh) J. Agardh	X		X	S/R	
285. <i>Meristotheca gelidium</i> (J. Agardh) E. J. Faye and M. Masuda	X			S/R	
286. <i>Solieria filiformis</i> (Kützing) P. W. Gabrielson	X			S/R	
287. <i>Flahaultia tagetiformans</i> W. R. Taylor			X	S/R	
288. <i>Sarcodiotheca divaricata</i> W. R. Taylor	X			S/R	NRM
289. <i>Wurdemannia miniata</i> (Sprengel) Feldmann and G. Hamel			X	I,S/R, Ep	
Dumontiaceae			X	S/R, Ep	
290. <i>Dudresnaya crassa</i> M. A. Howe					

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
Nemastomatales	X		X	S/R	
Nemastomataceae					
291. <i>Predaea feldmanii</i> Børgesen					
Acrosympytales			X	S/R	
Acrosympytaceae					
292. <i>Acrosympyton caribaeum</i> (J. Agardh) Sjöstedt					
Phyllophoraceae			X	I,S/R	
293. <i>Gymnogongrus griffithsiae</i> (Turner) Martius					
294. <i>G. tenuis</i> J. Agardh			X	I,S/R	
Rhizophyllidaceae			X	I,S/R	
295. <i>Ochtodes secundiramea</i> (Montagne) M. A. Howe					
Gracilariales	X	X	X	I,S/R	
Graciliaceae					
296. <i>Gracilaria blodgettii</i> Harvey					
297. <i>G. bursa-pastoris</i> (S. G. Gmelin) P. C. Silva	X		X	I,S/R	
298. <i>G. cervicornis</i> (Turner) J. Agardh	X		X	I,S/R	
299. <i>G. cuneata</i> Areschoug	X			I,S/R	
300. <i>G. cylindrica</i> Børgesen	X		X	I,S/R	
301. <i>G. damaecornis</i> J. Agardh	X		X	I,S/R	
302. <i>G. debilis</i> (Forsskål) Børgesen	X		X	I,S/R	
303. <i>G. dominguensis</i> (Kützing) Sonder ex Dickie			X	I,S/R	
304. <i>G. lacinulata</i> (M. Vahl) M. A. Howe			X	I,S/R	
305. <i>G. isabellana</i> Gurgel, Fredericq and J. N. Norris	X	X	X	I,S/R	
306. <i>G. mammillaris</i> (Montagne) M.A. Howe	X		X	I,S/R	
307. <i>G. multipartita</i> (Clemente) Harvey			X	I,S/R	
308. <i>G. ornata</i> Areschoug			X	I,S/R	
309. <i>G. tikvahiae</i> McLachlan	X		X	I,S/R	
310. <i>Gracilariaopsis andersonii</i> (Grunow) E. Y. Dawson	X		X	I,S/R	NRP

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
311. <i>G. lamaneiformis</i> (Bory de Saint-Vincent) E. Y. Dawson, Acleto and Foldvik	X		X	I,S/R	
312. <i>G. longissima</i> (S. G. Gmelin) M. Steentoft, L. M. Irvine and W. F. Farnham			X	I,S/R	
313. <i>Hydropuntia caudata</i> (J. Agardh) Gurgel and Fredericq			X	I,S/R	
314. <i>H. cornea</i> (J. Agardh) M. J. Wynne	X		X	I,S/R	
315. <i>H. crassissima</i> (J. Agardh) M. J. Wynne			X	I,S/R	
Halymeniales			X	S/Ep	
Halymeniaceae					
316. <i>Dermocorynus dichotomus</i> (J. Agardh) Gargiulo, M. Morabito and Manghisi					
317. <i>Halymenia echinophysa</i> F. S. Collins and M. A. Howe	X			S/R	
318. <i>Halymenia floresii</i> (Clemente) C. Agardh	X	X	X	S/R	
319. <i>H. floridiana</i> J. Agardh	X		X	S/R	
320. <i>H. pseudofloresia</i> F. S. Collin and M. A. Howe			X	S/R	
321. <i>H. rosea</i> M. A. Howe and W. R. Taylor			X	S/R	
322. <i>Cryptonemia crenulata</i> (J. Agardh) J. Agardh	X		X	S/R	
323. <i>Gratelouphia filicina</i> (J. V. Lamouroux) C. Agardh	X			I,S/R	
324. <i>G. gibbesi</i> Harvey			X	S/R	
Rhodymeniales	X	X	X	I,S/R, Ep	
Champiaceae					
325. <i>Champia minuscula</i> A. B. Joly and Ugadim					
326. <i>C. parvula</i> (C. Agardh) Harvey	X	X	X	I,S/R, Ep	
327. <i>C. parvula</i> var. <i>postrata</i> L. G. Williams			X	I,S/R, Ep	
328. <i>C. salicornioides</i> Harvey			X	I,S/R	
329. <i>Coelothrix irregularis</i> (Harvey) Børgesen			X	I,S/R	
330. <i>Gastroclonium parvum</i> (Hollenberg) C. F. Chang and B. M. Xia			X	I,S/R	
Lomentariaceae	X	X	X	I,S/R	
331. <i>Ceratodictyon intricatum</i> (C. Agardh). R. E. Norris					
332. <i>C. planicaule</i> (W. R. Taylor) M. J. Wynne	X	X	X	I,S/R	

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
333. <i>C. variabile</i> (Greville ex J. Agardh) R. E. Norris	X		X	I,S/R	
334. <i>Lomentaria divaricata</i> (Durant) M. J. Wynne			X	S/Ep	
335. <i>L. rawitsherii</i> A. B. Joly	X		X	S/Ep	
Rhodymeniaceae			X	S/R	
336. <i>Asteromenia peltata</i> (W. R. Taylor) Huisman and A. J. Millar					
337. <i>Botryocladia occidentalis</i> (Børgesen) Kylin	X	X	X	S/R	
338. <i>B. pyriformis</i> (Børgesen) Kylin			X	I,S/R	
339. <i>B. spinulifera</i> W. R. Taylor and I. A. Abbott			X	I,S/R	
340. <i>Chrysymenia enteromorpha</i> Harvey			X	S/R	
341. <i>C. halymenioides</i> Harvey			X	S/R	
342. <i>Coelarthrrum cliftonii</i> (Harvey) Kylin			X	S/R	
343. <i>Cordylecladia peasiae</i> F.S.Collins			X	S/R	
344. <i>Rhodymenia pseudopalmata</i> (J. V. Lamouroux) P. C. Silva			X	S/R	
Faucheaceae			X	S/Ep	
345. <i>Gloiocladia atlantica</i> (Searles) R. E. Norris					
Peyssonneliales			X	S/R	NRM
Peyssonneliaceae					
346. <i>Metapeyssonnelia tangerina</i> D. L. Ballantine and Ruiz					
347. <i>Peyssonnelia armorica</i> (P. Crouan and H. Crouan) Weber-van Bosse in Børgesen			X	S/R	
348. <i>P. boergesenii</i> Weber-van Bosse			X	S/R	
349. <i>P. boudouresquei</i> Yoneshigue			X	S/R	
350. <i>P. conchicola</i> Piccone and Grunow			X	S/R	
351. <i>P. inamoena</i> Pilger			X	S/R	
352. <i>P. nordstedtii</i> Weber-van Bosse			X	S/R	
353. <i>P. rubra</i> (Greville) J. Agardh			X	S/R, Ep	
354. <i>P. simulans</i> Weber-van Bosse			X	S/R, Ep	
355. <i>P. stoechas</i> Boudouresque and Denizot			X	S/R	

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
HETEROKONTOPHYTA	X	X	X	I, S/R, Ep	
Phaeophyceae					
Dictyotales					
Dictyotaceae					
356. <i>Canistrocarpus cervicornis</i> (Kützing) De Paula and De Clerck					
357. <i>C. cervicornis</i> f. <i>pseudohamatus</i> (Cribb) M. J. Wynne			X	S/R	
358. <i>Dictyopteris delicatula</i> J. V. Lamouroux	X	X	X	I, S/R, Ep	
359. <i>D. jamaicensis</i> W. R. Taylor			X	I, S/R, Ep	
360. <i>D. jolyana</i> E. C. Oliveira and R. P. Furtado			X	S/R	
361. <i>D. justii</i> J. V. Lamouroux	X		X	S/R	
362. <i>D. polypodioides</i> (A. P. De Candolle) J. V. Lamouroux	X		X	S/R	
363. <i>Dictyota bartayresiana</i> J. V. Lamouroux	X		X	I, S/R, Ep	
364. <i>D. caribaea</i> Hörning and Schnetter Montagne			X	I, S/R, Ep	
365. <i>D. ciliolata</i> Kützing	X	X		I, S/R	
366. <i>D. dichotoma</i> (Hudson) J. V. Lamouroux	X		X	I, S/R, Ep	
367. <i>D. hamifera</i> Setchell			X	S/Ep	
368. <i>D. guineensis</i> (Kützing) P. L. Crouan and H. M. Crouan			X	I, S/R, Ep	
369. <i>D. jamaicensis</i> W.R. Taylor	X	X	X	S/R	
370. <i>D. menstrualis</i> (Hoyt) Schnetter, Hörning and Weber-Peukert	X		X	I, S/R, Ep	
371. <i>D. mertensii</i> (Martius) Kützing			X	I, S/R	
372. <i>D. pinnatifida</i> Kützing	X	X	X	I, S/R	
373. <i>D. pulchella</i> Hörning and Schnetter	X	X	X	I, S/R, Ep	
374. <i>Lobophora variegata</i> (J. V. Lamouroux) Womersley ex E. C. Oliveira	X	X	X	I, S/R, Ep	
375. <i>Padina boergesenii</i> Allender and Kraft	X	X	X	I, S/R	
376. <i>P. gymnospora</i> (Kützing) Sonder	X	X	X	I, S/R	
377. <i>P. haitiensis</i> Thivy	X		X	I, S/R	
378. <i>P. pavonica</i> (Linnaeus) Thivy	X	X	X	I, S/R	
379. <i>P. sanctae-crucis</i> Børgesen	X	X	X	I, S/R	
380. <i>Spatoglossum schroederi</i> (C. Agardh) Kützing	X	X	X	I, S/R	

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
381. <i>Stylopodium zonale</i> (J. V. Lamouroux) Papenfuss			X	I, S/R	
382. <i>Zonaria tournefortii</i> (J. V. Lamouroux)		X	X	S/R	
Ectocarpales	X	X		I, S/Ep	
Acinetosporaceae					
383. <i>Hincksia rallsiae</i> (Vickers) P. C. Silva					
384. <i>H. onslowensis</i> (Amsler and Kapraun) P. C. Silva			X	I, S/Ep	
Asteronemataceae			X	I, S/R, Ep	
385. <i>Asteronema breviarticulatum</i> (J. Agardh) Ouriques and Bouzon					
386. <i>A. rhodochortonoides</i> (Børgesen) D. G. Müller and E. R. Parodi			X	S/Ep	
387. <i>Feldmannia duchassaingiana</i> (Grunow) Aisha and Shameel		X	X	I, S/Ep	
388. <i>F. mitchelliae</i> (Harvey) H. S. Kim		X	X	I, S/R, Ep	
389. <i>Herponema tortugense</i> (W. R. Taylor) W. R. Taylor			X	S/Ep	
Chordariaceae			X	S/Ep	
390. <i>Myrionema strangulans</i> Montagne					
391. <i>Cladosiphon zosterae</i> (J. Agardh) Kylin	X			S/Ep	
392. <i>Levrtingia brasiliensis</i> (Montagne) A. B. Joly		X		I/R	
393. <i>Streblonema invisible</i> Hoyt	X			S/Ep	
Ectocarpaceae	X		X	I,S/Ep	
394. <i>Kuetzingiella elachistaformis</i> (Heydrich) M. Balakrishnan and Kinkar					
395. <i>Ectocarpus confervoides</i> Harvey in J.D. Hooker		X		I, S/R, Ep	
396. <i>E. siliculosus</i> (Dillwyn) Lyngbye			X	I, S/R, Ep	
397. <i>E. siliculosus</i> var. <i>dasycarpus</i> (Kuckuck) Gallardo	X	X		I, S/R, Ep	
398. <i>E. variabilis</i> Vickers			X	I,S/Ep	
Scytosiphonaceae			X	I, S/R	
399. <i>Chnoospora minima</i> (Hering) Papenfuss					
400. <i>Colpomenia sinuosa</i> (Roth) Derbes and Solier	X		X	S/R	
401. <i>Hydroclathrus clathratus</i> (C. Agardh) M. A. Howe			X	S/R	

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
402. <i>Rosenvingea intricata</i> (J. Agardh) Borgesen			X	S/R	
403. <i>R. sanctae-crucis</i> Børgesen		X		S/R	
Onslowiales			X	S/Ep	
Onslowiaceae					
404. <i>Onslowia bahamaensis</i> E.C. Henry					
405. <i>O. endophytica</i> Searles	X		X	S/En	
406. <i>Verosphacela ebrachia</i> E.C. Henry			X	S/Ep	
Sphacelariales			X	I, S/Ep	
Sphacelariaceae					
407. <i>Sphacelaria brachygonia</i> Montagne					
408. <i>S. novae-hollandiae</i> Sonder		X	X	I, S/Ep	
409. <i>S. rigidula</i> Kützing		X	X	I, S/Ep	
410. <i>S. tribuloides</i> Meneghini			X	I, S/R	
Ralfsiales	X	X		I/R	
Neoralfsiaceae					
411. <i>Neoralfsia expansa</i> (J. Agardh) P. E. Lim and H. Kawai ex Cormaci and G. Furnari					
Fucales			X	S/R	
Sargassaceae					
412. <i>Sargassum buxifolium</i> (Chauvin) M. J. Wynne					
413. <i>S. cymosum</i> C. Agardh	X		X	I,S/R	
414. <i>S. filipendula</i> C. Agardh	X	X	X	I,S/R	
415. <i>S. fluitans</i> (Børgesen) Børgesen	X	X	X	I,S/F	
416. <i>S. furcatum</i> Kützing	X		X	I,S/R	
417. <i>S. natans</i> (Linnaeus) Gaillon		X	X	I,S/F	
418. <i>S. platycarpum</i> Montagne			X	I,S/R	
419. <i>S. polyceratum</i> Montagne			X	I,S/R	
420. <i>S. polyceratum</i> var. <i>ovatum</i> (F.S. Collins) W. R. Taylor			X	I,S/R	
421. <i>S. ramifolium</i> Kützing			X	I,S/R	
422. <i>S. vulgare</i> C. Agardh		X	X	I,S/R	
423. <i>Turbinaria tricostata</i> E. S. Barton			X	I,S/R	

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
424. <i>T. turbinata</i> (Linnaeus) Kuntze			X	I,S/R	
Sporochnaceae	X			S/R	
425. <i>Sporochnus pedunculatus</i> (Hudson) C. Agardh					
CHLOROPHYTA	X	X	X	I, S/En	
Ulvophyceae					
Phaeophilales					
Phaeophilaceae					
426. <i>Phaeophila dendroides</i> (P. L. Crouan and H. M. Crouan) Batters					
Ulvales		X	X	I, S/Ep	
Ulvellaceae					
427. <i>Epicladia ventriculosa</i> (Børgesen) M. J. Wynne					
428. <i>Ulvella lens</i> P. L. Crouan and H. M. Crouan		X	X	I, S/Ep	
429. <i>U. viridis</i> (Reinke) R. Nielsen, C. J. O'Kelly and B. Wysor		X	X	I, S/Ep	
Ulvaceae	X		X	I, S/R	
430. <i>Ulva compressa</i> Linnaeus					
431. <i>U. chaetomorphoides</i> (Børgesen) Hayden, Blomster, Maggs, P. C. Silva, M. J Stanhope and J. R. Waaland			X	I, S/R, Ep	
432. <i>U. flexuosa</i> Wulfen	X	X	X	I, S/R	
433. <i>U. lactuca</i> Linnaeus	X		X	I, S/R	
434. <i>U. intestinalis</i> Linnaeus	X	X	X	I, S/R	
435. <i>U. linza</i> Linnaeus	X	X	X	I, S/R	
436. <i>U. rigida</i> C. Agardh			X	I, S/R, Ep	
Kornmanniaceae			X	S/Ep	
437. <i>Pseudodoclonium marinum</i> (Reinke) Aleem and E. Schulz					
Cladophorales			X	S/R	NRP
Anadyomenaceae					
438. <i>Anadyomene howei</i> D. S. Littler and M. M. Littler					
439. <i>A. menziesii</i> Harvey	X	X	X	S/R	

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
440. <i>A. pavonina</i> (J. Agardh) Wille	X			S/R	NRP
441. <i>A. saldanhae</i> A.B. Joly and E.C. Oliveira	X		X	S/R	
442. <i>A. stellata</i> (Wulfen) C. Agardh			X	I,S/R, Ep	
443. <i>Microdictyon marinum</i> (Bory de Saint Vincent) P.C. Silva	X		X	S/R	
Boodleaceae			X	I,S/R	
444. <i>Cladophoropsis fasciculata</i> (Kjellman) Wille					
445. <i>C. membranacea</i> (Hofman Bang ex C. Agardh) Børgesen	X	X	X	I,S/R	
446. <i>C. macromeres</i> W.R. Taylor			X	I,S/R	
447. <i>Phyldodictyon anastomosans</i> (Harvey) Kraft and M. J. Wynne		X	X	I/R	
448. <i>P. pulcherrimum</i> J. E. Gray		X		I/R	
Phitophoraceae			X	I, S/R	
449. <i>Dictyosphaeria cavernosa</i> (Forsskål) Børgesen					
450. <i>D. ocellata</i> (M. A. Howe) Olsen-Stojkovich			X	I, S/R, Ep	
Siphonocladaceae			X	S/R, Ep	
451. <i>Chamaedoris peniculum</i> (J. Ellis and Solander) Kuntze					
452. <i>Ernodesmis verticillata</i> (Kützing) Børgesen	X		X	I,S/R	
453. <i>Siphonocladus rigidus</i> M.A. Howe			X	I, S/R, Ep	
454. <i>S. tropicus</i> (P. L. Crouan and H. M. Crouan) J. Agardh			X	I,S/R, Ep	
Valoniaceae			X	I, S/R, Ep	
455. <i>Valonia aegagropila</i> C. Agardh					
456. <i>V. macrophysa</i> Kützing			X	I, S/R, Ep	
457. <i>V. utricularis</i> (Roth) C. Agardh			X	I, S/R, Ep	
458. <i>V. ventricosa</i> J. Agardh			X	I, S/R, Ep	
Chaetosiphonaceae			X	S/Ep	
459. <i>Blastophysa rhizopus</i> Reinke					
Cladophoraceae	X	X	X	I, S/R, Ep	
460. <i>Chaetomorpha aerea</i> (Dillwyn) Kützing					
461. <i>Ch. antennina</i> (Bory) Kützing	X	X	X	I, S/R	
462. <i>Ch. bracygona</i> Harvey			X	I, S/Ep	

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
463. <i>Ch. clavata</i> Kützing			X	I, S/Ep	
464. <i>Ch. crassa</i> (C. Agardh) Kützing			X	I, S/Ep	
465. <i>Ch. geniculata</i> Montagne			X	I, S/Ep	
466. <i>Ch. gracilis</i> Kützing	X	X	X	I, S/Ep	
467. <i>Ch. linum</i> (O. F. Müller) Kützing	X	X	X	I, S/Ep	
468. <i>Ch. minima</i> F. S. Collins and Hervey			X	I, S/Ep	
469. <i>Cladophora albida</i> (Nees) Kützing	X	X	X	I, S/R, Ep	
470. <i>Cl. catenata</i> (Linnaeus) Kützing			X	I, S/R, Ep	
471. <i>Cl. coelothrix</i> (Hudson) Kützing	X		X	I, S/R, Ep	
472. <i>Cl. constricta</i> F. S. Collins			X	I, S/Ep	
473. <i>Cl. corallicola</i> Børgesen			X	I, S/Ep	
474. <i>Cl. crispula</i> Vickers			X	I, S/R, Ep	
475. <i>Cl. dalmatica</i> Kützing			X	I, S/Ep	
476. <i>Cl. fracta</i> (O.F. Müller ex Vahl) Kützing	X			I, S/R, Ep	
477. <i>Cl. glomerata</i> var. <i>crassior</i> (C. Agardh) Hoek			X	I, S/R, Ep	
478. <i>Cl. intertexta</i> F. S. Collins	X		X	I, S/R, Ep	
479. <i>Cl. laetevirens</i> (Dillwyn) Kützing	X			I, S/Ep	
480. <i>Cl. lehmanniana</i> (Lindenberg) Kützing	X	X		I, S/Ep	
481. <i>Cl. liebetruhii</i> Grunow	X	X		I, S/Ep	NRP
482. <i>Cl. liniformis</i> Kützing	X	X		I, S/Ep	NRP
483. <i>Cl. montagneana</i> Kützing	X	X	X	I, S/Ep	
484. <i>Cl. pellucida</i> (Hudson) Kützing			X	I, S/Ep	
485. <i>Cl. sericea</i> (Hudson) Kützing	X		X	I, S/R, Ep	
486. <i>Cl. vadorum</i> (Areschoug) Kützing	X	X	X	I, S/Ep	
487. <i>Cl. vagabunda</i> (Linnaeus) van den Hoek	X		X	I, S/R, Ep	
488. <i>Rhizoclonium africanum</i> Kützing	X	X	X	I, S/Ep	
489. <i>Rh. crassipellitum</i> West and G. S. West			X	I, S/Ep	

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
490. <i>Rh. riparium</i> (Roth) Harvey	X	X	X	I, S/Ep	
491. <i>Rh. tortuosum</i> (Dillwyn) Kützing	X			S/Ep	
Bryopsidales					
Bryopsidaceae					
492. <i>Bryopsis hypnoides</i> J. V. Lamouroux					
493. <i>B. pennata</i> J. V. Lamouroux	X	X	X	I,S/R	
494. <i>B. pennata</i> var. <i>leprieri</i> (Kützing) Collins et Hervey	X			I,S/R, Ep	
495. <i>B. plumosa</i> (Hudson) C. Agardh	X		X	I,S/R	
496. <i>B. ramulosa</i> (Montagne)			X	I,S/R	
497. <i>Pseudobryopsis blomquistii</i> Díaz-Piferrer			X	S/R	
498. <i>Trichosolen duchassaingii</i> (J. Agardh) W. R. Taylor	X		X	I,S/R	
Derbesiaceae			X	S/R	
499. <i>Derbesia fastigiata</i> W. R. Taylor					
500. <i>D. marina</i> (Lyngbye) Solier			X	I,S/R, Ep	
501. <i>D. osterhoutii</i> (L. R. Blinks and A. C. H. Blinks) J. Z. Page		X	X	S/Ep	
502. <i>D. vaucheriaeformis</i> (Harvey) J. Agardh		X	X	I,S/R	
503. <i>Pedobesia simplex</i> (Meneghini ex Kützing) M. J. Wynne and Leliaert		X		I/R	NRP
Codiaceae					
504. <i>Codium decorticatum</i> (Woodward) M. A. Howe	X		X	I,S/R	
505. <i>C. intertextum</i> Collins and Hervey		X	X	I/R	
506. <i>C. isthmocladum</i> Vickers	X		X	S/R	
507. <i>C. taylorii</i> P. C. Silva			X	I/R	
Caulerpaceae		X	X	S /A	
508. <i>Caulerpa ashmeadii</i> Harvey			X	S/A	
509. <i>C. brachypus</i> Harvey			X	S/A	
510. <i>C. chemnitzia</i> (Esper) J. V. Lamouroux	X	X	X	S/A	
511. <i>C. cupressoides</i> (H. West) C. Agardh	X	X	X	S/A	
512. <i>C. cupressoides</i> var. <i>lycopodium</i> Weber-van Bosse			X	S/A	
513. <i>C. cupressoides</i> var. <i>turneri</i> Weber-van Bosse	X	X		S/A	
514. <i>C. cupressoides</i> var. <i>flabellata</i> Børgesen	X	X	X	S/A	

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
515. <i>C. fastigiata</i> Montagne	X	X	X	S/A	
516. <i>C. mexicana</i> Sonder ex Kützing		X	X	S/A, R	
517. <i>C. mexicana</i> f. <i>laxior</i> (Weber-van Bosse) W. R. Taylor			X	S/A	
518. <i>C. mexicana</i> var. <i>pectinata</i> (Kützing) W. R. Taylor			X	S/A	
519. <i>C. microphysa</i> (Weber-van Bosse) Feldmann	X	X	X	S/A	
520. <i>C. paspaloides</i> (Bory de Saint Vincent) Greville			X	S/A, R	
521. <i>C. paspaloides</i> f. <i>phleoides</i> (Bory de Saint-Vincent) Weber-van Bosse	X			S/A	
522. <i>C. paspaloides</i> var. <i>laxa</i> Weber-van Bosse	X			S/A, R	
523. <i>C. paspaloides</i> var. <i>wurdemannii</i> Weber-van Bosse	X	X	X	S/A	
524. <i>C. lamourouxii</i> (Turner) C. Agardh	X	X	X	S/A	
525. <i>C. prolifera</i> (Forsskål) J. V. Lamouroux		X	X	S/A	
526. <i>C. prolifera</i> f. <i>obovata</i> J. Agardh			X	S/A	
527. <i>C. prolifera</i> f. <i>zosterifolia</i> Børgesen	X	X	X	S/A	
528. <i>C. racemosa</i> (Forsskål) J. Agardh	X	X	X	S/R	
529. <i>C. racemosa</i> var. <i>macrophysa</i> (Kützing) W. Taylor			X	S/R	
530. <i>C. racemosa</i> var. <i>occidentalis</i> (J. Agardh) Børgesen			X	S/A	
531. <i>C. serrulata</i> (Forsskål) J. Agardh			X	I, S/A	
532. <i>C. sertularioides</i> (S. Gmelin) M. Howe	X	X	X	I, S/A, R	
533. <i>C. sertularioides</i> f. <i>brevipes</i> (J. Agardh) Svedelius			X	I, S/A	
534. <i>C. sertularioides</i> f. <i>farlowii</i> (Weber-van Bosse) Børgesen	X			I; S/A, R	
535. <i>C. sertularioides</i> f. <i>longiseta</i> (Bory de Saint-Vincent) Svedelius	X	X	X	S/A, R	
536. <i>C. verticillata</i> C. Agardh	X	X	X	I, S/A, M	
537. <i>C. webbiana</i> Montagne			X	S/A	
538. <i>Caulerpella ambigua</i> (Okamura) Prud'homme van Reine et Lokhor			X	S/A, Ep	
Halimedaceae	X	X	X	S/A	
539. <i>Halimeda copiosa</i> Goreau and E. A. Graham					
540. <i>H. discoidea</i> Decaisne	X		X	S/A	

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
541. <i>H. favulosa</i> M. A. Howe			X	S/A	
542. <i>H. goreauii</i> W. R. Taylor	X		X	S/A	
543. <i>H. gracilis</i> Harvey ex J. Agardh	X	X	X	S/A	
544. <i>H. incrassata</i> (J. Ellis) J. V. Lamouroux	X	X	X	S/A	
545. <i>H. lacrimosa</i> M.A. Howe		X	X	S/A	
546. <i>H. monile</i> (J. Ellis and Solander) J.V. Lamouroux	X	X	X	S, I/A, R	
547. <i>H. opuntia</i> (Linnaeus) J. V. Lamouroux	X		X	S/R	
548. <i>H. scabra</i> M. A. Howe	X		X	S/A	
549. <i>H. simulans</i> M. A. Howe			X	S/A	
550. <i>H. tuna</i> (J. Ellis and Solander) J.V. Lamouroux		X	X	S/A	
Dichotomosiphonaceae			X	S/A	
551. <i>Avrainvillea asarifolia</i> Børgesen					
552. <i>A. digitata</i> D. S. Littler and M. M. Littler			X	I, S/R	
553. <i>A. elliotti</i> A. Gepp and E. S. Gepp	X	X	X	S/A	
554. <i>A. levis</i> M. A. Howe			X	S/A	
555. <i>A. longicaulis</i> (Kützing) G. Murray and Boodle			X	S/A, R	
556. <i>A. mazei</i> G. Murray and Boodle			X	S/A	
557. <i>A. nigricans</i> Decaisne			X	S/A, R	
558. <i>A. rawsonii</i> (Dickie) M. A. Howe			X	S/A	
559. <i>Cladocephalus luteofuscus</i> (P. L. Crouan and H. M. Crouan) Børgesen			X	S/A	
560. <i>C. scoparius</i> M. A. Howe			X	S/A	
Pseudocodiaceae	X			S/A	
561. <i>Pseudocodium floridanum</i> Dawes and Mathieson					NRP
Rhipiliaceae			X	I, S /A	
562. <i>Rhipilia tomentosa</i> Kützing					
563. <i>Rhipiliopsis profunda</i> (Eiseman and S. Earle) J. N. Norris and S. Blair			X	S/Ep	
564. <i>R. stri</i> (Earle and J. R. Young) Farghaly and Denizot			X	S/A	

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Table 1. (Continued)

Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
Udoteaceae	X	X	X	I,S/R, A	
565. <i>Boodeopsis pusilla</i> (F. S. Collins) W. R. Taylor, A. B. Joly and Bernatowicz					
566. <i>Penicillus capitatus</i> Lamarck	X	X	X	S/A, R	
567. <i>P. capitatus</i> f. <i>laxus</i> Børgesen	X	X	X	S/A	
568. <i>P. dumetosus</i> (J.V. Lamouroux) Blainville			X	S/R	
569. <i>P. dumetosus</i> f. <i>expansus</i> Børgesen	X	X	X	S/A	
570. <i>P. lamourouxii</i> Decaisne	X	X	X	S/A, R	
571. <i>P. pyriformis</i> A. Gepp and E. Gepp			X	S/A, R	
572. <i>Rhipidosiphon floridensis</i> D. S. Littler and M. M. Littler			X	S/A	
573. <i>Rhipocephalus oblongus</i> (Decaisne) Kützing			X	I,S/A	
574. <i>R. phoenix</i> (J. Ellis and Solander) Kützing		X	X	S/A, R	
575. <i>R. phoenix</i> f. <i>brevifolius</i> A. Gepp and E. S. Gepp	X	X	X	S/A, R	
576. <i>Rhipocephalus phoenix</i> f. <i>longifolius</i> A. Gepp and E. Gepp	X		X	S/A, R	
577. <i>Udotea caribaea</i> D. S. Littler and M. M. Littler			X	S/A	
578. <i>U. conglutinata</i> (J. Ellis and Solander) J.V. Lamouroux	X		X	S/A	
579. <i>U. cyathiformis</i> Decaisne			X	S/A	
580. <i>U. cyathiformis</i> f. <i>sublittoralis</i> (W. R. Taylor) D. S. Littler and M. M. Littler	X		X	S/A	
581. <i>U. dixonii</i> D. S. Littler and M. M. Littler	X	X	X	S/A	
582. <i>U. flabellum</i> (J. Ellis and Solander) M. A. Howe	X		X	I, S/A	
583. <i>U. looensis</i> D. S. Littler and M. M. Littler	X		X	S/A	
584. <i>U. luna</i> D. S. Littler and M. M. Littler			X	S/A	
585. <i>U. occidentalis</i> A. Gepp and E. Gepp	X		X	S/A	
586. <i>U. spinulosa</i> M. Howe			X	I, S/A	
587. <i>U. unistratea</i> D. S. Littler and M. M. Littler			X	I, S/A	
588. <i>U. wilsonii</i> A. Gepp, E. S. Gepp and M. A. Howe			X	S/A	

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Species	States			Level/ Habitat	OBS
	CAMP	YUC	QROO		
Dasycladales					
Dasycladaceae					
589. <i>Batophora oerstedii</i> J. Agardh	X	X	X	I, S/R, Ep	
590. <i>B. occidentalis</i> (Harvey) S. Berger and Keaver ex. N. J. Wynne			X	I, S/R	
591. <i>B. occidentalis</i> var. <i>largoensis</i> (J. S. Prince and S. Baker) S. Berger and Keaver ex M. J. Wynne			X	I, S/R, M	
592. <i>Cymopolia barbata</i> (Linnaeus) J. V. Lamouroux			X	S/R	
593. <i>Dasycladus vermicularis</i> (Scopoli) Krasser	X		X	S/R	
594. <i>Neomeris annulata</i> Dickie			X	S/R	
595. <i>N. cokeri</i> M. A. Howe			X	S/R	
596. <i>N. dumetosa</i> J. V. Lamouroux			X	S/R	
597. <i>N. mucosa</i> M. A. Howe			X	S/R	
Polyphysaceae	X	X	X	I, S/R	
598. <i>Acetabularia caliculus</i> J. V. Lamouroux					
599. <i>A. crenulata</i> J.V. Lamouroux	X	X	X	I, S/R	
600. <i>A. farlowii</i> Solms-Laubach		X	X	I, S/R	
601. <i>A. schenckii</i> K. Möbius	X		X	I, S/R	
602. <i>Chalmasia antillana</i> Solms-Laubach			X	S/R	
603. <i>Parvocaulis polyphysoides</i> (P. L.Crouan and H. M.Crouan) S. Berger, U. Fettweiss, S. Gleissberg, L. B. Liddle, U. Richter, H. Sawitzky and G. C. Zuccarello		X	X	S/R	
604. <i>P. pusillus</i> (M.A. Howe) S. Berger, U. Fettweiss, S. Gleissberg, L. B. Lidle, U. Rithcer, H. Sawitzky and G. C. Zuccarello			X	S/R	
Orden Ulotrichales	X		X	I, S/Ep	
Ulotrichaceae					
605. <i>Ulothrix flacca</i> (Dillwyn) Thuret					

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RESULTS

A total of 605 species of benthic marine algae were found in Yucatan Peninsula (Table I), of the total of marine algae identified, 38 species correspond to Cyanobacteria, 317 to Rhodophyta, 70 to Phaeophyceae and 180 to Chlorophyta (Figure 2). The percentage of species for each group is: Cyanobacteria 6.2%; Rhodophyta, 52.3%; Phaeophyceae, 11.6%; Chlorophyta, 29.9%, of them three species are new records from Mexican Caribbean, *Centroceras hyalacanthum*, *Metapeyssonnelia tangerina* and *Sarcodiotheca divaricata*. In addition sixteen species are new records for the study area; seven corresponds to Cyanobacteria, three to Rhodophyta and six to Chlorophyta (Table 1, column of observations). The family with highest species richness of the division Rhodophyta was Rhodomelaceae with 64 species, eleven of the genus Chondria and eight of *Laurencia*, *Neosiphonia* and *Polysiphonia*. It is followed in importance by the family Corallinaceae, with 39 taxa of which twelve belong to the genus *Neogoniolithon* and seven to the genus *Amphiroa*. Ceramiaceae has 26 species, of which 13 are of the genus *Ceramium*.

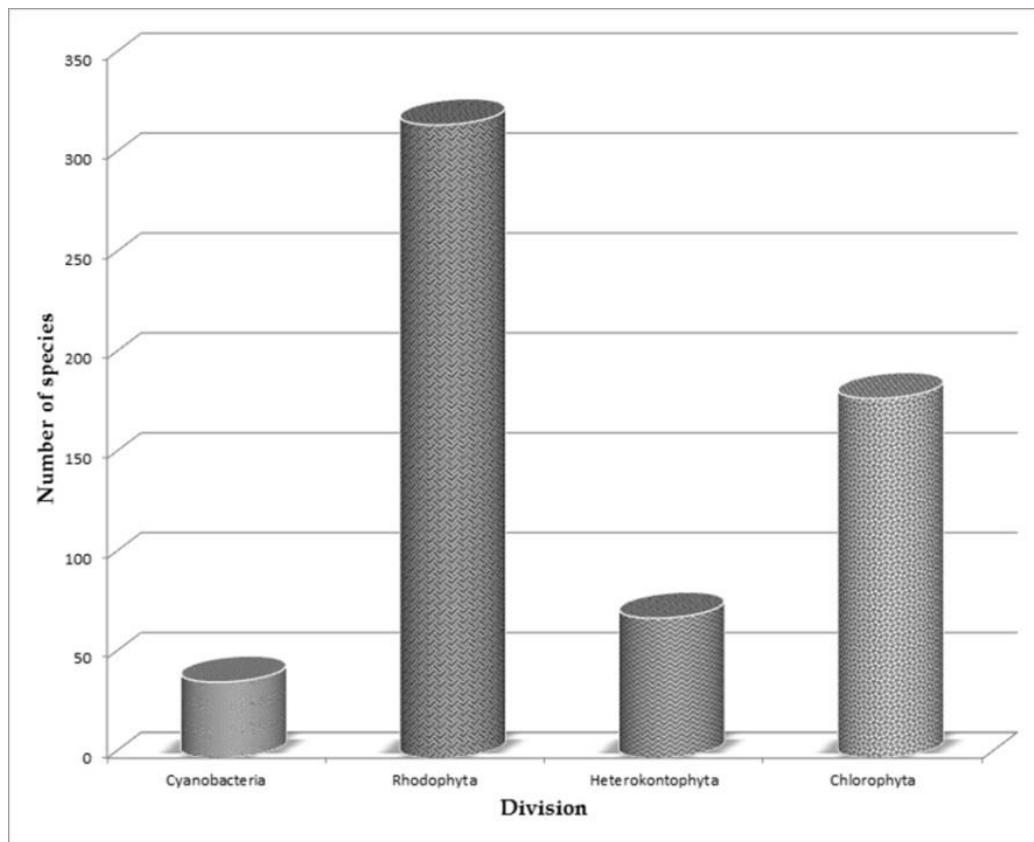


Figure 2. Total number of species for Divisions in Yucatan Peninsula.

Regarding the class Phaeophyceae, the family Dictyotaceae was represented by twenty seven species, eleven of the genus *Dictyota* and five of the genus *Padina*. Concerning Chlorophyta the families Caulerpaceae and Cladophoraceae were the best represented with 31

taxa each one, 30 of genus *Caulerpa* and 19 of *Cladophora*. Udoteaceae was represented by 24 species of which twelve belong to the genus *Udotea*. The group with the lowest number of species was the division Cyanobacteria; the families Oscillatoriaceae, Phormidiaceae, Schizotrichaceae and Entophysalidaceae were represented by four species each one (Figure 3). The number of species found each state is: Campeche 271; Yucatan 214 and finally Quintana Roo with 551 (Figure 4), these data shows that the last state has the greatest diversity of marine algae in the Gulf of Mexico and Mexican Caribbean's shores [1, 2, 5, 8].

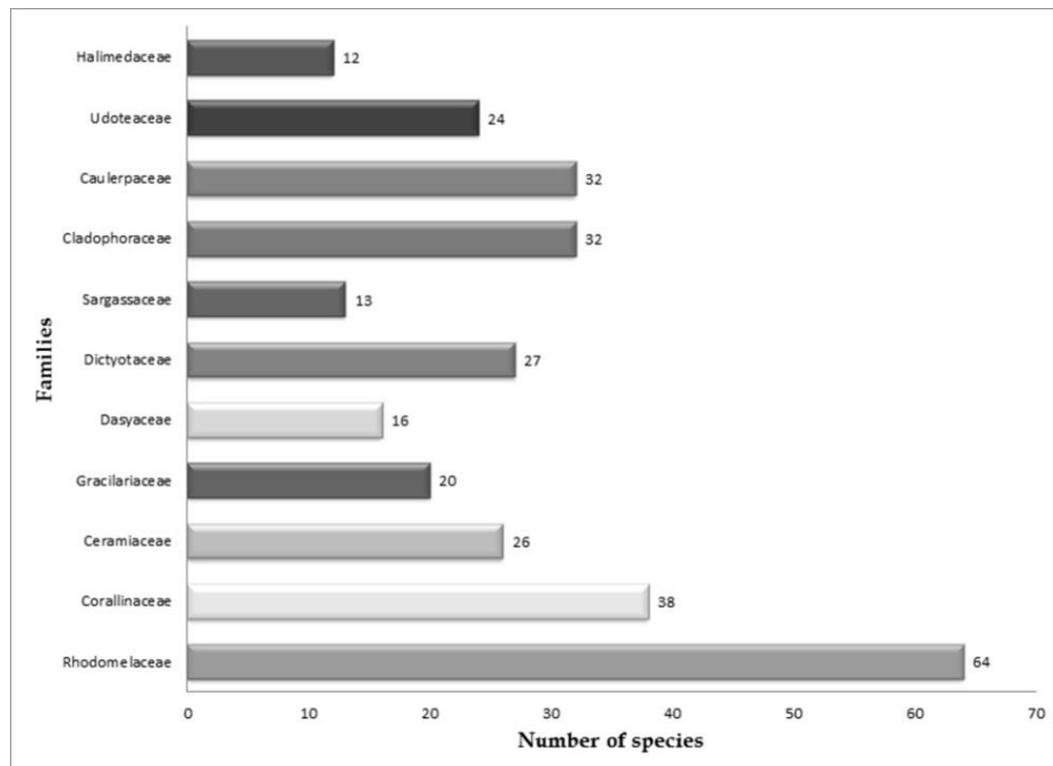


Figure 3. Number of species of best represented families in Yucatan Peninsula.

Most marine algae are indifferent to the chemical nature of their substrate; epiphytic algae can develop on other algae. Epiphytes that occur on a certain species of alga are closely related to the texture of the host, whose life span should be long enough to allow the epiphyte to complete its life cycle on it. In some cases, the occurrence of an epiphyte on a host is fortuitous, whereas in others, there is a high degree of specificity. The presence of epiphytic marine algae on other larger algae is a well-known phenomenon. Most epiphytes use the host as a support structure [20]. A significant number of epiphytes were found in this chapter, in total 257; of which 240 occurred on different algae, seagrasses and mangrove roots, with no preference for any one of them (Figure 5). The other 17 did show specificity, such as *Catenella impudica*, *Bostrychia scorpioides*, *B. montagnei* and *Laurencia laurahuertana*, among others. In fact, it is known that a large number of species of algae are obligate epiphytes and in many cases form permanent associations with some species of algae, marine phanerogams and mangroves.

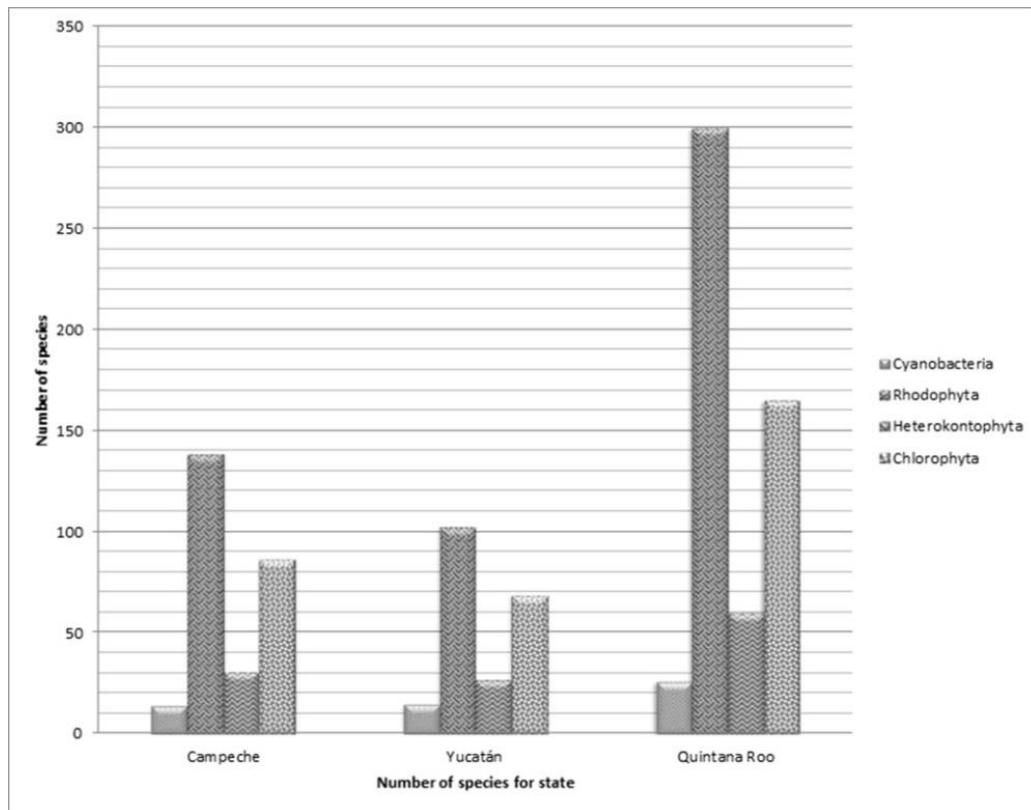


Figure 4. Number of species for states in Yucatan Peninsula.

On the other hand, there are genera as *Amphiroa*, *Hydrolithon*, *Palisada*, *Neogoniolithon*, *Cerarium*, *Chondria*, *Udotea* and *Caulerpa* which represent a taxonomic defiance, because of their high morphological plasticity and that there are probably cryptic species. The use of DNA sequence data has profoundly altered our understanding of the phylogenetic relationships among seaweeds and new Order, families, genera and species have been established into Rhodophyta, Chlorophyta and Phaeophyceae, among others, based on DNA sequence data and supported by morpho-anatomical characters [21, 22, 23]. In this sense, it is necessary to use molecular methods to resolve the taxonomic problems that arise in the above-mentioned genera.

Species of *Padina*, *Acetabularia*, *Liagora* and *Halimeda* were observed in Yucatan and Quintana Roo but they are not well distributed. In Quintana Roo *Sargassum* and *Turbinaria* species dominated in rocky shore environment. *Neogoniolithon*, *Udotea*, *Caulerpa* and *Halimeda* showed dominance in rocky with sandy areas. Coralline algae like *Amphiroa*, *Jania*, *Hydrolithon* and *Neogoniolithon* dominated in the reef areas of Peninsula, these organisms are of major ecological importance in the coral reefs of Campeche, Yucatan and Quintana Roo. Commercially important seaweeds like *Gracilaria cervicornis*, *G. damaecornis*, *G. debilis*, *Gracilariaopsis andersonii*, *Hydropuntia crassissima* and *Eucheuma isiforme* were found on rocky coast of several localities of Campeche and Quintana Roo. *Sargassum cymosum*, *S. vulgare* and *Turbinaria turbinata* were found in large quantities in Quintana Roo coast.

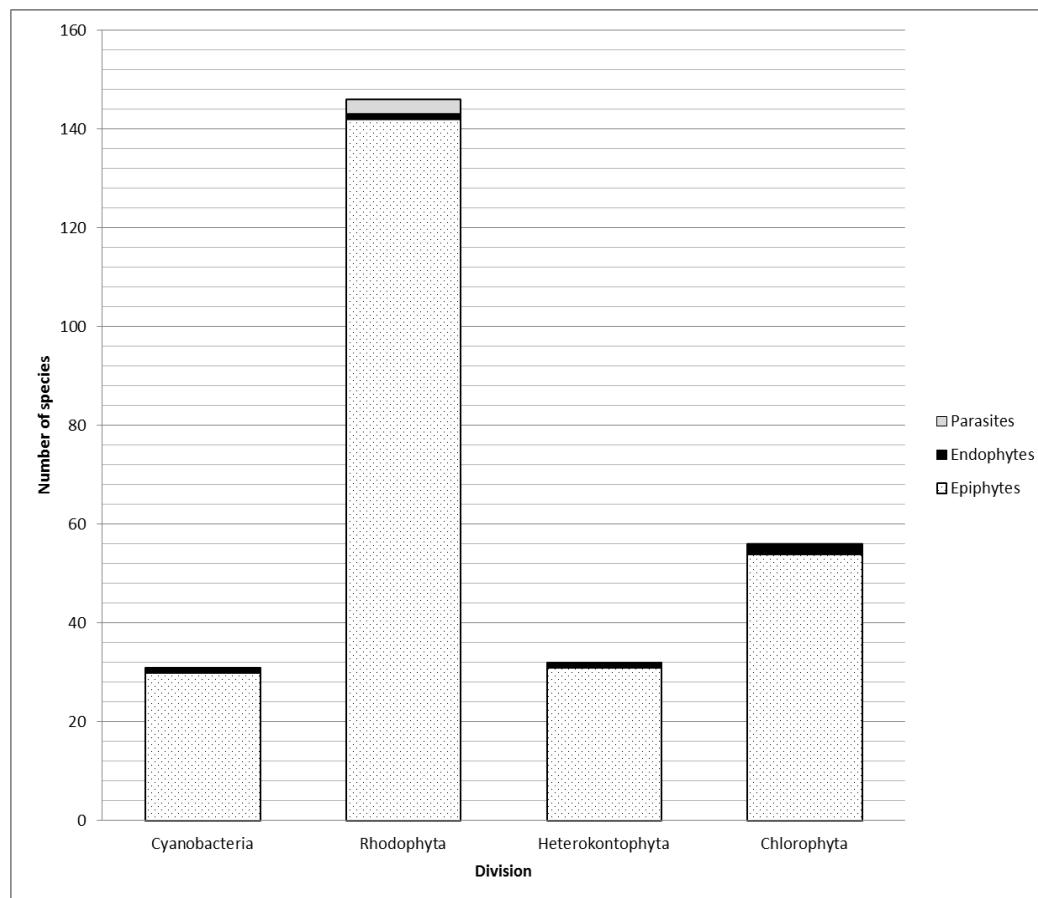


Figure 5. Number of species epiphytes, endophytes and parasites in Yucatan Peninsula.

Seaweeds are potential renewable resource in the marine environment. Most of the compounds of marine algae show anti-bacterial activities. Many metabolites isolated from marine algae possess bioactive principles. Compounds with cytostatic, antiviral, anthelmintic, antifungal and antibacterial activities have been detected in green, brown and red algae. For example, *Ulva fasciata* have showed antimicrobial activities against *Staphylococcus aureus*. Several extractable compounds such as cyclic polysulfides and halogenated compounds are toxic to microorganisms and they are responsible for the antibiotic activity of seaweeds [24]. Seasonal and geographical variation also contributes in the antimicrobial activity levels of marine algae. Species found in Yucatan Peninsula as *Ulva compressa*, *U. lactuca*, *Caulerpa lamourouxii*, *C. mexicana*, *C. sertularioides* and *C. paspaloides* are potential species for use as a source of bioactive substances.

CONSERVATION

The biological diversity, high productivity, and ecosystem services provided by tropical coastal systems are well recognized; indeed, these same characteristics may promote human settlement and urban development. Approximately 60% of the total human population lives in

coastal areas and human impacts on coastal systems are increasing [10]. While losses of coral reefs and mangrove habitats are probably the most significant in terms of losses of biodiversity it should not be forgotten that other critical coastal habitats are also disappearing. Wetland areas, estuaries and seagrass beds are known to be key nursery areas for coastal fisheries and yet are being destroyed rapidly without there being full ecological and economical appraisal of the consequences even in developed countries, also the eutrophication caused by excess of nutrients and sewage discharged into coastal waters is an expanding problem and incidents are known from almost for every coastal countries. The initial effects are of altered species composition both in the water columns and in benthic communities [25]. Furthermore, examples of infrastructure damage and coastal use alteration produced by coastal storms are numerous; for instance, one of the most recent events of this kind was hurricane Sandy which impacted the mid-Atlantic region on Oct. 29 and 30, 2012 with economic damages estimated in 30 - 50 billion US dollars. These hazards are becoming more common, as can be stated by the increasing trend found in the number and intensity of storms in the last decade [11]. Yucatan Peninsula has been affected by several hurricanes in the last decade. In 2005, "Emily" made landfall in Playa del Carmen as a category IV, affecting the zones of Xel-Ha at Riviera Maya, about 145 miles south of Cancun. In the same year "Wilma" struck the Yucatan and Quintana Roo, as a category IV, with sustained winds of 250 km/h. In 2007, Hurricane "Dean" hit southern Quintana Roo, hurting mainly 2 types of vegetation: mangrove and evergreen tropical forest. Hitting the coast in category V, just north of the Majahual, with maximum winds of 280 km/h. In 2009, the most intense hurricane was "Bill" category IV, with maximum sustained winds of 215 km/h, with gusts of 260 km/h. In 2010, three hurricanes hit the area: the most intense was "Igor" with category IV, and maximum winds of 240 km/h and gusts of 295 km/h. The hurricane Alex made landfall on the southwestern tip of the state of Quintana Roo, as a tropical storm, 90 miles southwest of Chetumal, Quintana Roo, with maximum sustained winds of 95 km/h and gusts of 110 km/h. "Karl," was another cyclone which affected Mexican territory, impacting as a tropical storm, 15 miles south-southwest of Puerto Bravo, Quintana Roo, with maximum sustained winds of 100 km/h and gusts of 120 km/h. In early August 2011, "Ernesto" made landfall as a Category I in southern Quintana Roo. Under these arguments it is evident that the Yucatan Peninsula is exposed to natural disasters and the ever-increasing human influence. In addition, the total diversity of the Yucatan peninsula flora, including previous records and the results of this investigation are 739 species; however, of these total species 134 of them were not located in the present study (Table 2) probably due to the effects of hurricanes, anthropogenic influence, especially for the modification on the coast for both of these influences which brings diverse habitats disappear with its species, the climatic conditions present and the negative effect of the expansion of the national oil industry in offshore waters, because the unfortunately accidental blowout of the Ixtoc-I in June 1979 caused the first- world massive oil spill in tropical environment. More than 3.4 million of barrels of crude oil were liberated in an ecosystem, which produced two effects one for the oil and other for the long-term environmental consequences derived from the residual hydrocarbon compounds accumulated in coastal of the Southern Gulf of Mexico [26]. In this chapter, is found a great marine algae biodiversity in Coral Reefs rather than the coast of Yucatan and Campeche. The best way to conserve marine diversity is to protect habitat and landscape diversity in the coastal area. Marine protected areas are only a part of the conservation strategy needed. It is suggested that

a framework for coastal conservation is integrated coastal area management where one of the primary objectives is sustainable use of insular and coastal biodiversity.

Table 2. List of floral species for Yucatan peninsula that were not recorded in the present study

Species	Nomenclatural Status	Reference
CYANOBACTERIA		[2]
1. <i>Lyngbya aestuarii</i> Liebman ex Gomont		
2. <i>L. major</i> Hansgirg	<i>Oscillatoria major</i> Vaucher ex Forti	[2]
3. <i>L. mucicola</i> Lemmermann	<i>Leptolyngbya mucicola</i> (Lemmermann) Anagnostidis and Komárek	[2]
4. <i>L. penicillata</i> (Gomont) Hoffmann		[2]
5. <i>L. perelegans</i> Lemmermann	<i>Leptolyngbya perelegans</i> (Lemmermann) Anagnostidis and Komárek	[2]
6. <i>Oscillatoria laetevirens</i> Hofman-Bang ex Forti		[2]
7. <i>O. margaritifera</i> Kützing ex Gomont		[2]
8. <i>Phormidium corallinae</i> (Gomont ex Gomont) Anagnostidis and Komárek	<i>Oscillatoria corallinae</i> Gomont ex Gomont	[2]
9. <i>Phormidium persicum</i> Gomont	<i>Pseudanabaena persicina</i> (Reinke ex Gomont) Anagnostidis	[2]
10. <i>Porphyrosiphon miniatus</i> (Gomont) F. E. Drouet	<i>Arthospira miniata</i> Gomont	[2]
11. <i>Heteroleibleinia infixa</i> (Frémy) Anagnostidis and Komárek		[2]
12. <i>Plectonema nostocorum</i> Bornet ex Gomont	<i>Leptolyngbya nostocorum</i> (Bornet ex Gomont) Anagnostidis and Komárek	[2]
13. <i>Hydrocoleum comoides</i> Gomont	<i>Blennothrix comoides</i> (Gomont) Anagnostidis and Komárek	[2]
14. <i>H. glutinosum</i> Gomont ex Gomont	<i>Blennothrix glutinosa</i> (Gomont ex Gomont) Anagnostidis and Komárek	[2]
15. <i>Sirocoleum guyanense</i> Kützing ex Gomont		[2]
16. <i>Calothrix aeruginea</i> Thuret ex Bornet and Flahault		[2]
17. <i>C. juliana</i> Bornet and Flahault ex Gomont	<i>Homoeothrix juliana</i> (Bornet and Flahault ex Gomont) Kirchner	[2]
18. <i>Dichothrix fucicola</i> Bornet and Flahault		[2]
19. <i>D. penicillata</i> Zanardini ex Bornet and Flahault		[2]
20. <i>D. rupicola</i> F. S. Collins		[2]
21. <i>Symploca hydnoides</i> Kützing ex Gomont		[2]
22. <i>Trichodesmium thiebautii</i> Gomont ex Gomont		[2]
23. <i>Arthospira major</i> (Kützing ex Gomont) W. B. Crow	<i>Spirulina major</i> Kützing ex Gomont	[2]

Table 2. (Continued)

Species	Nomenclatural Status	Reference
24. <i>Spirulina meneghiniana</i> Zanardini ex Gomont		[2]
25. <i>S. princeps</i> West and G. S.West		[2]
26. <i>S. subtilissima</i> Kützing ex Gomont		[2]
27. <i>S. tenerrima</i> Kützing ex Gomont		[2]
28. <i>S. versicolor</i> Cohn ex Gomont		[2]
29. <i>Leibleinia epiphytica</i> (Hieronymus) Compère		[2]
30. <i>L. gracilis</i> (Rabenhorst ex Gomont) Anagnostidis and Komárek		[2]
31. <i>Microchaete vitiensis</i> Askenasy ex Bornet and Flahault		[2]
32. <i>Anabaena propinqua</i> Setchell and N. L.Gardner	<i>Trichormus propinquus</i> (Setchell and N. L.Gardner) Komárek and Anagnostidis	[2]
33. <i>Nodularia harveyana</i> Thuret ex Bornet and Flahault		[2]
34. <i>Isactis plana</i> Thuret ex Bornet and Flahault		[2]
35. <i>I. centrifuga</i> Bornet		[2]
36. <i>Rivularia polyotis</i> Roth ex Bornet and Flahault		[2]
37. <i>Mastigocoleus testarum</i> Lagerheim ex Bornet and Flahault		[2]
38. <i>Entophysalis granulosa</i> Kützing		[2]
39. <i>Solentia stratosa</i> Ercegovic		[2]
40. <i>Aphanothece elabens</i> (Brébisson ex Meneghini) Elenkin		[2]
41. <i>Agmenellum termale</i> (Kützing) Drouet and Daily	<i>Merismopedia thermalis</i> Kützing	[2]
42. <i>Coelosphaerium dubium</i> Grunow		[2]
43. <i>Dermocarpa acervata</i> (Setchell and Gardner) Pham-Hoàng Hô		[2]
RHODOPHYTA		[2]
44. <i>Bangiopsis dumontoides</i> (P. L.Crouan and H. M.Crouan) V. Krishnmurthy		[2]
45. <i>Erythrocladia pinata</i> W. R.Taylor		[2]
46. <i>Acrochaetium antillarum</i> W. R. Taylor		[2]
47. <i>A. bisporum</i> (Børgesen) Børgesen	<i>Colaconema bisporum</i> (Børgesen) I.-K. Hwang and H.-S.Kim	[2]
48. <i>A. robustum</i> Børgesen		[2]
49. <i>A. unipes</i> Børgesen		[2]
50. <i>Lithophyllum daedaleum</i> Foslie and M. Howe	<i>Lithophyllum congestum</i> (Foslie) Foslie	[2]
51. <i>L. prototypum</i> (Foslie) Foslie		[2]
52. <i>Amphiroa brasiliiana</i> Decaisne		[2]

Species	Nomenclatural Status	Reference
53. <i>Acrothamnion butlerae</i> (F.S. Collins) Kylin		[8]
54. <i>Aglaothamnion uruguayanum</i> (W. R. Taylor) N. E. Aponte, D. L. Ballantine and J. N. Norris		[2]
55. <i>Anthithamnion antillanum</i> Børgesen		[2]
56.A. <i>cruciatum</i> (C. Agardh) Nägeli		[2]
57.A. <i>decipiens</i> (J. Agardh) Athanasiadis		[2]
58.A. <i>ternatum</i> A. B. Joly and Cordeiro	<i>Antithamnionella breviramosa</i> (E.Y. Dawson) Wollaston	[2]
59. <i>Ceramium brasiliense</i> A. B. Joly		[2]
60.C. <i>dawsonii</i> A. B. Joly		[2]
61.C. <i>evermannii</i> Setchell and N. L. Gardner		[2]
62.C. <i>tenerrimum</i> (G. Martens) Okamura		[2]
63.C. <i>uruguayanum</i> W.R. Taylor		[2]
64. <i>Grallatoria reptans</i> M.A. Howe		[2]
65. <i>Griffithsia caribaea</i> G. Feldmann		[2]
66.G. <i>scchousboei</i> Montagne		[2]
67. <i>Gymnothamnion elegans</i> (Schousboe ex C. Agardh) J. Agardh		[2]
68. <i>Platysiphonia caribaea</i> D.L. Ballantine and M.J. Wynne		[2]
69. <i>Dasya antillarum</i> (M. A. Howe) A. J. K. Millar		[2]
70.D. <i>arbuscula</i> (Dillwyn) C. Agardh	<i>Aglaothamnion sepositum</i> (Gunnerus) Maggs and Hommersand	[2]
71. <i>Bryocladia cuspidata</i> (J. Agardh) De Toni		[2]
72. <i>Chondria atropurpurea</i> Harvey		[2]
73.C. <i>sedifolia</i> Harvey		[2]
74. <i>Herposiphonia secunda</i> (C. Agardh) Ambronn		[2]
75. <i>Herposiphonia tenella</i> (C. Agardh) Ambronn		[2]
76. <i>Laurencia chondrioides</i> Børgesen		[2]
77. <i>Laurencia corymbosa</i> J. Agardh		[2]
78. <i>Micropeuce sarcocaulon</i> (Harvey) Kylin ex P.C. Silva		[8]
79. <i>Neosiphonia tongatensis</i> Harvey ex Kützing) M.-S. Kim and I.K. Lee		[2]
80. <i>Ophidocladus simpliciusculus</i> (P. L. Crouan and H. M. Crouan) Falkenberg		[2]
81. <i>Polysiphonia denudata</i> (Dillwyn) Greville ex Harvey		[2]
82. <i>Polysiphonia foetidissima</i> Cocks ex Bornet		[2]
83. <i>Polysiphonia hapalacantha</i> Harvey		[2]

Table 2. (Continued)

Species	Nomenclatural Status	Reference
84. <i>Polysiphonia havanensis</i> Montagne		[2]
85. <i>Polysiphonia opaca</i> (C. Agardh) Moris and De Notaris		[2]
86. <i>Wrightiella blodgettii</i> (Harvey) F. Schmitz		[2]
87. <i>Pterocladiella caloglossoides</i> (Kützing) Santelices and Hommersand		[2]
88. <i>Pterocladiella caerulescens</i> (M. A. Howe) Santelices		[2]
89. <i>Gracilaria armata</i> (C. Agardh) Greville		[2]
90. <i>Gracilaria compressa</i> (C. Agardh) Greville		[2]
91. <i>Gracilaria curtissiae</i> J. Agardh		[2]
92. <i>Gracilaria gracilis</i> (Stackhouse) M. Steentoft, L.M. Irvine and W.F. Farnham		[2]
93. <i>Gracilaria usneoides</i> (C. Agardh) J. Agardh	<i>Hydropuntia usneoides</i> (C. Agardh) Gurgel and Fredericq	[2]
94. <i>Gracilaria venezuelensis</i> W. R. Taylor		[2]
95. <i>Grateloupia dichotoma</i> J. Agardh	<i>Dermocorynus dichotomus</i> (J. Agardh) Gargiulo, M. Morabito and Manghisi	[2]
96. <i>Halymenia duchassaingii</i> (J. Agardh) Kylin		[2]
97. <i>Eucheuma acanthocladum</i> (Harvey) J. Agardh		[2]
98. <i>Eucheuma isiforme</i> var. <i>denudatum</i> D. P. Cheney		[2]
99. <i>Kappaphycus inermis</i> (F. Schmitz) Doty ex H. D. Nguyen and Q. N. Huynh		[2]
100. <i>Solieria tenera</i> (J. Agardh) M. J. Wynne and W. R. Taylor		[2]
101. <i>Hypnea cornuta</i> (Kützing) J. Agardh		[2]
102. <i>Wurdemannia miniata</i> (Sprengel) Feldmann and G. Hamel		[2]
103. <i>Contarinia magdae</i> Weber-van Bosse		[2]
104. <i>Chrysymenia planifrons</i> (Melvill) J. Agardh		[2]
PHAEOPHYTA	<i>Dictyota implexa</i> (Desfontaines) J.V. Lamouroux	[2]
105. <i>Dictyota linearis</i> (C. Agardh) Greville		[2]
106. <i>Acinetospora crinita</i> (Carmichael) Sauvageau		[2]
107. <i>Feldmannia indica</i> (Sonder) Womersley and A. Bailey		[2]
108. <i>Sphacelaria fusca</i> (Hudson) S. F. Gray		[2]
109. <i>Hummia onusta</i> (Kützing) J. Fiore		[2]

Species	Nomenclatural Status	Reference
110. <i>Sargassum hystrix</i> J. Agardh		[2]
111. <i>Sargassum vulgare</i> var. <i>foliosissimum</i> (J. V. Lamouroux) C. Agardh		[2]
CHLOROPHYTA		[2]
112. <i>Gomontia polyrhiza</i> (Lagerheim) Bornet and Flahault		[2]
113. <i>Blidingia marginata</i> (J. Agardh) P. J. L. Dangeard		[2]
114. <i>B. minima</i> (Nägeli ex Kützing) Kylin		[2]
115. <i>E. prolifera</i> (O. F. Müller) J. Agardh	<i>Ulva prolifera</i> O.F. Müller	[2]
116. <i>Dictyosphaeria versluysii</i> Weber-van Bosse		[2]
117. <i>Valoniopsis pachynema</i> (G. Martens) Børgesen		[2]
118. <i>Cladophora brasiliiana</i> G. Martens		[2]
119. <i>Cladophora conferta</i> P. L. Crouan and H. M. Crouan		[2]
120. <i>Cladophora constricta</i> F. S. Collins		[2]
121. <i>Cladophora jongiorum</i> Hoek		[2]
122. <i>Cladophora patentiramea</i> (Montagne) Kützing		[2]
123. <i>Cladophora pellucidoidea</i> Hoek		[2]
124. <i>Rhizoclonium crassipellitum</i> var. <i>robustum</i> G. S. West		[2]
125. <i>Bryopsis halliae</i> W. R. Taylor		[2]
126. <i>Codium carolinianum</i> Searles		[2]
127. <i>Codium spongiosum</i> Harvey		[2]
128. <i>Caulerpa cupressoides</i> var. <i>serrata</i> (Kützing) Weber-van Bosse		[2]
129. <i>Caulerpa lanuginosa</i> J. Agardh		[2]
130. <i>Caulerpa paspaloides</i> var. <i>compressa</i> (Weber-van Bosse) M. A. Howe		[2]
131. <i>Caulerpa taxifolia</i> (M. Vahl) C. Agardh		[2]
132. <i>Rhipilia tomentosa</i> Kützing f. <i>zonata</i> A. Gepp and E.S. Gepp		[2]
133. <i>Udotea verticillosa</i> A. Gepp and E. S. Gepp		[2]
134. <i>Ostreobium quekettii</i> Bornet and Flahault		[2]

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Chapter 3

BENTHIC ASSEMBLAGES IN SOUTH AMERICAN INTERTIDAL ROCKY SHORES: BIODIVERSITY, SERVICES, AND THREATS

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ABSTRACT

Rocky shores are areas of high diversity and productivity providing goods and services. Since humans are altering nature at an unprecedented rate, producing shifts in important parameters for life such as temperature, habitat availability, water quality, among others, it is expected that species will respond by changing their natural distributions and/or abundances. To understand how species will respond to such changes, it is necessary to learn the processes that determine these patterns. The South American Research Group on Coastal Ecosystems was established to assess marine diversity and biomass along both coasts of South America through an international collaboration. The main goals of SARCE are to: (1) Test hypotheses about latitudinal gradients and patterns of local and regional biodiversity, (2) Identify the relationship between biodiversity and ecosystem functioning, (3) Assess the effect of environmental gradients and anthropogenic stressors, (4) Carry out capacity building and training activities aimed to solve environmental problems for the benefit of society. The SARCE network has sampled the coasts of nine countries around South America with a standardized protocol in more than 150 sites (2010-2014), ranging from 11° North to 55° South. This chapter provides a description of the biodiversity of the sites sampled by SARCE, along with a review of the uses and services that these ecosystems provide to human populations and the main threats and impacts these uses have caused.

INTRODUCTION

Biodiversity has been a subject of interest for many decades by scientists and conservationists. More recently, other groups such as managers, government agencies and industries have also been involved in establishing its ecological and economical value, as well

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as the consequences of its loss. Up to date, an important number of papers have attempted to identify the importance of biodiversity for ecosystem functioning (Loreau et al. 2001, Pachepsky et al. 2001, Cardinale et al. 2002, Pfisterer & Schmidt 2002, Gessner et al. 2004) and the processes by which any diversity loss will be negatively reflected in the number and quality of services that a particular system might provide (Balvanera et al., 2006; Cardinal et al, 2006, O'Connor et al., 2006).

Coastal marine ecosystems have a very high biodiversity (Ray 1996). Within these, the macroalgal habitats rank among the highest along with coral reefs and seagrass communities, due to the fact that they are dominated by bio-engineering organisms that build three-dimensional structures, providing substrate, food and habitat complexity, which ultimately increases species richness (van Oppen et al. 1996, Phillips 1997, Walker & Kendrick 1998, Wysor et al. 2000, Duarte 2000, Engelhardt & Ritchie 2001, Duffy et al. 2001, Sommerfield et al. 2002, Bulleri et al. 2002). On the other hand, due to their particular location (i.e. land-sea interface) these coastal areas are also severely impacted by human activities such as fisheries overexploitation, alteration of the physical environment, pollution, introduction of alien or invasive species and recreational activities, all of which have inevitably impoverished marine biodiversity (Beatley 1991, Norse 1993, Gray et al., 1997, Walker & Kendrick 1998, Cury 1999, Bax et al. 2001, Tilman & Lehman 2001, Piazzi et al. 2001, Barnes 2002).

In this sense, the study of biodiversity is crucial for the sustainable use of coastal resources (Gray 1997), especially in Marine Protected Areas (Ray 1985, Olsen 1999, Ward et al. 1999). Biodiversity has been measured at many different levels and scales and by different methods (France & Rigg 1998). This has made comparisons difficult, so a unified approach to study biodiversity at a global scale was much needed (Rabb & Sullivan 1995, Valero et al. 1998, Mikkelsen & Cracraft 2001). As a response to this need, the NaGISA project (Natural Geography in Shore Areas: www.nagisa.coml.org) of the Census of Marine Life program (CoML: www.coml.org) provided the necessary framework to study biodiversity in rocky shores at a global scale. The NaGISA project was a collaborative effort aimed at inventorying and monitoring habitat specific biodiversity with a standard protocol in coastal marine areas at a global scale (Konar et al. 2010). Thanks to NaGISA (2003-2010), the first global baseline of nearshore biodiversity was initiated [see: Diversity in the Nearshore: The NaGISA Collection (2010) PLoS Collections: <http://dx.doi.org/10.1371/issue.pcol.v01.i06>], and in South America, it has continued through the South American Research Group on Coastal Ecosystems network (SARCE). This network was established to assess marine diversity and biomass along the Pacific and Atlantic (including the Caribbean) coasts of South America through an international collaboration. The main goals of SARCE are to: (1) Test hypotheses about latitudinal gradients and patterns of local and regional biodiversity, (2) Identify the relationship between biodiversity and ecosystem functioning, (3) Assess the effect of environmental gradients and anthropogenic stressors, (4) Carry out capacity building and training activities aimed to solve environmental problems for societal benefit. The SARCE network includes more than 30 researchers from 9 South American coastal countries and has sampled with a standardized protocol in more than 150 sites around the continent (Figure 1). In this chapter we provide a description of the biodiversity of the sites sampled with the SARCE protocol (<http://sarce.cbm.usb.ve/for-scientists/>), along with a review of the uses and services that these ecosystems provide to human populations and the main threats and impacts these uses have caused.



Figure 1. Map of South America showing the localities sampled by the SARCE network (South American Research Group in Coastal Ecosystems) in the Caribbean Sea, and in the Atlantic and Pacific oceans.

THE INTERTIDAL ROCKY SHORES IN SOUTH AMERICA: MAIN FEATURES AND ASSOCIATED BIODIVERSITY

The Caribbean

Colombia

The Caribbean coastline of Colombia has an extension of 1760 km, of which 25% are rocky shores (Posada & Henao 2008), mainly composed by unstable shores highly affected by wave action and coastal erosion. Most of these shores have steep slopes and in the areas

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where the platform occurs can harbor rich and abundant macro-algal communities (Garcia & Diaz-Pulido 2006). The tide range is 0.5 m due to this is common to find in small areas a mixture of organisms that belongs to different intertidal levels (high, mid and low tide), factors as wave action, substrate type and slope, determine the community composition (Lopez-Victoria et al. 2004). Due to the small tidal range only high and low tide levels can be easily differentiated. According to Lopez-Victoria et al. (2004) the rocky shore can be divided into two types of rocks, cohesive or non-cohesive, each having a particular associated community (algae and macroinvertebrates). The first type of rocks is stable, hard and with low erosion rates, with a high rate of colonization and a well developed community with advanced succession stages. The second type of rocks is unstable, the shores are highly affected by wave action, and therefore, species diversity and richness is lower, and the community cannot reach advanced succession stages. The climate presents two main periods: dry and rainy seasons with a transition season in between. The sea surface temperature and salinity during the dry and rainy seasons vary between 25.5-27.5°C / 35.6-37 ppt and 27-29.5°C / 34.5-36.5 ppt respectively. The waves are higher during the dry season (1.5 to 2.5 m) in relation to the rainy season (0.5 to 1.4 m) (Posada & Henao 2008). An upwelling system is present from December to March in the north coast and the sea surface temperature can drop below 20°C.

In the Colombian Caribbean, the SARCE project sampled in 15 sites within two localities: Santa Marta and Darien. In Santa Marta (Figure 2A), the rocky shore is dominated by cliffs (metamorphic schist rocks), with different size boulders at the base that gives complexity to the shore and offers a variety of habitats that can be exploited by intertidal organisms. The cliffs are part of the Sierra Nevada de Santa Marta system that branches down to the sea. Due to the upwelling, there is a major change in algae composition, species of *Sargassum* can reach a meter in length and other algae species grow and cover most of the rocky substrate. Along the different sites of the Santa Marta bay, the geology varies from cliffs that continue as rocky shores with boulders in the north (Punta Verde) which are highly exposed to wave action, to rocky platforms between 5 to 10 m wide in the south (Playaca). The most abundant invertebrate species in the high intertidal in the north are *Nerita versicolor* and *Littorina* sp, while the low intertidal is dominated by coralline algae, by *Palisada perforata*, *Zoanthus pulchellus* and *Hypnea musciformis*, and the invertebrates *Echinometra lucunter* and *Isognomon bicolor*. In the south, the high intertidal is mostly rock; with some areas with filamentous algae. The most abundant macroinvertebrate species are *Plicopurpura patula*, *I. bicolor* and *Dendropoma* sp. In the low intertidal, dominant species are coralline and filamentous algae along with *Laurencia obtuse*, *E. lucunter*, *I. bicolor*, *Spirobranchus giganteus* and *Balanus* sp. The low intertidal is also covered by the canopy of large *Sargassum*. The east side of the bay (Playa Grande) is characterized by a rocky platform covered by a thin layer of vermetids. Here, the high intertidal is mostly rock with some areas covered by filamentous algae, the dominant macroinvertebrate species being *N. tesellata* and *Brachidontes domingensis*. In the low intertidal, dominant species are the macroalgae *Acanthophora spicifera*, *Dictyopteris deliculata* and *Neoralfsia expansa* and the invertebrates *Dendropoma* sp. and *I. bicolor*. Other localities sampled in the Santa Marta region were Inka Inka, Puerto Luz, and Aeropuerto. The first two were rocky platforms, while the third was an exposed sandy beach with flat rocks that may be periodically covered by sand due to wave action. In these, the high intertidal was dominated by *N. tesellata*, *P. patula*, *Echinolittorina ziczac* (Inka Inka); *E. ziczac*, *E. angustior* and *P. patula* (Puerto Luz); and *E. interrupta*, *E.*

angustior and *Chthamalus* sp. (Aeropuerto). The low intertidal was dominated by coralline algae, vermetids, filamentous algae, *E. lucunter*, *I. bicolor*, *Mitrella ocellata*, *Sargassum* (Inka Inka), *A. spicifera*, *L. obtuse*, filamentous algae, *Dendropoma* sp., *E. lucunter*, *I. bicolor* (Puerto Luz), and *A. spicifera*, *Lyngbya* sp., coralline algae, *Centroceras* sp., *B. domingensis*, *Fissurella nimbosa*, *Stramonita haemastoma* (Aeropuerto).

The locality of Darien is located west of the Uraba Gulf, where mangroves and soft bottoms dominate the landscape; the sediments and nutrients are brought by the Atrato River, one of the largest rivers in the Atlantic basin of Colombia. Tropical rainy forest is the most common type of vegetation; however, grasses for cattle growth have replaced large extensions of this forest. In this region, the volcanic rock shore is located north of the delta of River Atrato, followed by large sandy beaches and abrasion platforms of coralline origin towards the Panama border. This area has little urban development and human settlements are small, there are no roads and the main way of transportation is by boats and most of the settlements are located on the coast. The Darien was sampled in the Trigana area which is located north to the Atrato River delta, with a rocky shore of volcanic origin, interrupted by sandy beaches, and with several small islands in front of the coast. The intertidal in this area is affected by freshwater runoff. The sites sampled were Isla Napú, an islet with a narrow rocky platform that falls to the sea reaching a maximum of 2 m depth in the surrounding areas; Trigana, a platform 10 m wide; Titumate, an islet with a soft slope and shallow sandy bottom (< 1 m) and sea grasses; Capurgana, located in the northwest part of the Uraba Gulf with a rocky shore composed by abrasion platforms of coralline origin; Sapzurro, a bay close to the Panama border, with a soft slope shore and an abrasion platform of coralline origin; and Isla Narza, an islet of volcanic origin in front of Capurgana village, the shore consisting of a cliff in the exposed side and boulders in the sheltered side. In these sites, the high intertidal was dominated by *E. angustior*, *E. ziczac* and *E. interrupta* (Napú), *E. angustior* and *S. rustica* (Trigana), *E. angustior*, *B. domingensis* and *N. tesellata* (Titumate), and *E. angustior* (Sapzurro and Isla Narza). The low intertidal is dominated by *L. obtusa*, *Pterocladiella capillacea*, *Lyngbia* sp., *Gracilaria domingensis*, *Centroceras* sp., the barnacles *Chthamalus* sp. and *Balanus* sp. which form a complex with vermetids (Napú); filamentous and coralline algae, *S. serratum*, *Centroceras* sp., *L. obtuse*, *G. domingensis*, *Chthamalus* sp., *S. rustica* (Trigana); *S. serratum*, *L. obtuse*, *Centroceras* sp., *Chthamalus* sp., *S. rustica* (Titumate); *L. obtuse*, coralline algae, *E. lucunter*, *Cittarium pica* (Sapzurro), and coralline and filamentous algae, *E. lucunter*, *Ceratozona squalida*, and *Chiton squamosus* (Isla Narza).

Venezuela

Rocky shores along the 3964 km of the Venezuelan coastline are very heterogeneous in terms of their geological composition and structure (Miloslavich et al., 2005). Due to small tidal ranges in the southern Caribbean (20-30 centimeters) (Torres and Tsimplis, 2012) Venezuelan rocky shores have been described considering only two levels or strata: high intertidal and low intertidal. The low intertidal is constantly under wave action whereas, the high intertidal is washed rarely by waves, only receiving sea's spray. Consequently, in some Venezuelan rocky shores, gaps openings and/or depressions in the substrate of only few centimeters of depth can generate zones that remain submerged most of the year. These habitats, henceforth called substrates depressions, are located between the high and the low intertidal on platform rocky shores and their species composition is completely different to

that found in the high and low intertidal. Given their large extensions, “substrates depressions” are different to rock pools or tide pools.

Characteristics of rocky shores are very heterogeneous and respond to the geomorphology of the different regions of the Venezuelan coast. In the Western coast, from the Paraguana Peninsula to Patanemo, rocky shores are emerging platforms and are composed of limestone rocks (Figure 2B). The Central coast, from Ocumare to Chirimena (Figure 2C), is characterized by narrow rocky stripes formed by sandstones and conglomerates. Sites sampled on the mainland of the Eastern coast, from Santa Fe to La Pared (Figure 2D), had a very steep slope, whereas those sampled in the insular region were emerging horizontal rocky platforms. Nevertheless, all rocky shores in the East are formed by limestone’s rocks. Most of the platforms are narrow (3-10 meters), except for San Juan de los Cayos platforms that are between 60 to 120 meters wide. The length of platforms is highly variable. In the western region, they can reach few kilometers, whereas in the central coasts they do not surpass hundreds or tens of meters (Kennedy et al., 2014; Ellenberg, 2010).

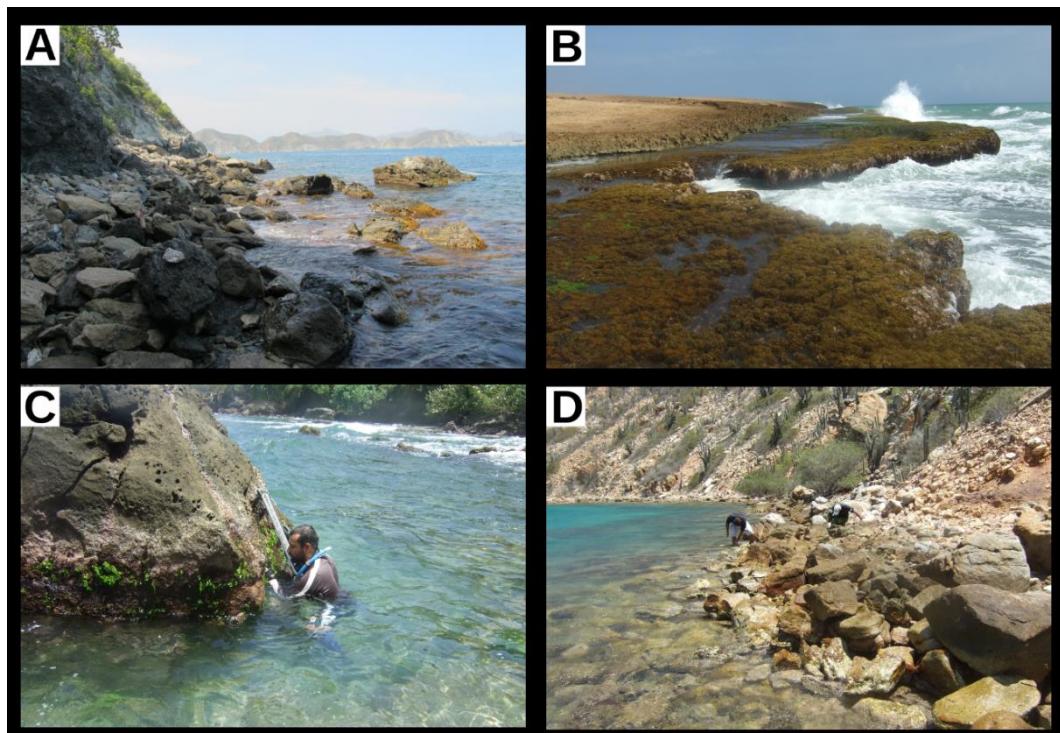


Figure 2. Sampling sites in the Caribbean. A. Colombia – Taganaga, Santa Marta. B. Venezuela - Cabo San Román, West Coast. C. Venezuela – Chuspa, Central Coast. D. Venezuela – Mochima, East Coast.

Estimates of rugosity were moderately high for both strata: 0.809 ± 0.002 and 0.745 ± 0.003 for low and high intertidal, respectively. The rock's irregularities form microhabitats that are used by some organisms like whelks, crabs, limpets and snails that protect them from desiccation and high temperatures during low tides, which in turns contribute to the high diversity reported for the Southern Caribbean. Crevices, scars and holes over the rocky substrate are due to erosion of wind and wave, as well as to the activity of some organism such as the sea urchin *Echinometra* sp. (Bak, 1994).

Despite a small tidal amplitude (Torres and Tsimplis, 2012), desiccation levels can vary significantly due to the effect of wind. Northern Trade winds blow on Venezuelan coasts intensively between December and June, increasing intensity and height wave, and consequently decreasing exposition levels. Besides, trade winds are responsible of annual upwelling, between January and May, in different zones of Venezuelan coast (Castellanos et al., 2002; Muller-Karger, 2004); which has been reported to enhance algae growth and increase the production of herbivores in rocky shores (Wieters, 2005; Bosman et al., 1987). This has not been tested for the Venezuelan Coast, however, the only study done (western region, Peninsula de Paraguna) found no correlation between Sea Surface temperature Changes generated by upwelling and changes in the structure of assemblages associated with rocky shores (Herrera unpublished data).

Like many rocky shores in the continent and the world, assemblages living in Venezuelan rocky shores are mainly composed of seaweeds and small mollusks. The most common seaweeds belong to phylum Rhodophyta, being genera such as *Laurencia* and *Polysiphonia* the most abundant. Also, algae of phylum Chlorophyta (mainly *Ulva* spp.) and Ochrophyta (mainly *Sargassum* spp) can be widely found. The species complex made of crustose coralline algae (commonly named CCA) was present in almost all sampled sites. It is very likely that the species composition of these complexes change among zones, sites, regions and strata; but identification of species of crustose coralline algae in the field is not possible. This complex was present as primary cover usually below corticated, articulated and foliose algae, as well as secondary cover on top of sessile and mobile animals. The most common mollusks living in Venezuelan rocky shores were snails, limpets, whelks, key-hole limpets and chitons.

The dominant functional groups in Venezuela were primary producers (macroalgae), small herbivores (gastropods and chitons), large herbivores (sea urchins and crabs), filter feeders (bivalves and barnacles) and predators (mainly the gastropods *Plicopurpura patula*, *Stramonita* and *Vasula* species; and octopuses). In the southern Caribbean, unlike other rocky shores, the dominant echinoderm was not a sea star but the sea urchin *Echinometra lucunter*. It has been proposed (but not tested) that *E. lucunter* plays a key role in structuring these assemblages due to its high densities, high herbivory rates and bio-erosive activity. Another peculiarity of Venezuelan rocky shores is the low density of barnacles in the intertidal. In Venezuela, they are only present in the central and western coast, usually associated to rock-walls, cliffs and artificial structures.

Continuous monitoring of assemblages associated with rocky shores in Venezuela has shown that they vary importantly at different temporal and spatial scales, and between strata. For example, during the rainy season, conspicuous changes occur due to massive algae cover decrease, and the composition is dominated by opportunistic species such as *Ulva*, *Dictyota*, *Padina* and *Chaetomorpha*. Also, from a spatial point of view and despite large variation at small spatial scales (10s to 100s meters), important differences can be detected among regions (e.g. presence of barnacles only in central and western coast).

Intertidal rocky shores of Venezuela are part of the highly diverse coastal ecosystems of the Southern Caribbean. Using SARCE's protocol, 31 sites across the Venezuelan coast were sampled, detecting a total of 217 species in total: 85 marine algae (40 Rodophyta, 20 Chlorophyta, 18 Ochrophyta, 5 Cyanobacteria, 2 seaweeds not identified), 89 molluscs (66 Gastropoda, 17 Bivalvia, 6 Polyplacophora), 21 cnidarians (17 Anthozoa, 4 Hydrozoa), 8 arthropods (5 Malacostraca, 3 Maxillopoda), 5 echinoderms (2 Echinoidea, 2 Ophiuroidea, 1

Holothuroidea), 5 marine sponges (Demosponge), 3 ascidia (Asciidae) and 1 seagrass (Tracheophyta).

In the high intertidal of Venezuelan rocky shores, algae presence was uncommon; and when they were, these usually were crustose calcified algae CCA and *Pseudolithoderma extensem*, or filamentous algae such as *Lyngbya* spp. and *Bostrychia tenella*. Mobile species were represented mostly by small herbivores mollusks such as *Nerita versicolor*, *Nerita peloronta*, *Nerita tessellata*, *Echinolittorina ziczac*, *Echinolittorina interrupta*, *Acanthopleura granulata*, *Echinolittorina angustior*, *Cecharitis muricatus*, *Tectarius antonii* and *Acmaea* and *Siphonaria* species. Carnivorous mollusks (i.e. *Plicopurpura patula*) were also present but were not as abundant as herbivores species. Assemblages in the high intertidal were highly dominated by few species, especially by Littorinids that commonly had abundances between thousands and tens of thousands of individuals per square meter. Neritidae species were not as abundant, but densities could reach hundreds per square meter. In crevices and gaps, bivalves belonging to genus *Brachidontes* and *Isognomon*, were found in low densities. Sessile mollusks of the family Vermetidae were also occasionally found in very dense patches with abundances ranging between the tens and hundreds of individuals per square meter.

Assemblages in depressions or mid platforms shallow lagoons were dominated by corticated foliose algae such as *Dictyota* and *Padina*, articulated calcareous algae such as *Halimeda opuntia*, foliose calcareous algae such as *Udotea* sp and *Penicillus* sp, and the foliose algae *Ulva* spp. Because these environments are constantly covered by water, cnidarians belonging to genus *Zoanthus* and *Palythoa* were commonly found. Principal mobile organisms in these microhabitats were small fishes belonging to Gobiidae family and hermits crabs. These two groups, however, were not considered in this study. These habitats are constantly submerged by water that is constantly being replaced, but due to their shallow characteristics, temperature is usually few degrees above normal Sea Surface temperature. Consequently, substrate tends to be dominated by one or two of the species mentioned above.

The low intertidal of Venezuelan rocky shores was dominated by macroalgae, mollusks and sea urchins; whereas some cnidarians and other echinoderms (sea cucumbers and brittle stars) were found occasionally. The most abundant and commonly found algae in all sampled sites, were the crustose calcified algae complexes CCA and *P. extensem*, the corticated corticated algae *Laurencia obtusa*, *Laurencia papillosa* and *Gelidiella acerosa*, the filamentous algae *Polysiphonia atlantica*, the leathery macrophyte *Sargassum* spp, and filamentous microalgae *Lyngbya* spp. Few species, as the opportunistic green foliose algae *Ulva* spp, the green filamentous algae *Chaetomorpha* spp, and cnidarians *Palythoa* and *Zoanthus* were not commonly seen in all sites; but when they were present, they occupied an important proportion of the primary and secondary substrata. The most abundant mobile species in the low intertidal were herbivores *E. lucunter*, *Chiton squamosus* and *Fissurella* spp, as well as carnivores *Stramonita rustica*, *P. patula* and *Vasula deltoidea*. The carnivore gastropod *P. patula* has its highest densities in the high intertidal (very close to the transition between the high and the mid), however it is present in the low intertidal as well. The sea urchin *E. lucunter* was commonly found in almost all the sites sampled, reaching densities of up to 72 ind/m². It is likely that *E. lucunter* plays a key role as the principal herbivorous on Venezuelan rocky shores, but this conceptual model has not yet been tested. Other large herbivores such as the gastropods *Cittarium pica* and *Astrea* spp, are found in low densities and small sizes, very likely due to the pressure of artisanal fishermen.

Trinidad and Tobago

Trinidad and Tobago is a twin-island state located on the continental shelf of north eastern South America. Trinidad is approximately 12 kilometers from the mainland while Tobago is 30 kilometers North East of Trinidad. Trinidad is the most southerly of the Caribbean islands. The continental origin of the islands is reflected in the similarity of terrestrial fauna and flora. The coastal areas of Trinidad and Tobago are largely comprised of sedimentary rocks. The north coast however is comprised of non-sedimentary rock with low grade metamorphic and small areas of volcanic rock (Georges, 1983). The geomorphology is generally of gently sloping beaches and cliffs. Current flow around Trinidad and Tobago is driven by the South Equatorial current coming north from South America. The current splits with movement to the west entering the Gulf of Paria and to the east moving and merging with the Atlantic Ocean.

Prior to the NAGISA project (2005), the intertidal rocky shores of Trinidad and Tobago had not been studied in any detail. The sites sampled with the SARCE project are on the north-east coast (Saybia, Toco) and the north coast (Maracas Bay). In the north-east coast location (Saybia, Toco) there is a fringing reef which offers some protection although there is a strong westerly longshore current. In the north coast (Maracas Bay) area there are generally strong offshore winds and a strong longshore current, although some protection is offered by the headlands. The mean tidal range in Trinidad and Tobago is around 1.2m and is semi-diurnal with a high and low every 12hrs.

The biodiversity associated with the intertidal sites typically included the common groups: macroalgae (green, red, and brown), bivalves (*Isognomon* sp. the most common but only found at Salybia and Toco Bay), gastropods (*Littorina* sp. the most common), polyplacophorans, crustaceans (barnacles found at all sites except Las Cuevas), and tunicates. The red algae, mostly *Heterosiphonia* were the most dominant species, while brown algae were least dominant, and *Chaetomorpha* sp. was the most common green algae (found at Maracas and Blanchisseuse). Coralline algae were well represented at all sites except for Salybia. There were greater numbers of species of soft corals (22) as opposed to soft corals (2), all of which were found in Salybia and Toco Bay, sites nearby to coral reef systems.

The Atlantic

Brazil

The Northeast: Ceará

The Ceará state coastline is dominated by long sand beaches, interrupted occasionally by beachrock reefs (Aquasis, 2003). The beachrocks have a more recent origin, and are composed by sand, shell fragments and pebbles cemented by calcium carbonate and iron oxide (Smith and Morais, 1984). These reefs are generally tabular, of variable extension and sloping gently towards the sea. The coastline is more E-W oriented, along typically equatorial latitudes. The climate is typically semi-arid, ruled by the intertropical convergence zone, with 2 seasons characterized by the pluviometry: a rainy season from January to June, and a dry season from July to December (IPECE, 2013). The coast is washed by the North Brazil current, running from E to W, following the strong trade winds that are characteristic for the region (Aquasis, 2003). The North Brazil current water mass is considered oligotrophic, with

temperatures varying little around 26°C and salinity around 36 (NOAA, 2014). The constant trade wind regime blowing from E-SE with 6.4 m.s⁻¹ on average, reaching more than 10 m.s⁻¹ during the dry season (Jimenez et al., 1999). Wind waves are permanently splashing over the reefs, sometimes combined with swell waves, ranging from 1.8 to 3.6 m in height (Aquasis, 2003). The tidal regime is typically semidiurnal, with a mean spring tidal range of 3.3 m, and mean neap tidal range of 1.2 m.

The beachrock reefs of Ceará host a very diverse community which is still poorly studied. The rocky intertidal shows a typical biodiversity zonation from the supralittoral to the subtidal zones. The supralittoral fringe is barely colonized, and the dominant species is *Echinolittorina lineolata*, a small mobile gastropod that fits into minute crevices avoiding extreme desiccation. The same species is also abundant in the high intertidal, but the space is occupied now by barnacles, especially *Chthamalus proteus* and patches of the green algae *Ulva fasciata*. The association of these two species characterizes the whole upper littoral zone, which is considerably poor in terms of species richness. The mid littoral zone is more diverse and the dominant species may vary at different locations. In Caucaia (Figure 3A), near urban capital Fortaleza, there is a belt of the bivalve *Brachidontes exustus* at the higher portion of the upper littoral zone, and a continuum of large colonies of the polychaete *Phragmatopoma caudata* is also present. The dominant algae species are *Chondracanthus acicularis*, *Gelidiella acerosa*, and *Hypnea musciformis*. Other dominant species are *C. proteus* and *U. fasciata*, which are still abundant in the lower littoral zone. In Trairi, there is not a conspicuous band of *B. exustus*, and the mid littoral zone is then dominated by *U. fasciata*, *Pterocladiella caeruleascens* and *Laurencia papillosa*. Large colonies of *P. caudata* are present, and the zoanthid *Palythoa grandiflora* also covers large areas of this zone. The mobile fauna present in the mid littoral zone is mainly composed of crabs, especially *Pachygrapsus transversus*, hermit crabs, such as *Clibanarius antillensis* and *Calcinus tibicen* (Herbst, 1791). The lower littoral zone is the most diverse, and fully dominated by algae. The most abundant species vary by location and site. In Caucaia, the most common species are *Centroceras clavulatum*, *C. acicularis*, and *U. fasciata*, while in Trairi the dominant species are *P. caeruleascens*, *Gracilaria* spp., *Amansia multifida*, and crustose coralline algae. The mobile fauna at the lower littoral zone is also more diverse and includes the species mentioned for the mid littoral zone plus the gastropods *Stramonita haemastoma* and *Tegula viridula* (Gmelin, 1791). Recent surveys of the whole littoral zone detected a total of 110 species for Caucaia and 103 for Trairi. Most species are shared by the two locations, but Trairi is considerably more diverse in terms of sessile organisms (both animals and algae), while Caucaia has more motile animals. In terms of composition, the most specious taxa, in decreasing order, were: Rodophyta (45 spp.), Chlorophyta (18 spp.), Mollusca (18 spp.), Ochrophyta (11 spp.), Crustacea (8 spp.), Porifera (7 spp.), Ascidiacea (7 spp.), Cnidaria (5 spp.), Polychaeta (3 spp.) and Echinodermata (2 spp.).

The data collected using the SARCE protocol for large and conspicuous organisms in the intertidal shows that there is a considerable biodiversity along the beachrock reefs in Ceará. There are about 130 species in total, the vast majority of them of algae, especially red and green algae. There is also a tenable difference among locations and sites along this stretch of coast, which highlights also a degree of beta diversity. It is worth mentioning that the protocol favored the algae component of the intertidal community by accounting only for organisms “over” the substrate. Previous surveys aimed at producing inventories had come out with different numbers. For instance, results from the PROBIO initiative in Ceará indicated for the

same area 109 species of algae, 53 species of Crustacea, 44 species of Mollusca, 28 species of Ascidiaceae, 24 species of Polychaeta, 22 species of Cnidaria, and 9 species of Echinodermata (Matthews-Cascon and Lotufo, 2006). Even these numbers are underestimating the total diversity, because the effort was still punctual.

The Northeast: Sergipe

Sergipe is the smallest Brazilian State, and the third shortest coast in extension (160 km). Located in the northeastern, it limits with the State of Alagoas in the north, and the State of Bahia in the south. Aracaju, the main city, comprises 25% of the state's population and has two harbor complexes. Sergipe has no real rocky shores, but rather beaches with boulders and rocky outcrops, and few areas with biolithic substrates (*Pragmatopoma caudata*). Beaches are composed by fine sand, and the linear coast is fringed by estuaries and mangroves, associated with the rivers Real, Vaza-Barris, Sergipe and São Francisco.

The State has 47.3% of its territory inside of the "Drought Polygon" polígono das secas (FAO). The climate is tropical, with the highest humidity by the coast and in semi-arid backlands. The highest rainfall occurs between January and March.

In Sergipe, the SARCE project sampled, from south to north in three beaches: Praia do Saco, Coroa do Meio, and Praia do Jatobá. A total of 106 taxa were found represented by 34 species of invertebrates, 66 of macroalgae, and 6 species of filamentous cyanobacteria. The supralittoral zone is characterized mostly by bare boulders, which may be colonized by periwinkle gastropods of the complex *Echinolittorina ziczac*, and filamentous cyanobacterias. The high/medium intertidal, not always well zonated, contains a belt of the barnacle *Chthamalus bisinuatus* and the mussel *Brachidontes solisianus*, usually fouled by the red algae *Bostrychia* spp. and other filamentous red and green macroalgae. The low intertidal was the most diverse characterized mainly by barnacles (*Tetraclita stellifera*), oysters (*Crassostrea rhizophorae*), crab (*Aratus pisonii*), *Lottia (Collisela) subrugosa*, and mussels (*Perna perna*). Regarding macroalgal assemblages, the biomass was dominated in general by filamentous, leathery and terete functional groups. A total of 66 taxa were found: 41 Rhodophyta, 16 Chlorophyta and 9 Phaeophyceae, dominated by Rhodomelaceae (9 species), Ceramiaceae (5 species.), Corallinaceae, Cystocloniaceae, Cladophoraceae and Ulvaceae (4 species). The most conspicuous species were *Gayralia brasiliensis*, *Rhizoclonium riparium*, *Ulva flexuosa*, *Sargassum platycarpum*, *Centroceras clavulatum*, *Gracilaria cincinnis*, *Jania adhaerens*, *Hypnea valentiae*, *Solieria filiformis* and *Pterocladiella capillacea*.

The Northeast: Bahia

In Bahia, rocky substrates are mainly biogenic and sandstone, but some granitic substrate is also found. The SARCE project sampled five locations: Itacaré (Arruda, Corais, Figure 3B, 3C, 3D), Ilhéus (Backdoor, Praia do Sul), Itaparica (Penha, Mar Grande), Salvador (Stella Maris), and Litoral Norte (Guarajuba, Itacimirim), Litoral Norte and Itacaré located within a State marine protected area. Among these, Corais, Penha and Stella Maris are the only sampling sites that are characterized by granitic substrate.

The total number of species found at these sites varied between 29 (Mar Grande) and 58 (Arruda). Macroalgal diversity at all sites was very high and dominated the assemblage. The total number of macroalgal species varied between 18 (Mar Grande) to 46 (Arruda), with red algae being the most speciose group, followed by green and brown algae. In the high

intertidal, the most abundant species were *Brachidontes*, *Chthamalus*, *Lyngbya* and *Ulva flexuosa*. The mid intertidal was dominated by *Ulva lactuca*, *Palisada perforata* and *Gelidiella acerosa*, but in general, *P. perforata* and *G. acerosa* were also abundant species in this zone. The low intertidal was dominated by *Sargassum*, but *Bryothamnion triquetrum* and *Amphiroa anastomosans* were also dominant species at Penha and Praia do Sul respectively.

The Southeast: Espírito Santo

Espirito Santo State is bordered by Minas Gerais, Bahia and Rio de Janeiro. Climate is coastal humid tropical. Rainfall is highest during summer (1.000 mm and 1.500 mm/year), and mean air temperatures are around 22°C and 24°C. The south coast is rocky, with sandstone cliffs, and in the central coast, biolithic and granite formations can be found. The south-central coast is very indented with coves and bays sheltered by rocky outcrops. The coast is more indented in the center-south, and open sea to the north. The State comprises the higher seaweed diversity and biomass in Brazil, been influenced by the South Atlantic Central Water upwelling. The SARCE project sampled sites at the localities of Paraty, Ubu (Figure 3E), and Manguinhos.

A total of 183 taxa were found comprised by 48 invertebrate species and 131 macroalgae conspicuous taxa. The supralittoral zone is mostly bare but periwinkle gastropods of the complex *Echinolittorina ziczac*, and the green filamentous algae *Rhizoclonium* may be found. The high/mid intertidal, not always well zonated, contains a belt of the barnacle *Chthamalus* sp., oysters (*Crassostrea rhizophorae*), the mussel *Brachidontes solisianus*, and a complex of the red algae *Bostrychietum*. The low intertidal was more diverse and characterized by the barnacles *Tetraclita stellifera*, and *Lottia (Collisela) subrugosa*, muricid gastropods, and *Palithoa caribeorum*. Regarding macroalgal assemblages, the biomass was dominated in general by foliose, terete and calcareous (crustose and articulated) functional groups. A total of 131 taxa were found: 69 Rhodophyta, 37 Chlorophyta and 25 Phaeophyceae. The most conspicuous species were *Anadyomene stellata*, *Caulerpa* spp. (mainly *C. racemosa* and *C. cupressoides*), *Codium* (mainly *C. intertextum* and *C. isthmocladum*), *Valonia aegragopila*, *Canistrocarpus cervicornis*, *Colpomenia sinuosa*, *Dictyopteris delicatula*, *Dictyota menstrualis*, *Neoralfsia expansa*, *Padina gymnospora*, *Sargassum cymosum*, *Arthrocardia flabellata*, *Dichotomaria marginata*, *Gelidium* spp., *Hypnea spinella*, *H. valentiae*, *Jania adhaerens*, *Lithotamnium/Lithophyllum* complex, *Ochthodes secundiramea*, and *Palisada flagellifera*.

The Southeast: São Paulo

Nine rocky shores were sampled along 150 km of the coast of São Paulo State, Brazil, within three localities: Baixada Santista (Guaiúba/Guarujá, Ilha Porchat/São Vicente, Itaquitanuva/Praia Grande), São Sebastião (Baleeiro/São Sebastião, Feiticeira/São Sebastião, Itassucê/São Sebastião), and Ubatuba (Enseada/Ubatuba, Itaguá/Ubatuba, Praia Grande/Ubatuba). This coastline faces south - southeast, with variable complexity, from long linear stretches in Bertioga (Figure 3F) and southern São Sebastião, where long sandy beaches prevail, to very intricate coasts in Ubatuba, where small sandy beaches (tens to a few hundred meters) and mangrove forests are interspersed along a general rocky shoreline, forming several small bays and coves (Tessler et al. 2006). This general feature is an outcome of major tectonic dynamics leading to a gradual emergence towards the southwest, leading to

the formation of coastal plains and long sandy shorelines, and to submersion towards the northeast, where a sinking mountain range, part of the Serra do Mar system, makes up most of a remarkably convoluted shoreline and coastal islands (Martin & Suguio 1975, Almeida 1976). The rocky intertidal is usually steep, never forming large platforms, and often broken into very large boulders. As in most of the Serra do Mar, rocks are mostly constituted by gneiss and granite (Almeida & Carneiro 1998). The climate regime varies from tropical to humid subtropical (Sant'Anna Neto 1990) within this area. In Ubatuba, where historical climate data are available and have been extensively modeled (e.g. Valentim et al. 2013), temperature is maximum during February [27.8°C air temperature (AT), 28.6°C sea surface temperature (SST)] and minimum during July (21.1°C AT, 21.9 °C SST). Continuous measurements during the austral summer of 2011, taken at Baleeiro, São Sebastião, showed that temperature at the rock surface in the mid intertidal averaged 28.8 °C and occasionally exceeded 40°C (Kasten & Flores 2013).

The sampled shores varied from sheltered (Enseada, Itaguá), moderately exposed (Guaiuba, Ilha Porchat, Itaquitanuva, Baleeiro, Feiticeira, Itassucê) and exposed (Praia Grande), within an area where wave height frequencies from 0.5 to 2.0 m sum up 90%, with a wave height interval between 1.0 to 1.5 m making up half the observations (Bomtempo 1991). Wave exposure is apparently related to the midshore height (MH), from the upper limit of the coralline algal turf to the upper limit of the chthamalid barnacle cover. Roughly, the MH is lower than 0.5 m at sheltered shores, between 0.5 and 1.0 m at moderately exposed shores, and higher than 1.0 m at exposed shores. In this area, coastal primary production is comparatively low when compared to temperate areas prone to intensive seasonal upwelling (Gianesella et al. 2008). Estimates of nitrate concentration based on SST time series taken in the São Sebastião Channel indicated variation from only 0.2 to 0.7 µM (Flores unpublished data). Local upwelling of South-Atlantic Central Waters (SACW) may take place sporadically, during summer months, but more frequent inputs to the coastal zone take place via remote forcing, mostly during the passage of cold fronts during winter (Ciotti et al. 2010). The tidal regime at this coastline is a semidiurnal one, with the tidal range at spring tides ranging from 1.1 to 1.5 m. There is often a clear intertidal zonation, with the barnacle *Chthamalus bisinuatus* dominating the upper midlittoral (level 1), the mussel *Brachidontes solisianus*, and the volcano barnacle *Tetraclita stalactifera* prevailing in the lower midlittoral zone (level 2), and a coralline algal turf, associated to a very diverse assemblage of other macroalgae, making the most of the infralittoral fringe (level 3). These three levels were the targets of sampling protocols attempting a complete report of species presence and abundance.

Intertidal biological assemblages at the study sites - The upper levels sampled in this survey (levels 1 and 2) showed little variation among localities, but species turnover was very high in the lowest level (level 3), rendering almost shore-specific assemblages. At this lowest level, diversity was very high due to the presence of a large number of small macroalgal species. The most common species at all sites in level 1 in terms of cover were *Chthamalus bisinuatus* and *Brachidontes solisianus*, while *Collisella subrugosa* was one of the most abundant reaching densities of more than 70 ind/m². Level 2 was dominated by *Phragmatopoma caudata*, *Brachidontes solisianus*, *Tetraclita stalactifera*, and *Chthamalus bisinuatus*. Level 3 showed differences in among the different sites, with *Collisella subrugosa*, *Fissurella clenchi*, *Phragmatopoma caudata*, *Ulva lactuca*, *Stramonita haemastoma*, and *Caulerpa fastigiata* as some of the most abundant and conspicuous species.

The South: Paraná and Santa Catarina

The rocky coasts along south Brazil are formed by granitic or basaltic rock, resulting from the erosion of the border of the Serra do Mar mountain chain, which lies parallel to the coastline. Biolithic formations are also observed as an important coastal substrate, mainly at Paraná and Santa Catarina States. It is not a continuous ecosystem, but forms more or less extended outcroppings between sandy beaches and around numerous coastal islands. In some beaches there is a large rocky wall with different inclinations, where the intertidal zone is 5 – 6 m wide, but in most cases boulders of different sizes accumulate in front of these walls and the intertidal community covers a band of just 1.5 – 2 m high in each boulder. Usually the tide ranges from -0.2 to 1.8 m and water temperatures range from 17 – 23 °C but surface water temperatures can reach peaks of 26 – 28°C. The Paraná comprises the shortest coast in extension in the South and the second shortest in Brazil (98 Km). The area is between two Estuarine Complexes (Paranaguá and Guaratuba Bays), resulting in low transparency and high concentration of dissolved organic matter.

The monitoring of rocky coasts in the Brazilian southern region covered the following beaches from north to south: Morro do Farol (Figure 3G) and Praia Grande (Mel Island), Farol Island (Matinhos), Ferry Boat and Morro do Cristo (Guaratuba), in state of Paraná; First outcrop and Third outcrop (Itapema do Norte, Itapoá), Papagaio Point and Praia de Cima (Palhoça), in state of Santa Catarina; and Praia da Cal and Guarita Park (Torres) in state of Rio Grande do Sul. The northern seven sites listed are close to large estuarine systems (Paranaguá Bay, Guaratuba Bay, Babitonga Bay) and consequently exposed to low salinities (33-34) and high loads of sediment (turbid waters) and high concentration of dissolved organic matter.

A total of 160 species were found, around 60 invertebrates and 100 conspicuous macroalgae distributed along the three states, but known species richness in the southern Brazilian coast can reach 220 taxa at Santa Catarina (ca.), 131 taxa in Paraná (Pellizzari et al. 2014) and 85 taxa in Rio Grande do Sul (ca.). Rhodophytes dominated over Chlorophytes and Phaeophycean. The supralittoral zone mostly comprises bare space used by the periwinkle gastropods *Echinolittorina lineolata* (d'Orbigny, 1840), which are the most common and characteristic organisms at the lower part of this zone. Abundances can be as high as 150 individuals per 100 cm². The high intertidal contains a dense belt of the barnacle *Chthamalus bisinuatus* Pilsbry, 1916, where many *Echilittorina* are still present. The mid intertidal is dominated by the mussel *Brachidontes solisianus*, usually fouled by the algae *Pyropia* (formerly known as *Porphyra*) *suborbicularis*, *Bostrychia* spp., and *Gelidium pusillum* during the winter time. In this zone sand accumulates among the bivalves, sometimes almost covering all the shells, in which a community of vagile invertebrates such as polychaetes and nematodes is found. The community of the low intertidal is more variable among sites. In some beaches, barnacles (*Tetraclita stalactifera*) are very common (Morro do Farol, Morro do Cristo, Ponta do Papagaio), while in others, the mussel *Perna perna* is the dominating species (Ferryboat, Praia de Cima, Praia da Cal, Guarita Park). Below the barnacle and mussels zone, high densities of the sabelariid polychaete *Phragmatopoma caudata* are found forming sand reefs that can extend 50-70 cm away from the substrate. Not all rocks are covered by the sand reefs and macroalgae are also very abundant in this zone. Regarding seaweed assemblages, filamentous, foliose and terete functional groups dominated the biomass. Species with higher coverage in the low intertidal were *Acantophora spicifera*, *Centroceras clavulatum*, *Gelidium* spp., *Gymnogongrus griffithsiae*, *Hydropuntia caudata*,

Hypnea musciformis, *Pyropia acanthophora*, *Laurencia* spp., *Bryopsis pennata*, *Cladophora* spp., *Codium taylorii*, *Gayralia brasiliensis*, *Ulva lactuca*, *U. flexuosa*, *Bachelotia antillarum*, *Colpomenia sinuosa*, *Dictyota* sp., *Padina gymnospora* and *Sargassum* spp. The most important herbivores in the area are sea-urchins and turtles. In some beaches, hydroids are also common in the low intertidal such as *Obelia dichotoma*, *Orthopyxis sargassicola*, and *Acharadria crocea*. The sea anemone *Bunodosoma caissarum* as well as the sponge *Hymeniacidon heliophila* were also frequent. When the tide is very low and the sublittoral fringe gets exposed, a few ascidian species can be found (*Polysyncraton aff. amethysteum*, *Didemnum galacteum*, *Botryllus planus*, and the introduced *Eudistoma carolinense*). Among the grazers, there were five mollusk species and one sea-urchin, while among the predators, *Stramonita brasiliensis* was the only ubiquitous and abundant invertebrate species. No sea-stars were found, however, 20 years ago, *Asterina stellifera* was common in the intertidal zone of this region.

Along the Brazilian coast in general, macrofauna does not show significant differences in composition, however seaweed assemblages are strongly marked by latitudinal differences on their composition and biomass. The highest diversity of macroalgae is found between the coasts of Espírito Santo and Bahia States, while the highest biomass is found in the Brazilian Northeastern and also Santa Catarina, in the South, associated probably to the influence of the South Atlantic Central Water (ACAS), distance to large estuaries (affect water transparency), and finally to the availability of hard substrates.

Uruguay

The Uruguayan marine and estuarine coastlines (ca. 500 km, between 34° and 35°S) include sandy beaches interrupted by streams and coastal lagoons and rocky (mainly metamorphic and igneous) outcrops forming capes or peninsulae. Since the Uruguayan coast is under the influence of the Río de la Plata estuary, one of the largest estuaries of South America, a salinity gradient roughly oriented east–west can be identified. Based on salinity, three main regions can be identified: a west region influenced by freshwater (<1ppt), a central region that is influenced by water of variable salinity (1–30 ppt) and an east region open to ocean waters (>30 ppt) (Brazeiro, Borthagaray, and Giménez, 2006; Defeo et al., 2009; Giménez et al., 2010). Diluted waters (i. e. salinity <33.2) dominate shallow coastal area (i.e. depths <50m) and can reach the offshore producing a buoyant fresh water layer during extreme continental discharge that determine variations in coastal water input (Ortega and Martínez, 2007). Upper waters temperature could exceed 20°C (e.g. Tropical Water) (Thomsen, 1962) at surface. In the boundary between the estuarine and oceanic zone (Punta del Este), water temperature can fluctuate between 10.7°C in winter and 24.6°C in summer, (Burone and Bayseé, 1985; Milstein and Juanicó, 1985). The coast experiences a semidiurnal tide (range < 0.5 m) with the water level influenced mainly by wind conditions (direction and speed). Winds blow south-west during winter and north-east during summer. The rocky platforms have variable slopes and are exposed to different degrees of wave action according to their orientation. SARCE sampling sites are located in the east region (Figure 3H).

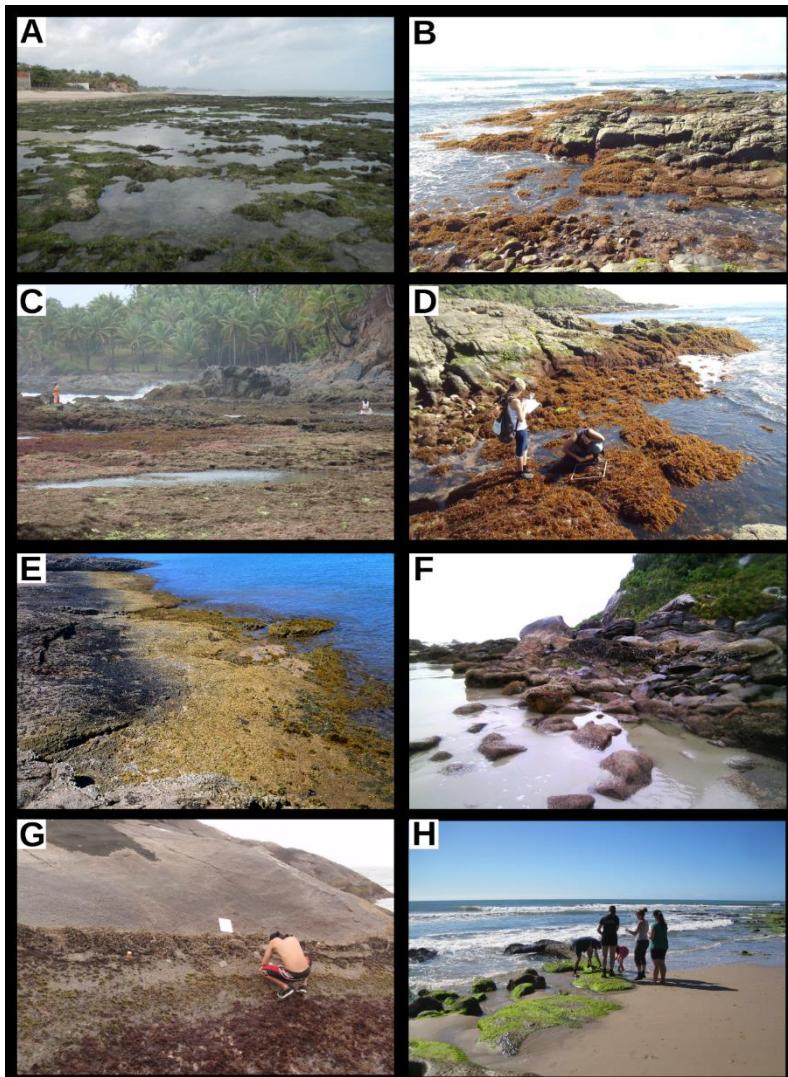


Figure 3. Sampling sites in the Brazilian and Uruguayan Atlantic. A. Northeast Brazil – Caucaia. B. Northeast Brazil – Bahia/Itacaré. C. Northeast Brazil – Bahia/Arruda, octopus fishing. D. Northeast Brazil – Bahia/Itacaré. E. Southeast Brazil – Costao de Ubu/Espirito Santo. F. Southeast Brazil – Sao Lourenco. G. South Brazil – Morro de Farol/Parana. H. Uruguay – Punta del Este.

Across the Uruguayan coast, intertidal species richness of both macroalgae and invertebrates, increased from west to east; this was most notable for sessile fauna and macroalgae (Giménez et al., 2010). In the east region, two to three zones can be identified, following classical zonation schemes: a high intertidal zone dominated by a cyanobacterial film, a middle intertidal zone dominated by barnacles and a low intertidal and shallow subtidal zone characterized by a dense cover of mussels and/or macroalgae. Intertidal mussel beds are thus a conspicuous feature of Uruguayan rocky shores, providing important economic and ecological services (Borthagaray and Carranza, 2007; Riestra and Defeo, 1994; Riestra and Defeo, 2000). Along this gradient, the intertidal mussel beds changes in species composition and structure. Currently, the western region is characterized by the invasive

mussel *Limnoperna fortunei*. *Brachidontes darwinianus* and *Mytella charruana* occupy consolidated substrata along the central region (Maytíá (Maytíá and Scarabino, 1979; Neirotti, 1981; Scarabino et al., 2006), overlapping with *Brachidontes rodriguezii* from the eastern half of the central region and being replaced by this species in the eastern region (e.g. Amaro (Amaro, 1965; Maytíá and Scarabino, 1979; Scarabino et al., 2006). *Mytilus edulis*, in turn, is distributed from the eastern half of the central region, being the dominant mussel species in this zone. *Brachidontes rodriguezii* and *Mytilus edulis* originate dense banks in the more saline part of the Río de la Plata, the first being characteristic of the intertidal (also occurring in the Atlantic shores), the second mostly subtidally although some intertidal exposed zones have been observed to be dominated by this species (Borthagaray and Carranza, 2007). The brown mussel *Perna perna* originates large banks in the subtidal of the eastern coast (Rocha) but its presence (in very low abundances) reaches Punta del Este. The Uruguayan coast was massively colonized by this species in the late '50ths. Since this first colonization, *P. perna* almost disappeared in the late 70s to 1997, when a new process of colonization occurred in the area (Carranza and Borthagaray, 2008; Orensanç et al., 2002). The annotated list of macroalgal species of the Uruguayan coast given by Coll and Oliveira (1999) reported the presence of 69 species sampled from 27 sites located along the central and east sectors of the Uruguayan coast. Conversely, a single site (Cerro Verde) can yield more than 40 invertebrate taxa, including the small mobile (e.g. amphipods, polychaetes), and encrusting (e.g. bivalvia, hydrozoa) fauna. Under the SARCE sampling protocol, two sites located in the eastern region showed a combined richness of 20 species, including 9 metazoans (4 Gastropoda, 2 Bivalvia, 2 Cnidaria Anthozoa and 1 Cirripedia), 4 Chlorophyta and 7 Rhodophyta bortha (Borthagaray and Carranza, 2007).

Argentina

The Argentinean marine coast extends along more than 4700 km and twenty degrees of latitude. It comprises the Argentinean and Magellanic biogeographical provinces, which are delimited by the Valdés Peninsula. The Argentinean Biogeographic Province extends from 36 to 43° S, including the provinces of Buenos Aires and Río Negro, and the north of Chubut province. The Magellanic Biogeographic Province, extends from 43°S to 56°S along southern Chubut province as well as Santa Cruz and Tierra del Fuego provinces (the latter includes the Malvinas/Falklands and South Atlantic Islands) (López Gappa et al., 2006, Balech and Ehrlich, 2008). Intertidal rocky platforms in Argentina increase in frequency and extend from North to South. In the northernmost coastal province (Buenos Aires), rocky coastal stretches are markedly discontinuous. They rarely exceed 1 km length and are frequently associated to urban areas. Most intertidal platforms in this province are formed by consolidated sediments (e.g., limestones, sandstones, calcretes) that support both epilithic and endolithic biota (Bagur et al. 2013, 2014). The only exceptions are a handful of metamorphic rock (orthoquartzite) platforms adjoining the city of Mar del Plata (38° S).

SARCE sampled two sites were sampled in the province of Buenos Aires: Playa Chica, an orthoquartzite platform located in the urban zone of Mar del Plata (Figure 4A) and at a calcrete platform located immediately north of the port of Quequén. Both localities are exposed to waves and face the open sea. The tidal regime at these sites is semidiurnal and microtidal (mean and maximum amplitude are 0.83 and 1.65 m respectively). Water temperature varies from a media of 5° C in winter to a media of 18 ° C in summer (Servicio Meteorológico Nacional-Argentina, <http://www.smn.gov.ar>). The next province to the south,

Rio Negro, presents intertidal platforms of varying substrate, including sedimentary (e.g., sandstones, limestones) and igneous rock types (e.g., granite, ignimbrites) (Kokot et al. 2004). Tidal regimes are semidiurnal and macrotidal through the whole coastal range. The sampling sites in this province were: El Espigón, La Lobería (Figure 4B), Playa Los Suecos, and Punta Colorado. El Espigón and La Lobería face the open ocean and are characterized by sedimentary rock substrates and maximal tidal amplitude of 4.32 m. Playa Los Suecos and Punta Colorado are located within the San Matías Gulf and show igneous rock substrates and maximal tidal amplitude of 8.72 m (Kokot et al. 2004). Southwards, the rocky shores of Chubut province are exposed to unusually harsh physical conditions, particularly with regard to desiccation (see Bertness et al. 2006). The region is characterized by persistent and intense winds (up to 90 km/h, annual average 16.6 km/h) and low precipitation (mean 235.9 mm/yr (Paruelo et al., 1998, Labraga & De Davies, updated 2013). The tidal regime is semidiurnal and macrotidal. Consolidated sediments are the dominant substrate type across these rocky shores. Sampling sites in Chubut were Puerto Lobos, Punta Este (Figure 4C), and Camarones. Puerto Lobos is located by the Southern end of the San Matías Gulf and its maximal tidal amplitude is about 6 m. Punta Este is located within the Nuevo Gulf, 8 km south from the city of Puerto Madryn. Mean tidal amplitude at this site is 3.8 m (Maximal: 5.7 m). The town of Camarones is located within the homonymous bay. This site is characterized by monthly-averaged wind speeds ranging from 13 to 31 km/h and an average tidal amplitude of 4 m, platforms are characterized by sedimentary rocks although some igneous rock are present. The southernmost continental sampling site was Puerto Deseado (Figure 4D) in Santa Cruz Province. This site is located in the Deseado Massif geological province, and characterized by igneous rock substrates (rhyolites; see Pankhurst and Rapela, 1995; Pankhurst et al., 1998). Climate is also dry and windy with a mean annual precipitation around 200 mm and an average annual air temperature of 8.2 °C (Servicio Meteorológico Nacional-Argentina, <http://www.smn.gov.ar>). The tidal regime is mesomacrotidal (Isla and Bujalesky, 2008), with amplitudes ranging between 2.5 and 5.5 m. Two additional sites were sampled in Tierra del Fuego Island: Estancia Viamonte (Figure 4E) and Playa Larga (Figure 4F). Estancia Viamonte is located 40 km south of the city of Río Grande and characterized by an extensive limestone abrasion platform (the low tide level is ca. 2 km distant from the high tide line) that faces the open ocean. The tidal regime is macrotidal, with amplitudes ranging between 2.2 and 8.4 m (Bujalevsky 1997, 2007). The area shows a dry and windy climate (340 mm/yr precipitation) with the mean annual temperatures of 5-6 °C and low between-month variations (Bujalevsky 1997, 2007). Playa Larga is located 3.5 km east of the city of Ushuaia in the Beagle Channel. The rocky shore at this site is characterized by metamorphic rocks and a sharp slope. The tidal regime is microtidal (1.1 m mean amplitude). Mean annual temperature and precipitation are 6°C and 500 mm, respectively. This shore faces the dominant SW-W winds and, thus, is exposed to considerable wave splash. The subtidal all along the Beagle channel is characterized by dense forests of *Macrocystis pyrifera* (Figure 4G) down to the channel's mouth to the Atlantic at Estancia Moat, a planned sampling site (Figure 4H).



Figure 4. Sampling sites in Argentina. A. Mar del Plata. B. La Lobería. C. Punta Este. D. Puerto Deseado. E. Río Grande. F. Playa Grande. G. Estancia Moat – *Macrocystis pyrifera*. H. Estancia Moat.

The main feature of this extensive coast is the low biodiversity of its rocky intertidal shores, which at the same time involve low biomass (Wieters et al. 2012). From North to South, the two localities in Buenos Aires Province have different geological substrates, and are 120 km apart. Even if both assemblages have the same species composition; the structure and relative abundance of species between localities were different. In Mar del Plata, the locality with quarzitic substrate, the bivalve *Brachidontes rodiguezii*, the limpet *Siphonaria lessoni* and the introduced barnacle *Balanus glandula* are the more abundant species of the high intertidal. In the mid intertidal level, several algae species were added to the

assemblages, being *Hildenbrandia* sp. *Polysiphonia fucoides*, *Ulva* sp. and two non-indigenous red algae *Anfeliopsis devoniensis* and *Schyzimenia dubyi* the most abundant. In the low intertidal level, the most representative species are *Polysiphonia fucoides* and *Siphonaria lessoni* in Mar del Plata and *Corallina officinalis* and *Balanus glandula* in Quequén. The presence of non-indigenous algae species is limited to *Schyzimenia dubyi*, and in very low coverage.

The Rio Negro Province comprises two localities and also an area of ecotone among two biogeographic regions, the Argentinean and Magellanian provinces. The differences among localities involve not only changes in the species composition but abundance of the ones that are present in both regions. In El Espigón and Loberia, a great variability was found between sites, the high intertidal is inhabited mainly by *Mytilus platensis* in one site and by *Ralfsia expansa* and *Enteromorpha linza* in the other. The mid intertidal level could have up to 98 % coverage of *Brachidontes rodriguezii* in one site and 0 % in the other. *Siphonaria lessoni* is the second more abundant species in this level. In the low intertidal the areas are patchily covered by *E. linza* and *Corallina officinalis* in one site or almost exclusively covered by *C. officinalis* in the other. In Playas Doradas, the most abundant species that inhabits the high intertidal are *Siphonaria lessoni* and *Brachidontes rodriguezii*, but in a very low percentage cover (approximately 12 %). In the mid intertidal, *Brachidontes purpuratus* replaces *B. rodriguezii* and it is the most abundant species followed by *Ralfsia expansa* and *S. lessoni*. For the low intertidal, *C. officinalis* is the most abundant followed by a complex of *Aulacomya actra* and *Mytilus platensis* forming mussel beds. The Chubut Province is characterized by sites with no human settlements. In the north of the province, the biodiversity pattern is similar to the localities in the province of Rio Negro, with *B. purpuratus* being the most abundant species in the high and mid intertidal and *C. officinalis* in the low intertidal. In Puerto Madryn, a site with a local population of 80,000 residents, the pattern is similar but with a greater proportion of the green algae *Ulva* sp. in the mid intertidal, depending on the season. High and mid intertidal are dominated by the mytilid complex of *Brachidontes rodriguezii* and *Brachidontes purpuratus* that produce an heterogeneous habitat that facilitates settlement for several species. Also the non-indigenous barnacle *Balanus glandula* is present in high and mid intertidal levels, while the gastropod *Trophon geversianus* is a carnivore specialized on mytilid bivalves. The low intertidal is dominated by the alga *Corallina officinalis* and the herbivore gastropod *Tegula patagonica*. In Camarones, the zonation is similar to Puerto Madryn, presenting zones with 100% of coverage of *Brachidontes purpuratus* dominating the mid intertidal, and the invasive species *Balanus glandula* in the mid and high intertidals. The low intertidal is dominated by the calcareous algae *Corallina officinalis*, while *Aulacomya atra* and *Siphonaria lessoni* are abundant in some localities. The gastropod *Trophon geversianus* is less common in this zone, probably due to the harsh physical stress.

Santa Cruz is the last province of the continent and the one with less population, with nearly 10,000 residents on the coast, but with an important port in the sampling locality Puerto Deseado. Here, even if biodiversity increased slightly, patterns of the most abundant species were kept. The high and mid intertidal were dominated by *Brachidontes purpuratus* and the algae *Bostrichia*, while in the low tide *Corallina officinalis* and *Chondria* were the most abundant. In the low intertidal level the presence of the non-indigenous red algae *Anotrichium furcellatum* was detected as one of the most abundant. In Tierra del Fuego Island, assemblages are different according to their degree of exposure (open ocean vs Beagle

channel). In the open ocean locality, Estancia Viamonte, near Ushuaia (56,000 residents), mussel beds are composed mainly by *Mytilus edulis platensis* and covered from 50 to 87% of the mid and high intertidal. In the low intertidal, the encrusting algae *Corallina* sp. is the more abundant sessile species. The biodiversity of mollusks increased in this site, being *Nacella magellanica*, *Kerguelenella lateralis* and *Trophon gerversianus* the most abundant. In the locality in the Beagle Channel, Playa Larga, macroalgal biodiversity increased, being the most conspicuous group in the low and mid intertidal along with *M. edulis platensis*. The limpet *Notochthamalus scabrosus* is the more abundant species in the high intertidal. As observed in the open ocean site, the biodiversity of mobile mollusks increased with *S. lessoni*, *K. lateralis*, *N. magellanica* and *T. gerversianus* the most abundant species in the three intertidal levels.

The Pacific

Colombia

In general terms, two main regions/features can be recognized on the littoral of the Pacific coast of Colombia: mangrove swamps and muddy flats to the south and rocky shores to the north; with a hybrid zone almost in the middle of the coast: Málaga and Buenaventura Bays. The shoreline is very broken, interrupted by numerous small rivers and creeks characteristic of one of the雨iest and most bio-diverse areas in the World: The Tumbes-Chocó-Magdalena region. Despite this condition or perhaps due to it, most of the coast is unpopulated, with only two relatively large cities: Buenaventura (the most important commercial port in Colombia), located almost in the middle of the coast and Tumaco, a smaller city located at the south, near the border with Ecuador. Although these two are the main cities, there are numerous small towns, such as Guapi and Bahía Solano, among others. The transportation system in the region is precarious. The underdeveloped roads infrastructure is limited to Buenaventura and Tumaco, and all other settlements can only be reached by boat or in few cases by plane, a fact that makes it difficult and expensive to undertake research projects in the Pacific coast of Colombia.

The Pacific coastline has an extension of nearly 1544 km, of which 636 km are exposed rocky shores (Londoño-Cruz et al., 2008, Londoño-Cruz et al., 2014). Despite this exposure, wave action is moderate most of the year round, reaching, on average, wave heights of up to 1 m in most locations (INVEMAR, 2003). Tidal range is relatively large (ca. 4.5 – 5.0) and has a semidiurnal frequency (ca. 6:15 hrs. between high and low tide). Currents, on the other hand, respond to prevalent winds and to the movement of the Intertropical Convergence Zone (ITZC). The most important surface currents are the North Equatorial Current, the North Equatorial Counter-current, the Panama Gulf Current, and the Colombia Current. Although there are hypothesis regarding the existence of upwellings in the Pacific coast of Colombia, these have not been unambiguously confirmed; if they do occur, they happen during the first months of the year and at the northernmost of the Colombian Pacific (Vides and Sierra-Corra 2003). Rocks forming the large extension of rocky shores on the Colombian Pacific are composed by volcanic rocks from the Secondary or Tertiary periods and by sedimentary rocks from the Quaternary. The volcanic rock characterizes the rocky shores of the northern regions and the Gorgona and Malpelo Islands, while the sedimentary rocks characterize the rocky shores of central (Málaga Bay, Pichidó Isthmus, and Tortuga Gulf) and southern (Gallo

Island) regions (INVEMAR, 2004). Due to the relatively large tidal range, the rocky intertidal can be easily divided into three levels, which vary in dimension depending on the slope of the shore. It is very common to find cliffs along the coast, with scattered abrasion platforms and rocky/boulder beaches. Zonation in the intertidal zone is very typical, with periwinkles and *Nerita* spp. occupying the upper intertidal; barnacles, limpets, other snails and bivalves in the middle and a richer arrange of species in the lower. In these rocky shores, the algal coverage is very low as compared to shores in higher latitudes or the Colombian Caribbean; so although species richness in general is high, species abundances are relatively low. It is also important to note that space seems not to be a limiting factor, since there is plenty of free space in almost every rocky shore along the coast. One might hypothesize that the reason for this low abundance is low algal coverage and long exposure periods during low tide, which may bring very high temperatures or very low salinities (during high rainfall).

The localities sampled by SARCE (from North to South) include El Choco (Punta Ardita, Cabo Marzo) (Figure 5A), Málaga Bay (Los Negritos, Isla Palma), and Gorgona Island (La Ventana, La Camaronera, Piedra Redonda) (Figure 5B). Punta Ardita at El Choco is the northernmost locality, near to the border with Panamá, practically undisturbed by human presence. The volcanic rocky shores in this locality are edged by large sandy beaches. The high intertidal is mostly bare rock with *Cladophoropsis* sp., *Nerita scabricosta*, *Echinolittorina conspera*, *Chthamalus panamensis*, *Lottia mesoleuca*, and *Acanthina brevidentata*. The mid intertidal is dominated by *Cladophoropsis* sp., *Acanthina brevidentata*, *Fissurella microtremia*, *Phragmatopoma* sp., *Fissurella microtremia*, and *Lottia mesoleuca*. The most common species in the low intertidal are *Cladophoropsis* sp., *Echinometra vanbrunti*, *Telmatactis* sp., bryozoa, and *Balanus* sp. Cabo Marzo is an isolated locality with no human settlements nearby and practically undisturbed. Rocks, as in the previous locality, are volcanic. There is some coralline formation in this place, waters are very transparent. Wave conditions are relatively rough. Dominant species of Cabo Marzo are *Chthamalus panamensis*, *Echinolittorina conspera*, and *Nerita scabricosta* in the high intertidal, Corallinales, *Fissurella virescens*, and *Siphonaria maura* in the mid intertidal, and Corallinales, *Chiton stokesii*, *Siphonaria maura*, *Nucella melones*, and *Chama frondosa* in the low intertidal.

At Málaga Bay the rocks are sedimentary. This bay is part of a National Natural Park and there is a relatively large human settlement (Juanchaco) at the mouth of the bay, as well as a Navy Base along with several other scattered minor settlements. Seasonal tourism is, perhaps, the main economic income for the inhabitants. The first site, Isla Palma, is an island (uninhabited), while the second site, Los Negritos, is an intertidal rocky reef with both volcanic and sedimentary rocks. Dominant species at Isla Palma were *Chthamalus panamensis*, *Balanus* sp., *Lottia mesoleuca*, *Echinolittorina paytensis*, *Echinolittorina dubiosa*, and *Echinolittorina apicina* in the high intertidal; *Verrucaria* sp., *Lithophyllum* sp., *Nerita funiculata*, *Lottia mesoleuca*, and *Balanus* sp. in the mid intertidal; and *Cladophoropsis* sp., *Bostrychia* sp., *Lithophyllum* sp., *Echinometra vanbrunti*, *Nucella melones*, and *Brachidontes* sp. in the low intertidal.

Gorgona Island is also a National Natural Park. Most of the island's shores are rocky and cliffy. Rocks are volcanic with few exceptions. Basically all sort of rocky shore types can be found in the island. This locality is perhaps, the most sampled area in the entire Pacific coast of Colombia. The main rocky ecosystems sampled (La Ventana, La Camaronera, and Piedra Redonda) are located at the south and western sides of the Island. At La Ventana, the

dominant species were *Nerita scabricosta*, *Cladophoropsis* sp., *Echinolittorina conspera*, and *Siphonaria gigas* in the high intertidal, *Nerita funiculata* and *Cladophoropsis* sp. in the mid intertidal, and *Nucella melones* and *Nerita funiculata* in the low intertidal. At La Camaronera, high intertidal is dominated by *Echinolittorina conspera* and *Nerita scabricosta*, the mid intertidal by *Nerita funiculata*, and the low intertidal by *Cladophoropsis* sp., *Nerita funiculata*, and *Tegula pellisserpentis*. At Piedra Redonda, the high intertidal is dominated by *Nerita scabricosta*, the mid intertidal by *Cladophoropsis* sp., *Nerita funiculata*, and *Fissurella virescens*, and the low intertidal by *Cladophoropsis* sp. and *Nucella melons*.

Ecuador

The coast of Ecuador extends for 4,403 km from north to south and includes several isles, islets and estuaries. The continental platform exceeds 100 km in amplitude mainly at the Gulf of Guayaquil (Sonnenholzner et al, 2013) and a depth of 200 m from the coastline (Mora et al, 2010). About a third of the coast is covered by mangroves, mostly in the north and in the south. The central and part of the north coasts are characterized by large sandy beaches interrupted by a few rocky areas, cliffs, lagoons and rocky reefs (Sonnenholzner et al, 2013; Miloslavich et al, 2011). The rocky shore intertidal has mid to steep slopes formed by stratified rocks within cliffs entering the sea and forming platforms within the sandy beaches. At the base of some of the cliffs, an eroded narrow terrace can be observed, or the beach may be narrow with boulders. Despite the importance of rocky shores, they have been poorly studied in Ecuador, and knowledge on its biodiversity is limited to some taxonomic studies on specific groups such as molluscs (Bonilla 1967; Cruz 1977, 1983, 1992a, b, 1996, 2007 y 2009; Mora and Reinoso 1981; Mora 1989, 1990; Arias 2012), polychaetes (Villamar 1983, 1986, 1989), echinoderms (Avilés 1984, Sonnenholzner et al. 2013), and macroinvertebrates (Massay et al. 1993; Arroyo and Calderón 2000; Mair et al. 2002; Cruz et al. 2003; Ayala 2010; Mora et al. 2010).

SARCE sampled at two localities at the central and south-west of the coast of Ecuador: Caráquez Bay (Punta Bellaca and Punta Gorda) and at the Santa Elena Peninsula, the localities of Puntilla de Santa Elena (Base Naval and La Lobería) (Figure 5C) and Ballenita (El Barco and El Faro) (Figure 5D) which are located at the provinces of Santa Elena and Manabí. The sites with more human impact were Punta Bellaca and Ballenita, while Punta Gorda and Puntilla de Santa Elena were less impacted.

Punta Bellaca and Punta Gorda are characterized by almost vertical, high cliffs of up to 100 m interrupted by deep valleys with steep slopes (Ochoa et al, 1987). These cliffs are unstable and landslides are common. The beach is narrow and in some places, eroded rock terraces can be found inserted within sandy beaches (Boothroyd et al, 1994). Weather in this area is tropical dry with an average temperature of 25°C. Rainfall is not uniform due to the complexity of the Oceanic Front, and varies between 200-800 mm (Ochoa et al, 1987). A total of 16 species were found (10 at Punta Bellaca and 4 at Punta Gorda), mostly represented by molluscs (50%), macroalgae (25%), and crustaceans (25%). The most diverse group was the mollusks represented by 7 species of gastropod and one bivalve species. The most abundant species were the gastropods *Nodilittorina aspera*, *Nodilittorina paytensis* and the macroalgae *Enteromorpha* sp. and *Bachelotia* sp..

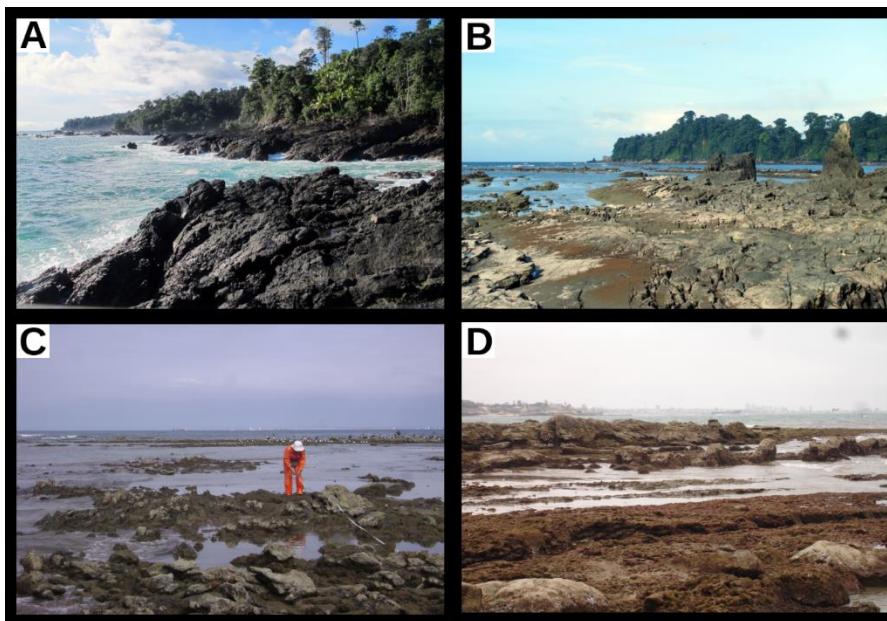


Figure 5. Sampling sites in the Colombian and Ecuadorian Pacific. A. Colombia – Nuqui/Choco. B. Colombia – La Ventana/Gorgona. C. Ecuador – Puntilla de Santa Elena. D. Ecuador – Ballenita.

The high intertidal was mostly represented by bare rock and patches of sand, but some rocks were colonized by the *Brachidontes semilaevis/Balanus amphitrite* complex. The most common species in the mid intertidal were *Balanus amphitrite* and *Enteromorpha* sp. and *Bachelotia* sp. in the low intertidal.

At the Santa Elena Peninsula, Ballenita is a public watering place with hotels all along the border of the coast. The weather is tropical with a mean average temperature of 24°C. The intertidal is characterized by short, vertical, and unstable cliffs. The rocky platforms are inserted within the sandy beaches, and have a soft slope (Ochoa et al, 1987). Boothroyd et al. (1994) proposed that the low cliff originated from a system of barrier/littoral plain formed by sand poorly cemented to the carbonates and clay. Wave energy is highest during the rainy season (Brito, 2014). The rainy season occurs in January-April followed by the dry season which extends to November-December (Ochoa et al, 1987). Precipitation varies from 62.5 to 125 mm (Ochoa et al, 1987).

The Puntilla de Santa Elena is within a marine protected area known as “Reserva de Producción de Fauna Marina Costera Puntilla de Santa Elena” or REMACOPSE. The intertidal here is irregular, with low vertical, unstable cliffs that continue at sea, emerged, for a few hundred meters. Between these formations, sandy beaches with coarse sand and steep slopes are found. The base of the cliffs are continuously eroded by wave action (Boothroyd et al, 1994; Soledispa, 2008). From the geological point of view, the most outstanding feature at La Lobería is the Cayo Formation, represented by sandstone, chert and silicified clays (Soledispa, 2008). Wave action is stronger than in the previous site and also highest during the rainy season (Brito, 2014). At the Navy Base, the Beach is characterized by medium size rocks covering a great extension that goes into the sea. According to Soledispa (2008), these lay directly on top of the Cayo Formation where deposits from the quaternary are found and composed by calcarean sandstone and conglomerates with abundant fossils. When the tide is

low, numerous intertidal pools can be observed among the sand. Weather in this area is arid, with a mean annual temperature of 24°C, and precipitation, determined by the Humboldt Current, varies between 62.5 and 125 mm (Ochoa et al, 1987).

At these localities, a total of 66 species were found. These were mostly represented by molluscs (39%), macroalgae (24%), crustaceans (14%), cnidarians (9%), bryozoans (5%), echinoderms (5%), sponges (3%), and tunicates (1%). Ballenita had a higher number of species (30 species) in comparison to Puntilla de Santa Elena (19 species). The most diverse group were the mollusks (29 gastropod species plus 2 bivalve species) followed by macroalgae (9 species of rodophytes, 3 of chlorophytes, 3 of phaeophytes plus an unidentified species), and barnacles. The most abundant species were *Balanus amphitrite*, *Brachidontes semilaevis*, *Nodilittorina aspera*, *Nodilittorina paytensis* and one bryozoan. The dominant species in the high intertidal were *Nodilittorina aspera*, *Nodilittorina paytensis*, and the complex *Balanus amphitrite/Brachidontes semilaevis*, while the mid intertidal was dominated by *Pachygrapsus transversus*, *Echninometra vanbrunti*, and *Nerita funiculata*; and the low intertidal by *Nodilittorina aspera*, *Thais brevidentata*, *Padina* sp., and a bryozoan species. The vertical zonation was more evident in the high and mid intertidal which are dominated by littorinid gastropods, barnacles and mussels (*Nodilittorina aspera*, *Nodilittorina paytensis* and the complex *Balanus Amphitrite/Brachidontes semilaevis*) as observed by Cruz (2009) and Brito (2014) at the Santa Elena peninsula. This pattern is dependant on the tide and time of exposure to air (Sibaja-Cordero and Vargas-Zamora, 2006).

Peru

The coastline of Peru extends for 2414 km along the Peruvian Biogeographic Province and is greatly under the influence of the Humboldt Current System, one of the major upwelling systems of the world (Miloslavich et al., 2011). SARCE sampled at seven localities, from north to south: Paita, Huarmey (Figure 6A), Ancón, Paracas (Figure 6B, 6C), Marcona, La Meca, and Punta Colorada (Figure 6D). The geological and physical conditions of these localities are very variable according to their origin and latitude, which ranges from a tropical warm province in the north, to a cold, sub-Antarctic province in the south. These changes are reflected in the composition of the intertidal flora and fauna.

In the north, Paita, located near the border with Ecuador, at the Panamic Province of the Tropical West Pacific is one of the most intense upwelling zones in the coast of Peru and characterized by high productivity (Fahrbach 1981, Huyer 1987, Grados 2002, Graco 2007). It is considered subtropical with very dry weather. Coastal diversity is high at these warm conditions (Ramírez et al., 2003), however, it is temporally affected by ENSO events (Paredes et al. 1998, Paredes et al. 2004), that produce the migration of some vertebrate species and the arrival of larvae or propagules of more tropical species. Sampled areas are relatively small beaches (~100 m in extension), exposed to wave action and located south of the bay of Paita. In this bay, 5 to 9 km from the sampling sites, functions the second largest port of Peru, dedicated mainly to fishing activities and transportation of agriculture products. The coast is characterized by black metamorphic rocks, over which Cretaceous rocks can be found, mainly from the quaternary forming sandstones and cliffs of up to 50 m (Palacios Moncayo 1994). Tides are semidiurnal that may reach 1.73 m (HIDRONAV, 2012), and SST varies between 15-29°C (INEI, 2014), with the highest values in summer (February-March) and the lowest in spring (September-October). Paita is also under the influence of the

Peruvian Coastal Current which is characterized by cold Waters but also of tropical equatorial surface warm waters (Zuta & Guillen 1970, Cabrera et al. 2005). Very little is known about the biodiversity of these coasts. An abundant species is the barnacle *Pollicipes elegans* which is commercially exploited for exportation (Villena 1995, Oliva 1995, Pinilla 1996). Population density of this barnacle is very high during ENSO events, but after the event, population decreases significantly and is replaced by other invertebrates such as *Semimytilus algosus*, *Austromegabalanus psittacus* and *Balanus* spp (Kameya and Zeballos 1998). As for macroalgae, a total of 35 species were identified in the intertidal zone, of which 22% are considered to be endemic. This diversity is seasonal, decreasing during the winter or during other cold events such as La Niña (Benavente 1994).

In central Peru, the sites sampled at the Bay of Huarmey are exposed to wave action and located at 6.5-11.7 km north of the Port of Huarmey, important for mineral transportation and fishing activities. The rocky shores are part of the Casma Formation, from the late Cretacic, mainly volcanic spills of weathered andesite and inserted sediments. The weather is considered dry, subtropical desert, and tidal amplitude reaches 1.16 m (HIDRONAV, 2012). SST varies between 18-22 °C (Puerto de Chimbote, INEI 2014). Upwelling events are not frequent, but when they occur, SST may decrease to 15 °C (Berru Paz et al 2007). The most common species found in the rocky shores are *Fissurella* spp, *Polyplacophora*, *Pyropia* spp., *Chondracanthus chamaissoi*, which are also commercial species and monitored by IMARPE as artisanal fishing resources (Tam et al. 2007). The sites sampled at Ancón are within the area known as Volcánico de Ancón, which is characterized by pyroclastic rocks and volcanic andesites, typically metamorphic with plagioclases. Also a desert area, it was declared a natural protected area in 2011 along with the islands in front of the coast. The main port of Peru, El Callao, is located 33 km south of Ancón. Sampled sites are protected from wave exposure, tides reach 1.16 m, and SST varies between 14-22°C (Tarazona, unpublished). Upwelling events are frequent and generate hypoxia and even anoxia by the effect of bubbling from the bottom of sulphur compounds and other gases (Tarazona 1984, Tarazona et al. 1988, Tarazona et al. 1996). Biodiversity studies have been carried out since the 1970s (Paredes, 1974), and report 127 invertebrate species. The high intertidal is characterized by barnacles (*Jehlius cirratus* and *Notochthamalus scabrosus*) and littorinid gastropods (*Nodilitorina peruviana* and *Austrolittorina araucana*), the mid intertidal by a zone of mytilids in two bands, the upper band of *Perumytilus purpuratus* and the lower band of *Semimytilus algosus*, among macroalgae, and the low intertidal is characterized by *Austromegabalanus psittacus* (Paredes & Tarazona 1980). Other species found in the intertidal are *Fissurella* spp., *Polyplacophora*, *Chondracanthus chamaissoi*, and *Patallus mollis*. The locality of Paracas is located within the protected area known as Reserva Nacional de Paracas, the first marine reserve in Peru. The landscape is a coastal cordillera that reaches the sea forming cliffs of 50 to 400 m in height (Palacios et al. 1995). One of the sampling sites is located in the Ambo Formation from the Carboniferous, and the rocks are characterized by carbon sheets, which were formerly exploited. The other site is located on the Paracas Formation from the early Tertiary, characterized by phosphate sandstone and bentonites (Fernandez Dávila 1993). Both sampling sites are protected from wave exposure, tidal range is 1.12 m (HIDRONAV, 2012), and SST varies between 13 a 17 °C, however, at spatial scales of 1 to 2 kilómetros, increases of up to 7°C may be observed due to water circulation and wave exposure in the bay (Romero 2000; Quispe et al. 2010, Moron et al. 1998).

Intertidal fauna is represented by *Concholepas concholepas*, *Fissurella* spp., *Pyropia* spp., Polyplacophora, *Lessonia nigrecens*, among other species.

In the south of Peru, Marcona is an important area of mineral extraction, but also an area for the conservation of sea lions and penguins (Punta Marcona). Rocky shores of the sampling sites are characterized by granitic formations from the Coastal Basal Complex, on which sedimentary rocks of the San Juan and Pisco formations have deposited sandstone of calcareous origin (Caldas Vidal 1978). These shores are exposed to wave action, however this is mitigated by a surrounding rocky reef. Tidal amplitude reaches 1.23 m (HIDRONAV, 2012) and SST varies between 12-24°C, with a marked seasonal pattern (Apaza & Figari 1999), and predominance of cold coastal waters. Upwelling events are common in this area (Rojas de Mendiola 1981). The most common species in these shores are the macroalgae *Lessonia* spp., *Macrocystis pyrifera* and *Pyropia* spp., and the invertebrates *Loxoechinus albus* and *Concholepas concholepas* (Galindo et al 1999). La Meca is located near the Wetlands of Ite, which were once heavily polluted by heavy metals from mining. Sampled sites are continuous rocky shores of sedimentary origin with sandstone and some volcanic outcrops from the Chocolate Formation of the coastal cordillera (Acosta Pereira et al. 2012). The sites are exposed to wave action but this is mitigated by rocky reefstidal range reaches 1.38 m (HIDRONAV, 2012) and SST is around 14 °C. This area is visited by artisanal fisherman extracting crabs (*Leptograpsus variegatus*), *Concholepas concholepas*, and macroalgae. The most southern locality is Punta Colorado, also characterized by outcrops of the coastal cordillera and some volcanic Rocks. The shore is exposed but some rocky reefs are also present. Between these two localities, there are several artisanal fishing ports (Estrella Arellano et al. 1998).

Chile

The coastline of continental Chile extends over 4200 km (from ca. 18°S to 56°S) encompassing from subtropical to sub-Antarctic waters (Santelices, 2001). The regular and relatively straight coast changes south of Chiloé Island (41°29'S) which is replaced by many gulfs, islands, channels and fjords. The rocky shores in northern and central Chile are mostly exposed to strong wave action (Thiel et al., 2007). Substratum is composed of rock of volcanic, granitic or sedimentary origin. Most of the coastal range consists of Jurassic and Cretaceous volcanic rocks (Fariña et al., 2008). Most of the coastline is influenced by the flowing Humboldt Current System, coastal upwelling and periodic occurrence of El Niño-Southern Oscillation (ENSO) (Thiel et al., 2007).

Northern Chile: Iquique, Antofagasta and Copiapó

This area represents one of the driest regions of the world, annual precipitation is extreme low (1 mm to 80 mm) with occasional rainfall episodes during austral summer, but no large differences between winter and summer exist (Schulz et al. 2011) (Figure 6E, 6F).

Species richness at Iquique, Antofagasta and Copiapó intertidal rocky sites was 41, 37 and 52 respectively. The high intertidal communities are dominated by the chthamalid barnacle *Jehlius cirratus* and the periwinkle *Echinolittorina peruviana*, occasionally small limpets *Siphonaria lessoni* and *Scurria variabilis* can be also found. Few macroalgae are present, mostly *Porphyra* sp. and *Pyropia* sp. The middle intertidal is dominated by the anemones *Phymactis papillosa* and *Anemonia alicemartinae*, the purple mussel *Perumytilus purpuratus* and macroalgae such as the ephemeral green alga *Ulva* spp. and the fleshy

crustose brown *Ralfsia* sp., particularly in Antofagasta sites the middle and low intertidal are dominated by a dense turf of the red alga *Caulacanthus ustulatus* but in Antofagasta Bay extensive aggregations of the barrel-shaped tunicate *Pyura pectinifera* dominated the middle and low intertidal fringe, this is a non-indigenous species that affect the presence of native organisms (Caro et al. 2011). The low intertidal is dominated by a conspicuous belt of the kelp *Lessonia berteroana*, this brown alga is an ecosystem bioengineers and its holdfast provides habitat for high variety of small invertebrates (Vásquez & Santelices 1984), patches of the red algae *C. ustulatus* and *Corallina officinalis* var. *chilensis* are also present. At several sites the calcareous crusts of *Mesophyllum* sp. and *Lithophyllum* sp. dominates the substrata, over the crusts several individuals of the snail *Tegula atra*, the black sea urchin *Tetrapygus niger*, the edible barnacle *Austromegabalanus psittacus* and the large mollusc *Enoplochiton niger* can be found. At shadow protected places, the sea cucumber *Patallus mollis* and the anemone *Phymactis papillosa* (mostly the blue morph) are quite abundant. Several filamentous algae can be also found at middle and low intertidal, such as *Centroceras clavulatum*, *Polysiphonia* sp. and *Ceramium* spp. In some places the brown algae *Colpomenia sinuosa*, *C. tuberculosa* forms patches of several individuals.

Central-Northern Chile: Coquimbo, Los Vilos and San Antonio

In central Chile, Mediterranean climate is predominant characterized by a winter rainy season and a dry period in summer. The ocean proximity moderates temperatures, averages between 10°C in winter and 17°C in summer can be found. Presence of snow and frost are rare, day-night oscillation is also lower. Species richness at Coquimbo, Los Vilos and San Antonio intertidal rocky sites was 58, 69 and 70, respectively. The chthamaloid barnacle *Jehlius cirratus* dominates the sessile communities at high intertidal. The mobile communities are dominated for *Echinolittorina peruviana* and the small limpet *Siphonaria lessoni*. Mostly fleshy crustose macroalgae are present, such as *Hildenbrandia lecanellieri*, *Ralfsia* spp. and patches of the lichen *Thelidium chilensis*. The middle intertidal is dominated mostly by beds of the purple mussel *Perumytilus purpuratus*, and red algae *Mazzaella laminarioides*, *Hildenbrandia lecanellieri* and the turf-forming alga *Gelidium chilensis*. The mobile organisms in the middle zone are dominated by small limpets such as *Scurria araucana*, *Scurria variabilis* and the pulmonate gastropod *Siphonaria lessoni*. The low intertidal zone is dominated in rocky exposed shores mainly by crustose algae such as *Lithothamnium* spp., *Hildenbrandia lecanellieri* and the articulate calcareous coralline *Corallina officinalis* var. *chilensis*. In lower proportion the mussel *Semimytilus algosus* can be found and a conspicuous belt of the *Lessonia spicata*. The most common mobile organisms in the low intertidal zone were *Scurria araucana*, *S. scurria* and the key hole-limpets *Fissurella crassa* and *F. costata*. Several species such as *Perumytilus purpuratus*, *Gelidium chilense* and *Corallina officinalis* var. *chilensis* are considered ecosystem bioengineers and its loss can have significant changes in the community structure (Kelaher et al. 2007). On the other hand, it is important to mention that in Central Chile a meso-scale eddy activity has been described (around 30°S) (Hormazábal et al. 2004). Therefore expected differences in the structure of populations across this region can be found (Narváez et al. 2006).

Central-Southern Chile: Concepción and Valdivia

This area represents one of the雨iest regions in Chile, where the annual precipitation is very high, reaching up to 1250 mm (average last 10 years = 847 mm) at Concepción and 2400 mm (average last 10 years = 1800 mm) at Valdivia, with constant rainfall episodes during austral winter (June–September), and also occasionally rainfall during spring, and even during austral summer (December–February) (Figure 6G).

Species richness at Concepción and Valdivia intertidal rocky sites was 48 and 52 respectively, the communities at the high intertidal are dominated principally by the chthamalid barnacle *Jehlius cirratus* and the littorinid snails *Austrolittorina araucana*, occasionally the small limpets *Siphonaria lessoni*, *Scurria scurra* can be also found. The middle intertidal is dominated by dense beds of mussels *Perumytilus purpuratus* and *Semimytilus algosus* covered by the red macroalgae *Mazzaella laminarioides*, and in some sites, the red macroalgae *Mastocarpus latissimus* and *Gelidium pseudointricatum*. Among mobile species, the limpets *Scurria scurra* and *S. variabilis*, and the snail *Tegula atra* are common inhabitant in the middle zone. The low intertidal is dominated by the red macroalgae *Ahnfeltiopsis furcellata* and patches of *Corallina officinalis* var. *chilensis*. At several sites, the foliose green macroalgae *Ulva* sp. is also found. Over and into primary substrate individuals of the snails *Tegula atra* (in some places assorted with *Prisogaster niger*) and *Acanthina monodon* are very abundant. At shadow protected places, the anemone *Phymactis papillosa* is quite abundant. Others species as the polychaete *Phragmatopoma moerchi*, the solitary ascidian *Pyura chilensis*, and the kelp *Lessonia spicata*, although less important in density, are considered important component on these latitudes because are considered ecosystem bioengineers, which may change significantly the surrounding community structure (Cancino & Santelices 1984, Sepúlveda et al. 2003a, 2003b).

Southern Chile: Punta Arenas

This area represents one of the most austral regions of the world, where annual precipitation is high, reaching up to 640 mm at Punta Arenas, with constant rainfall, snow and hail episodes during all year (Figure 6H). Winds are frequent and often exceed 100 km/h. The minimum temperature during winter can drop up to -2°C approximately (Butorovic 2013). Species richness at Punta Arenas intertidal rocky sites was 48. The communities at high intertidal are dominated by the barnacle *Jehlius cirratus* and the red macroalgae *Porphyra* spp. and *Pyropia* spp., and over the primary substrate the small limpets *Siphonaria lessoni* can be found in medium densities. In the middle intertidal patches of several macroalgae can be found, such as the coarsely branched *Nothogenia fastigiata*, *Mazzaella laminarioides*, the brown alga *Adenocystis utricularis*, *Ulva* sp. and filamentous of several Ceramiales species (e.g. the introduced species *Polysiphonia morrowii*), in this zone *S. lessoni*, and patches of *Perumytilus purpuratus* are also found. The low intertidal is dominated by the brown algae *Caepidium antarcticum* and *Lithophyllum rugosum*, however, the most conspicuous component are the gastropods *Nacella magellanica* and *N. deaurata*, which are found in high densities.

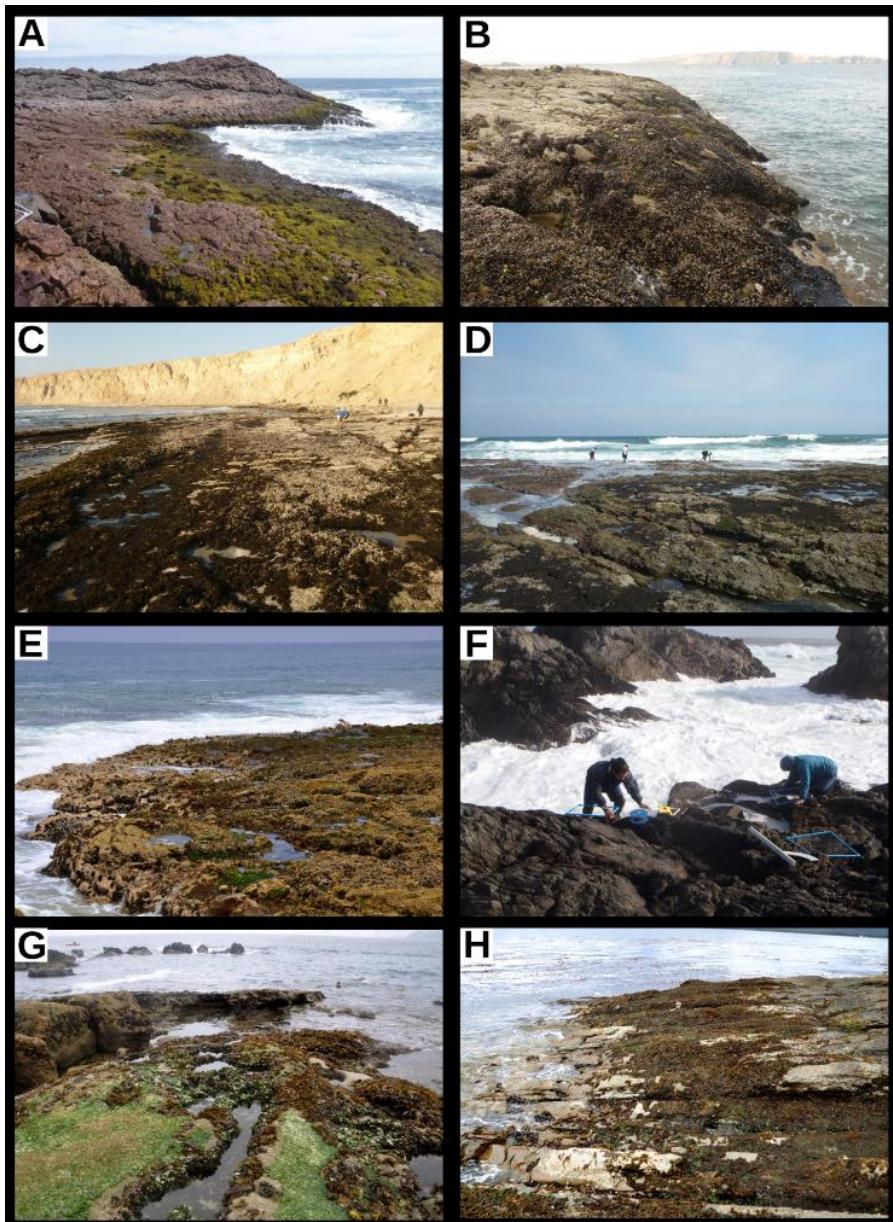


Figure 6. Sampling sites in the Peruvian and Chilean Pacific. A. Peru – Huarmey. B. Peru – Paracas. C. Peru – Paracas. D. Peru – Tacna/Punta Colorada. E. Northern Chile - Huayquique. F. Northern Chile - Copiapo. G. Central-southern Chile – Cocholgue. H. Southern Chile – Fuerte Bulnes.

USES AND THREATS TO THE INTERTIDAL ROCKY SHORES IN SOUTH AMERICA

The intertidal rocky shores around South America represent a valuable resource for local populations in many aspects. The main uses given to these shores along with the threats that such uses produce is summarized in Table 1. In general, localities with dense human settlements face the problems associated to urbanization and sewage discharges along with unregulated tourism, while in less densely populated areas, the uses are basically associated to the extraction of invertebrates and macroalgae for food. Industrialization (e.g. oil and gas extraction, mining) is another issue affecting the services that these ecosystems may provide.

**Table 1. Summary of main uses, threats and impacts at intertidal rocky shores
in South America**

Country/locality	Uses	Threats/Impacts
<i>CARIBBEAN</i>		
Colombia	Food (snails, lobster, crab, fish, octopus, chitons) Urbanization, tourism	Decline in species abundance (some under threat categories by IUCN) Pollution, sedimentation
Venezuela	Food (snails, bivalves, sea urchins) Tourism, urbanization	Decline in species densities Freshwater runoff, sedimentation, pollution (sewage), oil spills, solid waste
Trinidad and Tobago	Food (fish), tourism, urbanization	Pollution, freshwater runoff, overfishing
<i>ATLANTIC</i>		
Northeast Brazil	Food (artisanal and tramp fisheries of shrimp, crab), tourism, urbanization	Pollution (sewage, petrochemical), freshwater (urban, agriculture) runoff, solid waste, erosion
Southeast Brazil	Tourism, food, urbanization, marinas	Pollution (ore mining, petrochemical, heavy metals, sewage), maritime traffic, sedimentation (dredging navigation channels)
South Brazil	Food (octopus, crabs, oyster, mussel), tourism, urbanization	Pollution (sewage), invasive species, destruction of sand dunes, freshwater runoff, port activities
Uruguay	Food (macroalgae, mussels), tourism,	Invasive species (<i>Rapana</i>)
Argentina	Urbanization, food, tourism	Invasive species, pollution (sewage)
<i>PACIFIC</i>		
Colombia	Food (lobsters, fish, snails, shrimp)	Rock removal
Ecuador	Tourism, urbanization, food	Pollution (sewage), sedimentation, gasoline spills
Peru	Food (crabs, snails, macroalgae, chitons, sea urchins) Mining	Pollution (heavy metals from mining)
Chile	Food (macroalgae, snails)	Pollution (sewage), decline in macroalgal density

The Caribbean

In the Colombian Caribbean, besides populated human settlements, the main economic activity is tourism, so the marine environment is under pressure constantly due to these related activities and waste disposal. Exploitation of some resources also occurs, for example the snail locally known as Burgao or Cigua (*Cittarium pica*), lobsters (*Panulirus* spp.), the Caribbean king crab (*Damithrax spinosissimus*), various fishes (snappers, groupers), octopuses and chitons (Lopez-Victoria et al. 2003). Due to the exploitation, some times exceeding sustainable population limits, several of these species have been allocated in different risk categories of red lists (Ardila et al. 2002, Mejia et al. 2002). In less densely populated areas such as Taganaga, next to the Tayrona Natural National Park, small fishermen villages (ca. 4000 people) have precarious sanitary services polluting the coast with untreated sewage.

In Venezuela, some of the threats to Venezuelan rocky shore's biodiversity are related to freshwater runoff, sedimentation, pollution, tourist pressure, oil spills and urbanization (Miloslavich et al., 2003; Paz-Villaraga et al., 2015). In particular, two of the most important sources of freshwater on the Venezuelan coast are the Tocuyo River, and the Tuy-Carenero Rivers system. The Tocuyo River discharges near Morrocoy National Park (Bastidas et al., 1999), and the sediment plume of Tuy-Carenero system can be large enough to affect the rocky shores of Cabo Codera and Chirimena (Cedeño, 2009). Both rivers are highly polluted, they receive untreated water from a wide array of agricultural and industrial sources, and the discharge from drain sewage from urbanization and rural areas; including untreated waters from Caracas, the capital city of Venezuela. However, no correlations were found between the structure of assemblages associated with rocky shore and their relative distances to these rivers. It is very likely that other factors such as the selective collection, for human consumption, of gastropods, bivalves, and urchins could be affecting these communities. Some populations of invertebrates have shown an alarming decrease of their densities, which might be related to fishermen activities. Some of the gastropods in this situation are *Cittarium pica* and *Astrea tecta*, whose juveniles can be found on the low intertidal (Díaz-Ferguson et al., 2010). *C. pica* is the second gastropod most heavily fished in the Caribbean (Gómez-Gaspar, 1999; Miloslavich and Huck, 2009; Schmidt et al., 2002); however, there are no statistics available for this fishery (Robertson 2003) in the Venezuelan coast. When *C. pica* was present (7 of 31 sites), the diameter sizes ranged between 25mm and 40mm, which represented a clear diminution when compared to values reported in the Archipielago Los Roques National Park on 1987, where maximum size was 115 mm (Castell, 1987; Osorno et al., 2009). Also, this size is classified as small for *C. pica* in the Colombian Caribbean coast, Virgin Island and Puerto Rico (Schmidt et al., 2002; Robertson, 2003; Osorno et al., 2009). Minimum and maximum densities of *C. pica* were 0.4 ind/m² and 1.2 ind/m², respectively; which is lower than densities reported by Castell in 1987 (5.6 ind/m²). Finally, despite intertidal rocky shores in Venezuela are not the principal touristic attraction on the coast, some of them (e.g. Peninsula of Paraguaná, Morrocoy and Mochima Nationals Parks, Patanemo, La Sabana and Chirimena) are visited by an important number of tourists, where random collection of shells and invertebrates is a common practice.

In Trinidad & Tobago, the rocky shore areas are very important for shoreline protection and they provide habitats for various species of fish, crustaceans, molluscs and macroalgae. Some rocky areas are very popular for recreational fishing and ecotourism. The main threats

to biodiversity and the marine ecosystem in T&T is from land-based activities. These include expanding industrialization and urbanization (eg. land clearing for housing etc), and accompanying pollution and contamination (solid, liquid and gaseous wastes). As with the rest of the region, overfishing and unmanaged coastal development and agricultural practices also exacerbate these problems. More recently, extreme weather conditions reflected in increased rainfall during the wet season and extremely dry seasons (attributed to climate change) continue to result in increased flooding, freshwater runoff and sedimentation. Trinidad and Tobago is a highly industrialized country with 2 very large industrial estates involved in a range of activities dominated by the petrochemical sector. As the largest oil and natural gas producer in the Caribbean, Trinidad and Tobago's also houses one of the largest natural gas processing facilities in the Western Hemisphere. With 11 ammonia plants and seven methanol plants, Trinidad and Tobago is the world's largest exporter of ammonia and the second largest exporter of methanol, according to IHS Global Insight (2013). Trinidad and Tobago's coastal areas contain rich biodiversity reserves including productive and critical habitats- coral reefs, sea grass beds, estuaries, mangrove forests and coastal swamps, beaches and bays. These coastal areas account for approximately 90% of annual fish production. Fishing occurs throughout the marine environment around both islands, in estuaries, nearshore coastal waters and deep oceans. Today, the local fishing industry is largely artisanal, based on resources occurring in the coastal and territorial waters, and is characterized by multi-species, multi-gear and multi-fleet operations (Fisheries Division, 2002). In 2005, the marine fisheries sector contributed \$63 million to the Gross Domestic Product (GDP). Other coastal and marine resources include crustaceans (shrimps, lobsters, crabs), cephalopods (squid), cetaceans (marine mammals including whales, dolphins, and porpoises) and sea turtles. Historically, T&T has not been a recognized tourist destination and as recent as 2010 T&T's contribution to the overall Caribbean was only 10.9%. It was estimated that on an annual basis approximately 33% of visitors to Trinidad and Tobago use the coastal resources (Tourism Development Company, 2010). Several beaches in Trinidad and Tobago (Pigeon Point, Maracas, Mayaro etc.) are very popular for recreation and tourism but it is the Buccoo Reef in Tobago which generates the greater tourism income (both local and foreign). The reefs provide livelihoods for a large portion of the local population through both fisheries and tourism (Burke, 2008). In 2006, the value of the reefs to recreation and tourism was estimated to be between US\$100 and \$130 million, or approximately 45% of Tobago's GDP for that year. At the same time, the value of the reef fisheries was approximately 0.8 to 1 million USD. The coral reef shoreline protection value was calculated at between US\$18 and US\$33 million in 2006 (WRI 2008). These ecosystem services (coral reef and rocky shores) are important to the island, at the same time they are most vulnerable to erosion and storm damage.

The Atlantic

In the region of Ceará in Brazil, the intertidal reefs are vital for many human populations established along the shore. Most of the small villages depend on the artisanal fisheries and tourism for subsistence, but the aquaculture has also gained importance in the last decades. The reefs play an essential role as nursery habitat for many fish species and also for the spiny lobster, the most important economic resource of the region (Igarashi 2010; Godinho and

Lotufo 2010; Cunha et al. 2008). Tourism is a relevant source of income for the state's economy and is present in more or less intensity along the whole coast. In the last three decades, the development of tourism has followed what happened throughout the world, with an increasing number of tourists visiting especially the coastal zone, attracted by the warm water and constantly sunny days of the region (SETUR 2009; Aquasis 2003). The beachrock reefs in Ceará have been strongly impacted by human activities along the shore. The reefs closer to large urban areas, such as Caucaia, receive a large amount of pollutants carried by the rivers that run through farmlands, industrial districts and densely populated cities (Nilin et al. 2007). Locations outside the influence of urban areas are also under stress, because of the exploitation of algae for industrial use, mainly *Gracilaria birdiae* (Plastino and Oliveira 2002). Although not properly evaluated, the impact of algae exploitation is easily noticed when the areas are visited. As an alternative, the cultivation of the algae has been stimulated in different coastal communities, with variable degrees of success. Also, fishermen looking for young lobsters, crabs and especially octopuses, constantly visit these reefs. The strategy used by fishermen for capturing octopus is dislodging the animal with the use of chlorine or large amounts of salt thrown directly on the burrows or tide pools. Aquasis (2003) has presented and discussed extensively the importance of the state's coastal zone, pointing out the conflicts and problems with the management (or absence of management) at both local and regional scales. The main problem is that rocky shores are one of the least studied areas of the Brazilian coast, and the northeast region as a whole is going through an accelerated process of development and increasing pressure over these coastal ecosystems.

At Sergipe, the coastal zone is a contrasting area, in which there are many activities, interests and conflicts, in a scenario that consists of urbanized areas, agricultural (sugar cane, orange and coconut), extractive, industrial and port activities, besides tourism and sale of properties. Moreover, this area is permeated by low density of occupation and occurrence of ecosystems of high environmental significance, but which have been subject of accelerated occupation, a tourism subproduct. This issue generates environmental degradation that hinder the practice of many activities, including tourism. Regarding the disorderly occupation, it noteworthy that 25% of the territory is coastal zone. Sergipe's coastal zone has extensive areas of mangroves associated with estuaries. However, mangroves have been the target of multiple human impacts, mainly shrimp farming and crab catching. In addition, mangroves and dunes are turning into garbage dumps, without any legal or environmental criteria in the area. Petroleum, natural gas, limestone and potassium (largest mine in the Southern Hemisphere) are the main products from mineral extraction, Sergipe is the 6th Brazilian state in oil production, following Rio de Janeiro, Rio Grande do Norte, Amazonas, Bahia and Espírito Santo. Pirambu is a new port area in the State comprising a large off-shore terminal operating primarily with petro and chlorochemical, besides being a vector to expand the economy and the tourism, it is also a potential environmental problem. The most important stressing factors on Sergipe rocky shores are the harbor presence, the trampling effects of tourists and shrimp and crab catching. Other stressing factors are the influence of the petro and chlorochemical industries, sewage pollution, and coastal erosion.

In Bahia, the main use observed at the rocky shores is trampling, especially for fisheries of octopus, sea urchin and fish. However, there is no sign of overfishing in these areas, as there were low numbers of fishermen and most was subsistence fishing by local communities. Even though all sampling sites are considered important touristic areas, there is no evidence of strong pressure in most sampling sites. Itaparica and Litoral Norte are the closest locations

to Bahia state capital, Salvador, and thus a popular touristic destination. Tourism in Litoral Norte increased during the past 15 years with the construction of luxurious hotel complexes and the improvement of a state highway. During the holiday season it is common to see people walking on the rock shores. However, considering the number of visitors in that area, it is likely that the rocky shores are affected by trampling and fishing, but this needs further experimental tests. This is especially important in Litoral Norte as it provides feeding and resting habitats for adult and sub-adult green turtles (Jardim et al., 2014). Natural sedimentation is also common in Litoral Norte. Mar Grande (Itaparica location) and Praia do Sul (Ilhéus) are the most threatened sampling sites regarding pollution. Both are located close to urban areas and are subjected to urban runoff, solid waste and domestic sewage discharge. Even though Stella Maris is located in Salvador, it is not a high populated area when compared to the other parts of Salvador and not highly exposed to urban runoff and pollution. Ilhéus is the second largest city, among all sampling sites, with around 220 thousand inhabitants. Itacaré sites are inside an ecological touristic area with a relative low number of visitors. Thus, touristic pressure and water pollution and solid wastes, here, are not a threat.

Espirito Santo, in contrast to the Paraná State where ca. 68% of the territory is preserved by specially protected areas (APA), has only 2% of APA. Furthermore the coastal area of Espírito Santo is out of the Conservation Units (UC). The most important stressing factors on Espírito Santo rocky shores, directly or indirectly, are tourism, sewage pollution, industrial complex presence (trading coffee, chocolate, edible oils, citric juices and cellulose), and a harbour complex that handles petrochemical (mainly oil and natural gas, being the second petroleum province in the country). Espírito Santo also encompasses the second largest ore mining dock in the world managed by Vale do Rio Doce Company.

In São Paulo, coastal land use and human impacts - The Baixada Santista, at the Southern end of the sampled coastline, is a major economic zone within São Paulo State and heavily urbanized area, which includes the cities of Praia Grande, São Vicente, Santos and Guarujá. Together, these cities sum up 1.6 million habitants, imposing severe impacts on the coastal environment. Particularly problematic is the Santos Harbour, the largest in South-America. Apart from a very intense traffic, the channel needs to be frequently dredged to allow the passage of large cargo vessels, further impacting the seafloor and the water column due to excessive siltation and suspended materials, including heavy metals and other major pollutants. Further north, socio-economical activities are leaded by tourism, although there is increasing pressure for the expansion of the São Sebastião Harbour. At the northernmost locality, Ubatuba, the coastal impact is relatively small, although the population has been gradually increasing. Today, the population in Ubatuba is around 85.000 habitants, and domestic sewage is already a major pollution source.

In Paraná, the most important stresses on rocky shores communities are the trampling effects of tourists and fisherman, the selective collecting for food, oyster and crabs catching, and mussel seeds for cultures, sewage pollution and bio-invasions. All the sites studied receive a large amount of tourists every summer (from the end of December to the beginning of February) and weekends. Coastal environmental problems in the South also include unplanned occupation nearby the shoreline. Besides the destruction of the frontal dunes, the occupation invades the beach altering the balance of the whole coastal system. Trampling effects on the community have been studied only in one rocky coast at the southeastern region and a negative effect on *Chthamalus bisinuatus* was observed suggesting that the cumulative effect over years is significant (Ferreira & Rosso, 2009). Furthermore, the small towns at the

coast double or triple their population during summer months and domestic sewage pollution and consequent eutrophication of coastal areas is certainly occurring, but the consequences to rocky shore communities are not known. The brown mussel (*Perna perna*) is the main item harvested both to be used directly for food, for commercialization or as seeds for cultures. The Brazilian government started a regulation since 2006 forbidding the extraction of this species from natural stocks from September to December each year and also regulating its extraction during the rest of the year. Although the brown mussel was supposedly introduced in Brazil from Africa (Sousa et al. 2004), it is well established in the intertidal community along the southeast and south Brazilian coasts. More recently the brown mussel belt has been invaded by another mussel, *Isognomon bicolor* (Adams, 1845), which forms dense aggregations in some sites in southeastern Brazil displacing *P. perna*, but that have not been so abundant in the Paraná and Santa Catarina coasts. We only found *I. bicolor* in one beach (Praia de Cima) during 2010 surveys and none in 2013 surveys. Also in the south of Brazil, the Paranaguá Harbor is the largest cereal port in Latin America, exporting mainly soybean, and the 3rd largest port of containers from Brazil, following Itajaí, a strategic zone to monitor alien or invasive species. The port area also presents serious problems of waste disposal. The presence of large ports along the south coast (Paranaguá, São Francisco, Itajaí and Imbituba) in addition to the extensive area of bivalve culture in Santa Catarina poses a constant threat of species invasion in this region. During the surveys we found introduced barnacles at most sites visited, being *Megabalanus coccopoma* (Darwin, 1854) the most frequent, but also *Amphibalanus amphitrite* (Darwin, 1854) and *A. reticulatus* (Utinomi, 1967) (Kloh et al. 2013). In the Paranaguá Bay, *Ulva australis* (formerly known as *U. pertusa*) was detected as a free floating thallus. Monitoring is being carried out to confirm the alien species in the area.

In Uruguay, human uses of rocky shores are mainly recreational, although some species e.g. mussels) may be harvested by tourists or by a subsistence, small scale hand-gathering fishery and/or to be sold in local markets (Carranza et al., 2009; Scarabino, 2004). Extraction of the algae *Ulva* spp. may also occur associated to uses in local gastronomy, especially during the summer. Sport fishing (generally unregulated) are frequently observed in these sites, although some rocky shores are included in the National Protected Area System (SNAP). Commercial fisheries are restricted to subtidal mussel beds located at Isla Gorriti (34°57'S 54°58'W) and Isla de Lobos (35°0'S 54°53'W), targeting the blue mussel *Mytilus edulis* (Defeo, 1991; Niggenmayer and Masello, 1992; Riestra and Defeo, 1994). To date, threats to rocky shores biodiversity have not been evaluated at a national level. However, although not occurring in the intertidal, the invasive rapa whelk *Rapana venosa* is a matter of concern since this species preys mainly over mussels in the estuarine-oceanic interphase (Carranza et al., 2010; Carranza, Delgado, and Martinez, 2013). Other exotic species such as *Isognomon bicolor* (Breves et al., 2014) has been detected, but does not seem to have established so far.

In Argentina, the Buenos Aires province coastline is highly urbanized and harbors important ports. Playa Chica is located ca. 1.2 km of Mar del Plata Harbour (the most important fishing port in Argentina) and Quequén is located ca. 2 km m from Quequén Harbour. Both sites are subject to intense recreational use by summer visitors and pollutants associated to maritime traffic and urban runoff, such as polycyclic aromatic hydrocarbons (PAHs), trace metals, and Tributyltin (TBT), all of which have been detected in their nearby ports (Marcovecchio et al. 1998, Bigatti et al. 2009, Albano et al. 2013). The Quequén site may also be impacted by a nearby (ca. 5 km) sewage effluent (López-Gappa et al. 1990). Río

Negro is not very populated (El Espigón, Punta Colorada) and human settlements are mostly limited to small summer vacationing villages (La Lobería, Playa Los Suecos). Yet, the shipping of iron pellets from a loading dock in Punta Colorada might have contributed with pollutants to this area in spite that the dock in question was intermittently operational over the past two decades. In Chubut Province, Puerto Lobos is an artisanal fishermen place, with no evident contamination, and no ports are present. In Puerto Madryn, the local population is about 80,000 residents but in the summer season this number may duplicate due to the tourism. In this city, the 2nd port in importance regarding fisheries landings in Argentina is settled, as well as different industries in nearby the port. Pollutants such as (PAHs), organochlorinated compounds, trace metals and TBT are present in areas with intense maritime activity in Golfo Nuevo coasts (Commendatore et al., 2000; Esteves et al., 2006; Gil et al., 2006; Commendatore and Esteves, 2007; Massara Paletto et al., 2008; Bigatti et al., 2009; Commendatore et al., 2012). Imposex (masculinization of female gastropods) has been detected in the port zone but at a low frequency in the sampling sites. These are used mainly for tourism at Punta Este during the summer season. In Camarones, the population is around 1300 habitants and the port is used by fishing boats. Near the port, imposex and TBT contamination were detected (Bigatti et al., 2009), while the sampling sites far from this place are imposex free. The sampling site "Algueros" is a place of algae collection for industrial purposes, and the other places are used by tourist for recreation and sport fishing. At Puerto Deseado, near the port, where the maritime traffic is high, TBT contamination has been detected (Bigatti et al., 2009), however, TBT was not detected in the sampling sites. Recollection of the limpet *Nacella magellanica* is common within the local people. At Tierra del Fuego Island, Playa Larga is likely the most impacted by human activities due to its proximity to Ushuaia. This city is situated in the coast of the Beagle Channel and hosts the southern port of South America, characterized by intense maritime traffic. Contamination by TBT (Bigatti et al., 2009), PAHs (Esteves et al., 2006), metals (Giarratano et al., 2010) and sewage were detected at this area, and up to 100% incidence of imposex was observed in female gastropods.

The Pacific

In the rocky shores of the Colombian Pacific, the main resources exploited are lobsters (*Panulirus gracilis*) and fishes (snappers, groupers), however, some other species such as oysters (families Ostreidae and Pteriidae), and snails (families Littorinidae and Muricidae) are locally exploited. Another source of perturbation is the removal of rocks in the search for shrimps (*Upogebia* spp.) that are used as bait in fishing activities (Lopez-Victoria et al. 2003). The population density on the Pacific coast is very low in comparison to the Caribbean, with most of the shore basically uninhabited. In this way, human disturbance is localized and/or of low impact.

The rocky shores of Ecuador are used for urbanization, fishing, tourism, recreation, and marinas. Punta Gorda is relatively far away from human settlements and therefore, less impacted, but Punta Bellaca, more accessible was once a fishing ground for the lobster *Panulirus gracilis* and it is used sporadically at present by tourism. The main threats detected in the coast of Ecuador are sedimentation, pollution with sewage waters, diesel spills at the marinas, development of vacational complexes and unplanned human settlements.

In Peru, fisheries are a key component of the countries economy. Such fisheries are mostly pelagic resources, however, several species of the coastal zone are also fishing targets. At Paita, the barnacle *Pollicipes elegans* is commercially exploited and exported (Villena 1995, Oliva 1995, Pinilla 1996). Along the coast, there are several benthic species subject to artisanal fisheries in the intertidal including invertebrates and macroalgae: *Fissurella* spp, Polyplacophora, *Pyropia* spp., *Chondrocanthus chamaissoides*, *Patallus mollis*, *Concholepas concholepas*, *Lessonia nigrecens*, *Lessonia* spp., *Macrocytis pyrifera*, *Pyropia* spp., and *Loxoechinus albus* among others (INRENA, 2002). At Paracas, subtidal artisanal fisheries also occurs (Mendo & Wolff 2003). Mining has been very intensive in Peru and some areas show pollution associated to mineral exploitation including heavy metals (Jacinto et al. 2001, Jacinto et al. 2003, Jacinto et al. 2008).

In Chile, the impact of human activities on the rocky intertidal has been studied extensively (see Fernández et al. 2000 and references therein). Several types of human impacts clearly affecting nearshore ecosystems can be identified along the coast of Chile, although the intensity, extent, and persistence of these sources vary geographically (Fernández et al. 2000). One of the most important human impacts along the Chilean coast, in terms geographical extent and persistence, are sewage discharges and the harvesting of invertebrates and algae in rocky shores (Gross & Hayek 1998). The removal of several important ecologically species during low tides have a dramatic effect on the structure of the intertidal communities. Historically, intertidal populations were exploited as a food resource but in modern times, flora and fauna are also collected for fish bait, for research, as souvenirs, and for home aquaria uses. A keystone muricid gastropod *Concholepas concholepas*, locally known as “loco” is intensively targeted by food gatherers affecting the functioning of food webs at intertidal rocky shores (Castilla, 1999). The increasing international demand for brown large macroalgae and local requirement as food for abalone aquaculture has caused deterioration of natural kelp populations along the rocky shore in Chile, especially between 18° and 42°S (Vega et al. 2014). Impact of non-indigenous species have been poorly documented, some species have displayed an expansion of their geographical range and increasing of their abundance, such as the anemone *Anemonia alicemartinae* (Hausermann & Forsterra 2001) and the red alga *Mastocarpus* sp. (Macaya et al. 2013). Together with exploitation of marine species, sewage discharges are important in geographical extension and persistence having an impact along the Chilean coast (Fernández et al. 2000).

GAPS IN OUR KNOWLEDGE AND FUTURE PROSPECTS

Knowledge of the intertidal rocky shore ecosystem is very variable among the different South American countries, and also between different areas within each of the countries. While some countries seem to have a long tradition of research in these ecosystems (e.g. Chile), other are just beginning to study them (e.g. Venezuela). In the Southern Caribbean, rocky shores remain virtually unexplored, despite the high diversity that these ecosystems support (Miloslavich et al., 2010). For example, in Venezuela, most of the research articles on these ecosystems are non-published descriptions or informal inventories about the fauna and algae that inhabit them. Few studies have considered quantitative description of patterns of temporal and across different scales, which would allow proposing underlying mechanisms

that drive assemblages associated with intertidal rocky shores (Cruz-Motta, 2007). Furthermore, the total number of scientific publications for this ecosystem is the lowest for coastal and marine ecosystems of Venezuela (Miloslavich et al., 2003). Consequently, describing patterns and determining processes affecting assemblages associated with Caribbean intertidal rocky shores is still a prevailing necessity. Caribbean rocky shores harbor an important biodiversity, however their economic benefits and ecosystem services are still poorly studied and understood. Threats to biodiversity in this ecosystem, and other coastal ecosystems, are imminent; therein lies the importance not only of knowing their biodiversity, but also of monitoring the ecosystem to be able to understand their patterns and processes, their connectivity to other coastal ecosystems, the population dynamics of key species, and finally to have the necessary knowledge to transfer to policy makers so they can take scientifically based informed decisions.

There are several limitations to achieve these goals. The first of them is the funding required to go to the field on a yearly basis, and the commitment to do so, especially at such large geographical scale like the one presented in this chapter. Initiating a long term time series is not an easy task. The second is related to human capacity. The team required to produce quality information is quite complex, with background in marine ecology, biology, taxonomy, genetics, fisheries, and oceanography to mention a few. This expertise is rarely found altogether within a same country, therefore, the importance of establishing and collaborating within the umbrella of an international network. Initiatives like SARCE, and previously NaGISA of the Census of Marine Life, have contributed significantly in the region to increase our understanding of these important but traditionally neglected ecosystems.

Finally, for all the South American region, the use and abuse of the rocky intertidal resources has been intensive during the last years, needing a full re-evaluation of the human impacts along the South American coastline, in order to demonstrate the need for conservation of these ecosystems. The implementation of marine reserves and laws aimed to halt the collection of organisms has proved to be successful in some areas but ultimately depends on the enforcement of the laws and compliance by the public (e.g. Chile). Even, if collecting is stopped through enforcement, other impacts of human use, ranging from local and specific activities such as trampling or overturning of rocks to large scale impact such as pollution and climate change, still persists. Therefore, effective protection of rocky intertidal communities will require an approach that may need to go beyond the singular focus on collecting to reduce the full suite of impacts (Smith et al. 2008).

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Chapter 4

EVALUATION OF BIOMASS AND REPRODUCTIVE ASPECTS OF INVASIVE ALGAE *ACANTHOPHORA SPICIFERA* IN PUNTA ROCA CAIMANCITO B.C.S MEXICO

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ABSTRACT

Acanthophora spicifera is a red algae, native to the Caribbean, was introduced to the Hawaiian Islands in the early 1950's, where he Invasive catalog. His success as an invader is attributed to having the ability to reproduce both sexually and vegetatively by fragmentation or by spores. Their growth is accelerated and invades Pacific coral reefs. Prevents nutrients and sunlight to penetrate these ecosystems producing that reduce populations of resident seaweeds and corals. In Punta Roca Caimancito, BCS, a blanket of *A. spicifera*, which formerly dominated the brown algae of the genus *Sargassum* found. The temperature at which develops in Punta Roca Caimancito was 20-29. It can be found growing on a variety of substrates epilithic hard rock, dead coral or shells, even as an epiphyte on other species of macroalgae or epizoica invertebrates. They have a simpodial and apical growth, presents secondary branches, has a rough or rough texture, has a disk-shaped, in its main axis no thorns. It is characterized by a highly branched and

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bushy, leafy thallus. Apical meristem, spines of 3 mm, which may vary morphologically. In cross-section was observed that pericentral cells are dense. Commonly axial cells in the center. In the study area this invasive algae reproduces asexually (fragmentation). The extension of the mantle in Punta Roca Caimancito has continued to increase since 2006 in which you registered for the first time. The current extension (2009) is 31536.93m² or 3.16 Hectares. The maximum average biomass dry weight was 8.12 t/ha and 3.16 minimum 1.18 Ton/3.16 h. The color varies from brown to red. The average length of the thalli was 163 mm and 108 mm maximum minimum in the period October 2008 to October 2009. The annual average was 154 mm. The ANOVA showed differences between different months being October others to present longer than season. The maximum number of branches value was 7 and at least 5 branches per thallus. ANOVA performed for the numbers of branches not show significant differences. The average monthly number of spines has a maximum value of 5.4 mm² and a minimum of 3.9 mm². The ANOVA shows differences per month, October being the one with the highest number of spines. The biomass is higher in the autumn season. And in winter drastically reduces the population. The average of the highest biomass is 0.26 kg/m² and was presented in November; the minimum dry weight biomass was presented in February 0.0375 kg/m². The average annual biomass dry weight is 0.29 kg/m². The flora and fauna that was associated with *A. spicifera* goes from epiphytic algae molluscs, echinoderms, sponges to fish. The maximum monthly average was 0.20 kg/m² and a minimum of 0.031 kg/m². The result of the correlation indicates no relationship between biomass and plant-fauna ($r = -0.1892$). We conclude that *A. spicifera* its development at temperatures ranging from 20-29°C. Morphological characters posing *A. spicifera* of Punta Roca Caimancito are similar to those reported by other authors. The main mode of reproduction of *A. spicifera* is asexually by fragmentation and occurs all year round (perennial). Sexual reproduction was limited in spring-summer, only empty conceptáculos were observed. Presents greater lengths during autumn and lower in winter. The number of spines is not related to the length of the branch. The maximum number of branches was 7 in autumn and winter and minimum of 4 branches per talo in summer. The maximum number of thorns thorns was 5.4 mm⁻² and the minimum was 3.9 mm⁻² spines. The percentage of wet weight biomass of *A. spicifera* is greater in autumn with 3.50 kg/m² and the lowest was in winter with 0.59 kg/m². The percentage of biomass dry weight of *A. spicifera* is greater in autumn with 0.86 kg/m² and the lowest was in winter with 0.0375 kg/m². The impact of *A. spicifera* in Punta Roca Caimancito is negative for coral reefs because high densities of this algae can affect the uptake of light and nutrients and thus affect their growth.

INTRODUCTION

Invasive species play an important role in marine and terrestrial ecosystems, and damaging to native species and move. Within this theme different definitions that must be understood are handled, the first is naturalized, it relates to non-native species that were established in the region. The second definition is the invasion that has been used for the species has become naturalized and has spread widely in the region. And last and most important invasive species refers to any species that occupy a region in which it was not historically present (Sax et al. 2005).

Invasive species have always been a controversy around the world, because as the name says, invading regions and affect native organisms. This occurs both on land and in the marine environment. Within the marine environment have been studied invasive species in

much of the world's oceans (Carlton et al. 1990; Shiganova 1998; Godwin 2003; Work et al. 2003).

Ecological and Economic Impact of Marine Invasive Species

Alterations of ecosystems caused by global climate change with introduced species are the result of biotic homogenization; this is a process by which ecosystems dominated dominant species and opportunists. This pattern has always been observed in localities affected by environmental degradation and invasive species (FAO 2010).

The ecological impact of non-residential marine groups has been observed in some ecosystems in the Bay of San Francisco on the Asian clam *Potamocorbula amurensis*, Schrenck 1861, which was discovered in 1980 in North America, is characterized by be an invasive species that has colonized freshwater bodies in many countries in Europe and America. This produces major environmental and economic problems as it has a great ability to reproduce. Studies have been done in Portugal where they say this clam sequesters carbon and alters the channel and ecosystem functioning, also presents risks of mass mortality from sudden changes in temperature (Carlton et al. 1990; Godwin 2003).

Another invasive species such as jellyfish *Mnemiopsis leidyl*, A. Agassiz 1865 in the Black Sea, feeding on eggs and larvae of fish and has been a fall in stocks of economic importance (Shiganova 1998).

Among vertebrates, the fish *Lutjanus Kasmira*, Forsskål 1775, is an invasive fish from the 1950 in the Marquesas Islands belonging to the French Polynesian. Its introduction was intentional and harmed native reef fish (Work et al. 2003; Godwin 2003).

Finally the starfish *Asterias amurensi*, Djakonov 1950, was discovered in the year 1980 in Tasmania, Victoria and South Australia. *A. amurensis* has the potential to create large populations in new areas. It is a threat and is considered a pest because it caused the decline of fish belonging to Hand Brachionichthyidae Family. Also in mariculture has mainly played havoc in cultured mussels, oysters and salmon (Godwin 2003; Dommisse et al. 2004).

Impact on Coral Reef

Coral reefs are an important ecosystem as it forms part of the habitat of many organisms and is one of the most productive in the world. These ecosystems can be composed of reef zones, barriers, patches or atolls. Coral reefs are a potential attraction for tourists and are important because they form a natural protection and prevent the erosion of the waves on the coast.

The economic value of reefs is considerable. For example, in Indonesia the annual contribution of these ecosystems for tourism is 191 million dollars, 221 million dollars fishing health and \$ 4.8 million dollars, making an annual total of 327 million dollars. Also in Hawaii fisheries in these ecosystems generates 2.5 million annually, tourism \$ 304 million, and the value of biodiversity is around \$ 17 million. Therefore, coral ecosystems in this region generate an annual total of 363.5 million dollars (Cesar et al. 2004).

Currently, coral reefs are being depleted rapidly in many parts of the world due to factors such as illegal fishing, coral mining, marine pollution and sedimentation. Another important

aspect that affects the reefs are invasive species such as the red algae *Acanthophora spicifera* (M. Vahl) Børgesen 1910, this like the others mentioned aspects contribute to the decline of coral reef ecosystems where it has invaded.

One effect of *A. spicifera* on coral reefs is competing for light and nutrients associated with corals and algae. On the other hand, industrial pollution (chemicals and industrial wastes) is an anthropogenic factor that contributes to the deterioration of coral reefs (Cesar 2002).

Economic Importance

It has now been recognized that biodiversity and marine resources of the world are threatened by human activities influence. In particular, overfishing and climate change have produced an alteration and destruction of habitat. Invasive algae are increasingly popular because they often have dramatic effects on ecosystem structure and function (Schaffelke et al. 2007).

Globally about 221 species of algae of commercial importance, of which 145 are used for food, for production of phycocolloids 110 (agar, carrageenan, acids, alginic) are known. Some algae are only used for direct food source and you are *Ulva* Linnaeus, 1753, *Caulerpa*, J.V Lamouroux, 1809, *Codium* Stackhouse, 1797, *Pyropia* J. Agardh, 1899 *Laminaria* Lamouroux, 1813 and *Undaria* Suringar, 1873 (Khan et al. 2003).

In countries like Japan, China, Chile, Indonesia, USA have also been used for pharmaceutical or nutritional studies. In this case, the chemical substances extracted from seaweed are used to treat diseases. While nutrition, are used as a food supplement and as part of the diet of many organisms.

Food additives are also extracted as carrageenan, agar and alginates (phycocolloids) these are the most traditional uses of algae. The red seaweed *Digenea* C. Agardh, 1822, produces an acid derived from glutamic acid, which is used as a central nervous system stimulant, the prototype of amino neuroexcitation used in experimental animals. Other red algae as *Ptilota* C. Agardh, 1817 produce a protein called lecithin. *Asparagopsis* Montagne in Barrer-Webb and Berthelot, 1840 *Sarconema* Zanardini, 1858, are used to control goiter is iodine deficiency (Khan et al. 2003).

The seaweed production has increased in the past twenty years and has reflected an overall increase in trade and economic activities. This production is currently given in 35 countries among which we can find North Korea, South Korea, Japan, China, Chile, Indonesia, United States and India. These countries account for 95% of world production of algae and 90% of production comes from crops. Annual earnings for algae production globally is estimated between \$ 5.5 and \$ 6 billion. The total of the products consumed by humans is \$ 5 trillion. An annual production of 8 million tons of wet weight, either algae extracted from wild and cultivated is obtained (Pickering, et al. 2007; Schaffelke et al. 2007). The brown algae are the most widely grown with over 5 million tons, while red algae approximately 1 million tons are produced annually and finally green algae with approximately 33,700 tons per year. The algae is cultivated kelp *Laminaria japonica* J.E Areschoug, 1851, production of this algae constitutes 60% of the total, the rest is for *Pyropia* and *Kappaphycus* Doty, 1988, *Undaria* Suringar, 1873, *Eucheuma* J. Agardh, 1847 and *Gracilaria*, Greville 1830. *Pyropia* is one of the most grown in China and its production

generates \$ 1.8 billion annually (Mumford et al. 1988). Philippines contribute about 80% of the production of *Eucheuma* Weber-van Bosse cottonicon, 1913 which equates to 130,000 tons per year (Khan et al. 2003). Khan et al., 2003 mentions that between 1981 and 2000 the production of aquatic plants increased from 3.2 million tons to 10.1 million tons of wet weight. By 2000 world trade in seaweed left an economic impact of \$ 6 billion, while in 1990 it was only \$ 250 million (Khan et al. 2003; Valentine et al. 2003).

Algae Introduced

The assessment of the ecological impacts of invasive species has been recognized as a research priority in recent years (Johnson et al., 2007). The impact of invasive algae has been identified as one of the major stressors in coastal ecosystems. A recent study in Hawaii confirmed that the economic impact of invasive species is higher than \$ 30 million dollars per year (Schaffelke 2007). However, relatively few studies on the impact of invasive algae in relation to marine animals (Johnson et al. 2007).

Currently there have been over 260 species of introduced algae. Current key impacts of invasive algae have spread to other taxa. It is believed that invasive algae are potentially destructive and can cause a potentially serious impact, which can alter ecosystem structure monopolize space. Particularly worrying is its rapid spread is the effective spread, along with significant environmental and economic consequences (Schaffelke 2007).

Documented impacts of invasive algae are really few. As is the case of *Caulerpa taxifolia* (M. Vahl) C. Agardh, 1817, this alga was documented as invasive in the Mediterranean since 1980. *C. taxifolia* was introduced into the Mediterranean through the wastewater from the Oceanographic Museum in Monaco where he was planted aquarium purposes. Currently covers more than 13,000 hectares of seabed in this region and directly affects all the other vegetation and algae, especially Posidonia. But go slowly eliminating native vegetation indirectly so does the wildlife that feed or live in that environment (fish, sponges, sea urchins, and other less mobile) (Anderson 2005).

Codium fragile Suringar, 1867 is kind is known worldwide and has had an easy reproduction (asexual) and may displace other native algae and crustaceans, polychaetes and tunicates (Trowbridge 1999).

Sargassum muticum (Yendo) Fensholt 1955, is an invasive species native to the coasts of China-Japan and the Pacific Northwest. Its primary means of dispersal have been boat and floating pieces of sticks, has a rate of growth and high fertility. It also produces the displacement of other native species (Harries et al. 2007).

Undaria pinnatifida (Harvey) Suringa 1873 r is native to Asia and now invades the coastal zone in many countries around the world. In 1971 he was found in the Mediterranean later in the Atlantic Ocean in Britain and subsequently settled in UK, Spain, New Zealand, Australia, Argentina, and the North Pacific Ocean (Martin et al. 2008; Russell et al. 2008). The shipping traffic is perhaps the most important vector of accidental dispersal of the species, which can be introduced into new geographic areas. This can be carried attached to the hulls of ships as well as spores in ballast water. In summary, invasive algae have been great and dramatic changes in marine ecosystems, as you move through geographical or ecological barriers and displace residents algae (Kilar et al. 1986; Martin et al. 2008; Valentine et al. 2003).

***Acanthophora Spicifera* an Invasive Seaweed**

Acanthophora spicifera was introduced to the Hawaiian Islands in the early 1950's, and was classified as invasive. Today it is one of the most common in this archipelago. Successful Invasive *Acanthophora* is attributed to having the ability to reproduce both sexually and vegetatively by fragmentation.

The advantages that may have reproductive capacity are: (1) the extent of distribution of the species, (2) increase in the abundance of organisms and individual biomass and (3) colonization of areas where the sexual propagules have a high mortality rate. Plus it plays throughout the year. Pacific reef is in constant competition with the resident marine algae such as *Laurencia* spp. and *Hypnea cervicornis*. It is characterized by epifitae different taxa including invertebrates and other algae such as *Laurencia* (J.V Lamouroux 1813) *Gracilaria* (C. Agardh) Greville 1830), *Padina* ((Linnaeus) Thivy in WR Taylor 1960), *Caulerpa* ((Forsskål) JV Lamouroux 1809), *Halimenia*, and seagrasses, *Halodule* Den Hartog. Has a wide adaptability to environmental conditions.

In the last three decades have presented two important negative alterations are invading seaweed 1) threat in the coral reef habitat by preventing the growth of corals and other photosynthetic organisms in the absence of light and given its high abundance also affects recruitment, biodiversity and sustainability of the structure of reef ecosystems, 2) at the periphery of mangroves creates a barrier that directly affects water quality and flows, ie, decreases the wave propagation and this affects the entire biota (Smith et al. 2002; Walters et al. 2002; O'Doherty et al. 2007; Schaffelke et al. 2007; Tsuda et al. 2008; Weijerman 2008).

Another important aspect is that *A. spicifera* not only cause negative effects where it has been introduced, as has also been found to be a source of food for the green turtle, *Chelonia mydas* (Linnaeus 1758), herbivorous fish and sea urchins crustaceans (Kilar et al. 1986; Russell 2003).

In an experimental study in Kaloko Honokohau, Hawaii in 2005, he tried to control *Acanthophora* using herbivorous fish. The obtained results showed that the introduction of herbivorous fish can reduce the biomass itself *Acanthophora* but for better control, biological suggested combining this method with a regular manual removal (Weijerman 2008).

The main objective of this work was to identify and investigate the phenology, biomass and reproductive aspects of *A. spicifera* Punta Roca Caimancito beach Bay of La Paz, BCS providing critical information to their taxonomy, ecology and reproduction in a new ecosystem is invasive algae.

Description of Genus

Genus of *Acanthophora* (J.V. Lamouroux 1813) is within the Phylum Rhodophyta in *Chondriaceae* tribe. This is one of the oldest groups of eukaryotic plants.

Within this class we find about 4000 species (Guiry et al. 2010; Lee 2008). Genre *Acanthophora* described 27 species of which only 6 have been taxonomically recognized as: *Acanthophora aokii* Okamura 1934 *Acanthophora dendroides* Harvey 1855, *Acanthophora nayadiformis* (Delile) Papenfuss 1968 formerly *Fucus navadiformis* (Delile 1813), *Acanthophora pacifica* (Setchell) Kraft 1979 *Acanthophora ramulosa* Lindenberg ex Kützing 1843, and *Acanthophora spicifera* (M. Vahl) Børgesen 1910 (Cecere 2002).

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Description of the Species

One of the unique features of *Acanthophora spicifera* is that the main shaft has no thorns. They are upright plants that grow up to 250 mm, with solid cylindrical branches 2-3 mm wide. (Oliveira et al. 2005) Some branches are short and have irregular shapes with numerous spines that are arranged radially. The apical growth is present, grows attached to a hard substrate with a long and irregular bra which arise many erect spines. In deep water, where there is less water movement, they are smaller and can measure 40-100 mm long, are rather compact and very dense thallus. Compared with specimens from shallow water, where the petals are 100 to 250 mm and more open branches. The coloration of this algae can vary, it is usually red but can see in the following colors: purple, the Yellow, orange and brown. The greater the depth the algae will be darker. In shallow areas the color is lighter or sandy color. *A. spicifera* is abundant in shallow calm waters, reefs, intermediate and low intertidal rocky areas. Usually lives embedded in hard substrates such as rocks, mollusks and corals. Can also be found fragments of algae are floating freely in the water column. As for structural characteristics, must be the apices are pyramidal with trichoblasts. Pericentral cells are dense and Corticadas, axial cells are commonly in the middle. *A. spicifera* commonly associated with other algae that are more tolerant to exposure of the tide and are able to retain water when exposed to air (Kilar et al. 1986; Perrone et al. 2006).

Geographical Distribution

Acanthophora members of the genus are found in all latitudes from Ecuador to the coldest seas. The mean sizes of algae are varied depending on the geography of the region. The more fleshy species usually occur in temperate areas, while in tropical areas can find smaller and filamentous (De Reviers 2003; Lee 2008).

Floristic Records of Algae

Since the last century there have been collections of marine algae in the Gulf of California (Dawson 1944). Although no taxonomic studies of macroalgae made almost over 260 years in the Gulf of California, in any of them referring to the presence of *Acanthophora spicifera* in the Gulf of California is made. (Howe 1911; Setchell and Gardner 1924; Dawson 1953; Dawson 1966; Norris 1972; Norris 1975; Mendoza-Gonzalez and Mateo-Cid 1986; Martinez-Lozano et al. 1991; Mateo-Cid et al. 1993; Serviere-Zaragoza et al. 1993; Mateo Cid et al. 1994; Casas-Valdez et al. 1997; Serviere-Zaragoza et al. 1998; Rodriguez-Morales and Siqueiros-Beltrones 1999; Aguilar-Rosas et al. 2000; Paul Chavez and Riosmena-Rodríguez 2000 and Aguilar-Rosas et al. 2002). For this reason, it is necessary to perform extensive sampling of this species in the Gulf of California, in order to have further evidence of its distribution in the Gulf of California. In 2006 *A. spicifera* it began observing in the Gulf of California and has been dispersed in shallow areas. *A. spicifera* could harm local flora decreasing coverage and biomass of these.

In the Bay of La Paz *A. spicifera* associated with rocky reefs where we can observe that the forests of *Sargassum* area residents, which exhibit rapid growth, may be observed

displaced. *Acanthophora* has been established at points where could financially affect residents because fishermen associated commercial fish are extracted *sargassum* forests. So it could also be endangered coral reefs because they can take to prevent sunlight necessary for their development. This event directly affect the fish that live there, also disturbs the attraction also directly harm the regional economy (Riosmena et al. 2009).

Acanthophora spicifera algae is a native of the Caribbean and now has spread throughout many tropical and subtropical marine ecosystems. In the Hawaiian archipelago this algae was introduced by ships since the 50's and is considered an invasive species that has caused severe impacts on the ecosystem.

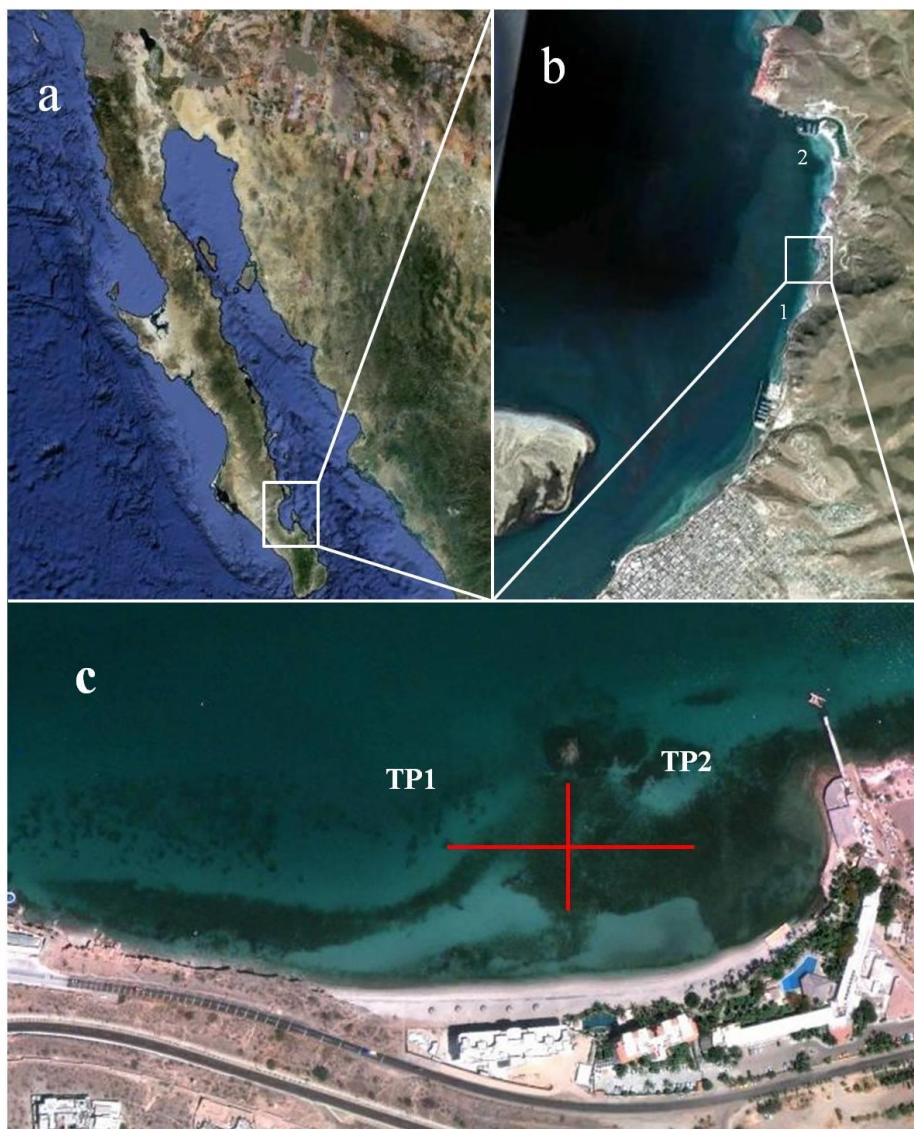


Figure 1. a) Image of the Baja Peninsula where the Bay of La Paz, Baja California Sur, Mexico b) Punta Roca Caimancito beach that lies between the Coromuel (1) and Costa Baja beach (2), c) location is located study area, Punta Roca Caimancito beach (TP1) transect parallel to the coast line (TP2) transect perpendicular to the shore line.

However, recent studies indicate that this algae has the Mexican Pacific coast come (Riosmena-Rodriguez et al. 2009) no research has been about their adaptive capacities and the effects it has on the ecosystem. This algae is found in parts of the Bay of La Paz (southwestern Gulf of California). Therefore it is essential to study some aspects of its life cycle as their type of reproduction (sexual and asexual), biomass, distribution and behavior of the same in the marine environment as it can be harmful to many organisms. An example is the coral reef as was mentioned harms the ecosystem along with all the associated species.

The aim of the work was establish the phenology reproductive, estimate the variation in the biomass an annual cycle, and other aspects of *A. spicifera* in the Bay of La Paz, BCS, Mexico.

Study Area

The Bay of La Paz (Figure 1a) is a semi-protected body of water that is located on the south eastern side of the peninsula of Baja California. It covers approximately 2635 km², has an oval shape with a width of 35 km and 80 km long and is separated from the Gulf by a narrow peninsula. Its depth can vary from 10 m to 450 m.

It also presents a system of mixed type semidiurnal tide with a higher level at 1 m during spring tides (Obeso-Fog et al. 2008). Punta Roca Caimancito beach (Figure 1b) is in the extreme southwest of the Bay (24°12'07.36 "N and 110°18'03.10" W), between the beach and the Coromuel Costa Baja (figure 1c). It is characterized by a shallow area of sandy bottom with patches of rock. On this beach you pass a deep channel through which water enters and leaves the Ensenada de La Paz. This beach has waves of very low intensity and algal community is located at shallow depths (<2 m) (Figure 2) (Ceseña-Arce 2003).

MATERIALS AND METHODS

In the study area where Punta Roca Caimancito *A. spicifera* distributed randomly placed two quadrants PVC 25x25 cm (0.0625 m²) at a distance of 20 m from each other at a depth of 1.5 m. Within each quadrant all thalli of *A. spicifera* present, and associated organisms (flora and fauna) were collected. The material was placed in plastic bags previously labeled.

Then, in the laboratory of Marine Botany UABCS partner agencies separated this invasive macroalgae and weight (g) of each taxonomic group with an analytical balance (Chyo JL180) was obtained. Subsequently, *A. spicifera* samples were dried in an oven (VWR-1350F) at 60°C to obtain the dry weight (g). With these data, the biomass (g. dry weight m⁻²) *Acanthophora* and partner agencies estimated. Furthermore, in the study area were collected randomly from 20 thalli *A. spicifera* with which the average maximum length (mm) was determined as the average number of branches (number of branches per thallus) and the number of spines per branch, the average of each side branch with thorns (number of spines per linear mm of secondary branches) was taken. The average number of spines in three heights of the plant (apical, middle and bottom) was also compared. These measurements were made in order to determine whether the structural complexity of the plant varies over thallus and also temporally.

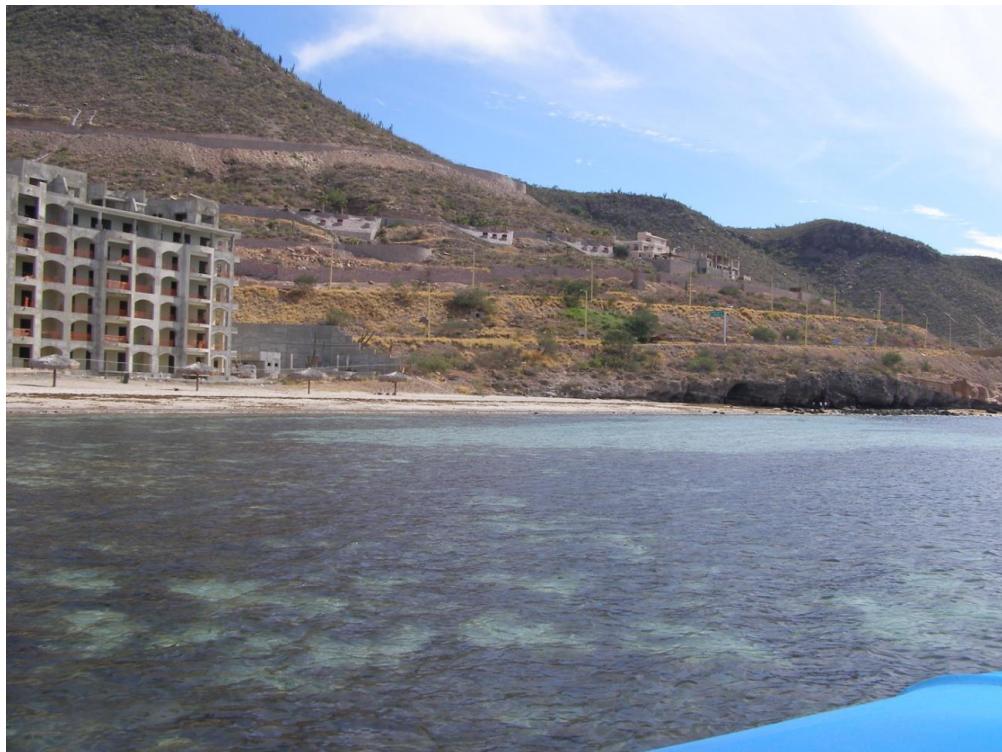


Figure 2. Mantle *Acanthophora spicifera* at Punta Roca Caimancito beach, BCS.

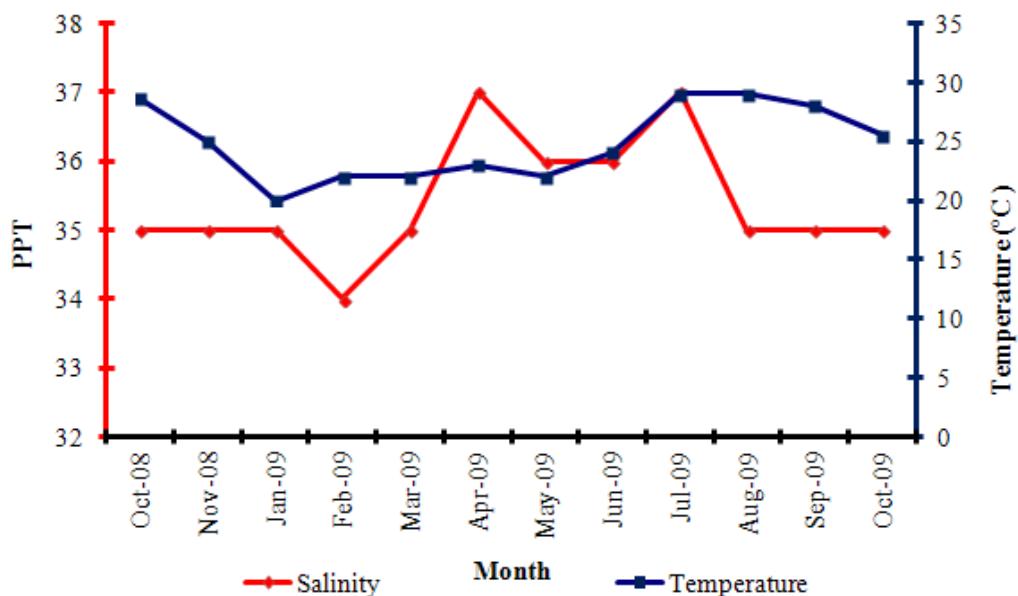


Figure 3. Seasonal variation of temperature (°C) and salinity at Punta Roca Caimancito.

This allows us to pursue a relationship with the diversity and abundance of associated organisms. It was also noted if the thalli containing reproductive structures, for this three

transects along the talus was performed and a sample of each side ie top, middle and base took part. The cuts were applied aniline blue staining in order to have a better resolution of the reproductive structures. Observations were made under a light microscope (Olympus CX31, CX40) with a resolution of 10, 20 and 40 X, and pictures of the different structures were taken with a (Olympus, Model C-4040ZOOM) digital camera.

The frequency of these samples was monthly within the study area, October 2008 to October 2009. Only in December 2008 did not sample.

RESULTS

Environmental Conditions

A maximum temperature of 29°C in the months of October 2008 and July and August 2009 and a low of 20°C in the month of January 2009 (Figure 3) was recorded. While the higher salinity (37) was recorded in April and July 2009 and the lowest (34) in February (Figure 3).

General Features and Morphological of *Acanthophora spicifera* in Punta Roca Caimancito

In Punta Roca Caimancito, an extension of the mantle (Figure 4) of *Acanthophora* has continued to increase since 2006, when it was first recorded in this area. The current extension (2009) is 31536.93 m² or 3.16 hectares.



Figure 4. a. Mantle *A. spicifera* Punta Roca Caimancito over time. In b) shows the area before the onset of *A. spicifera* in 2004 and 2005, one can observe a lower density of various algae. c) In 2006, first observed at Punta Roca Caimancito *A.spicifera*. d) shows how the mantle has increased in the last year (2009) sampling Punta Roca Caimancito.

**Table 1. Flora and fauna associated with *A.spicifera*
in Punta Roca Caimancito**

Flora associated a <i>A.spicifera</i>	Fauna associated a <i>A.spicifera</i>
<i>Halimeda</i> (Lamouroux, 1812)	Cnidaria (Hatschek, 1888)
<i>Caulerpa</i> (Lamouroux, 1809)	Sponges (Grant, 1836)
<i>Codium</i> (Stackhouse, 1797)	Crustacea (Brunnich, 1772)
<i>Ulva</i> (Linnaeus, 1753)	Pisces (Bateson, 1885)
<i>Laurencia</i> (Lamouroux, 1813)	Molliska (Linnaeus, 1758)
<i>Ceramium</i> (Roth, 1797)	
<i>Spyridia</i> (Harvey in Hooker, 1833)	
<i>Gracilaria</i> (Greville, 1830)	
<i>Hypnea</i> (Lamouroux, 1813)	
<i>Jania</i> (Lamouroux, 1812)	
<i>Amphiroa</i> (Lamouroux, 1812)	
<i>Lithophyllum</i> (Philippi, 1837)	
<i>Gelidiella</i> (Feldmann y Hamel, 1934)	
<i>Champia</i> (Desvaux, 1809)	
<i>Gigartina</i> (Stackhouse, 1809)	
<i>Padina</i> (Adanson, 1763)	
<i>Dictyota</i> (J.V Lamouroux, 1809)	
<i>Sargassum</i> (C.Agardh, 1820)	
<i>Hydroclathrus</i> (Bory de Saint-Vincent, 1825)	
<i>Rosenvingea</i> (Børgesen, 1914)	

The estimated maximum biomass entire mantle was 8.12 ton DW in November, and the lowest was 1.18 ton in February DW (Figure 5). The Wet weight was 110.71-ton maximum, and the minimum was 18.71 ton WW (Table 6 and 7).

A. spicifera in this area can be found growing on a variety of hard substrates, including epifitando other species of seaweeds or invertebrates (Table 1) (cnidarians, corals, sponges, mollusks) (Figure 6). However, a major substrate adheres is rock, coral and shells died (Figure 6), this is referred to as epizoic and epilithic, that is, which are subject to animals and rocks respectively. The coloration of *A. spicifera* going from brown to red (Figure 7a and b). In mature thalli coloration goes from light to dark (Figure 7a) brown.

Present an apical sympodial growth and presents secondary branches, has a roughened or rough texture, has a discoidal holder irregularly, in the main axis no spines. It is characterized by a highly branched and bushy, leafy (Figure 7a) talo. Thalli that were found were usually mature and very few were juveniles. We can also see runners with rhizoidal form at the bottom of the algae, they also serve to hold onto the substrate and give rise to a new thallus (Figure 7c).

A. spicifera presents an apical growth meristemal (Figure 8a). It has thorns with an average length of 4.5 mm, which can vary morphologically. These are pointy and there is a space between them, that is, are not on each other (Figure 8b). In cross-section was observed that the pericentral cells are dense Figure 9b). Axial cells are in the center of the talus and give support (Figure 9c).

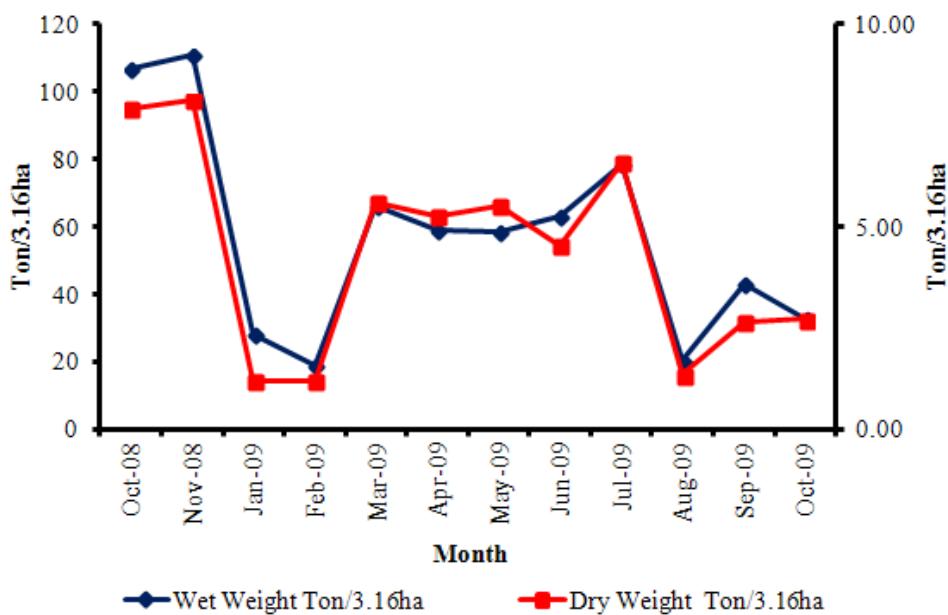


Figure 5. Total biomass mantle *A. spicifera* in Punta Roca Caimancito wet weight (blue) and dry weight (Red).

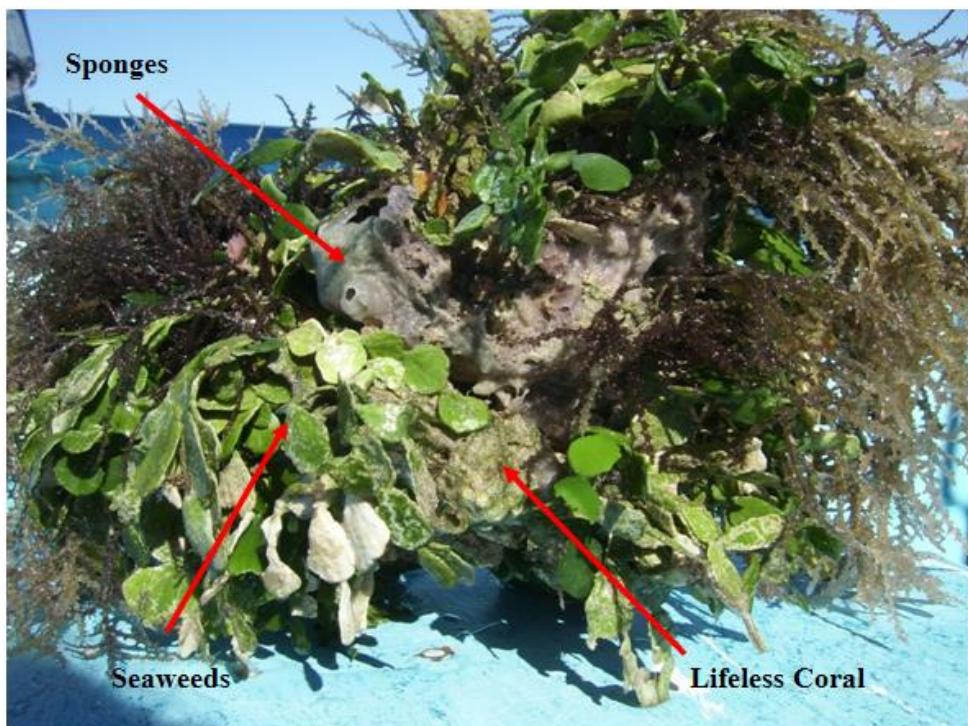


Figure 6. *A. spicifera* specimens growing on different substrate types (coral, algae and spong).

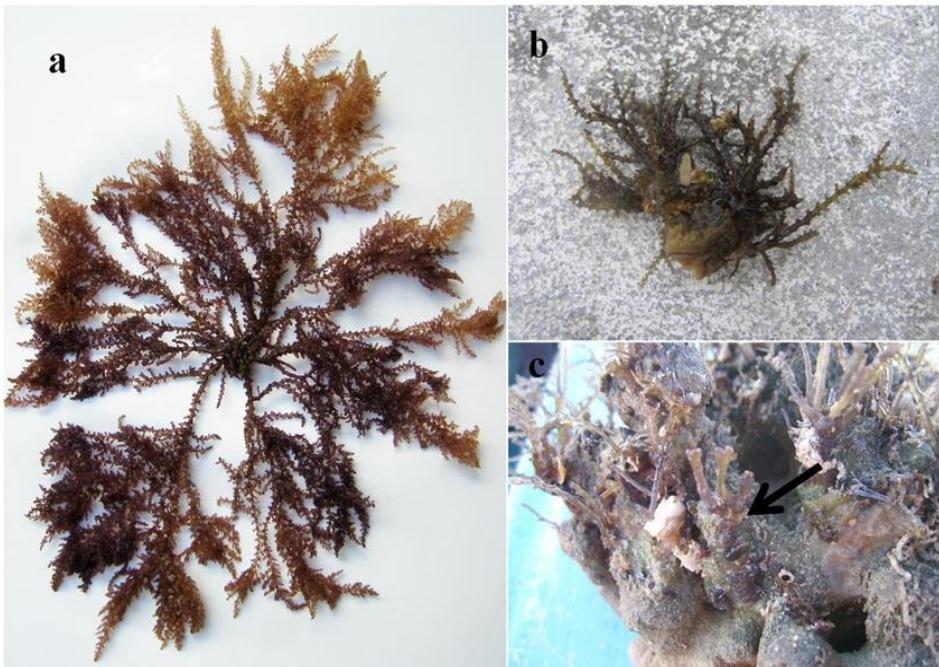


Figure 7. Anatomical characteristics of the thallus of *A. spicifera* Punta Roca Caimancito BCS, Different shades of color are distinguished; **a)** red specimen, **b)** brown specimen. **c)** proliferation of youth fronds in the bottom of the runners (black arrow).

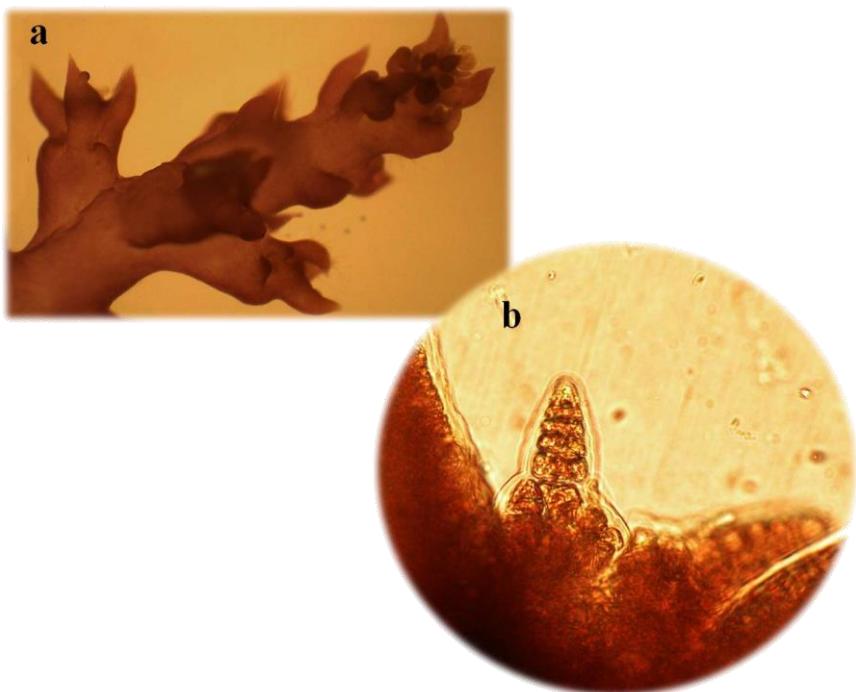


Figure 8. **a)** Morphology of spines. **b)** Meristemal cells in the apical growth zone *A. spicifera*.

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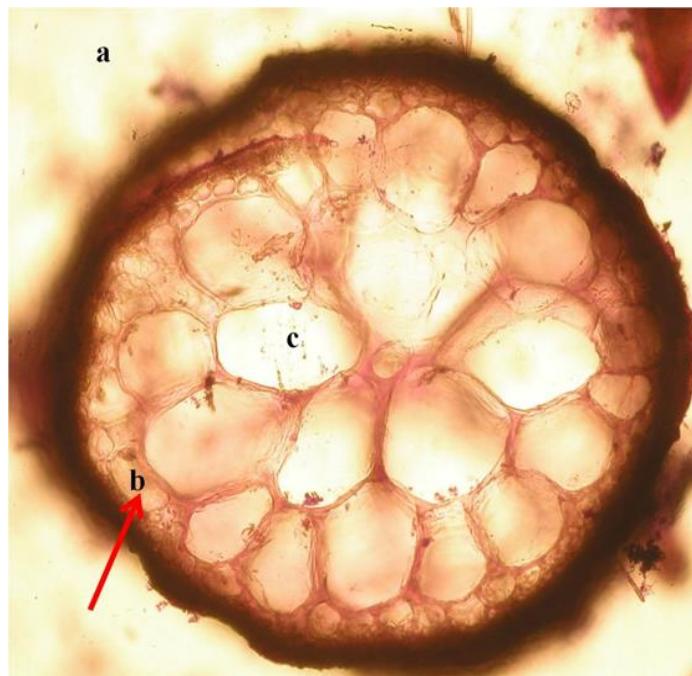


Figure 9. a) Cross section where marrow cells that support the thallus of *A. spicifera*, b) pericentral cells (red arrow) c) axial support or cells are observed.



Figure 10. *A. spicifera* pericentral cell in the apical part of the thallus.

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In this cross-section (Figure 10) we can see that the pericentral cells are less dense by being in the apical region where they do not act as supporting cells. Marrow cells alone have these characteristics, as they are found in the basal part of the stalk (Figure 10).

In the study area this invasive algae reproduces mainly asexually (fragmentation). However, indications were observed also reproduced sexually. Female gametophytes were observed in the apical part (Figure 11a) where the bones are, and only cystocarp spina found. It was observed that was ripe cystocarps (Figure 11b). Male gametophyte, called spermatangia (Figure 11c) have long, thin filaments called compact trichoblasts found in the apical part of the male gametophyte (Figure 11d).

The average maximum length of the thallus of *A. spicifera* was 163 mm in the fall of 2008 (October) and the minimum length was 108 mm in summer (August) (Figure 12).

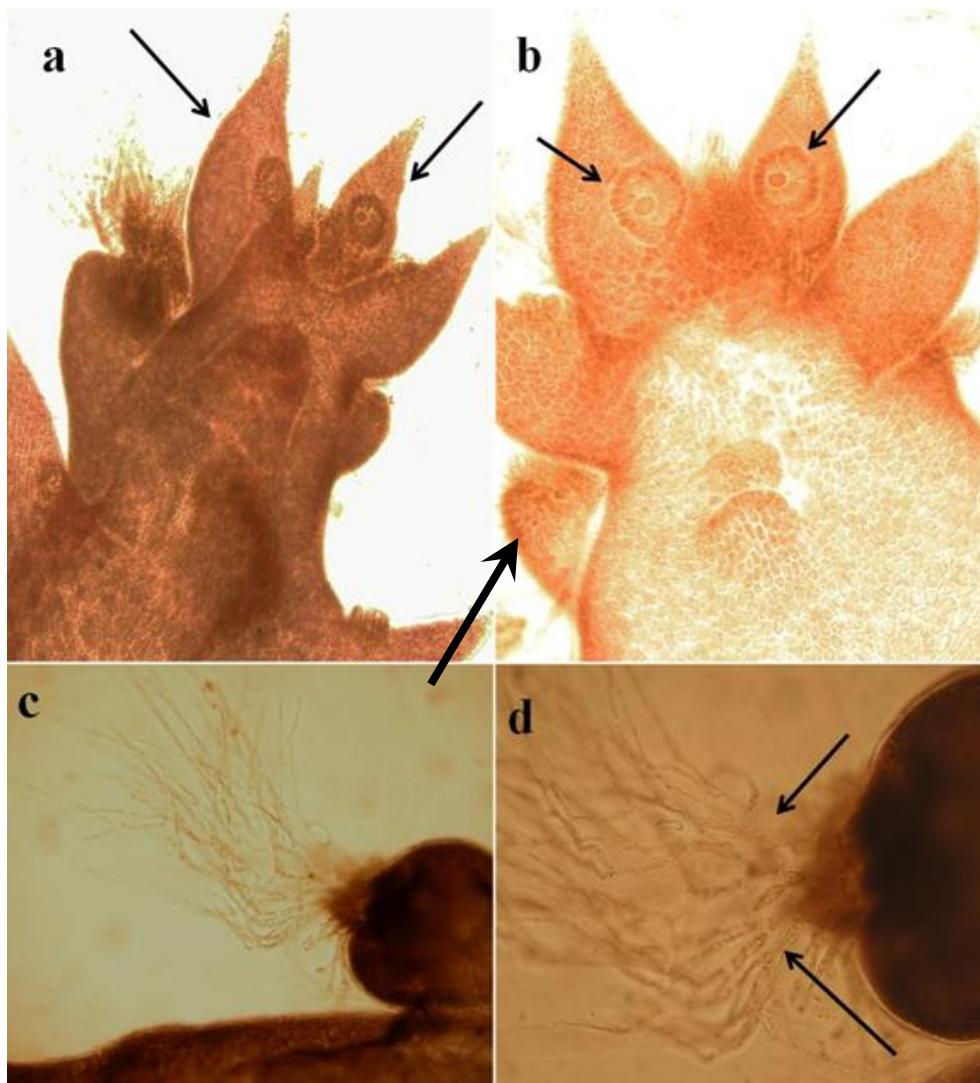


Figure 11. a) The arrows show the area sympodial growth of the female gametophyte. b) Mature cystocarp. c) Structure of the male gametophyte. d) Approach to spermatangio where trichoblasts, the thallus of *A. spicifera* (black arrows).

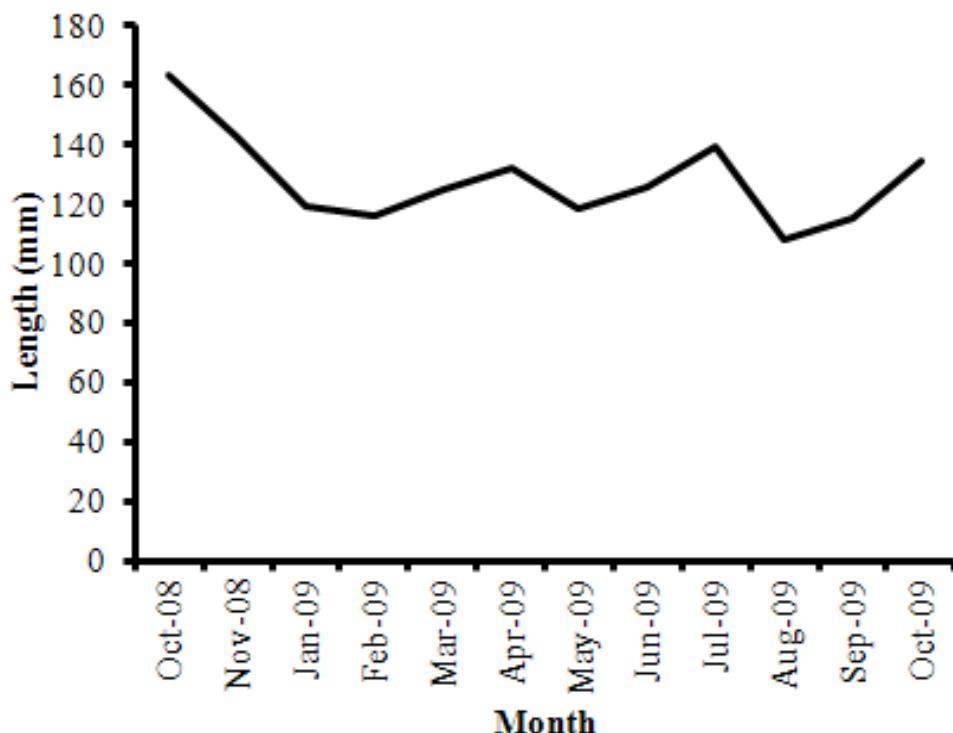


Figure 12. Average monthly length thalli *A. spicifera* in Punta Roca Caimancito.

The annual average was 154 mm. Before analyzing ANOVA data was obtained that are normal and are not homogeneous ($p < 0.05$). The result of ANOVA by ranks (Kruskal-Wallis) (Appendix, Table 3) shows that the length of the thallus varied significantly over time ($p < 0.001$). Thallus length was significantly higher in the month of October 2008. Branch number per talli did not change significantly during the study period. The monthly average was 7 branches maximum and a minimum of 4 branches per thallus (Figure 13).

The annual average was 5 branches. An analysis of variance of a channel, where a priori tests indicated that the data are normal ($p = 0.579$) and varianzas are homogeneous ($P = 0.670$) was performed. The resulting ANOVA (Table 4.) Showed no statistical difference in the number of branches between months ($p > 0.05$).

Number of Spines. The number of spines by 4.5 mm long linear branches secondary in the thallus of *A. spicifera* not vary significantly between areas (apical, medium, low) of the plant (ANOVA, $p > 0.05$). The maximum monthly average was 5.4 linear 4.5 mm thorns and spines minimum 3.9 mm by 4.5 (Figure 14). The annual average was 4.5 spines 4.5 mm length of the side branch. However there were significant differences (ANOVA, $p < 0.05$) were recorded throughout the year (Table 5). Tukey's test indicated that the density of spines in November (2008) was significantly higher than in the other months.

Percentage of Wet and Dry Weight

The average wet weight biomass (WW) was higher in November (2008) WW 3.5 kg/m² and lowest in February with WW 0.59 kg/m² (Table 6).

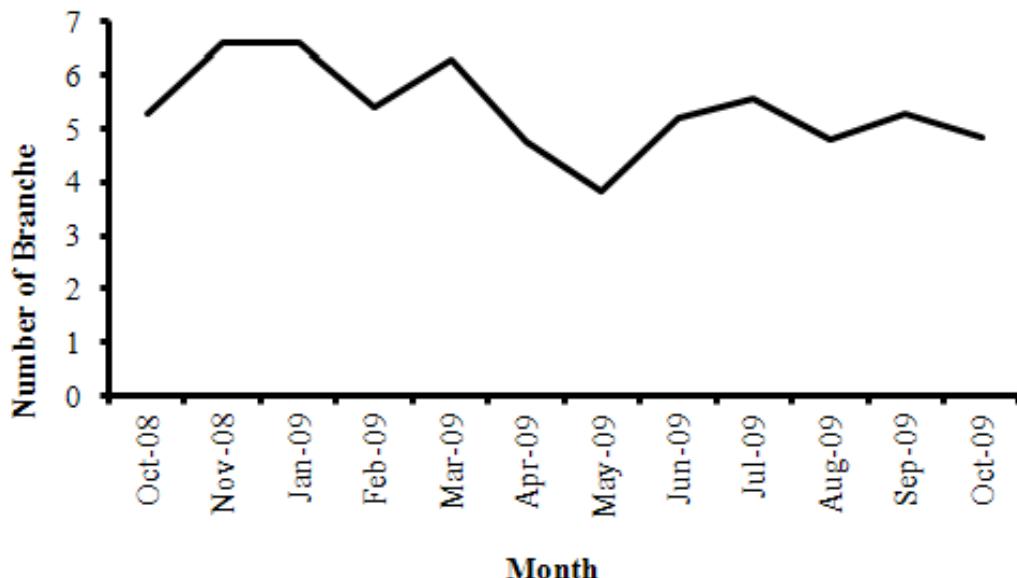


Figure 13. Seasonal variability in the average number of branches per thallus *A. spicifera* in Punta Roca Caimancito.

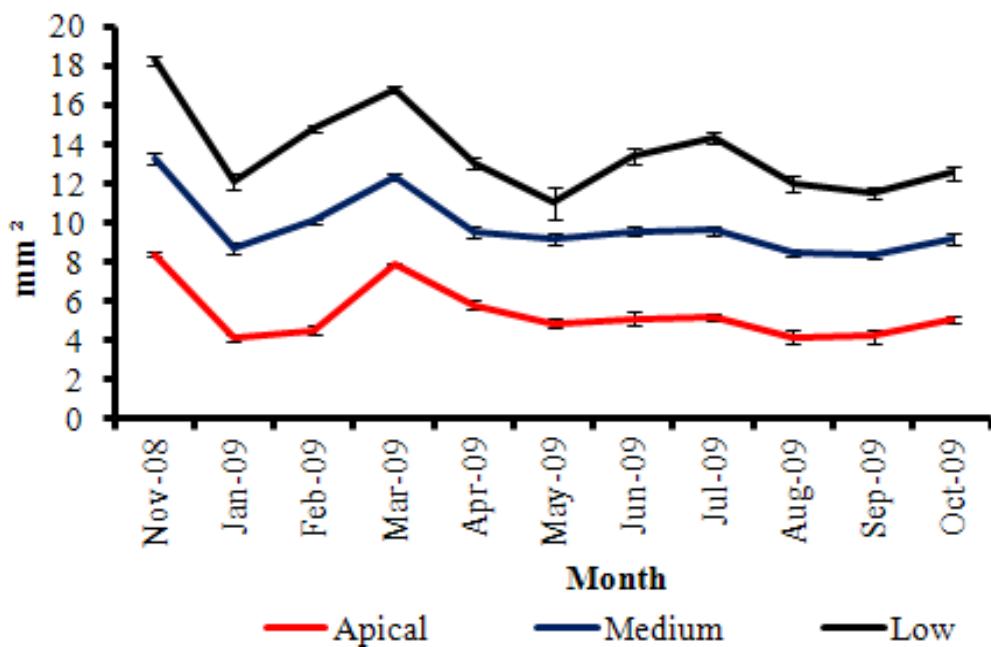


Figure 14. Number of thorn in 4.5 mm linear length of the secondary branches of the thalli of *A. spicifera* in Punta Roca Caimancito.

The annual mean biomass was 1.63 kg WW/m² (Figure 15). The variation of biomass dry weight (DW) showed a similar trend, the highest monthly average was recorded in October 2009 and was 0.86 kg DW/m² and the minimum in February (2009) is 0.0375 kg DW/m² (Table 7) (Figure 16). The annual average biomass dry weight was 0.29 kg DW/m² (Table 7).

Priori testing resulted not exhibit normal ($p < 0.050$) nor homogeneity of variance ($p < 0.050$). So the ANOVA (Table 8) rank (Kruskal-Wallis) showed us that there are significant differences in biomass throughout the year ($P < 0.001$).

Flora and Fauna of *Acanthophora spicifera*

The flora and fauna associated with *A. spicifera* was represented by several groups, of which the most common were molluscs, echinoderms, epiphytic algae from different divisions, seagrasses, sponges and fish (Figure 17). The maximum of these organisms monthly biomass was 0.20 kg/m^2 (6.27 ton for the entire mantle) in September and the minimum of 0.03 kg/m^2 (1.01 ton) in November. The annual average biomass associated with this cloak of *A. spicifera* organisms was 0.071 kg/m^2 (Table 9).

The result of the correlation indicated no relationship between dry weight biomass and biomass *Acanthophora* flora-fauna in dry weight ($r = -0.1892$).

DISCUSSION

Acanthophora spicifera is native Caribbean but now has been documented in many tropical and subtropical coastal zones around the world, which has been considered as an invasive species (Collado-Vides, et al. 1995; O'Doherty et al. 2007; Quiros-Rodríguez et al. 2010; Tsuda et al. 2008 Serviere-Zaragoza et al. 1992).

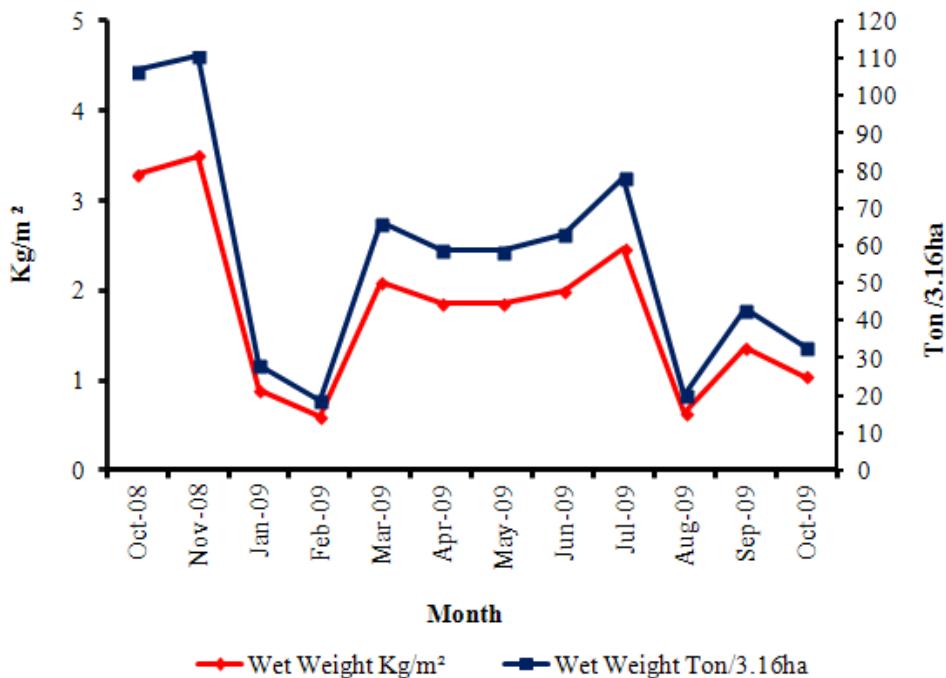


Figure 15. Seasonal variability in the wet biomass *Acanthophora spicifera* per square meter per hectare in Punta Roca Caimancito.

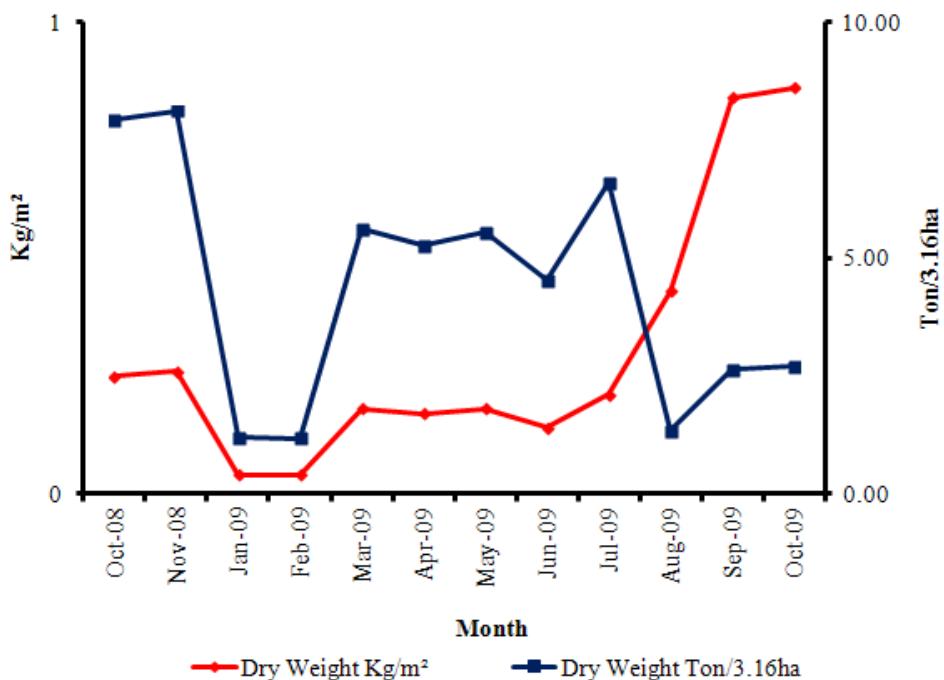


Figure 16. Seasonal variation of biomass dry weight and *Acanthophora spicifera* per square meter per hectare Total in Punta Roca Caimancito.

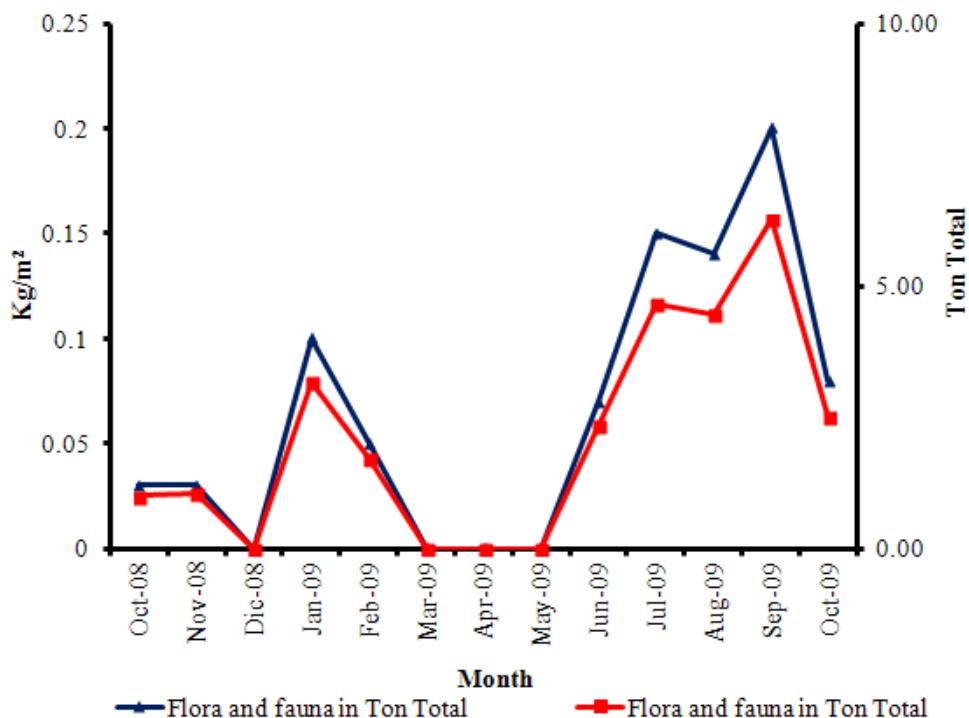


Figure 17. Monthly Average biomass of all the flora and fauna associated with the mantle of *A. spicifera* Punta Roca Caimancito.

Caribbean of Panama for example, it has been reported that the optimum temperature for this species is 25°C. Also on Pearl Harbor, O'ahu, Hawaii, we can find it adapted to a temperature range of 23-29°C (Coles 2006). In our study area (Punta Roca Caimancito) temperature conditions ranged from 20-29°C. And considering that tolerates a wide temperature range, this species could in turn spread through all the bays and shallow waters of the Gulf of California, and that within this system water temperature varies between 16-29°C (White-Betancourt et al. 2004) similar to those in our study area (Naim 1993) values. In the Caribbean, this species can be found from the intertidal zone to a depth of 8-22 m (Kilar et al. 1986; Littler et al. 2000). In Pearl Harbor, O'ahu, Hawaii dwells at an average depth of 9.2 m (Coles 2006). At sites where it is distributed within the bay of La Paz (Mexico), this algae can be found from 50 cm to 5 m depth in the subtidal zone in Punta Roca Caimancito this depth distribution could be associated with the availability hard substrate (rock, coral, shell, etc.).

The length of the thalli of *A. spicifera* in Punta Roca Caimancito ranged from 99-171 mm and maximum sizes were recorded in October (autumn 2008) and the minimum in August (summer 2009). In Tanzania length posing *A. spicifera* is 200 mm (Olivera et al. 2005). In the Caribbean there have been *A. spicifera* lengths over 250 mm (Littler et al. 2000). Making a comparison with the thalli Bay Peace these are much smaller than those in the Caribbean and the Indian Ocean.

In Punta Roca Caimancito a clear seasonal variation was detected in the length of this species in other regions. This macroalgae showed larger sizes in autumn and minimum in summer. Hawaii for example, a peak in summer is recorded and subsequently a decrease in the length in the winter. In fact, it has been observed that during the winter the thallus showing signs of necrosis with minimal possibility of adhering to a substrate and persist (Tsuda et al. 2008). In the eastern Arabian Sea *A. spicifera* reaches greater lengths during spring (March) (Desai et al. 2003). *A. spicifera* is one of the most dominant algae in the subtidal zone of Punta Roca Caimancito. The biomass of this algae was higher in October 2008 with 15.70 kg/m⁻² and the lowest was in February 2009 with 1.33 kg/m⁻². The decrease in biomass detected in winter possibly because the availability of nutrients in the summer is higher than in winter (Reyes-Salinas et al. 2003). Other species of the same genus as *A. nayadiformis* reaches higher biomass values in summer and autumn with a strong decrease in winter. Therefore in the Mediterranean in those stations *A. nayadiformis* is the most dominant species among the community of subtidal algae with a rate approximately 40% (Cecere et al. 2000).

In this study we observed that *A. spicifera* had pericentral and central cells. The spines are dense and are oval in major axis extremities separated from each other. The length of the spines is 0.5 to 6 mm. For records of the species in the Caribbean measuring up to 0.55 mm in length (Littler et al. 2000). In this sense, some authors who have studied species of this genus show that if the spine is very swollen means there may be spores within it (Cecere et al. 2002). In our study this phase was observed, this might be because he had expelled the gametes. In the cross sections was observed that the spines containing an empty cavity may also be that under these environmental conditions sexual reproduction is not very common.

A. nayadiformis in the number of thorns varies depending on the length of the branch, that is, the longer the greater the number of spines (Cecere et al. 2002). The same author also mentions that the spines are made up of cells that build tissues and present of 3-5 spines on the apical side. *A. nayadiformis* plants develop from primordium spines are more robust and abundant monopodial growth (Cecere et al. 2002). The most common is that the thalli can

become vegetative propagules. Branches can be regenerated from anywhere in the talo and form new thalli without sexual reproduction (Cecere et al. 2002).

A. spicifera is an abundant algae in the subtidal zone of Punta Roca Caimancito where it forms part of a small reef where various organisms (flora and fauna) benefit to get shelter and available substrate (Table 1 and 2). Within associated algae we can find species phylum Chlorophyta (green), Rhodophyta (red) and Heterokontophyta (brown). A lot of animals living among *A. spicifera* such as fish, sponges, cnidarians, molluscs, arthropods were also found.

A. spicifera not only found in coral reefs but it also can be found associated complexes mangrove ecosystems (Barrios et al. 2003). However, in some Hawaiian coral ecosystems invaded by *A. spicifera*, has detected a negative impact because it prevents nutrients and sunlight reaching the coral community, which may attract some problems for communities of animals and plants who live there (Martinez-Danaras 2006).

In Punta Roca Caimancito thalli *A. spicifera* easily fragmented (even without waves or strong currents) generating clones that are dispersed by currents as in other regions (Kilar et al. 1986). This feature has favored the spread of this invasive algae by different sites within the Bay of La Paz. O'Doherty et al., 2007 mention *A. spicifera* that is a species capable of even flourish under range of environmental conditions for this species and do not need a special environment to reproduce asexually. Unlike sexual reproduction that does require specific environmental conditions that stimulate the production of Tetrasporangia (structures within which tetraspores occur) and also involves a lot of energy expenditure. In populations of *A. spicifera* present in the Hawaiian Islands has been suggested that this truncated life story and that have not been observed gametofitos O'Doherty et al., (2007). In Punta Roca Caimancito the tetrasporophytes were observed. Ie carposporangia but empty or perhaps initiating development were observed but not viable.

This alga has spread rapidly through the Bay of La Paz and is present throughout the year (perennial species). It is currently distributed to over 20 km in different parts of the east coast of the Bay of La Paz. Contrary to what happens with native algae like *Sargassum* is annual, we only see their fronds (higher density and size) during summer and winter only survive fasteners and lots of stipes (Riosmena-Rodríguez et al. 2009) or *Porphyra* that only occurs during the autumn-winter period (Smith 2002).

CONCLUSION

Acanthophora spicifera is a perennial species that is present throughout the year in Punta Roca Caimancito and tolerates a wide temperature range of 20-29°C. Morphological characters posing *A. spicifera* Punta Roca Caimancito are similar to those reported by other authors for other regions of the world.

The main mode of reproduction of *A. spicifera* is asexually through fragmentation and occurs throughout the year. Sexual reproduction was evidenced by the presence of carposporangia between spring and summer, however, these were never observed containing carospores. Presents *Acanthophora spicifera* presents larger during fall and lowest during the summer. The number of branches in the thallus of *A. spicifera* was significantly higher in the period of autumn-winter than in the summer.



Ecofriend, 2011; Schrope, 2008.

Figure 18. "Super Sucker" Vacuum invasive algae in the coral reefs of Hawaii.

The maximum number of spines was 5.4 4.5 mm linear spines on secondary branch and the minimum was 3.9mm for linear secondary branch. The percentage of biomass by wet weight of *A. spicifera* is higher in autumn and winter less. The percent dry weight of biomass is greater *A. spicifera* fall and lower in winter. *A. spicifera* impact in the study area can be positive for some species of wildlife that benefit from this alga to obtain shelter and food, but for the case of coral communities, the impact appears to be negative as the high density of the algae can affect light and nutrient uptake and thereby affect its growth.

RECOMMENDATION

As already mentioned *A. spicifera* is an invasive algae that has invaded marine ecosystems in the Pacific, and has been shown to be a highly competitive body (light and nutrients) with native corals and algae. It has also been noted that competes for space with a great diversity of sessile organisms. Here, in Hawaii has developed a technology to remove the algae from the invaded area. It is a vacuum machine called “Super Sucker,” which has been successful in controlling the algae as it can draw up to 800 kg per hour. Subsequently, these invasive algae are packed in bags and delivered to farmers for use as fertilizer. Therefore, it could recommend the use of these machines to control the high biomass of *A. spicifera* in places where it is distributed in the Bay of La Paz. Although it is also recommended to first assess the impact of the cleaner for other native organisms associated (National Geographic 1996-2011; Ocean Power Magazine 2011).

ANNEX

Table 2. ANOVA monthly average length of thalli of *A. spicifera*

Source Variables	gl	H cal	H cri	P
Length per Month	11	102.589	21.03	<0,001

Table 3. ANOVA the average number of branches per thallus of *A. spicifera*

Source Variables	gl	SC	CM	F	P
Among Months	1	0,0817	0,0817	0,0695	0,795
Residual	22	25,847	1,175		
Total	23	25,928			

Table 4. Monthly wet weight in g/cm² *A. spicifera* data extrapolates the area covered by the mantle (3.16 ha)

Wet weight	Oct 2008	Nov 2008	Jan 2009	Feb 2009	Mar 2009	Apr 2009	May 2009	Jun 2009	Jul 2009	Aug 2009	Sep 2009	Oct 2009
g/cm ²	211.26	215.39	55.88	38.12	130.72	116.39	116.05	124.91	154.93	39.87	52.92	65.04
kg/m ²	3.30	3.50	0.89	0.59	2.09	1.86	1.85	1.99	2.47	0.64	1.36	1.04
kg/ha	33801.44	35037.57	8940.72	5923.40	20914.65	18622.94	18567.20	19985.26	24788.19	6378.99	13606.26	10406.96
Ton/ha	33.80	35.03	8.94	5.92	20.91	18.62	18.56	19.98	24.78	6.37	13.60	10.40
Ton Total	106.81	110.71	28.25	18.71	66.09	58.84	58.67	63.15	78.33	20.15	42.99	32.88

Table 5. Monthly dry weight in g/cm² *A. spicifera* data extrapolates the area covered by the mantle (3.16 ha)

Dry weight	Oct 2008	Nov 2008	Jan 2009	Feb 2009	Mar 2009	Apr 2009	May 2009	Jun 2009	Jul 2009	Aug 2009	Sep 2009	Oct 2009
g/cm ²	12.47	15.70	2.38	1.33	11.10	10.43	10.94	8.98	13.41	2.66	5.23	5.38
kg/m ²	0.25	0.26	0.04	0.04	0.18	0.17	0.18	0.14	0.21	0.43	0.84	0.86
kg/ha	2512.31	2570.67	380.14	375.21	1775.59	1668.85	1750.54	1437.43	2085.68	425.28	837.15	860.75
Ton/ha	2.51	2.57	0.38	0.37	1.77	1.66	1.75	1.43	2.08	0.42	0.83	0.86
Ton total	7.93	8.12	1.20	1.18	5.61	5.27	5.53	4.54	6.59	1.34	2.64	2.71

Table 6. ANOVA dry weight monthly *A. spicifera*

Source Variables	gl	H cal	H cri	P
Month	11	64.820	21.03	<0,001

Table 7. The dry weight of the flora and fauna in monthly g/cm² *A. spicifera* data extrapolates the area covered by the mantle (3.16 ha)

Flora and Fauna	Oct 2008	Nov 2008	Jan 2009	Feb 2009	Mar 2009	Apr 2009	May 2009	Jun 2009	Jul 2009	Aug 2009	Sep 2009	Oct 2009
g/cm ²	2.00	2.07	6.30	6.30	0.00	0.00	0.00	4.63	9.20	8.80	12.40	5.00
kg/m ²	0.03	0.03	0.10	0.05	0.00	0.00	0.00	0.07	0.15	0.14	0.20	0.08
kg/ha	318.40	331.20	1006.40	544.00	0.00	0.00	0.00	739.20	1472.00	1408.00	1984.00	800.00
Ton/ha	0.32	0.33	1.01	0.54	0.00	0.00	0.00	0.74	1.47	1.40	1.98	0.80
Ton total	1.01	1.05	3.18	1.72	0.00	0.00	0.00	2.34	4.65	4.45	6.27	2.53

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Chapter 5

ENVIRONMENTAL IMPACTS ON MARINE BENTHIC COMMUNITIES IN AN INDUSTRIALIZED CARIBBEAN ISLAND-TRINIDAD AND TOBAGO

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ABSTRACT

The twin island state of Trinidad and Tobago is the Caribbean's southern-most island state located between 10° to 11° North latitude and 60° to 61° West longitude. Like most of the Caribbean small-island states, Trinidad and Tobago's coastal waters are an economically important natural resource and at the same time, a vulnerable one. Trinidad and Tobago is a producer of oil and natural gas with the energy sector being by far, the most important contributor to the country's GDP, Government revenues and foreign exchange. Crude oil production averaged 122,902 barrels per day (bbl/d) in 2004, while natural gas production averaged 2,938 million standard cubic feet per day (Ministry of Planning and Development Central Statistical Office, 2007). The petrochemical sector (at Point Lisas Industrial Estate, west coast of Trinidad) has continued to expand in line with natural gas production producing methanol, ammonia, urea, and natural gas liquids. In this respect, Trinidad and Tobago is the 5th largest exporter of liquid nitrogen gas (LNG) in the world, and the single largest supplier of LNG to the U.S.A. (between 70-75% of all LNG imported into the U.S.A, Ministry of Planning and Development Central Statistical Office, 2007). Coupled with this, La Brea on the south-west coast of Trinidad is home to the world famous Asphalt or Pitch Lake. This coastal area in Trinidad has one of the highest known natural seepage rates on earth - an estimated 100 barrels per dy per 2560 km².

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INTRODUCTION

Macrobenthic research and marine species diversity give a good indication of the nature of the environment at that location. Benthic organisms are effectively sessile living in the bottom sediment and they tend to act as integrators of the effects of various kinds and levels of disturbances including pollutants etc. Other marine organisms (e.g., fish and larger macrofauna) feed on the benthos, hence the status of the benthic community needs to be maintained if the quality of the environment (including our rich marine resources) is to be preserved. Against existing baseline information, knowledge of changes in abundances, species compositions and diversities of benthic organisms may be attributable to environmental impacts. In this respect, benthic research is very important towards assessments of environmental impacts on overall marine communities. This research is especially valuable to nations such as Trinidad and Tobago which has a history of maritime oil exploration and production.

BRIEF REVIEW OF LOCAL BENTHIC ECOLOGICAL ASSESSMENTS

For Trinidad and Tobago and the Gulf of Paria (west coast area, Figure 1), one of the earliest published descriptions of macrobenthic data was as a result of an extensive survey carried out in 1952 to 1953 (Van Andel and Postma 1954). This information provides significant baseline data since it was acquired prior to the drilling of the very first offshore wells (by Trinidad Northern Areas Ltd.) at Soldado. Later, the Institute of Marine Affairs (IMA) carried out several macrofaunal surveys in the coastal areas of the Gulf of Paria. The first of these was in the area of the Point Lisas Industrial Estate (PLIPDECO/IMA 1982, Vol. 5) (Figure 1, Inset Map, No.2). That macrobenthic survey (including chemical and geological data) was not strictly pre-construction since there were already a few existing (and operational) sites at that time eg. the Brechin Castle sugar factory and Federation Chemicals – FEDCHEM (now Trinidad Nitrogen (TRINGEN)). Such information is still important baseline data however, since the present day operations now include approximately 94 industries - petro-chemical related sites and factories as well as a number of light industries. Results (at that time) indicated that while the inshore coastal areas at Point Lisas were typical of coastal estuarine conditions, there was already evidence of a certain amount of environmental stress. A “hot spot” area close to FEDCHEM, was identified where a number of stations were already abiotic for macrobenthic organisms.

In a baseline survey of the Scotland Bay area (Figure 1, Inset Map, No. 1), Chaguanas (Alkins and Kenny 1980), the marine biological communities studied included benthic fauna and flora. Scotland bay at that time supported a wide range of fairly small communities of corals, a sea grass bed, a mixed coral/sponge/algae community, an algal community, an intertidal and sublittoral mud community and a sand and rock community. The authors described interesting community features and suggested that they should be protected from overuse or pollution. The coral communities in particular, had already been described earlier as “under physiological stress as they are growing on the edge of their salinity tolerance range” (Kenny 1975).

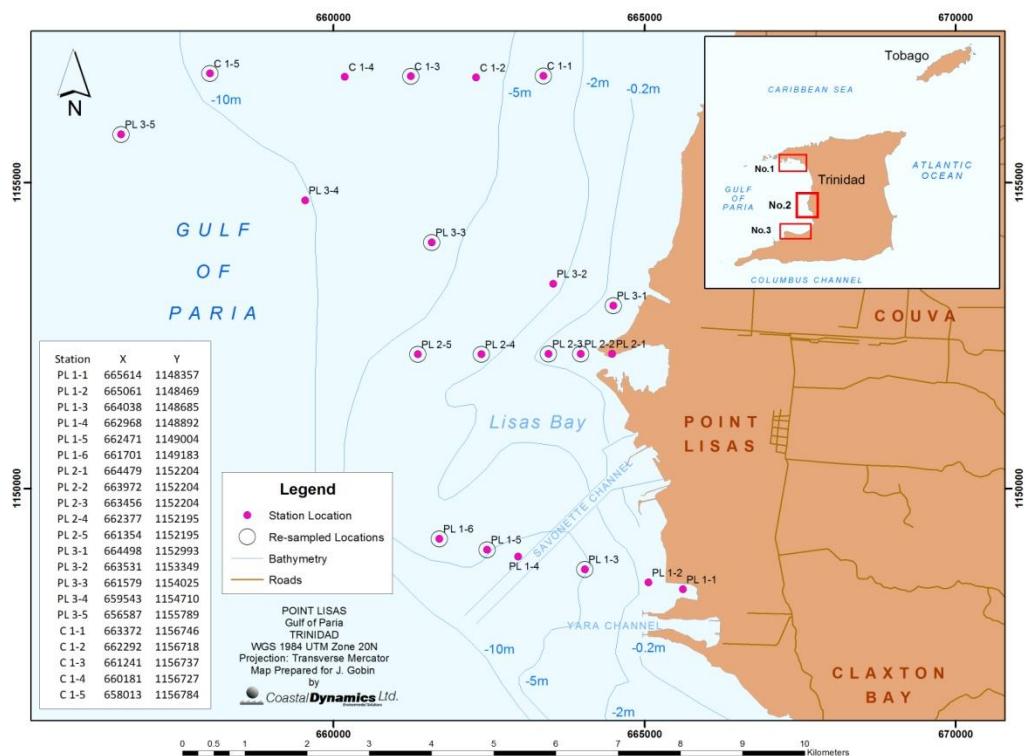


Figure 1. Map showing macrobenthic stations sampled (circled = re-sampled) in the Point Lisas coastal area.

Another detailed macrobenthic survey (including chemical and sediment geological data) was carried out in the coastal area extending from Diego Martin to Port of Spain (Figure 1, No. 1) during 1982 (Agard 1984). Over both a wet and dry season, forty seven (47) stations were sampled for macrofaunal content. The most abundant species was *Streblospio benedicti* (a polychaete) a good indicator of organic pollution (Pearson and Rosenberg 1978). Its' distribution was restricted to the Sea Lots/Laventille area where there were overloaded sewage treatment ponds with overflow pipes (Agard 1984). The amphipod *Ampelisca parapanamensis* which is very sensitive to low level pollution was the second most abundant species. Its' distribution was ubiquitous except for the areas dominated by *S. benedicti* and where there were elevated levels of petroleum hydrocarbon.

In general, Agard (1982) found that the spatial effects of pollution (high sediment organic content and low dissolved oxygen) on the benthic macrofauna at the Sea Lots/Laventille area, were far more pronounced than the temporal variation due to seasonal climatic change. The author described the presence of 5 ecological zones (ranging from very polluted, polluted, semi-healthy 1, semi-healthy 11 and healthy) each of which had its own characteristic faunal assemblage. This study provides good baseline information with which further monitoring results can be compared especially with respect to the presence or absence of the tentative indicator species identified: *S. benedicti* and *A. parapanamensis*.

Another comprehensive macrobenthic survey was carried out by the IMA in the area extending from Pointe-a-Pierre to La Brea (Figure 1, Inset Map, No. 3). This area is subject to chronic natural oil seepage and oil spillage from oil production activities (Agard and Gobin

1992; Agard, Gobin and Warwick 1992). Three (3) major station groups (based on hierarchical classification and multidimensional scaling ordination) showed concordance with differences in water depth and sediment type. Abundance/Biomass comparison plots indicated that macrobenthic communities near the oil refinery were grossly to moderately stressed while those close to the Trinidad Pitch Lake (one of the largest natural oil seeps in the world were not). Contamination occurs here at La Brea on what is probably an evolutionary time scale from one of the world's largest hydrocarbon seeps (Wilson et al., 1974; Geyer and Giammona, 1980). This is in contrast with contamination over ecological time from an oil refinery at Pointe-a-Pierre, a few kilometers away (Agard et al., 1988). Results near the La Brea oil seep suggest a diverse benthic macrofauna (Government of Trinidad and Tobago, 1984 and Agard and Gobin 1992, Gobin et al., 2012). It is thought that these organisms may rely on hydrocarbon degrading bacteria as a food source (Zobell and Feltham, 1938, Gobin et al., 2012).

There have been 2 other studies carried out by Nansingh (1993) and Price (*in prep*). Nansingh (1993) sampled quantitatively for macrofauna in the intertidal zones of 4 different areas of the Gulf of Paria – Caroni and Carli Bay (mudflat) areas, Granville and Williams Bay (sandy beach areas). Stations were sampled using cores at the 4 stations with additional mangrove root samples at Caroni Swamp. The mud flat stations reflected the greater diversity of species compared to the inner swamp area. Based on his results Nansingh and Jurawan (1999) described vulnerability of coastal areas and suggested that a potential oil spill could impact on these habitats with severe consequences. The authors applied a coastal environmental rating (an index of 1 implied “least” sensitive while 10 was “most” sensitive) and rated the studied areas as follows: Caroni swamp -9, Williams Bay-7, Granville Bay-7 and Carli Bay-7. Price (MPhil Thesis *in prep*) sampled the benthic macrofauna associated with seagrass beds at Williams Bay (Chaguaramas, Trinidad) William's Bay and St. Peter's Bay in Trinidad and compared them with La Guira Bay and Bon Accord Lagoon in Tobago.

Environmental Impacts on Macrofauna in the Point Lisas Industrial Estate (PLIE) Coastal Area

Trinidad and Tobago is a highly industrialised country with 2 very large industrial estates: Point Lisas Industrial Estate (PLIE) and La Brea Industrial Estate. The Point Lisas Industrial Estate (PLIE) is today, the heart of Trinidad and Tobago's petrochemical sector. The Estate is a world-class facility, covering 860 hectares and represents an investment of over US \$2 billion (<http://www.plipdeco.com/main/index.php?page=estate-management-overview>). The PLIE is home to 94 companies involved in a range of activities dominated by the petrochemical sector.

As the largest oil and natural gas producer in the Caribbean, Trinidad and Tobago's hydrocarbon sector moved from an oil dominant to a mostly natural gas based sector in the early 1990s. Trinidad and Tobago now houses one of the largest natural gas processing facilities in the Western Hemisphere- the Phoenix Park Gas Processors Limited (PPGPL). With 11 ammonia plants and 7 methanol plants, Trinidad and Tobago is the world's largest exporter of ammonia and the second largest exporter of methanol (IHS Global Insight 2013).

Following the original Point Lisas Industrial Estate survey (PLIPDECO/IMA 1982, Vol. 5), a detailed benthic survey was carried out during 1984 to 1986 in a similar coastal area of

Point Lisas (Gobin 1988). This quantitative study of polychaetes (Annelida- which contribute approx. 70% of total macrofauna here) was carried out to determine the distribution and abundance of these communities in the coastal area of the Estate. These distributions were evaluated with respect to proximity and effects of potential “polluting effluents” or disturbances. The polychaetes were well distributed over the study area except for the well known indicators of “organic pollution” *Capitella capitata* and *Streblospio benedicti* which were confined to some inshore stations. Additionally at some inshore stations there were elevated levels of zinc, petroleum hydrocarbons, ammonia and temperature (max. 41°C). There was also a marked seasonal shifting of sediment at some stations (eg. at Couva River mouth) accompanied by some patchy species distribution. A general conclusion of that study (Gobin 1988) was that there appeared to be no marked deterioration in the Point Lisas coastal area since the original study (PLIPDECO/IMA 1982). This was based on the fact that the “stressed stations” appeared to be at the same locations for both studies (although 8 years apart) with elevated levels of “pollutants” being confined still mainly to inshore areas.

With the continued expansion of developments and increased activities at the Point Lisas Industrial Estate, increasing volumes and variety of effluents continue to enter the Gulf of Paria. These continue to potentially pose serious threats to the quality of this environment which is a major fishing ground. These effluents have already been suggested as responsible for “contaminating” and “polluting” environmental status (Agard, Gobin and Warwick 1993). A more recent project approximately 25 years later (by the author JGobin 2010) attempted to evaluate changes in the benthic communities in the area. This is the first study of its kind in the history of benthic community analyses for Trinidad and Tobago.

MATERIALS AND METHODS

A subset (comprising of 13) of the original 25 stations which had been previously sampled in May 1985 (Gobin 1988) were re-sampled during May 2010 (Figure 1). The same methodology was used for both macrofaunal surveys (1985 and 2010). Benthic sediment grab samples were taken using a 0.025 m² van Veen grab at each of the thirteen (13) stations (2008). At each station, 3 replicate grab samples were collected and each sediment sample was sieved and washed (using sea water) through a .05 mm² sieve mesh. The fauna retained was stained using Rose-bengal (a proteinaceous dye) to facilitate sorting and preserved in a 10% formalin solution. All 39 samples were transported back to the laboratory where they were re-sieved and gross sorted, separating the polychaetes from all other taxa. All polychaetes were identified as far as possible to species level using the relevant taxonomic keys. All other taxonomic groups were identified to Family or Genus or species, as far as possible also using relevant keys. All identifications were carried out by the author (J. Gobin) for both surveys (1985 and 2010).

Species abundances, richness and SWI (Shannon-Wiener Index) diversities were calculated (Shannon and Weaver 1963) towards an overall understanding of the distribution of the benthic organisms at the stations (for 1995 and 2010 data). The macrobenthic data were analysed using the PRIMER (Plymouth, UK) multivariate analyses programmes (after Field, Clarke and Warwick 1982; and Agard, Warwick and Gobin 1993). Similarity matrices were used to produce plots (MDS- multidimensional space) in which similarity between stations is

represented as physical distances (Field, Clarke and Warwick 1982) - for both 1995 and 2010 data.

GENERAL RESULTS

In keeping with the macrobenthic review focus of this paper- only some results of this study are presented here. In the 1985 samples, a total of 3140 polychaete individuals belonging to 70 species were identified. Overall in 1985, the dominant polychaete was *Capitella capitata* (an indicator of high organic content- at station D) with *Armandia maculata* (Ophelidae) being the next. In the absence of any major changes one would expect about half the number of individuals and species for approx. half the number of samples (13). In the 2010 samples the number of individual polychaetes was severely reduced to 412 belonging to 43 species. The dominant polychaete was *Paraprionospio pinnata* (of the Spionidae). Species diversity (for polychaetes) values recorded at each station for the 1985 and 2010 survey are presented in the following figure (Figure 2). Stations 1.3 to C 1.5 (13 in total) have been re-labelled incrementally as: A to M on these plots.

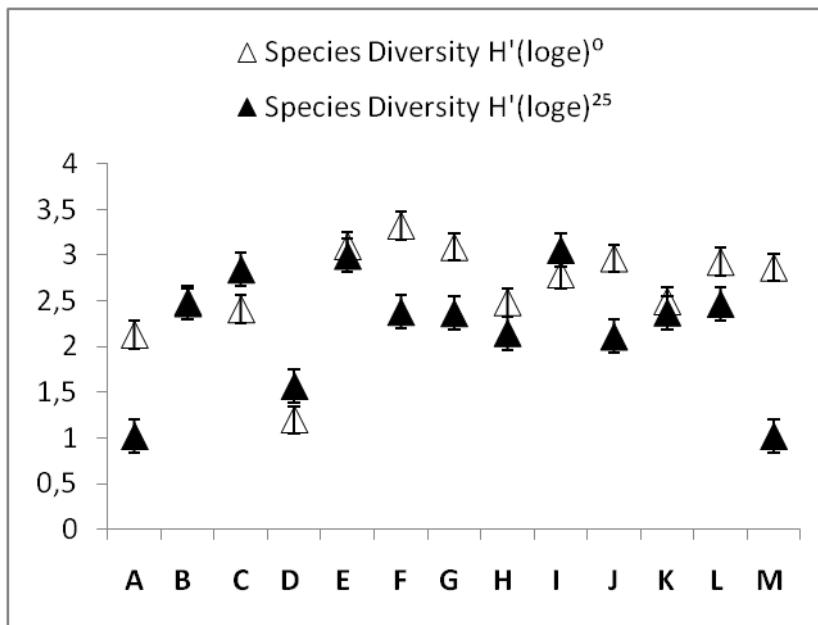


Figure 2. Species Diversity (H') at stations (A to M) sampled (with replicates combined) for 1985 (0 yrs = 0) and for 2010 (25 yrs later = 25).

Overall the benthic polychaete species have clearly decreased markedly in terms of species diversity at 7 of the 13 re-sampled stations, twenty-five years later. At least 3 stations (B, E and K) however reflected similar diversity for both sampling times. At the same time, three (3) stations C, D and I have increased species diversity after 25yrs. Station F had the greatest species diversity in 1985 with stations E and I having the highest in 2010. After 25yrs of continued industrial activity the macrobenthos in the Point Lisas area is still reasonably diverse.

DISCUSSION

Trinidad and Tobago's west coast has been reasonably very well surveyed in terms of its macrobenthic faunal species and their diversities (PLIPDECO/IMA 1982, Gobin 1988, IMA 1994 etc.). In addition to the number of studies reviewed (above), there have been a large number of surveys which contribute to the "grey literature." For example, there have been a number of macrobenthic assessments as components of Environmental Impact Assessments (EIAs)- a requirement by the local Environmental Management Authority (EMA) for proposed development activities. A large number of these have been done as pre-drilling surveys for oil and gas exploration activities and were concentrated on the East and North-east offshore areas of Trinidad. The author (J. Gobin) has also contributed (as the only specialist Benthic Ecologist) in Trinidad and Tobago to the majority (> 40) of these assessments between 1995 and 2007 (e.g., (i) 2005 Gobin, *J. Benthic Ecology Section of Document prepared for British Gas, TT: the North Coast Marine Area (NCMA) Report*; (ii) 1998 Gobin, *J. An Environmental Impact Statement on the effects of Siltation in the area of Atlantic LNG, Point Fortin. Benthic Ecology Section of a report prepared for Atlantic LNG, Point Fortin, by CANE and Associates Ltd.* etc.) There have been very few post-development (eg. post exploration drilling) surveys carried out in these areas although these have been proposed within the various EIAs' terms of reference (TORS). This is of course quite unfortunate, since continued monitoring surveys should follow baseline studies in order to provide key information on "real" changes (as a result of the activities) in macrobenthic species compositions and distributions compared to "predicted" changes (as is typical of EIAs).

This re-survey (25 years later) provides some significant benthic macrofaunal data (and the first of its kind) for Trinidad and Tobago and the Point Lisas Industrial coastal area.

Although only a small component of a more complex environment, these results confirm that macrobenthic species (polychaetes in this instance) are reasonably hardy organisms and are therefore good indicators of the state of the environment. The use of the type of data (polychaete species level) is supported by Warwick et al., (1990) and Somerfield and Clarke (1995) who confirm that aggregation patterns at different taxonomic levels are very useful for determining patterns of impact. Results suggest that in general, species diversities have markedly decreased at some of the stations over the years in those areas of the Gulf of Paria which were re-surveyed (25 years later). This was not surprising given the major expansions that have occurred at the PLIE and the increased volumes and contaminants being released in this coastal area. According to UNDP/EMA (1998) some pollutants in liquid effluent that are of greatest concern in Trinidad and Tobago are: "Total Dissolved Solids (TDS), mainly from the ammonia production sector in the Point Lisas Industrial Estate; Nitrogen (N) from the urea plant at PLIE (72%); Oil and Grease mainly from the ammonia production sector in the PLIE and Metals in effluent from the steel mill (at PLIE)."

The recent Global Environmental Outlook Report (GEO 5 2012) describes those damaged ecosystems globally as "great damage to the very ecosystems that support human livelihoods." The report further predicts that ecosystems will take centuries to recover from damages if they recover at all (<http://www.un-ngls.org/spip.php?article3907>). Global and large scale disturbances over time (eg. pollution, logging/farming, climate shifts etc.) have already altered "original baselines" of marine benthic ecosystems. In studies such as this,

recovery of the variables are therefore only being measured on a contemporary timescale. Jones and Schmitz (2009) tested the prediction of “irreparable harm” using a synthesis of recovery times compiled from 240 independent studies reported in the scientific literature. They provided startling evidence that most ecosystems globally can (given human will) recover from very major perturbations on timescales of decades to half-centuries.

Results of a similar (to this study) comparative tropical study (Webber and Webber 1998) also described increases in nitrate concentrations and increases and changes in the plankton community associated with excessive eutrophication of Kingston Harbour waters (Jamaica) over a 20 year period (1970s to 1990s). Much earlier predictions for Kingston Harbour, Jamaica (Wade 1976) was a- much deteriorated and possibly abiotic coastal area. This prediction was also made for this Point Lisas coastal area (IMA archival data, PLIPDECO/IMA 1980). Results of this study confirm a reasonable diverse benthic community.

In consideration of disturbance and effluent contaminants in the PLIE area the benthic communities may be considered in terms of benthic macrofaunal resistance and/or resilience. Resistance implies that the macrofauna are able to to some extent to tolerate these disturbances, while resilience defines the speed at which an ecosystem can return to its former state following a disturbance. Coastal ecosystems tend to be naturally resilient and Jones and Schmitz (2009) suggest that “recovery may be independent of the magnitude of perturbation and instead, idiosyncratic to the ecosystem type.” Community composition and ecosystem function may change very little where environmental impacts are such that organisms can acclimate to the change or at least tolerate it, for some time. Results of this study confirm macrofaunal resistance and/or resilience.

This high recovery potential for benthic communities was described for the Baltic sea as being due to very strong seasonality of the ocean, strong physical disturbance and short generation times of most coastal animal species (Hällfors et al., 1981). The author (J. Gobin) has confirmed that approximately 7 to 9 months is the average time needed for coastal species in Trinidad and Tobago to regenerate following dredging activities (Gobin, archival data). However, all organisms have limits to what they can temporarily or permanently tolerate, and when change exceeds some of these limits, the ecosystem functioning and in turn community compositions are likely to change. Monitoring surveys to determine or chart further changes to benthic communities are therefore a key recommendation for the PLIE and the oil and gas East coast area of Trinidad and Tobago.

It is well documented that small island developing states (SIDs) face special environmental hazards and problems not which of the least are impacts due to climate change. At the same time, most SIDs lack human resources in critical fields such as science and technology, governance and economics which are all required for a holistic and systems approach to sustainable development (http://www.unep.org/pdf/Emerging_issues_for_small_island_developing_states.pdf 2014). For example, virtually all Pacific island countries lack adequate skilled and trained workforce (http://www.ilo.org/wcmsp5/groups/public/@asia/@ro-bangkok/documents/projectdocumentation/wcms_120577.pdf).

This is interestingly not the case in Trinidad and Tobago which has a number of very well trained scientists, technologists, governance and economics professionals. Additionally there are 2 Universities (University of the West Indies and University of Trinidad and Tobago) as well as an Institute of Marine Affairs – institutions which can provide guidance and advice as well as a number of key Environmental and Maritime divisions and research departments

(within Ministries). Trinidad and Tobago is however typical of a SIDS economy which relies on a relatively narrow base of commodity; in this case oil and gas resources. This economic dependency has created a scenario where *scientific findings and data do not mix with oil and gas exploration!* In other words, Trinidad and Tobago's economic driver takes precedence over scientific findings and the “paper” requirements for surveys and studies detailing “impacts on the benthic communities” within the EIA requirement (as submitted by the various multinational and local companies) is exactly that! The author is not aware of any company being refused permission to carry out exploration activities in the waters of Trinidad and Tobago based on marine environmental concerns! Other scholars (Burdge and Vanclay 2010) were similarly not optimistic about the ability of EIAs and SIAs (Socio economic Impact Assessments) to make substantial changes in the politics of development decisions

Given the recent fluctuations in oil prices and the growing unsustainability of supplies, renewable energy is an alternate area with great potential for consideration by Trinidad and Tobago. At the same time, this much needed economic diversification will result in less degradation to the overall marine environment and the associated macrobenthic biodiversity. This even if the some components of the marine environment appear to be resilient or tolerant.

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Chapter 6

PREDICTION OF *ZOSTERA MARINA* SHOOT GROWTH, LEAF PRODUCTION, LEAF AREA AND SHOOT WEIGHT USING THE SHEATH LENGTH

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ABSTRACT

We examined the possibility of using the length of the outermost sheath (OSL) to predict values of different variables of *Zostera marina* (eelgrass), as our previous observations indicated a strong correspondence between eelgrass length structures (leaves and sheaths) and its biological and morphometric variables, i.e., growth, production, and leaf area. We first determined leaf growth and production by means of the Ibarra-Obando and Boudouresque (1994) technique, and then used correlation matrixes to explore the

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relationship between length of shoot leaves and sheaths, and the following variables: shoot growth (SG), leaf production (LP), shoot weight (SW = sum of weights of all leaves and sheaths in a shoot), and shoot leaf area (SLA) in order to predict them, based on a single shoot structure easy to measure in the field. Our results indicate that the OSL is a reliable and easy technique to measure a variable that can be used to predict the variables mentioned above on two-week and monthly periods. Then we must emphasize the importance to developing predictive equations for each study region as the only way to prevent over or underestimation of the variables of interest.

INTRODUCTION

Assessment of plant growth and production has been the object of much research, both in terrestrial and aquatic environments (reference). The trend through time has been toward a simplification of the methods used (reference). Examples of a simple and useful technique comes from agronomy, where the growth patterns or plant density indicates the seed production in some cultivars; or from forestry, where engineers use tree length and trunk circumference (diameter at breast height) to calculate tree growth, basal area, biomass or wood production (Husch et al., 1982; Brokaw, and Thompson, 2000). Snedaker and Snedaker (1984) extended these techniques to mangroves and other plants. Relatively simple techniques have been developed for aquatic plant biomass assessment (Maceina et al., 1984; Downing and Anderson, 1985), some of which are based on morphometric relationships (Daoust and Childers, 1998). For seagrasses, rather complicated mathematical models have been used to understand seasonal variations in *Z. marina*'s distribution, biomass, and production (Verhagen and Nienhuis, 1983; Bach, 1993; Bocci et al., 1997, Echavarria-Heras et al., 2012, 2013). Recently has been development some techniques to measure seagrass growth and others biological variables using statistical and allometric tools (Short and Duarte 2001; Gaeckle et al., 2006, Echavarría-Heras et al., 2013).

Seagrasses' vegetative morphology is rather simple (den Hartog, 1970). Vegetative shoots are produced through lateral shoot production. Each shoot has a series of leaves bound to their sheath, which correspond to rhizome node in a 1:1:1 (Leaf: sheath: rhizome node) relationship. This means that there is more than one sheath in each shoot. As a consequence, a strong relationship exists between these structures and growth and production dynamics (Bak, 1980; Short, 1983; Duarte, 1991; Ibarra-Obando and Boudouresque, 1994; Meling-López and Ibarra-Obando, 1997; Short and Short, 2000; Gaeckle et al., 2006).

Allometric models have been developed to assess eelgrass leaf production under natural (Solana-Arellano et al., 1991; Echavarria-Heras et al., 2013) or laboratory conditions (Hamburg and Hoffmann, 1986), and shoot length has also been estimated using biometric relationships (Bak, 1980). Ibarra-Obando and Boudouresque (1994) proposed using the length of the outermost sheath as a morphological index of leaf growth and production. The main differences between this and traditional techniques (i.e., Kentula and McIntire, 1986), is the use of the first node instead of the ligule, as the reference point to assess leaf growth. The possibility of using the length of the outermost sheath as a morphological index of shoot growth and production was tested by Meling-López and Ibarra-Obando (1997), who during an annual cycle marked eelgrass shoots simultaneously with a traditional technique (Kentula and McIntire, 1986) and with the Ibarra-Obando and Boudouresque (1994) technique. During

summer, a high and significant correlation between techniques was found, for shoot growth and production, which was not observed during winter because Kentula and McIntire's technique is more sensitive to high values and/or variance among measurements (Meling-López and Ibarra-Obando, 1997).

The observation that strong relationships exist between eelgrass morphological structures, that these relationships can be expressed in statistical terms, and that they reflect not only leaf growth and production but shoot growth and production as well (Ibarra-Obando and Boudouresque, 1994), allowed us to use regression equations to predict these and other variables, like leaf area, and shoot weight (we refer shoot weight as the sum of weights of all leaves and sheaths in a shoot) by measuring a single structure. Here we consider whether the sheath might be this structure. The sheath has two advantages: 1) It is less fragile than the leaves, and remains intact for longer periods of time, and 2) its measurement in the field is easy.

With this background, we formulated the hypothesis that shoot growth, leaf production, shoot weight, and leaf area of *Z. marina* can be assessed using regression equations that only incorporate the length of the outermost sheath. These equations would have the advantage that just the measurement of a single shoot structure would be required. Therefore, the objective of this study was to develop and validate these equations. We proceed in three different stages. The first one corresponded to the calculation of the regression equations. The second one was the validation of the equations for two-week periods, and the third one, the development of monthly predictive equations.

MATERIALS AND METHODS

Z. marina vegetative shoots were collected at San Quintín Bay, Baja California (30°24' N; 115°56' W) during August-December 1992, and February-August 1993. At every low spring tide (every two weeks), at a depth of -0.1m MLLW (Mean Low Water), 21 shoots at random were marked following Ibarra-Obando and Boudouresque (1994) technique. Marking new shoots and harvesting marked shoots were simultaneous processes in every field visit. A total of 459 vegetative shoots were marked during the two-week study period.

Shoots were marked with a hypodermic needle at the level of the ligule, and the length of the outermost sheath (OSL) recorded. We refer to the outermost sheath as the oldest one attached to the shoot (Figure 1). Once in the laboratory, shoots were dissected, and only the above ground parts were considered. Notice that in the laboratory leaves and sheaths were numbered from next to oldest (1) to youngest (5), acknowledging that fully developed sheaths are only present in the oldest leaves. As a consequence, the 1:1 proportion (Leaf: sheath) is not always present (Figure 1). The following variables assessed:

Sheath length. It is the distance (cm) from the first node to ligule. The OSL was recorded again in the lab to determine if there had been any increase in length during the incubation time. Results indicated there were no changes in length during this period (results not shown). The length of the other sheaths present in the shoot was also recorded.

Leaf growth. For marked leaves the distance (cm time⁻¹) from the ligule to the needle mark was measured, and to it, the OSL subtracted. This means that the remaining lower portion of the marked leaves represented new growth. In the case of new leaves, their whole

length was considered new growth. Whole leaf lengths were also measured to estimate the proportion represented by growth in each instance.

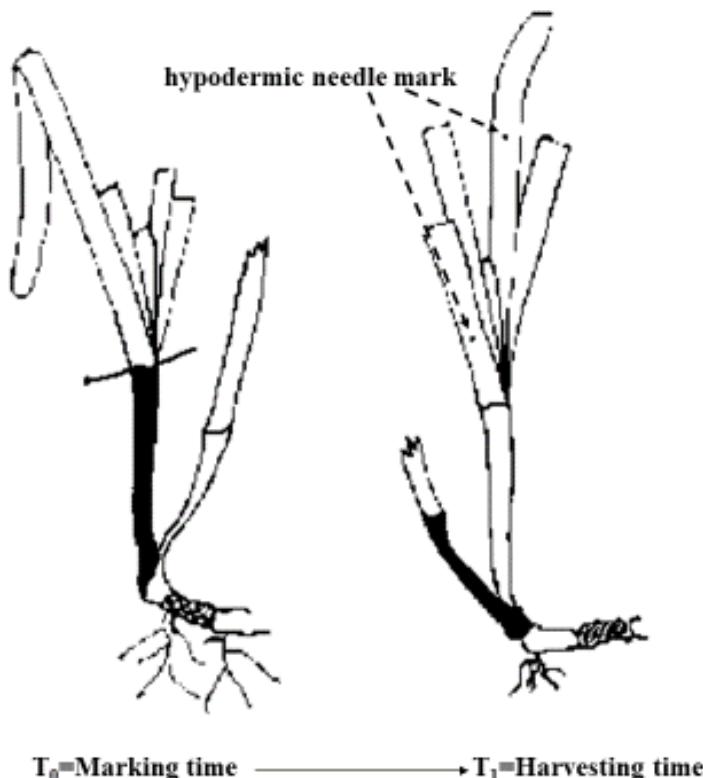


Figure 1. Description of field and laboratory work for the Ibarra-Obando and Boudouresque (1994) technique with *Zostera marina* vegetative shoots. At the marking time (T_0) shoots are marked at the level of the ligula with a hypodermic needle, and the length of the outermost sheath (OSL), indicated in black, is measured. Two weeks later (T_1) marked shoots are harvested. Dots in the leaves correspond to the needle mark. Once in the laboratory, shoots are dissected, and individual leaves and sheaths are separated. The oldest leaf has already been lost. Leaves and sheaths are numbered from next to oldest (1) to youngest (5), acknowledging that fully developed sheaths are only present in the oldest leaves.

Leaf production (LP). Leaf growth expressed in weight (g DW time^{-1}).

Sheath growth. This variable was considered proportional to LP. The percentage of leaf length represented by its growth was assigned to its sheath (cm time^{-1}). The portion of the sheath representing new growth during the incubation period was also identified in its lower portion.

Shoot growth (SG). The sum of growth for all leaves and sheaths in a single shoot during the incubation period expressed in length units (cm time^{-1}).

Shoot weight (SW). The sum of both leaf and sheath growth in a single shoot during the incubation period expressed in weight units (g DW time^{-1}).

Shoot Leaf Area (SLA). The sum of individual leaf lengths multiplied by their widths ($\text{cm}^2 \text{ time}^{-1}$). The sheaths were not included.

For all the variables mentioned above two-week averages were obtained and used to explore different combinations of correlation matrices to select the most appropriate shot structure to be used. Results not only showed significantly and high correlations between the different variables, but also in combination with some of the selected length structures (results not shown). It was decided to use only those length structures that showed high and significant correlations with SG, LP, SW, and SLA, and which were easy and fast to measure both in the field and in the laboratory. These structures were leaves and sheaths of the outermost sheath (OSL), and those in positions 1 and 2. Resultant regressions were later used as predictive equations.

To validate the above-obtained regression equations, a series of two-week samplings took place from October 1993 to March 1995, following the same procedure described above for field and laboratory. Results from the field and laboratory (observed values) were then compared with those estimated from the previously developed equations (calculated values).

Using the two-week data from August-December 1992, and February-August 1993, we calculated monthly average values for all the variables described in the first stage, and the two kinds of data sets (observed and calculated) were compared and analyzed statistically with the same procedure as above. High and significant correlations were found, allowing the calculation of monthly predictive equations, which were validated through monthly sampling from June 1996 to November 1997. SW values were calculated using the biomass (g DW m^{-2}) and density (shoots m^{-2}) relationship. It was found that the observed data were not statistically different from the calculated values, allowing the development of monthly regression equations for SG, LP, SW, and SLA.

As samples were independent and random, and data sets followed the normal distribution and presented variance homogeneity, parametric statistics were applied (Hays and Winkler, 1970; Zar, 1984) using the STATISTICA 6.0 (StatSoft) program. To test whether the whole set of homologue series (observed and calculated) were significantly different or not, an ANOVA test was used. Total averages of the two sets of data (observed and calculated) were compared with a t-student test. We considered the general assumptions for regression and correlation analysis. We used the r^2 value instead the r value to find out whether the observed values were significantly different from the calculated ones, considering them different if the r^2 value was not significant and/or smaller than 0.5, and no different if the r^2 value was significant and bigger than 0.5. In all cases, the confidence level was set at 95%.

RESULTS

Leaves length showed high correlation with their corresponding sheaths ($r^2 = 0.92$; $p < 0.01$), that was also valid for contiguous leaves and sheaths (Table 1). The dataset for two-week periods indicated that the sheath represented, in average, 17% of leaf length (0.69 ± 1 SE), varying between 15% during winter and 25% during summer (Figure 2). Individually, the sheath can represent up to 33% of its corresponding leaf length, with this high percentage corresponding to summer. For intermediate leaves the relationship is lower, as the sheath is not yet fully developed while internal leaves do not present a sheath; this indicates that leaves develop and mature earlier than sheaths. In this last analysis described above, we did not

consider the outermost leaf and sheath, as the oldest leaf falls apart during the incubation period.

Leaves and sheaths presented their maximum length during summer-autumn and their minimum values during winter-spring (Figure 3). These seasonal trends can also be observed in shoot growth, leaf production, shoot weight, and shoot leaf area (data not shown). SG, LF, SW, and SLA were highly correlated with leaves and sheaths. Shoot growth and leaf area showed their highest correlation with sheath number 1 ($r^2 = 0.9390$, and 0.9326 respectively; $p < 0.051$), while leaf production and shoot weight were highly correlated with sheath number 2 ($r^2 = 0.9047$, and 0.8691 respectively; $p < 0.05$). Correlation values with the outermost sheath were lower (Table 2), despite this fact, we selected the length of the outermost sheath (OSL) as the structure that could reflect SG, LP, SW, and SLA, as its length remains constant through time (growth has ceased). As already mentioned the sheath also has the advantage that measurement of its length, both in the field and in the lab, is easy.

Table 1. Correlation matrix for *Zostera marina* leaves and sheaths length. Only values for the most external or oldest structures (leaves and sheaths) are presented, as r^2 values were the highest ($p < 0.05$)

	Outermost Sheath	Leaf 1	Sheath 1	Leaf 2	Sheath 2
Outermost Sheath	X				
Leaf 1	0.9376	X			
Sheath 1	0.9677	0.9162	X		
Leaf 2	0.8872	0.9156	0.9361	X	
Sheath 2	0.8131	0.7270	0.8835	0.7812	X

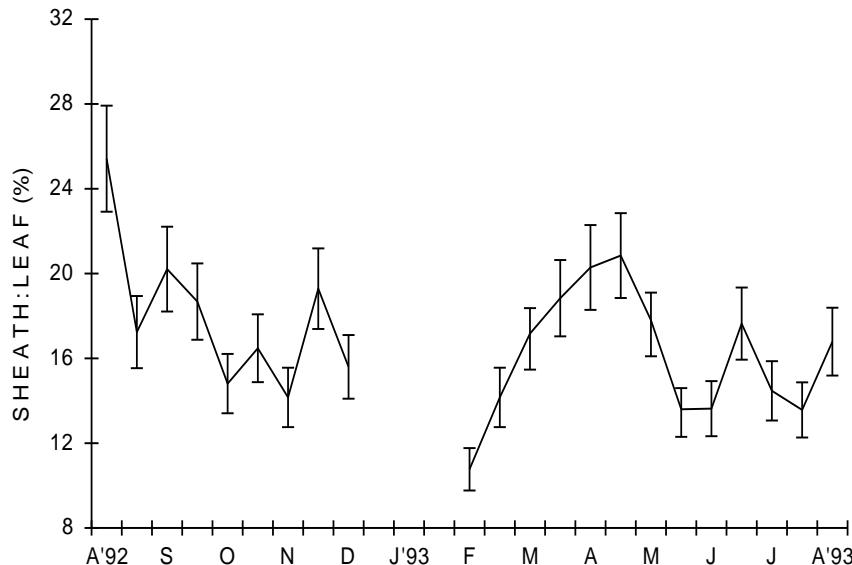


Figure 2. *Zostera marina* leaf length: sheath length throughout the two-week study period. Bars represent $\pm 1\text{SE}$.

Table 2. Correlation matrix for the assessed variables on *Zostera marina* vegetative shoots. Only correlations with the oldest structures (leaves and sheaths) are shown, as r^2 values were the highest ($p < 0.05$)

	Shoot Growth	Leaf Production	Shoot Weight	Shoot Leaf Area
Outermost Sheath	0.8955	0.6892	0.7839	0.9252
Leaf 1	0.8619	0.6282	0.7106	0.8788
Sheath 1	0.9390	0.7650	0.7968	0.9326
Leaf 2	0.8881	0.6980	0.7099	0.8680
Sheath 2	0.9220	0.9047	0.8691	0.9128

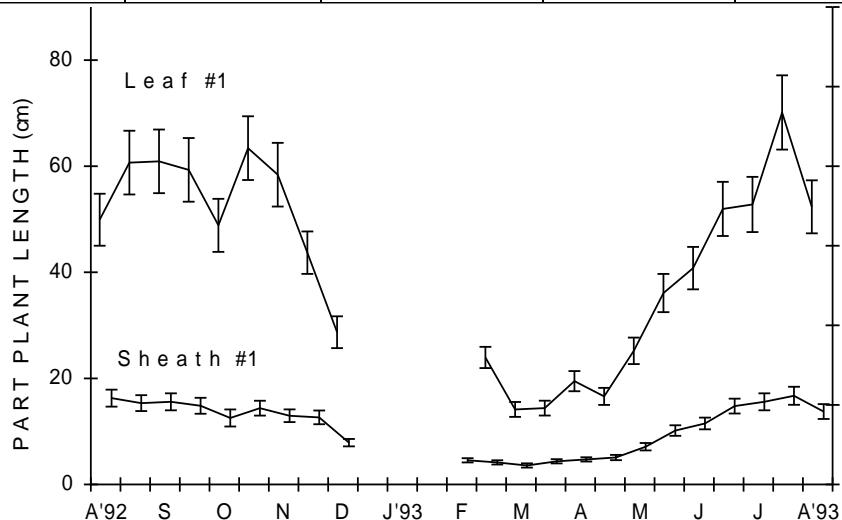


Figure 3. Averages for the two-week periods for leaf #1 and sheath #1 length (cm).

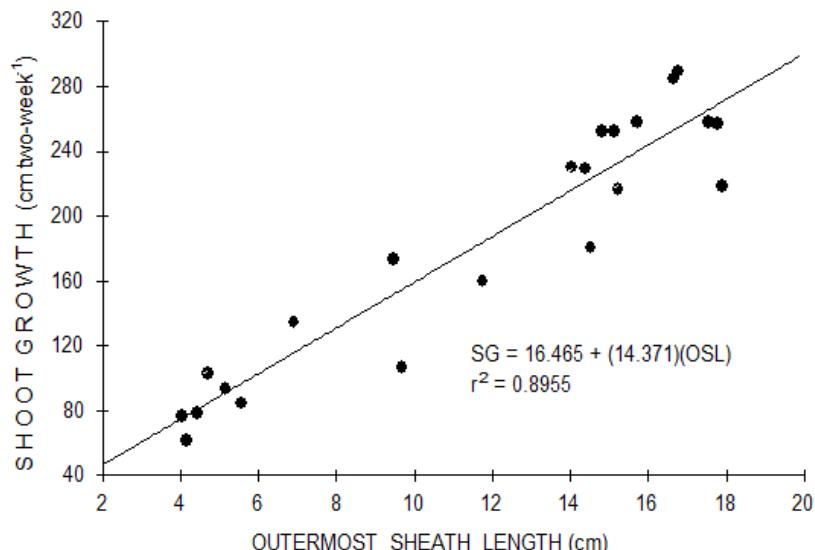


Figure 4. The regression line for Shoot Growth SG (cm two-week⁻¹), and Outermost Sheath Length OSL (cm). Standard error of estimate (S. E. E.) = 1.7; $p < 0.05$.

Table 3. Correlation matrix (r^2 values) among the measures of *Zostera marina* biological variables ($p < 0.01$)

Variables	Shoot Growth	Leaf Production	Shoot Weight	Shoot Leaf Area
Shoot Growth	X			
Leaf Production	0.8796	X		
Shoot Weight	0.8818	0.9387	X	
Shoot Leaf Area	0.9554	0.8392	0.8814	X

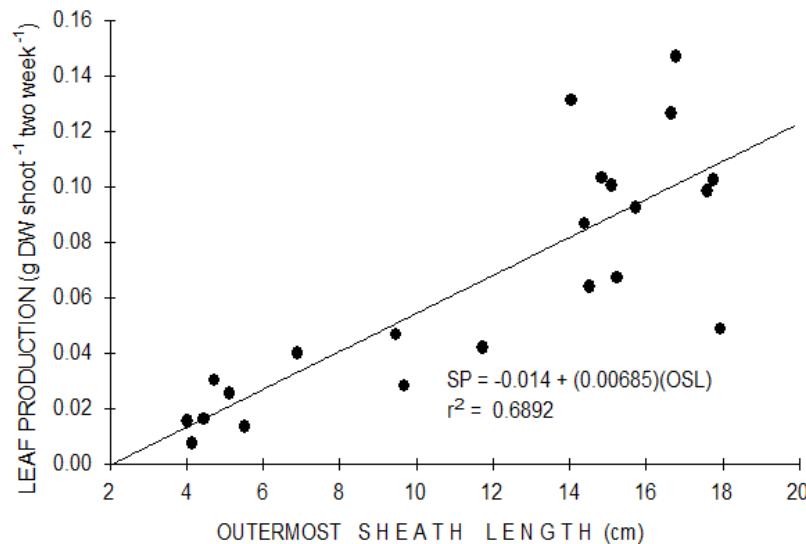


Figure 5. The regression line for Leaf Production SP (g DW shoot⁻¹ two week⁻¹) and Outermost Sheath Length (OSL) (cm). Standard error of estimate (S.E.E.) = 1.1; $p < 0.05$.

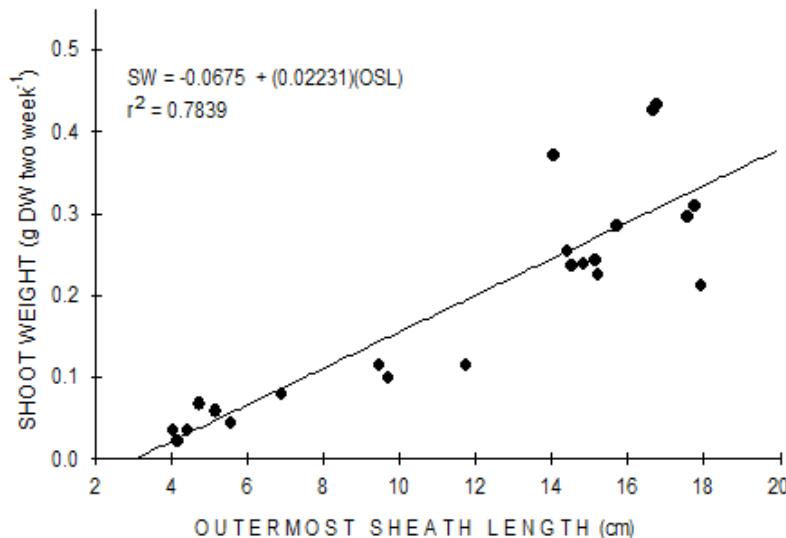


Figure 6. The regression line for Shoot Weight SW (g DW two week⁻¹) and Outermost Sheath Length (OSL) (cm). The standard error of estimate (S. E. E.) = 1.1; $p < 0.01$.

The predictive equations obtained were all significant ($p < 0.01$) and showed high correlation values (Figures 4, 5, 6, and 7). We also noticed that a high correlation existed between these variables (Table 3). These last correlations represent Thus, an alternative way to predict these variables.

Table 4. Equations developed to predict monthly values (mo^{-1}) of the assessed variables: Shoot Growth (SG), Leaf Production (LP), Shoot Weight (SW), and Shoot Leaf Area (SLA), with respect to the Outermost Sheath Length (OSL). Correlations (r^2) and Standard Error of the Estimate (SEE) are given ($p < 0.01$)

Variable to be predicted	Equations ($Y = a + bX$)	r^2	SEE
SG ($\text{cm shoot}^{-1} \text{mo}^{-1}$)	$SG = 16.223 + 28.23 \text{ OSL}$	0.9003	1.72
LP ($\text{g DW shoot}^{-1} \text{mo}^{-1}$)	$LP = -0.018 + 0.00729 \text{ OSL}$	0.7957	2.02
SW ($\text{g DW shoot}^{-1} \text{mo}^{-1}$)	$SW = -0.1289 + 0.04525 \text{ OSL}$	0.8966	1.37
SLA ($\text{cm}^2 \text{ shoot}^{-1} \text{ mo}^{-1}$)	$SLA = -35.29 + 18.108 \text{ OSL}$	0.9591	1.08

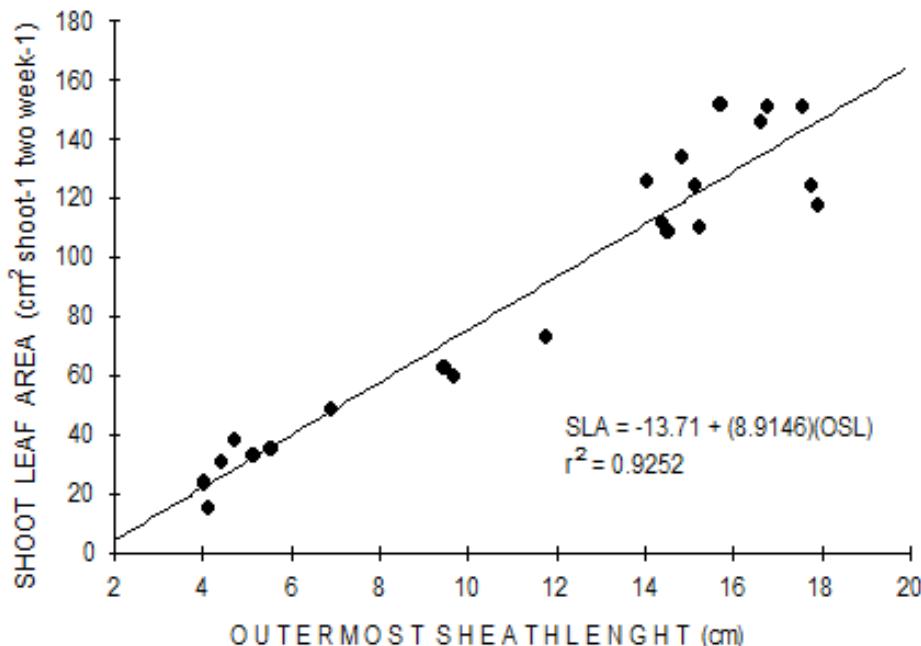


Figure 7. The regression line for Shoot Leaf Area (SLA) ($\text{cm}^2 \text{ shoot}^{-1} \text{ two week}^{-1}$) and Outermost Sheath Length (OSL) (cm). The standard error of estimate (S. E. E.) = 1.4, $p < 0.01$.

When the observed values for the two-week period were compared with the calculated ones, no significant differences were observed ($p > 0.05$). In a similar way, the t-student test indicated no significant difference ($p > 0.05$) between the total averages of the two series of data. This result was confirmed by the correlation values among the series of data ($r^2 = 0.8$; $p < 0.01$), indicating that there existed indeed a strong correspondence between observed and calculated data (Figures 8, 9, 10, and 11).

Equations to predict monthly values for each variable are presented in Table 4, all being significant ($p < 0.01$). It can be noticed that the fit was improved due to the reduction of

variance. SW values obtained during the monthly samplings from August 1996 to November 1997, were compared with the calculated values for SW from the predictive equation (Figure 12). Neither the ANOVA nor the t-student test indicated significant differences between the two sets of data or their averages ($p < 0.05$).

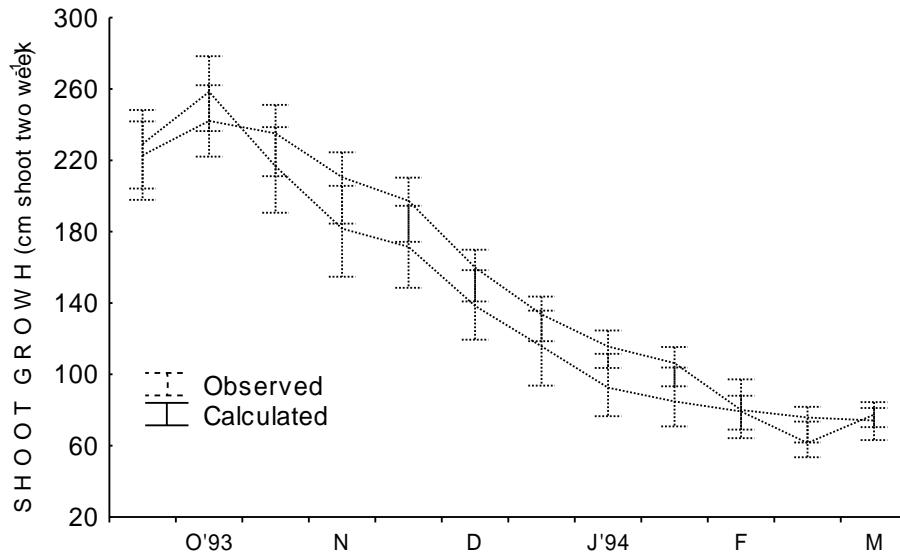


Figure 8. Comparison of observed and calculated Shoot Growth (SG) values (cm shoot^{-1} two week⁻¹) from October 1993 to March 1994. Average (142 and 154), highest (258 and 242), lowest (62 and 74), and SE (19.5 and 18.7), respectively from each data series. Bars represent $\pm 1\text{SE}$.

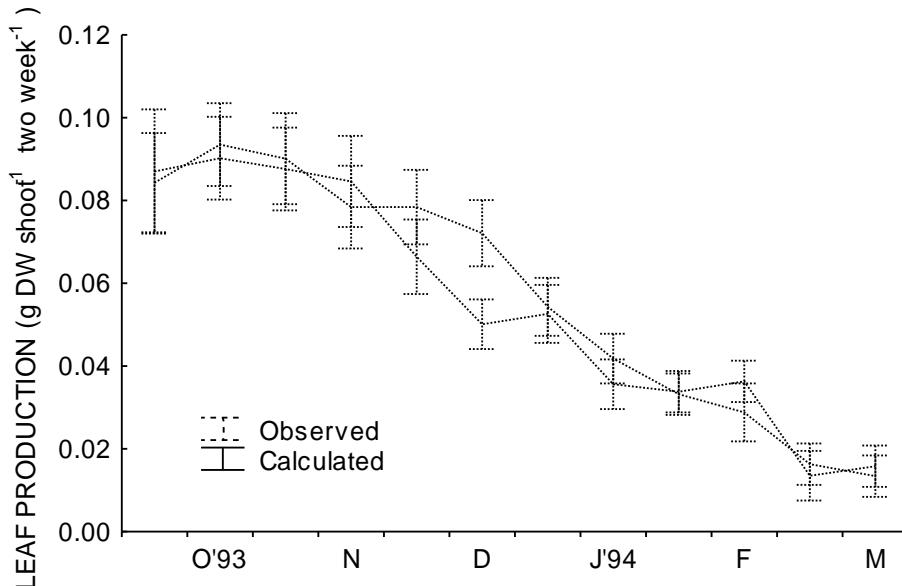


Figure 9. Comparison of observed and calculated values for Leaf Production (LP) (g DW shoot^{-1} two week⁻¹) from October 1993 to March 1994. Average (0.054 and 0.057), highest (0.090 and 0.094), lowest (0.013 and 0.013), and SE (0.0085 and 0.0085), respectively from each data series. Bars represent $\pm 1\text{SE}$.

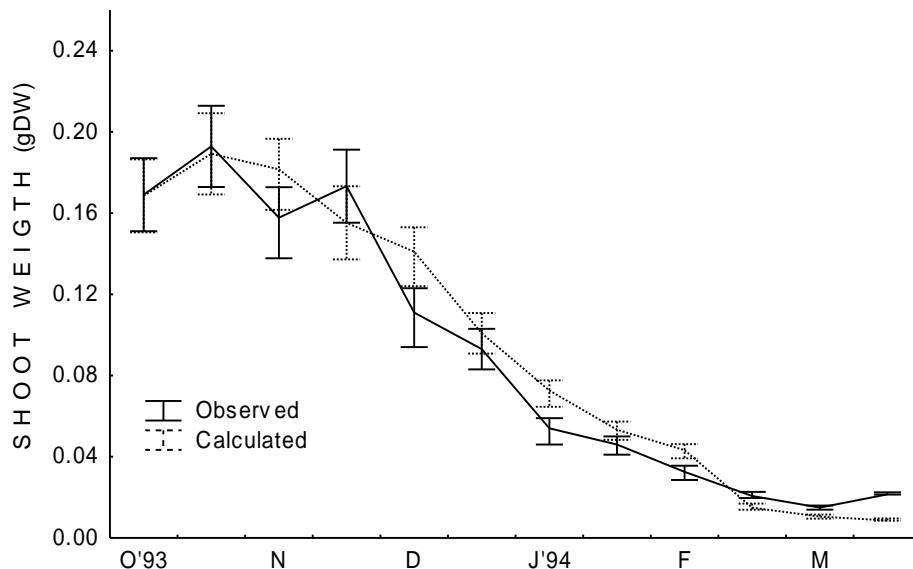


Figure 10. Comparison of observed and calculated values for Shoot Weight (SW) (g DW shoot^{-1}) from October 1993 to March 1994. Average (0.13 and 0.189), highest (0.19 and 0.18), lowest (0.019 and 0.013), and SE (0.019 and 0.020), respectively from each data series. Bars represent $\pm 1 \text{ SE}$.

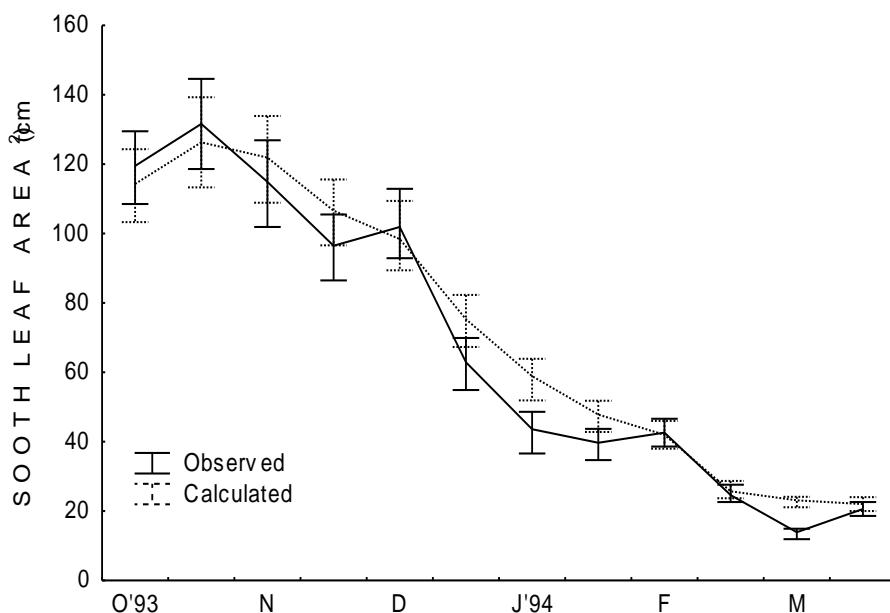


Figure 11. Comparison of observed and calculated values for shoot leaf area (cm^2) from October 1993 to March 1994. Average (67.7 and 71.9), highest (131.6 and 126.3), lowest (13.9 and 22.0), and SE (12.3 and 11.6), respectively from each data series. Bars represent $\pm 1 \text{ SE}$.

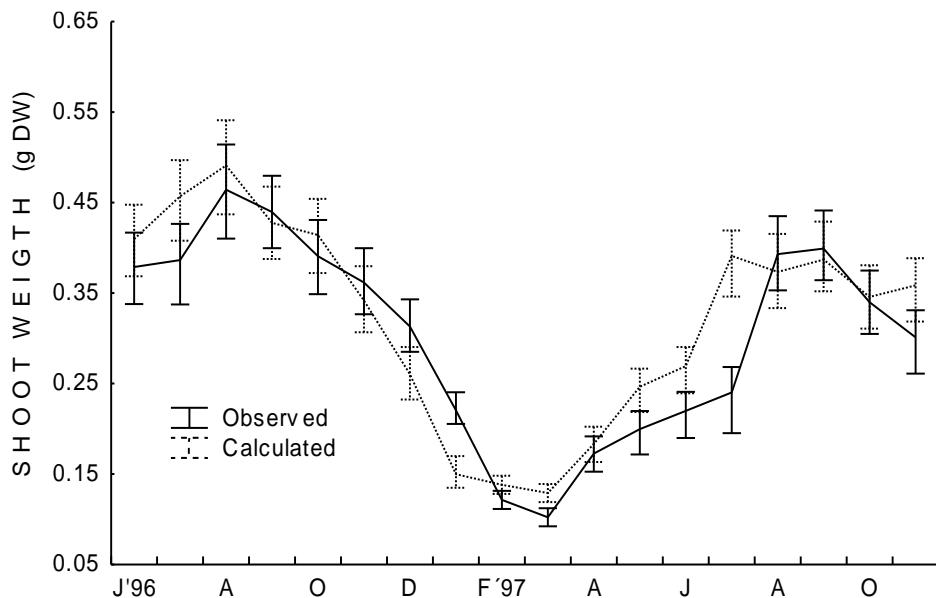


Figure 12. Comparison of observed and calculated values for Shoot Weight (SW) (g DW) from June 1996 to November 1997. Average (0.302 and 0.321), highest (0.464 and 0.491), lowest (0.102 and 0.129), and SE (0.25 and 0.26), respectively from each data series. Bars represent ± 1 SE.

DISCUSSION

In this study, we have explored whether the length of the outermost sheath could be used to predict *Z. marina* shoot growth and leaf production. Our results indicate that, although higher correlation values corresponded to leaves or sheaths in position 1 and 2 (Figure 1 and Table 1), and these structures could have been used as well, the use of the OSL is more convenient as it prevents shoot destruction. We validated our statistical models for two-week and monthly time intervals, finding no significant difference between observed and estimated values.

Using statistical techniques, not only we have confirmed Ibarra-Obando and Boudouresque (1994), and Meling-López and Ibarra-Obando (1997) results for SG and LP estimation but have also been able to predict two more variables: shoot weight and shoot leaf area. To transform SW estimates to biomass values we just need to incorporate shoot density values (Meling-López and Ibarra-Obando, 1999). Rapid assessment of biomass, growth and production are necessary, as these variables are considered basic in understanding seagrass beds structure (den Hartog, 1970), and to monitoring *Z. marina* beds (Gaeckle et al., 2006).

The fact that a strong correlation exists between all the selected variables (Table 3) represents another alternative to predict one variable from the other. Indeed, Poumian-Tapia and Ibarra-Obando (1999) have mentioned that eelgrass biomass in San Quintín Bay could be estimated from LAI (Leaf Area Index) values but this procedure is more time consuming, as all the leaves in a shoot need to be measured. Instead, the sheath method requires that only the OSL be measured.

The use of regression equations as a technique to estimate values for the previously mentioned *Z. marina* variables have the advantage of presenting a fast, reliable and non-destructive technique; however, these equations could be site specific and may need to be developed for every location. If it is true, this will require fieldwork to obtain values for those variables to be predicted. Although initial field work is required to establish the relationship between sheath length and leaf growth, Gaeckle et al., (2006) showed that a set of four periodic measurements is adequate. Once the regression equations have been developed, they would need to be validated with extra fieldwork, but once the relationship is established between sheath length and leaf growth, measurement of sheath length alone yields an accurate assessment of current leaf growth any time during the year (Gaeckle et al., 2006). Although the proposed sheath technique might seem tedious, complicated and time-consuming, once the regression equations have been developed, field work will be considerably reduced, and the lab work could be not necessary, and sampling can be extended to new locations, areas and depths, allowing comparisons,

The result indicates that two-week and monthly equations can be used to predict SG and LP, SW and SLA in an easy and reliable way, and that the OSL is a good indicator of eelgrass dynamics, instead most of the techniques used to asses both leaf growth and shoot production in *Z. Marina*, Lake leaf marking or plastochron are expensive, destructive, more lab time consuming (Kentula and McIntire, 1986, Ibarra-Obando and Boudouresque 1994, Short and Duarte, 2001), and the data are difficult to explore or needs an expensive statistical program as Echavarría-Heras et al., (2012, 2013) and Solana-Arellano et al., (1991, 2008).

Long-term monitoring of eelgrass growth and biomass is important to capture seasonal and yearly trends (Gaeckle et al., 2006), but both of them are hard to measure accurately (Short and Duarte, 2001), the technique we are proposed is a reliable form to save time and explore data in an easy way.

As seagrasses in general present a similar simple morphology (den Hartog, 1970; Duarte, 1991), equations like the ones we have developed for *Z. marina* on the Pacific coast of Baja California should be feasible to develop for other seagrass species, and locations. If we consider the possibility of a different growth dynamics in each geographic location, then the probability exists that the sheath length represents a different proportion of the total leaf length and as a consequence of SG, LP, SW, and SLA as well. Then we must emphasize the importance to developing predictive equations for each study region as the only way to prevent over or underestimation of the variables of interest.

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Chapter 7

DISTRIBUTION AND ECOLOGY OF THE PACIFIC LOBSTERETTE *NEPHROPSIS OCCIDENTALIS* FAXON, 1893 (CRUSTACEA, DECAPODA, ASTACIDEA), ON THE CONTINENTAL SLOPE OFF WESTERN MEXICO

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ABSTRACT

The geographic and bathymetric patterns of distribution of *Nephropsis occidentalis*, the only marine decapod crustacean of the infraorden Astacidea known from the eastern Pacific Ocean, were studied on the continental slope off the Mexican Pacific, and environmental drivers of those patterns were investigated. Samplings were performed using an Agassiz dredge and a benthic sledge in three main areas: the Gulf of California, the west coast of the Baja California Peninsula and the southern Mexican Pacific. Twelve sampling cruises were performed from 1991 to 2014, by which 171 hauls were obtained between 522 and 2309 m. Temperature, oxygen, salinity and total organic matter from sediments were sampled simultaneously, and data of surface production were recorded. The relationship between the patterns in abundance of *N. occidentalis* and potential environmental drivers was explored through generalised linear models. In addition, all previously published and unpublished records of the species were compiled and bathymetric patterns of distribution along latitude were explored. Within Mexico, 85 specimens of *N. occidentalis* were captured over a narrow bathymetric range, mainly between 1000 and 1300 m, at oxygen concentrations above hypoxia. Because of its high level of activity, this species is likely excluded from hypoxic waters. Males and females were of similar size and larger individuals were restricted to depths greater than 1100 m. The bathymetric patterns of distribution of *N. occidentalis* were associated with oxygen and temperature, probably because of the interdependence between aerobic capacity and temperature tolerance in ectothermic animals. In addition, surface production enhanced

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aggregations of *N. occidentalis* four months later. In the Mexican Pacific, *N. occidentalis* occurs in environmental conditions with 0.22-0.87 ml O₂ l⁻¹ and 3.4-4.4°C. Including unpublished records, a total of 61 localities where the species occurs were compiled and a continuous distribution of *N. occidentalis* along the continental slope of the Eastern Pacific from Mexico (ca. 27°N) to Chile (ca. 33°S) was confirmed. The first depth of appearance of *N. occidentalis* slightly decreased southwards and somehow followed the bathymetric distribution of the OMZ, thus confirming the effects of such structure on the distribution of the species. Finally, fishery potential of the species is briefly addressed and compared to what is known about similar deep-water species worldwide.

Keywords: Astacidea, *Nephropsis occidentalis*, oxygen minimum zone, Eastern Pacific, deep-sea ecology

INTRODUCTION

The family Nephropidae is a relatively diverse taxon in the world's oceans, with 21 species in the Atlantic, 34 species in the Indian Ocean, and 31 species in the Pacific (Wahle et al., 2012). Within the Pacific Ocean, this family presents a very heterogeneous distribution, with as many as 30 species occurring in the western part vs. none in the central Pacific, and only one, *Nephropsis occidentalis*, in the eastern Pacific (Wahle et al., 2012). This species also constitutes the only marine Astacidea species occurring in this region. Moreover, the own genus *Nephropsis* is rather diverse in the Indo-West Pacific (9 species) and the Atlantic (5 species) (Chan, 2010), but not in the eastern Pacific.

Species from the genus *Nephropsis* are burrowers and possess a robust first pair of chelae and small unpigmented eyes (Schiff and Hendrickx, 1997; Chan, 1998) (Figure 1). *Nephropsis* spp. are mostly distributed from ca. 135 to 2560 m depth, with the majority of species occurring between ca. 500 and 1250 m. From a morphological point of view, within the Nephropidae, the genus *Nephropsis* is closer to *Nephropides* than to the rest of the family's genera (Ahyong, 2006). However, phylogenetic relationships based on molecular analysis indicate that *Nephropsis* is closer to *Metanephrops* (Wahle et al., 2012).

Nephropsis occidentalis, commonly known as the Pacific lobsterette, was described by Faxon (1893) (Figure 1A) based on material collected off Acapulco and the Tres Marias Islands. It is a relatively large (up to 135 mm of total length: Hendrickx, 2003) benthic astacid lobster distributed from the southern Gulf of California and the west coast of the Baja California Peninsula to Valparaíso, Chile (Bahamonde, 1959; Manning, 1970; Holthuis, 1991; Hendrickx, 1995; Hendrickx, 2003). It has been recorded at depths from 270 to 1310 m, but in Mexico the bathymetric distribution of this species is restricted to depths between 1050 and 1310 m, below the core of the oxygen minimum zone (Hendrickx, 2003).

Oxygen minimum zones (OMZs) occur worldwide and are large oceanic areas where dissolved oxygen concentration in the water is below 0.5 ml l⁻¹ (Stramma et al., 2010). Those severely affect the distribution of marine benthic communities and, within OMZ cores, where conditions of severe hypoxia take place, macro- and megafaunal organisms are virtually absent (Levin, 2003; Gooday et al., 2009). At the lower boundaries of OMZs, where oxygen concentration increases gradually, megabenthic and benthopelagic organisms feature massive aggregations (Diaz and Rosenberg, 1995; Levin, 2003; Hendrickx, 2012a) and a rapid taxonomic replacement with depth is observed related with the size and swimming capacity

of taxa (Wishner et al., 1990; 1998; Murty et al., 2009). Below those boundaries, abundance of megafauna decreases with depth despite the continuous increase in dissolved oxygen in the water. Both the patterns in oxygen concentration in the water and food availability have been repeatedly discussed as the main drivers of fauna bathymetric distribution. However, the works available to date have mainly been performed at a community level, and intraspecific patterns of distribution in OMZ areas and autecology of key species have barely been addressed (Jeffreys et al., 2012; Hendrickx and Papiol, 2015).

The largest OMZ of the world's oceans is located in the eastern Pacific (Díaz and Rosenberg, 1995; Levin, 2003) and it distributes from ca. 60°N to 30°S (Helly and Levin, 2004). The amplitude of this OMZ varies with latitude, its lower boundary being found at shallower depths southwards, and its intensity being lowest at northern latitudes. Maximum thickness and intensity are observed at latitudes from ca. 25°N to 8°N, encompassing the continental margins of Mexico, Guatemala, El Salvador, Costa Rica, and Panama, where the OMZ ranges from ca. 100 to 1000 m depth (Helly and Levin, 2004; Fuenzalida et al., 2009). Below the OMZ off the Mexican Pacific, considerably abundant and diverse communities of benthic invertebrates have been reported across several studies (Zamorano et al., 2007; Méndez, 2007; Massin and Hendrickx, 2011; Hendrickx et al., 2011; Zamorano and Hendrickx, 2012). In this area, *N. occidentalis* is a typical member of the decapod crustaceans' community, which is dominated by some large benthic (e.g., *Heterocarpus affinis*, *Lebbeus scrippsi*) and benthopelagic (e.g., *Acantephyra brevicarinata*, *Nematocarcinus* spp.) shrimps, and large to medium-sized squat lobsters (e.g., *Galacantha diomedae*, *Munidopsis depressa*) (Hendrickx, 2001; 2012a; Papiol and Hendrickx, 2016).

Despite its potential as a fishery target (Retamal, 1977; Holthuis, 1991), little additional knowledge on the biology and ecology of *N. occidentalis* is available and, to our knowledge, only some information on the morphometrics of the species has been published (Hendrickx, 2003). A similar situation takes place for the rest of *Nephropsis* spp., for which knowledge is limited to sparse documents dealing with their distribution (Pequegnat and Pequegnat, 1983; Macpherson, 1991; Cartes et al., 2007), morphometrics (Dineshbabu, 2008), and physiology (McAllen et al., 2005).

During exploratory cruises off the west coast of Mexico performed from 1991 to 2014 a relatively large series of specimens of *N. occidentalis* was captured. The present contribution reports the material not cited in Hendrickx (2003) and provides information on the distribution and ecology of this species along the Pacific coast of Mexico. In addition, it integrates the information of the published and unpublished records of *N. occidentalis* across its entire range of distribution. Finally, the fishery potential of the species is briefly addressed comparing it with that of other astacid lobsters.

MATERIAL AND METHODS

The Mexican Pacific

Within the TALUD project, 12 cruises were performed on the Mexican Pacific slope from 1991 to 2014 (Table 1). A total of 170 stations were explored in three main areas: the southern Gulf of California (GC), the western coast of the Baja California Peninsula (WBaja),

and the southern Mexican Pacific (SMPac). Samples were obtained within and below the OMZ core (defined herein as the fringe where oxygen concentration is $<0.5 \text{ ml l}^{-1}$), from ca. 700 m to ca. 2200 m in both the GC and the WBaja, and from ca. 850 m to ca. 2200 m in the SMPac.

Sampling of Biological Data

Two different fishing gear were used for sampling: on the 1991 cruise (TALUD III) a total of 12 hauls were performed using an Agassiz dredge (horizontal length 2.50 m; vertical height 1 m), and in the rest of the surveys samples were obtained using a benthic sledge (horizontal length 2.35 m; vertical height 0.9 m) (see Hendrickx, 2012b). Both sampling gear were equipped with an outer collecting net of ca. 5.5 cm (2 1/4") stretch mesh and an inner net of ca. 2.0 cm (3/4") stretch mesh. Considering the similarity of the two gear and the low mobility of the target species, results obtained by both sampling gear were analysed jointly. All samplings were carried out on board of the R.V. "El Puma" at an average speed of 1.75 knots and the time on the bottom of each haul was on average 30 minutes.

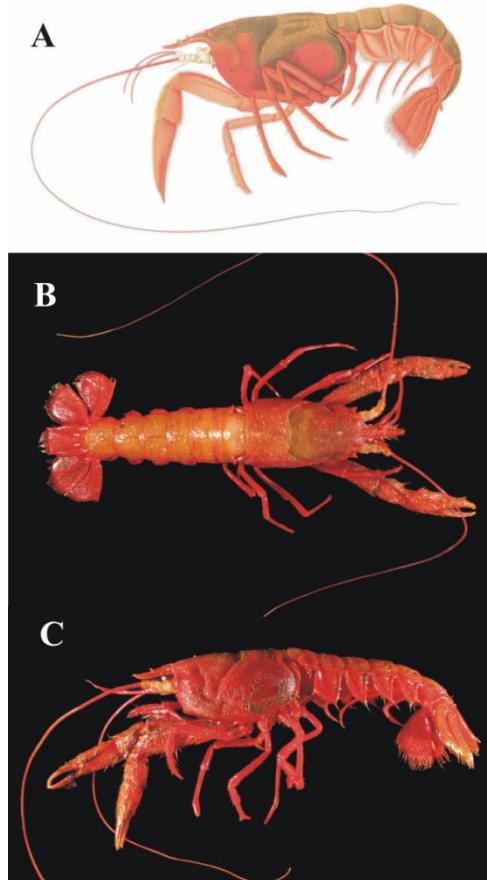


Figure 1. (A) Original illustration of *Nephropsis occidentalis* (from Faxon, 1895); (B) *Nephropsis occidentalis*, dorsal view (TALUD) (EMU-9830). C. Same, lateral view.

Once identified, all specimens of *N. occidentalis* were sexed, counted, measured (carapace length, CL in mm; ± 0.1 mm) and weighed (± 0.1 g) at the laboratory. Most specimens were preserved in ethanol and deposited in the Regional Collection of Marine Invertebrates (EMU) at UNAM in Mazatlán, Mexico.

Sampling of Environmental Data

Depth was measured with an EdoWestern analogic (TALUD III-VIII) or a Simrad digital (TALUD IX-XVIB) recorder. Temperature, salinity, and oxygen (the latter two only from TALUD VII and on) were measured around 20 m above the sea bottom (20mab) with a Seabird 19 CTD equipped with an oxygen sensor at each station. Rosette-mounted 10 litres Niskin bottles were also deployed and dissolved oxygen content was estimated with the Winkler method (Strickland and Parsons, 1972) during all samplings. Oxygen values obtained with the two methods (CTD and Winkler) were usually similar. Winkler data were used in the statistical analysis and those obtained with the CTD were plotted vs. depth.

Table 1. Date, depth range, minimum and maximum latitude and longitude, number of hauls performed and number of *Nephropsis occidentalis* specimens collected during the oceanographic cruises conducted within the TALUD research project

Cruise	Dates	Latitude range (N)	Longitude range (W)	Depth range (m)	# of hauls	# individuals
TALUD III	17-23 August 1991	22°35'48" 26°10'18"	106°37'42" 109°58'24"	712-1360	12	3
TALUD IV	23-28 August 2000	21°58'24" 25°53'59"	106°28'53" 110°11'17"	778-2250	15	4
TALUD V	13-17 December 2000	21°59'14" 25°46'01"	106°28'30" 109°42'39"	730-2140	13	11
TALUD VI	13-17 March 2001	22°00'01" 25°45'49"	106°28'06" 109°53'59"	770-1600	14	25
TALUD VII	5-10 June 2001	22°00'24" 26°06'30"	106°31'36" 110°10'30"	740-1600	15	7
TALUD VIII	16-19 April 2005	24°24'24" 26°03'42"	109°25'06" 110°50"6"	700-2200	10	0
TALUD IX	11-15 November 2005	24°23'48" 26°04'42"	109°17'36" 110°47'42"	626-2309	13	0
TALUD X	9-15 February 2007	26°35'16" 28°14'50"	110°21'10" 112°26'50"	820-1865	16	0
TALUD XII	28 March-2 April 2008	16°49'18" 19°30'27"	100°30'52" 105°26'20"	865-2125	18	12
TALUD XIV	7-11 April 2011	28°16'03" 29°08'53"	112°17'40" 113°25'28"	522-1165	7	0
TALUD XV	29 July-5 August 2012	22°58'15" 27°05'42"	110°27'54" 114°35'30"	750-2136	15	23
TALUD XVIB	20 May-3 June 2014	28°28'18" 31°48'00"	115°24'06" 117°13'00"	710-2093	22	0

Sediment Sampling and Analysis

Sediments were sampled by means of a Smith-McIntyre dredge or a modified USNEL box core at each sampling station and samples of the top 3 cm were obtained and stored at 4–8°C. At the laboratory, total organic matter contents of sediments (TOM_{sed}), calculated as the difference between dry weight (DW: 60°C to constant weight) and ash weight (500°C in a furnace for 2 h), were obtained and used as indicators of food availability for benthos (see Beaulieu, 2002).

Phytoplankton pigment concentration (PPC, mg Chla m⁻³) values were obtained from <http://reason.gsfc.nasa.gov/Giovanni> and were used as an estimate of surface primary production in the area. This was used to assess the response of bathyal decapod crustaceans to surface production processes (Cartes et al. 2004). Monthly average PPC values recorded for each locality on the date of sampling (PPC_{sim}) and 1–6 months before (PPC-1 to PPC-6) were used in order to evaluate the time lag between surface processes and the faunal response.

Data Analyses

Population Structure

Geographical patterns of distribution of *N. occidentalis* collected during the TALUD survey in western Mexico were evaluated by plotting the presence/absence of the species on a map. Abundance and biomass of *N. occidentalis* were standardized to a common swept area of 1 hectare (ind ha⁻¹ and g ha⁻¹, respectively). In order to determine the depth distribution of the species, abundance and biomass patterns with depth were analysed for the Mexican Pacific as a whole, grouping samples every 100 m. Statistical differences in bathymetric patterns of abundance and biomass of *N. occidentalis* were tested. All data were tested for normality using the Kolmogorov-Smirnov test. For data that were normally distributed, ANOVA were used. For data that did not satisfy the assumptions of normality, even after transformation, a non-parametric Kruskal-Wallis or Mann-Whitney U test was used.

Sexual and bathymetric differences in CL were tested for the whole Mexican Pacific using a Mann-Whitney U and a Kruskal-Wallis test, respectively.

Environmental Variables

The bathymetric patterns of near-bottom temperature ($T_{20\text{mab}}$), salinity ($S_{20\text{mab}}$), and oxygen ($O_{20\text{mab}}$), and of TOM_{sed} in each sampling area where the species was present were examined. In addition, environmental maximum and minimum thresholds of distribution of the species were recorded.

Drivers of Population Structure

In order to identify which variables explained the patterns of distribution of *N. occidentalis*, values of abundance at all depths were compared with independent explanatory variables by means of generalized linear models (GLM). Abundance values were log-transformed and the distribution family used was Gaussian with identity link function. The models were computed by adding single terms based on minimizing Akaike's Information Criterion and only including variables that were significant ($p < 0.05$). Environmental variables included were: $T_{20\text{mab}}$, $O_{20\text{mab}}$, PPC_{sim} , PPC-1 to PPC-6 , and TOM_{sed} .

All statistical analyses were carried out with STATISTICA 10 (StatSoft Inc.) and R 3.1.2 (<http://www.r-project.org/>) softwares.

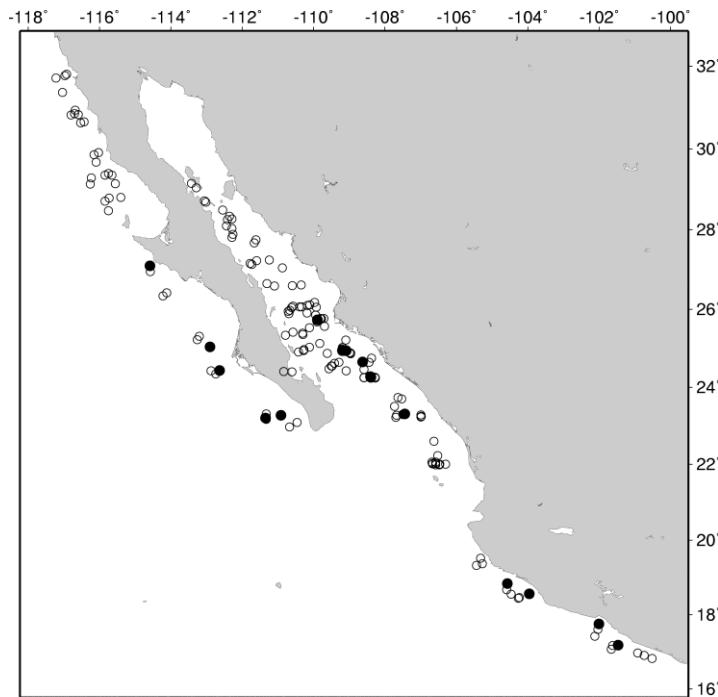


Figure 2. Position of the samplings performed during TALUD cruises with presence (●) and absence (○) of *Nephropsis occidentalis* indicated.

Worldwide Distribution

Previously published and unpublished records of catches of *N. occidentalis* worldwide were compiled and the geographic distribution of the species was explored. The bathymetric distribution of the species in relationship with latitude was investigated and compared with latitudinal patterns of dissolved oxygen concentration in the water described by Helly and Levin (2004).

RESULTS

The Mexican Pacific

Population Structure

A total of 85 specimens of *N. occidentalis* were collected in the Mexican Pacific in 18 hauls out of the 170 initially performed (Table 2). Northernmost latitude of collection of *N. occidentalis* was 27.1°N, off Baja California (Table 2; Figure 2).

Within the Gulf of California, *N. occidentalis* was neither collected on the peninsular slope nor at latitudes above 26°N. Therefore, samples obtained above 27.1°N off Baja California (TALUD XVI-B cruise; see Table 1) and samples obtained at the peninsular slope

and at the northern sampling sites within the Gulf of California (TALUD VIII, IX, X, XIV) were not considered for abundance and biomass estimations and comparisons. Seventeen of the hauls (= 94%) containing *N. occidentalis* were obtained between 980 and 1310 m, and only two specimens were caught in one haul located at 772-786 m (Table 2). Bathymetric analyses of abundance and biomass for the Mexican Pacific revealed greatest values of both parameters between 1100 and 1300 m (Figure 3). Moreover, on the continental slope of the Gulf of California, all specimens were caught between 1100 and 1300 m, and no specimens were present between 1000 and 1100 m. Main Kruskal-Wallis test for bathymetric changes in abundance ($H_{13,101} = 42.55$; $P < 0.001$) and biomass ($H_{13,101} = 43.02$; $P < 0.001$) were significant. However, the large number of hauls without *N. occidentalis* provided high intra-samples variance which probably led to the lack of statistical significance when testing for bathymetric differences in abundance and biomass across 100 m depth intervals.

All specimens collected were adults. Sex ratio (M : F) was 1:0.65. Overall, sizes of males and females were similar (Mann-Whitney U test, $n_F = 34$, $n_M = 51$, $P = 0.80$) and ranged from 18.3 to 42.3 mm, 84% of the specimens ranging from 24 to 40 mm (Figure 4a). The size of individuals changed with depth (K-W test $H_{3,85} = 10.83$; $P < 0.05$), larger individuals ($CL > 35$ mm) being restricted to depth greater than 1100 m (Figure 4b).

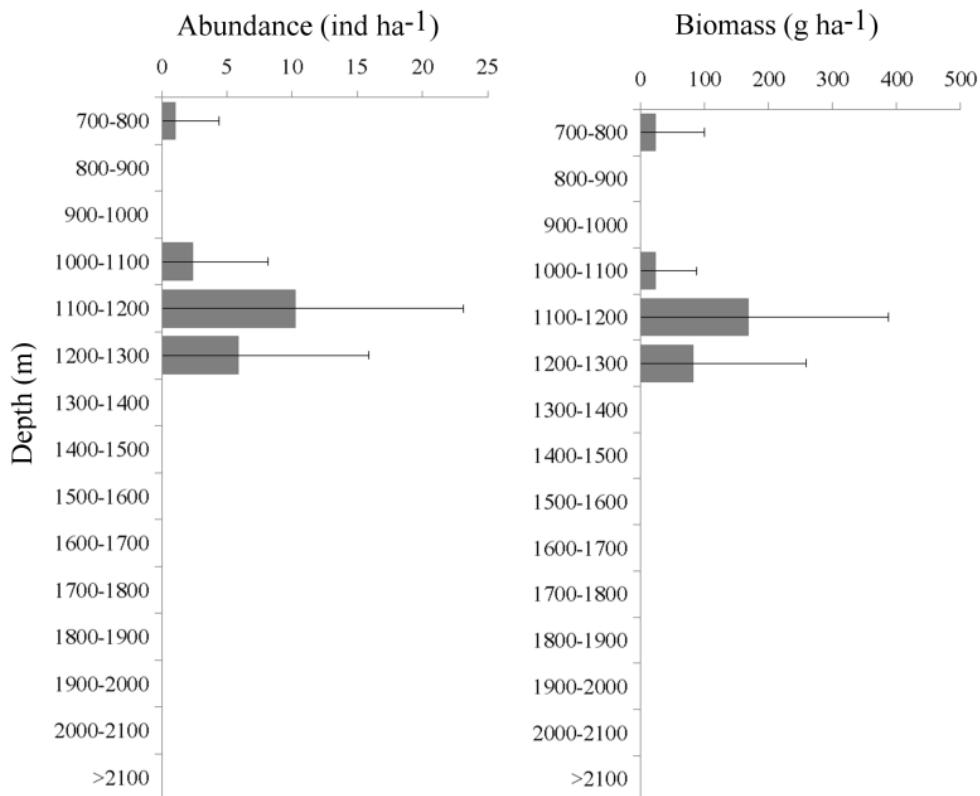


Figure 3. Bathymetric patterns in abundance and biomass of *Nephropsis occidentalis* collected in the Mexican Pacific considering the entire bathymetric interval sampled during the survey.

Table 2. List of specimens (number and size range by sex) of *Nephropsis occidentalis* collected during the TALUD cruises. Catalogue number of each lot, sampling location, date and depth are also indicated

EMU	Locality	Position		Date	Depth (m)	Males		Females (ovigerous)	
		Latitude (N)	Longitude (W)			N	CL range (mm)	N	CL range (mm)
Gulf of California									
4048	Off Bahía Santa María	24°38'48"	108°37'48"	Aug 19, 1991	1198	1	25.4	2	31.1-40.0
5517	Off Ensenada del Pabellón	24°16'24"	108°24'18"	Dec 15, 2000	1180-1200	5	25.3-37.3	4(1)	28.7-42.3(37.1)
5518	Southern Gulf of California	24°56'24"	109°05'36"	Aug 26, 2000	1200-1274	0		1	33.5
5534	Off Ensenada del Pabellón	24°15'18"	108°24'06"	Aug 25, 2000	1245	3	33.2-35.0	0	
5535	Southern Gulf of California	24°56'18"	109°11'48"	Dec 16, 2000	1280-1310	1	25.1	1	33.3
5536	Gulf of California	23°18'36"	107°27'56"	Mar 14, 2001	1050-1160	0		1	39.6
5966	Off Ensenada del Pabellón	24°16'12"	108°23'42"	Jun 7, 2001	1160-1180	4	24.3-35.0	3	25.1-32.6
5967	Off Isla Lechuguilla	25°43'50"	109°53'59"	Mar 17, 2001	1240-1270	6	31.7-35.5	2(1)	30.5-34.1(34.1)
5968	Southern Gulf of California	24°56'18"	109°06'42"	Mar 16, 2001	1190-1270	1	26.5	2	25.6
Southern Mexican Pacific									
8733	Off Lázaro Cárdenas	17°45'16"	102°00'29"	Mar 30, 2008	1198	2	30.6-34.7	1	20.0
8734	Off Guerrero	17°11'03"	101°28'05"	Mar 28, 2008	1180-1299	1	29.1	1	19.5
8735	Off Michoacán	18°33'43"	103°57'45"	Abr 1, 2008	1058-1088	2	21.4-24.2	2	21.7-24.2
8736	Off Colima	18°50'19"	104°34'14"	Abr 2, 2008	1101-1106	2	36.8-37.3	1	35.8
Western Baja California									
9826	Off western Baja California	24° 25'48"	112°38'06"	Jul 30, 2012	1212-1235	3	29.3-29.7	0	
9827	Off western Baja California	23°16'42"	110°54'55"	Aug 5, 2012	980-1036	3	24.4-26.3	4(1)	24.8-34.9(34.9)
9830	Off western Baja California	25°02'12"	112°54'06"	Jul 30, 2012	1210-1245	3	18.3-32.1	1	26.7
9829	Off western Baja California	23°12'02"	111°20'50"	Aug 4, 2012	1118-1150	3	27.5-33	4	20.3-30.7
9828	Off western Baja California	27°05'42"	114°35'30"	Aug 1, 2012	772-786	2	23.2-28.4	0	
Not in the collection									
	T VI-34 Off Isla Lechuguilla	25°43'50"	109°53'59"	Mar 17, 2001	1240-1270	9		4(1)	

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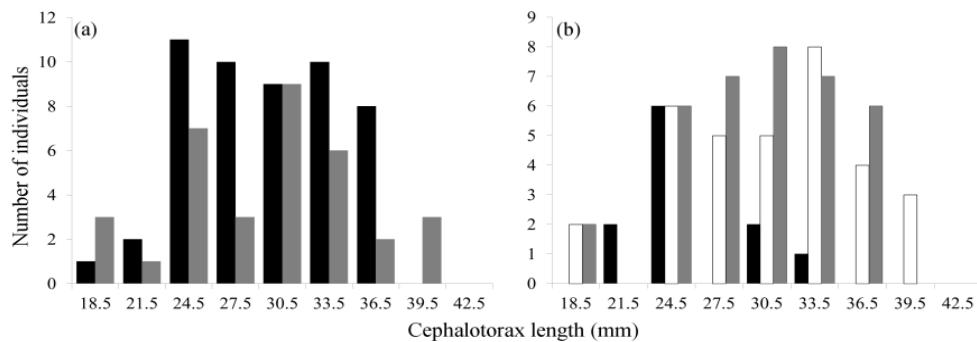


Figure 4. Cephalotorax length distribution (a) of males and females of *Nephropsis occidentalis* (black = males; grey = females) and (b) by depth range (black = 1001-1100 m; white = 1101-1200 m; grey = 1201-1300 m).

Environmental Variables

In the three areas where *N. occidentalis* was present, at depths greater than 700 m $T_{20\text{mab}}$ decreased with depth while both $O_{20\text{mab}}$ and $S_{20\text{mab}}$ increased with depth (Figure 5), the latter increasing very slightly. $O_{20\text{mab}}$ started increasing shallower on the slope off WBaja than in the GC and the SMPac. Patterns of $T_{20\text{mab}}$ were similar in the three areas, but $S_{20\text{mab}}$ was in general lower off WBaja. TOM_{sed} was not available for 15 samples (i.e., 9%). For the rest of data, both in the GC and the SMPac greatest values of TOM_{sed} were found at the shallowest depths sampled (ca. 700-900 m) (Figure 6). Below those depths, TOM_{sed} values were stable. Off the WBaja, TOM_{sed} values did not follow any bathymetric pattern and were generally lower than in the other two areas.

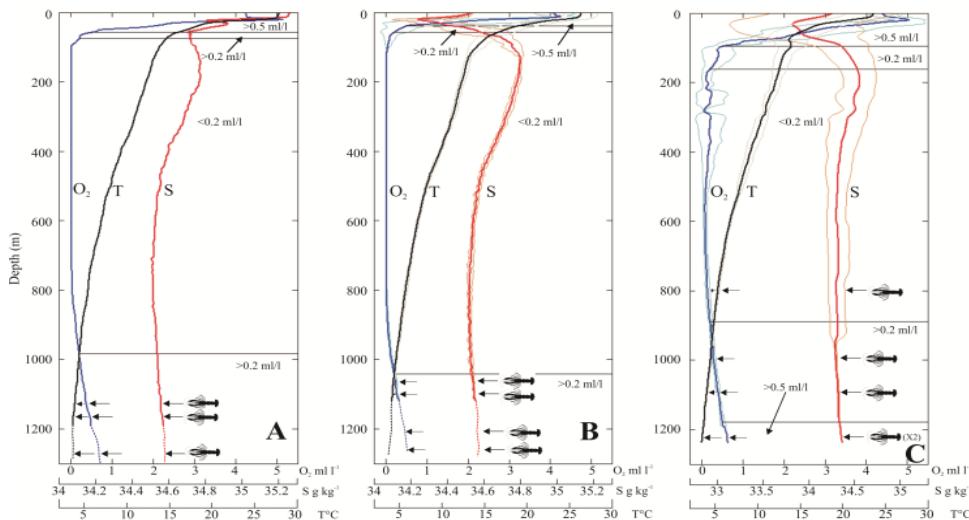


Figure 5. Bathymetric profiles of average (and standard deviation) temperature, salinity and oxygen measured for the three areas in which *N. occidentalis* was collected: (a) Gulf of California (Talud VII St. 19), (b) southern Mexican Pacific (TALUD XII St. 10, 13, 23, 28), and (c) western Baja California Peninsula (TALUD XV St. 8, 5C, 13, 2, 24). Upper and lower boundaries of the 0.2 and 0.5 ml l^{-1} dissolved oxygen concentrations (horizontal lines) OMZ and presence of *Nephropsis occidentalis* (arrows) indicated.

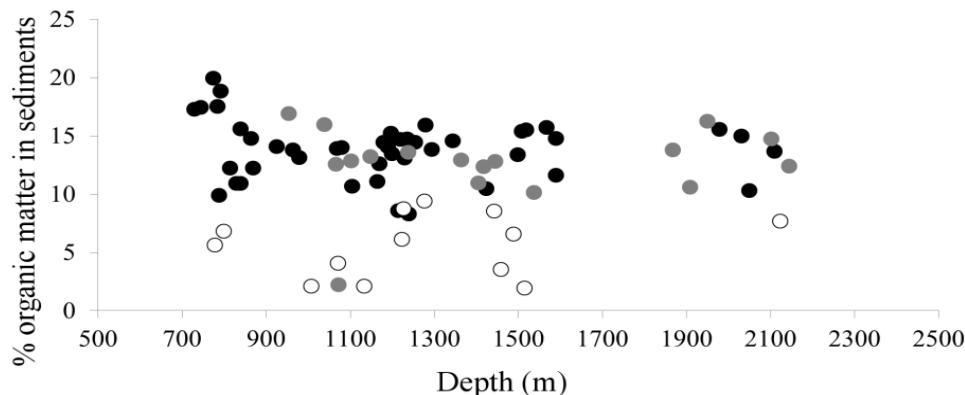


Figure 6. Percentage total organic matter in sediments by area (black = continental slope of the Gulf of California; grey=southern Mexican Pacific; white = western Baja California).

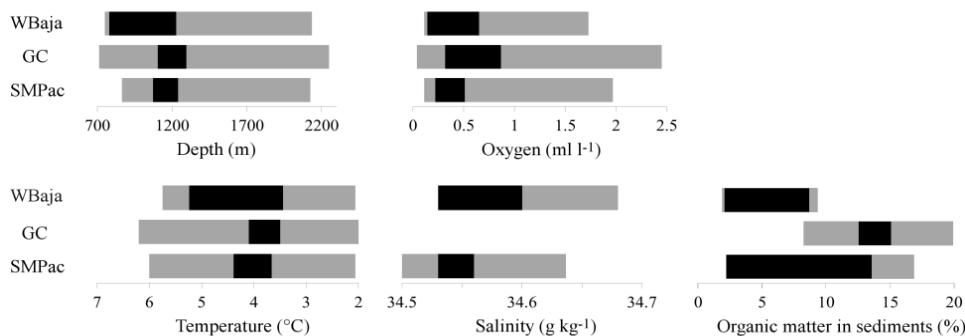


Figure 7. Ranges of depth, oxygen, temperature, salinity and organic matter in sediments sampled (light grey) and ranges corresponding to captures of *N. occidentalis* (98% of individuals captured: black; remaining 2% captured: dark grey). WBaja = western Baja California; GC = Gulf of California; SMPac = southern Mexican Pacific.

Ranges obtained for environmental parameters (Figure 7) indicate that *Nephropsis occidentalis* occurred over a relatively narrow oxygen range ($0.14\text{--}0.87 \text{ ml l}^{-1}$), although most specimens (98%; the two specimens collected at 779 m not being considered) were present at $O_{20\text{mab}} > 0.22 \text{ ml l}^{-1}$. Lowest oxygen concentration tolerated by *N. occidentalis* was similar in the three areas analysed. $T_{20\text{mab}}$ where *N. occidentalis* were collected ranged from 3.4 to 5.2°C (98% of specimens between 3.4 and 4.39°C). $S_{20\text{mab}}$ were not available for the continental slope of the GC. In the other areas, *N. occidentalis* was collected at $S_{20\text{mab}}$ between 34.53 and 34.60 g kg $^{-1}$. Regarding TOM_{sed}, both in the WBaja and at SMPac *N. occidentalis* was found from the lowest values measured (ca. 2%) to almost maximum values obtained (8.7% and 13.6%, respectively). In the GC, *N. occidentalis* appeared at greater values of TOM_{sed}, from 12.6% to 15.1%.

Drivers of Population Structure

The GLMs performed on the abundance data considering all samples explained 15% of the total variation (Table 3), with O_{20mab}, T_{20mab} and PPC-4 as the main drivers of abundance patterns of distribution.

Worldwide Distribution

A total of 61 records of *N. occidentalis* (Tables 2, 4) were compiled, 37 of which were unpublished records. Those confirmed that *N. occidentalis* is an endemic species of the eastern Pacific. The species is continuously distributed from the west coast of Baja California (27.1°N), Mexico, to Valparaiso (ca. 33°S), Chile, with confirmed captures from off the coasts of El Salvador, Nicaragua, Costa Rica, Panama, Ecuador, and Peru (Table 4; Figure 8). Considering all captures, *N. occidentalis* is restricted to depths greater than 700 m along its distribution range, except for two specimens collected at 533-569 m off Peru and a single specimen collected at 270 m off Valparaiso, Chile (33°S), coinciding with its southernmost distribution limit.

Table 3. Generalized linear models performed on abundance values of *Nephropsis occidentalis*

	Estimate	p	F	% Explained deviance
Intercept	1.24	<0.01		
O _{20mab}	-0.49	<0.01	0.023	5.39
T _{20mab}	-0.20	<0.05	0.016	6.08
PPC-4	0.13	0.07	0.08	3.23
Total explained deviance		14.70%		
AIC		99.58		

O = oxygen; T = temperature; 20mab = 20 m above the seabed; PPC-4 = phytoplankton pigment concentration four months before the sampling; AIC = Akaike's information criterion.

Table 4. List of worldwide records of *Nephropsis occidentalis*, other than those of the TALUD survey

	Depth range sampled (m)	Depth range captures (m)	Number of individuals captured	Number of hauls captures	Source
Mexico	22-3482	945-1236	32	5	(1) (2)
El Salvador	57-1368	1054	Unk	1	(3)
Nicaragua	122-1471	784-1116	Unk	5	(3)
Costa Rica	119-1530	836-1212*	Unk	6	(3)
Panama	108-1467	954	Unk	1	(3) (4)
Ecuador	500-1500	835-977	2	2	(5)
Peru	200-1500	700-1300	62	23	(6) (7)
Chile	Unk	ca. 270- 1000	5	3	(8) (9)

Unk = unknown. * = Depth range sampled for two hauls not known.

Source: (1) Faxon, 1893; (2) Manning, 1970; (3) J. López pers. comm.; (4) R. Vargas, pers. comm.; (5) Cornejo-Antepara, 2010; (6) Macpherson, 1990; (7) Kameya et al. 1997; (8) M. Retamal pers. comm.; (9) G. Guzman pers. comm.

The analysis of the bathymetric distribution of *N. occidentalis* with latitude revealed that shallowest depths of occurrence slightly decreased from north to south (Figure 9). Between latitudes of ca. 27°N to ca. 11.5°N organisms were found at ca. 1000-1300 m; between 11.5°N

and 11.5°S most samples were obtained at ca. 800-1000 m. At latitudes around 17°S organisms were distributed along a wider depth range, being observed from 800 to ca. 1250 m. The bathymetric distribution of the species somehow matched the profile of the OMZ described by Helly and Levin (2004) (Figure 9), this being especially noticeable in the U-shaped pattern of distribution from 27.1°N to ca. 6.5°N and in the relatively shallow samples collected at ca. 4°S at 551 m (depth range of haul 533-569 m) and at ca. 33°S at 270 m.

DISCUSSION

The distribution of a species depends on the influence of a variety of interacting abiotic and biotic factors both at the macro- and the mesoscale (Boschi, 2000; Sexton et al., 2009). Below OMZs, the interaction between dissolved oxygen concentration and food availability has often been discussed as the main driver of species' bathymetric distributions (e.g., Levin et al., 1991; Levin et al., 2009; Mosch et al., 2012; Levin and Sibuet, 2012). However, few studies have established direct relationships between fauna patterns and environmental drivers, especially regarding benthopelagic megafauna. The few existing works have usually been performed at the community level (Murty et al., 2009; Papiol and Hendrickx, 2016), and studies on population distribution and ecology are even scarcer (Jeffreys et al., 2012; Hendrickx and Papiol, 2015).

In this chapter the patterns of distribution of *Nephropsis occidentalis*, a benthic lobsterette living below the OMZ of the Eastern Pacific Ocean (Hendrickx, 2003), were analysed at the mesoscale level off Mexico, and the environmental factors controlling those patterns were explored. In addition, information on the distribution of *N. occidentalis* at the macroscale was compiled, and bathymetric patterns of distribution along latitude were investigated.

Mexican Pacific

Population Structure

Nephropsis occidentalis is a relatively large benthic decapod crustacean with a unimodal size distribution of the population off the Mexican Pacific ranging from 18.3 to 42.3 mm CL. Maximum size coincides with the specimen already reported by Hendrickx (2003), which constitutes the largest specimen known to date.

This lobsterette mainly inhabited depths between 980 and 1310 m, with oxygen concentrations above hypoxic values (i.e., > 0.2 ml l⁻¹; Kamykowski and Zentara, 1990), along the whole Mexican Pacific. Megafauna, such as crabs and shrimps, are rare where oxygen drops below 0.1 ml l⁻¹. Low swimming capacity benthic decapods (e.g., *Munidopsis* spp.; McAllen et al., 2005) with low metabolic rates (Company and Sardà, 1998) proliferate below the OMZ cores at water with oxygen concentration below 0.2 ml l⁻¹ (e.g., Wishner et al., 1990; Murty et al., 2009; Papiol and Hendrickx, 2016), and more mobile taxa with higher metabolic demands for oxygen are usually found in water with higher oxygen concentration. Although *N. occidentalis* is a benthic species with little natatory ability, *Nephropsis* is a very active genus (McAllen et al., 2005). Therefore, high metabolic requirements of *N.*

occidentalis probably exclude it from hypoxic water and its distribution is restricted to depths greater than ca. 1000 m, where water is more oxygenated. Surprisingly, two individuals were recorded in a haul performed at depths of 772-786 m and oxygen concentration of 0.14 ml l⁻¹. Temporal excursions into less oxygenated waters for escaping predators or finding food have been observed in other species (Gooday et al., 2009) and seem a plausible explanation for this finding, as some Nephropidae are known to be adapted to short periods of hypoxia (Eriksson et al., 2013).

The peak in abundance of *N. occidentalis* in the lower limit of the OMZ core and its distribution within a narrow depth range of ca. 300 m is somehow parallel to the pattern of distribution observed for decapod crustaceans below OMZs in other regions (e.g., Wishner et al., 1990; Murty et al., 2009). Aggregations of organisms below OMZ cores have been attributed to the large accumulation of food in these areas. The restriction of *N. occidentalis* within such a narrow depth range could be driven by the parallel restriction of its food source to this stratum. It is likely that *N. occidentalis* is sustained by benthic and benthopelagic macrofauna that peak in narrow bands below OMZ cores (Wishner et al., 1995; 2008; Mosch et al., 2012), as the species' powerful chelipeds and the presence of polychaetes, decapod crustaceans, and fish remains in their stomachs (authors' unp. data) suggest it is an active predator on macrofauna. The paucity of macrofaunal prey at greater depths (Wishner et al., 1995; Levin et al., 2000; Mosch et al., 2012) could cause the parallel disappearance of *N. occidentalis*.

Although the low number of organisms available forces cautious interpretation of the data, results suggest that within the narrow bathymetric range of distribution of *N. occidentalis* there was size structure in which larger individuals were restricted to depths greater than 1100 m. Bathymetric size segregation within a given habitat is usually attributed to food availability together with how species exploit existing food resources (Rowe, 1971; Carey, 1981). The depth pattern observed in *N. occidentalis* could be associated with the presence of different potential food sources (i.e., prey items) through the depth gradient (Wishner et al., 1995; Levin et al., 2009) coupled with ontogenetic variations that could take place in the diet of *N. occidentalis*, as reported for other Nephropidae (e.g., *Metanephrops thomsoni*; Choi et al., 2008).

Notwithstanding the relatively large range of sizes collected, all specimens obtained during the TALUD surveys were adults. Although the selectivity of the gear mesh size is biased towards capturing medium to large-size individuals, small specimens (i.e., <15 mm total length) of other species (e.g., *Galacantha diomedae*, *Munidopsis* spp.,) have been regularly collected using the same net (authors' pers. observ.). The bathymetric distributions of smaller specimens of *N. occidentalis* as well as their recruitment patterns remain therefore unsolved, as occurs with the majority of decapod crustacean species from below OMZs. Little is known about the occurrence of larvae or juveniles of deep-water decapod crustaceans in general and specially within or below the OMZ off the Mexican Pacific (see Hendrickx and García-Guerrero, 2007; Thatje et al., 2005). Besides, only three ovigerous females were obtained, ranging from 34.1 to 37.1 mm CL, which is very close to the maximum known size of the species (42.3 mm CL). These eggs-carrying females were collected in March, August and December, an indication that reproduction probably occurs all year-round.

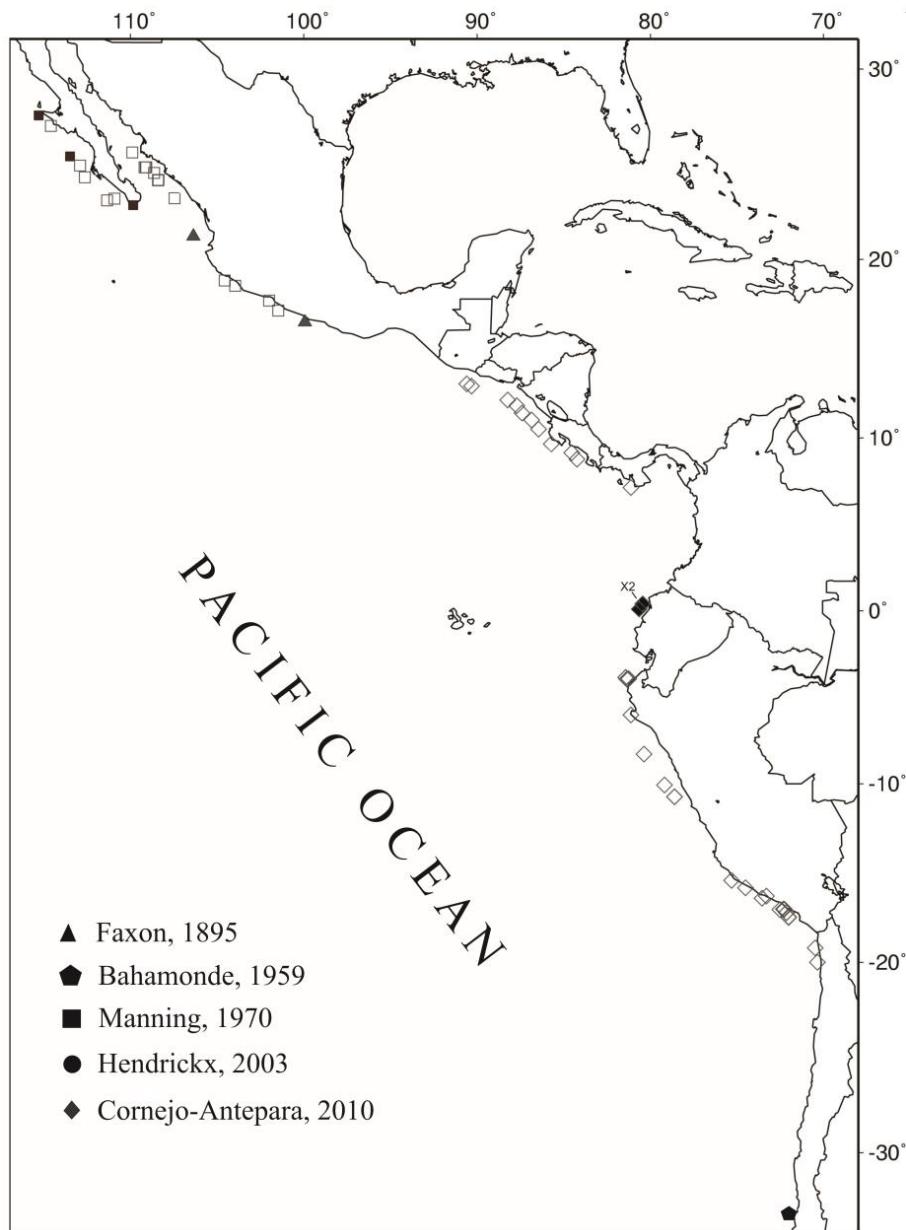


Figure 8. Distribution of *N. occidentalis* in the eastern Pacific including previously published records (solid symbols) and additional records (open symbols). See Tables 2 and 3.

Environmental Drivers of the Distribution of the Pacific Lobsterette

A large amount of variation was not explained by the models obtained in our study, probably due to the complex and very patchy distribution of megafauna in the Mexican Pacific (Méndez, 2007; Papiol and Hendrickx, in press), which is likely enhanced by the clustering of burrows observed in some species of Nephropidae (Dybern and Höisaeter, 1965). Besides, the availability of information on some additional variables (e.g., salinity, prey availability, or $\delta^{13}\text{C}$ of sediments) that have been identified as important drivers of

decapod crustaceans' distribution in other studies (Murty et al., 2009; Papiol et al., 2012; Fanelli et al., 2013) could contribute to increase the amount of variation explained in our models. However, combined effects of both oxygen and temperature partially controlled the distribution of *N. occidentalis* over the depth gradient. As mentioned above, metabolic rates associated with activity level of a species somehow define its minimum oxygen thresholds. Coherently, the active *N. occidentalis* is excluded from hypoxic environments. Also, the positive influence of temperature on metabolic rates (Childress et al., 1990) likely reinforces the exclusion of *N. occidentalis* from shallower, less oxygenated, warmer waters. In addition, aerobic capacity and temperature tolerance are interdependent processes within most ectothermic animals. There are both high and low species-specific critical temperatures that lead to tissue hypoxia through limited ventilation and circulation performance (Frederich and Pörtner, 2000; Pörtner, 2001; Ekau et al., 2010). In the Mexican Pacific, the optimum temperature range for aerobic performance of *N. occidentalis* seems to be between ca. 3 and 5°C at dissolved oxygen concentrations of between 0.87 and 0.22 ml l⁻¹.

Within OMZ areas, the interaction between oxygen and food availability has often been discussed as main driver of species' distribution. In the present chapter the foremost importance of food was not patent, most probably due to the lack of adequate food indicators (e.g., $\delta^{13}\text{C}$ composition of sediments or biomass of potential prey; Murty et al., 2009; Fanelli et al., 2013). However, food inputs generated at surface favoured aggregations of *N. occidentalis* four months later. The relationship between fauna patterns and surface production is coherent with the occurrence of short food chains (Fanelli et al., 2013) that have been proposed below OMZ cores (Wishner et al. 1995). Zooplankton taxa potentially inhabiting the lower boundary of the OMZ (Wishner et al., 1995; 2008; Roullier et al., 2013) likely channel the fresh organic matter sinking from surface to megafauna (Fanelli et al., 2011).

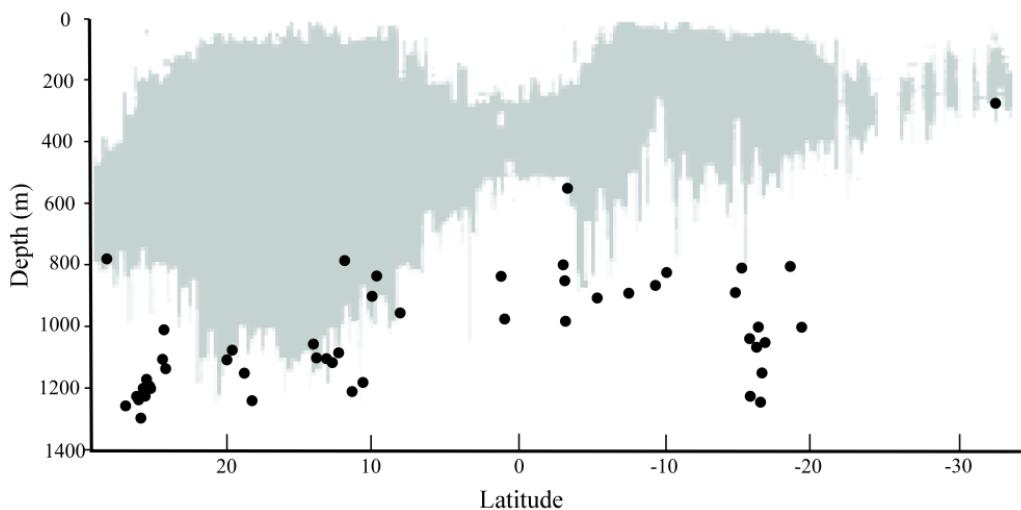


Figure 9. Bathymetric distribution (●) of *Nephropsis occidentalis* along a latitudinal gradient from Mexico to southern Chile. The depth range of the OMZ corresponding to upper and lower values of $\leq 0.5 \text{ ml l}^{-1}$ is indicated (grey) (adapted from Helly and Levin, 2004).

Worldwide Patterns of Distribution

The latitudinal range of distribution of *N. occidentalis* was not expanded with respect to previous knowledge, but the 37 additional records compiled in the present chapter confirmed that the species is continuously distributed all along a very large section of the continental slope off western America, from ca. 27°40'N off Baja California, Mexico, to ca. 33°S, off Valparaíso, Chile. Most works dealing with invertebrate zoogeographic regionalization at the macroscale have been performed on littoral and shelf areas (e.g., Brusca and Wallerstein, 1979; Boschi, 2000; Castillo and Guiñez, 2000), and some studies have been performed at hydrothermal vents (Won et al., 2003; Wolff, 2005) and seamounts (Samadi et al., 2006). Despite the relative scarcity of deep-water samplings, Wicksten (1989) investigated zoogeographic provinces based on decapod crustaceans occurring from 50 m to depths greater than 1500 m. Both shallow and deep-water studies coincided in the segregation of the ocean margin from California to central Chile into several provinces characterised by different species (Wicksten, 1989). *Nephropsis occidentalis* is distributed along this entire coast, and thus its distribution is considered particularly wide.

To our knowledge, *N. occidentalis* has not been reported further north or south of the range reported herein, thus some biotic and/or abiotic factors must be preventing the species' expansion beyond these geographical limits (Sexton et al., 2009). Among those factors, the most important usually listed are the geological history of each area, topographic barriers, physical-chemical gradients, and biological factors (Briggs, 1974; Vermeij, 1978; Wicksten, 1989). The northern and southern limits of distribution of *N. occidentalis* are related with the inflow of low salinity intermediate water masses (i.e., the North Pacific Intermediate Water, NPIW: Fiedler and Talley, 2006; and the Eastern South Pacific Intermediate Water, ESPIW: Schneider et al., 2003). The inflow of the NPIW in the north is coherent with the lower salinity and its greater oscillations observed in the southern Baja California in this study (see Figure 5). We hypothesize that the changes in the salinity due to the presence of haline fronts could be above the tolerance limit of *N. occidentalis*, constituting a barrier for the dispersal of the species. Small changes in the physical properties of the environment especially affect species living in the deep sea, where the environment is usually stable (Gage and Tyler, 1991). Although the salinity minima of both water masses (NPIW and ESPIW) are located shallower than the range of distribution of *N. occidentalis*, they could still be affecting the distribution of their planktonic larvae.

Inside the Gulf, the distribution of *N. occidentalis* was limited to the continental side of the slope. The sedimentary and less precipitous character of the continental shelf and slope contrasts with the steep and calcareous rocky nature of the peninsular coast (Shepard, 1950; Thunell, 1998), and may provide more suitable habitat for burrowing decapods such as *N. occidentalis*.

Our results (both by Winkler and CTD) suggested a deeper location of the lower boundary of the OMZ ($O_2 = 0.5 \text{ m l}^{-1}$) for the Mexican Pacific than that reported by Helly and Levin (2004). Nevertheless, the latitudinal pattern of the shallowest depth of collection of *N. occidentalis* was somehow parallel to that of the lower OMZ boundary, with a southward trend of shallower collection of *N. occidentalis*. This distribution pattern is consistent with the above discussed importance of oxygen concentration as a limiting factor for *N. occidentalis* proliferation below the OMZ. In addition, *N. occidentalis* was usually distributed over narrow bathymetric ranges, likely due to the edge effect at the OMZ lower boundary, as described above. In contrast, at latitudes of 15-19°S *N. occidentalis* occupied a relatively wide

bathymetric range. There is no clear explanation for this. The OMZ edge effects caused by the food accumulation and rapid transformation may be significantly reduced in this area where the OMZ is less intense, and there could be no need for *N. occidentalis* to adapt to this particular landscape. However, many other environmental (biotic or abiotic) factors could be causing this different distribution, and further studies would be required to clarify this issue.

Fishery Potential

With a worldwide increasing interest for new fishery resources in deep waters (Roberts, 2002; Norse et al., 2012), many species of decapod crustaceans that had been traditionally ignored are now regarded as potentially important. The “langoustines,” “lobsterettes” or “scampi” are no exception to this and recent surveys have been undertaken in order to evaluate the stocks and gather information on their biology (Lynch and Garvey, 2005; Choi et al., 2008; Paramo and Saint-Paul, 2012; Robey et al. 2013). In the specific case of the genus *Nephropsis*, Pequegnat and Pequegnat (1983) reported three species in the Gulf of Mexico. Densities (orgs ha⁻¹) varied considerably according to depth and from one species to another. *Nephropsis agassizii* was collected in depths of 900-1600 m with maximum density (ca. 200 orgs ha⁻¹) observed at 950 m. *Nephropsis aculeata* occurred in depths of 350-1350 and ranked second in population density (maximum of ca. 100 orgs ha⁻¹ at 500 m). The third and less abundant species, *N. rosea* (ca. 25 orgs ha⁻¹), was also the shallowest (500-750 m) with population peak at 700 m. Guéguen (2000) reported *N. aculeata* (321-491 m depth) and *N. rosea* (547-854 m depth) as two of the major species of decapod crustaceans from off the coast of Guyana, with catch per hour of trawl comprised between ca. 23 and 637 g. *Nephropsis aculeata* has also been reported as an abundant species off the Mississippi river and East Florida, with captures of up to 40 kg h⁻¹ (Holthuis, 1991). This species is distributed at depths of 137-824 m in the Gulf of Mexico, Caribbean Province and extended to the north off Massachusetts. Another species that has recently caught the attention is *Nephropsis carpenteri*, occurring around India and Japan. This forms part of the by-catch of the deep-sea shrimps’ fishery (e.g., *Aristeus*, *Solenocera*, *Metapenaeopsis*, *Heterocarpus*) off Chenna, India, and represents up to 40% of total catch with maximum size of 154 mm total length (Thirumilu, 2011). Morphometric relationships and fishery aspects of the Indian Ocean lobsterette *Nephropsis stewarti* have been documented by Dineshbabu (2008) for the SW coast of India. The species is fished between 250 and 500 m and yields an average annual catch of 23.3 t, with a sharp decrease after a peak of captures in 2001-2002, and is processed together with scyllarids lobsters and mostly exported. A survey in the same area in 2006, however, indicated that *N. stewarti* might have a very limited importance because catches are restricted to a rather reduced area (Jayaprakash et al., 2006). Small catches of *N. stewarti* of up to 0.5 kg h⁻¹ of trawl have also been reported off Madagascar (Crosnier and Jouannic, 1973). Although the maximum size of this species is greater than that of *N. occidentalis* (total length 113 mm in males, 158 mm in females), almost 90% of the catch corresponded to specimens with a length range of 80-105 mm, similar to what has been observed with *N. occidentalis*.

Because information related to the abundance and distribution of *N. occidentalis* in the eastern Pacific is still very limited, it is difficult to evaluate if a profitable fishery could be initiated. Holthuis (1991) referred to a potential interest for this species off the coast of Chile

and Retamal (1977) reported this lobsterette as a common by-catch of the *Heterocarpus reedi* fishery. Almost 40 years after this report by Retamal (1977), no fishery has apparently been developed for *N. occidentalis* off Chile (G. Guzman, pers. comm., 2014; M. Retamal, pers. comm., 2014) and captures of this species have been incidental, with only a few specimens available in museums collections (Table 2). Although it is likely that *N. occidentalis* still forms part of the *H. reedi* fishery (that produced a total capture of ca. 4,350 t year⁻¹ from 2006-2010) (Wehrtmann et al., 2012), no specific information seems to be available on the potential use of this lobsterette in the area or on its ecology (P. Arana, pers. comm. 2014).

Bottom trawling is the major fishery in deep-sea habitats (Kaiser et al., 2002), and technical advances in the last 6 decades have allowed the exploitation of these habitats (Thiel, 2003; Clark et al., 2007; Benn et al., 2010). For example, in the Mediterranean Sea, deep-water bottom trawling targeting *Aristeus antennatus* (400-800 m) is common (Cartes and Sardà, 1989; Cartes et al. 2008). However, it is well known that trawl fisheries have an enormous environmental impact, which is especially notable on deep-water communities (Gray et al., 2006; Althaus et al., 2009, Maynou and Cartes, 2011), and any intention to switch part of the current fishery activity in that direction should be carefully evaluated. Besides, in the particular case of western Mexico, targeting deep-water crustaceans or other deep-water species (e.g., Holothuroidea, Macrouridae) occurring below the OMZ would imply deployment of fishing gear at depths greater than 700-800 m in most areas, a costly operation with few guarantees of sustainability.

OUTLOOK

The investigation on the distribution and ecology of decapod crustaceans living below OMZ areas is still in its early stages, and further studies are not only necessary but urgently required in order to understand the role of each species within the communities. Additional multidisciplinary studies encompassing samplings of biotic and abiotic data are essential in order to better understand the distribution of *N. occidentalis*. However, considering that both oxygen and temperature are drivers of the bathymetric distribution of deep-water decapods, there is a potential susceptibility to the global pattern of expansion of OMZs resulting of climate change. Consequently, the study of deep-water communities in these areas should be considered a priority.

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Chapter 8

SEA TURTLES AS ECOSYSTEM INDICATORS: SITUATION IN MEXICO

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ABSTRACT

Sea turtles are migratory vertebrates that are linked to many coastal and marine habitats in different parts of the world depending on the stage of their life cycle. These agencies have given them a higher value as a sentinel species by characteristics such as longevity, size, resilience to environmental changes of the seas, and even changes induced by humans as environmental pollution. One of the main risks to sea turtles is drowning in gill nets or trawl fisheries used in flake or shrimp; it has been extensively analyzed in different regions of the country and the world. However, the effects of environmental pollution on the health of sea turtles is the least studied. The environment has been altered dramatically in recent years by rising temperatures, increased severity, and frequency of storms and rising sea level, where most human settlements have been deforested and changed land use for urban, port and tourist developments. In the case of turtles, these changes affect species differentially throughout his life. For example, climate change and temperature variations can affect the sex ratio of the hatchlings and nesting patterns since they depend on healthy beaches to lay eggs, so the migration patterns of females could be affected significantly by climate change. The dependence of sea turtles of seagrass meadows, mangrove forest, rhodolith beds, Sargassum forest, coral reefs and deep ocean to live, give them the importance of indicators of the environmental health of these ecosystems. Understanding how pollution and climate change may affect these ecosystems not only benefit conservation programs of populations of sea turtles, but also the diversity associated with them. On which they depend on millions of people living along the shores of the world using marine resources and ecosystem services for their economic activities and food safety.

INTRODUCTION

Several studies claim that over-exploitation of fishery resources, climate change, environmental pollution, and the resulting acidification of the oceans, threatening marine ecosystems. Some of the most common contaminants derived from human activity are pesticides, herbicides, chemical fertilizers, detergents, hydrocarbons, sewage, plastics and other solids. Many of these pollutants accumulate in the deep ocean, except plastic that accumulates mostly on the surface, where they are ingested by small marine organisms introduced in the global food chain (Beltran et al. 2005). The threat of extinction faced by sea turtles worldwide has meant that today all species are included in Appendix I of the resolutions of the Convention on International Trade in Endangered Species of Flora and Fauna Threatened (CITES 2001). The International Union for Conservation of Nature and Natural Resources (IUCN 2006) lists all species and subspecies of sea turtles in danger of extinction, with three of them in critical condition: the olive ridley (*Lepidochelys kempii*), hawksbill turtle (*Eretmochelys imbricata*) and the leatherback turtle (*Dermochelys coriacea*), while the Endangered Species Act of the United States and the Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC) regards them as threatened or endangered. In Mexico, the degree of threat and protection of sea turtles is established in the Mexican Official Standard NOM-059-ECOL (Official Journal, September 2010) while regulations for handling and care laboratory are reflected in NOM -162-SEMARNAT (February 2012).

A species that can illustrate the serious threat that hangs over these agencies is the hawksbill turtle. Exploitation that has made this kind of the value of its shell has caused a reduction in global population by over 80% in the last 105 years, and it is expected that this reduction will continue in the near future due to the activities of gathering of eggs in nesting areas, capture of juveniles and adult individuals for consumption, incidental killing in fishing gear (Gardner and Nichols 2001) or ship strikes both fishing tourism, intensely still happen in different areas where these organisms are distributed. The concern generated by this decline is reflected in different publications like Groombridge and Luxmoore (1989), the volume dedicated in 1999 by the journal Chelonian Conservation and Biology at depth examination of this kind, the “Status Listing Justification for the Hawksbill Turtle (*Eretmochelys imbricata*) as Critically Endangered on the 1996 IUCN Red List of Threatened Animals” by Meylan and Donnelly (1999) and “Status of the Hawksbill Turtle (*Eretmochelys imbricata*) in the Caribbean region” by Meylan (1989).

Currently, it is considered that only five populations exist hawksbill more than 1,000 nesting females annually in the Republic of Seychelles (Indian Ocean), Mexico, Indonesia and two in Australia. Four of these populations (Indonesia, Seychelles and in Australia) show a declining trend. The government of Australia has described the hawksbill populations in its territory as vulnerable; they are considered as the largest populations in the world (CITES 2001). In the last document prepared by the group of experts of sea turtles IUCN/SSC, it is mentioned that worldwide, only Mexico remains positive trends in population recovery (Guzman-Hernandez, 2005) as a result of more than ten years of protection. Cases like that of Mexico show that populations of this species may react positively to programs of long-term preservation (Frazier 2000).

BIODIVERSITY OF SEA TURTLES IN MEXICO

Mexico is considered one of the countries with the highest diversity of reptiles in the world and is considered as an important example sea turtles (Carabias et al. 2005). In the coast are six of the seven species in the world: the olive ridley (*Lepidochelys kempii*) that nests on the coasts of Tamaulipas and in small quantities in the coast of Campeche; hawksbill turtle (*Eretmochelys imbricata*) nesting on the coast of Campeche, Yucatan, Quintana Roo and another Pacific and Atlantic is the largest (Mortimer or Marquez or both) population, the green turtle (*Chelonia mydas*) whose records are in the Gulf of Mexico, Caribbean Sea and the Pacific; the loggerhead turtle (*Caretta caretta*) and the leatherback turtle (*Dermochelys coriacea*) nesting in the Caribbean and Pacific coasts. Since 1993, year in which the dramatic decline of the latter species was observed, actions were initiated along the Mexican Pacific coast looking for possible causes of this decline. For it was signed in 2003 the Tri Convention for the Recovery and Conservation of the Leatherback Turtle in the Eastern Pacific with the main objective to design and establish measures for the conservation and recovery of the stock of Eastern Pacific Leatherback and habitat which it depends, based on the available scientific evidence into account the environmental, socioeconomic and cultural characteristics of the parties. In that agreement it provides that, for the recovery of lutes, should be given full attention to terrestrial factors (alteration and destruction of nesting beaches, illegal collection of eggs, etc.) and marine (mainly the result of fishing activities and pollution), as well as playback or presence of the olive ridley (*Lepidochelys olivacea*) and the black turtle (*Chelonia agassizii*) whose nests are recorded in the Pacific (Marquez 2002; Guzman-Hernandez 2005; Sarti et al. 2007).

THREATS TO SEA TURTLES

Turtles have certain characteristics that make them particularly vulnerable to environmental disturbances such as:

CLIMATE CHANGE

In our country, it lives about 10% of the diversity of the planet, so it is considered a megadiverse country. The causes of this loss of biodiversity may be falling into two broad categories: 1) immediate causes: habitat destruction and fragmentation, overexploitation of wildlife resources, invasive species, pollution, and 2) structural causes: human population growth and consequent increase in resources mainly for food (Hawkes et al. 2006).

Urban and tourism development that has been taking place in coastal areas where turtles lay their eggs has caused problems at that stage of the life cycle. Buildings such as hotels, breakwater, fillers or sand extraction sites; as well as the elimination of the natural vegetation of the dunes, causing high erosion or soil depletion and affects suitable for sea turtles (Figure 1) environmental conditions.



Figure 1. Playa El Suspiro Turtle camp at Cabo San Lucas, BCS, under the effects of tropical storm Paul 2013.



Figure 2. Contamination by vegetation carried with the water in Playa el Suspiro, Los Cabos B.C.S. México after the storm “Norman” September 2012.

Van Houtan and Halley (2011) showed evidence supporting the damage of climate change on sea turtles. One of the consequences of climate change will increase the frequency and intensity of storms and hurricanes; events seriously harm sea turtles (Van Houtan and Bass 2007). There will also be a loss of their nesting sites as a result of sea level rise caused by climate change (Reece et al. 2013). The damages suffered by turtles are not limited to the

influence of the marine environment, but also to the land portion due to the need of land areas to spawn. Global changes in land use and poor logging practices, biodiversity impact and generate a large amount of organic waste that is carried by rivers to the sea (Fitzherbert et al. 2008). This shift logs and other organic waste can cause side impacts on multiple ecosystems (Foley et al. 2007). One of those ecosystems is the sandy beach where waste spewing from ocean currents and sea barriers are parallel accumulate. An excess of this type of plant residues can alter the nesting sea turtles and the survival of newly hatched individuals on their way from the nest to the sea (Figure 2). However, detailed studies of the effect of organic matter accumulated on beaches on nesting behavior and survival of nests and hatchlings of sea turtles are still as rare as needed on nesting beaches (Quinones et al. 2007).

Pollution

Jakimska et al. 2011b mentioned that turtles are exposed to many pollutants. Pollution is a negative outcome associated with the socioeconomic and technological development of humanity as one of the biggest problems that this development present is the generation of chemicals in various industrial activities have accelerated in recent decades. Some of these substances are released into the environment as byproducts of other processes and are used in different farming and crop protection (Kampalath et al. 2006). The seas and coasts are most affected since most of these chemicals eventually reach the sea. The seas not only receive the discharge of sewage and agricultural activities, but they are also dumped radioactive waste and much rubbish (and Vanegas Espina 2005). Currently there are some studies that have explored the effects of various pollutants on the health of marine turtles and their populations; among them we can mention the research conducted by Fitzgerald (2004) and Act-Quinonez et al. (2009) who determined the presence of heavy metals in marine turtles in northwestern Mexico; Morales-Rodriguez and Cobos-Gasca (2005) used as a biomarker to *Eretmochelys imbricata*, omnivorous species up to the beaches of Campeche each year to lay their eggs, to evaluate the temporal variation of the concentration of DDT and DDE between 1999 and 2000. Rosales et al. (2011) worked on understanding the role of chorioallantois in retaining organochlorine pollutants (pesticides) and their relation to other environmental variables: plasma sediment and olive ridley sea turtle (*Lepidochelys olivacea*) Baja California South. While Labrada and colleagues (2011) are evaluated the health status of the eastern Pacific green turtle (*Chelonia mydas*) inhabiting the coast of Baja California Sur, through physiological biomarkers. Thus, we can see that all these research highlights the extent of contamination affecting sea turtle populations.

Pesticides

Persistent organic pollutants (POPs) are organic compounds mostly man-made and characterized by its presence worldwide, its stability, the slower biodegradation, their accumulation in fatty tissues and its long half-life, van de Merwe and colleagues in 2010 showed damage *Chelonia mydas* embryos because of Persistent Organic Pollutants (POPs). Polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCs) and dichlorodiphenyl-trichloroethane (DDT) and its derivatives have contaminated many environments,

including oceans (Moore et al. 2002; Labrada et al. 2011), spread over all geographic regions because of its intensive use in agricultural and industrial activities. PCBs, as persistent organic compounds with a relative mobility, are among the chemicals that can reach any region that this is remote (Moore et al. 2002; Keller et al., 2004). Currently, atmospheric transport is recognized as the leading cause of dispersion and the primary source of pollution in the polar regions and the open sea. However, CBs continue to be detected in different environmental samples and animal tissues besides their use continues in some countries development due to lack of effective regulation (Godley et al. 1999, McKenzie et al. 1999; Lazar et al. 2011; Rosales et al. 2011).

Hydrocarbons

The study of oil pollution in the oceans and coastal areas, faces two opposite aspects of human activities: 1) the alteration of marine and coastal ecosystems caused by mining operations, refining, transportation, storage and use of oil as the main source of energy, and 2) the undeniable need to preserve and protect marine resources for our current uses and future generations (NAS 1985; Botello 2005). The exploration and extraction of hydrocarbons at sea pose a serious threat to sea turtles to stop their activities foraging and nesting habitat destruction seriously. Dredging not only destroys habitat but incidentally may cause serious injury or even kill sea turtles. The oil in the skin and shell of a sea turtle can affect breathing functions and salt gland and blood chemistry. When the oil slick reaches the beach, this is pasted into each grain of sand and rock affecting the turtles on the beach, at sea or in the sand where they lay their eggs. The latter is polluted and affected the development of embryos, on the other hand, at hatching, the chicks are also contaminated by the oil is on the beach (Figure 4). Ingestion of pellets tar is also of concern that the tar balls are the second most common type of debris ingested (NMFS/FWS 1992, 1998).

Spills in the Gulf of Mexico del Pozo Ixtoc-I off the coast of Campeche deserve special measurement. This spill was considered the largest in the world, because for nine months over 3'100,000 barrels of crude oil in marine waters (Botello 2005) were spilled. The oil spill from the platform of British Petroleum (BP) in April 2010 in this area affected the five species of turtles Lora (kemp's Ridley sea turtle), white (*Chelonia mydas*) loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*) and hawksbill (*Eretmochelys imbricata*). Of the seven known species of sea turtles living today, five live in the Gulf of Mexico (Fomix 2010). Sea turtles are not only damaged by direct losses. The daily consumption of petroleum products from shipping, burning coal and wood, as well as combustion motor, producing similar polycyclic aromatic hydrocarbon content of crude oil (Botello 2005).

Heavy Metals

The accumulation of heavy metals in marine life is of great interest because of the potentially toxic effects that these elements may cause, especially predators located in the highest parts of the food chain (Ley-Quiñónez et al. 2011) as the turtles.

Sewage and Garbage

It found the presence of debris such as plastic, Styrofoam, string, rubber, glass, metal, paper and woven in the stomachs of sea turtles are being transported by sea currents fibers. When ingested, these wastes can obstruct the digestive tract, causing health problems such as infections or death (Lazar and Gračan 2011).

Damage Caused by the Lights on Nesting Beaches

Alteration of nesting habitat has increased significantly (Witherington 2000). The beaches have been the pressure of growing demand (Chacon and Arauz 2001) for the development of tourism activities, construction of hotels, restaurants and residences (Lutcavage et al. 1997, Parra 2002), involving changes in the physical structure and an increase artificial light (Chacon and Arauz 2001). It has been documented that artificial lighting on nesting beaches affect sea turtles and produces disorientation of hatchlings emerging who diverted their way to the sea to follow the light signals (Kamrowski et al. 2012).

Other threats caused by the presence of man in the turtle habitat are the presence of domestic animals such as pigs, cats and dogs can become predators of eggs and chicks, and the use of motorized vehicles on beaches which crush eggs and hatchlings in addition to compact the sand difficult and output spawning nests (Day et al. 2007). Anthropogenic impact and beach erosion significantly impact the complex and delicate coastal and marine ecosystems, contributing significantly to the reduction of nesting habitat and therefore on populations of these organisms, since the females return to their natal beaches to nest (Márquez et al. 2007).

With these processes of biomagnification (being predators stops) and bioaccumulation (being lived animals), we can estimate the type and degree of exposure that are subject populations and from there information of interest for conservation and/or survival. It is known that sublethal exposures for extended periods of time can cause long-term toxic effects, such as reproductive disorders, decreased the ability of the immune defense system against infections and infestations, nervous and behavioral alterations and an increased risk of developing certain cancers (López-Castro et al. 2010; Ley-Quiñónez et al. 2013). These effects have been described in a considerable number of species, both terrestrial and marine, which leads us to believe that similar effects are also observed in marine turtles (García-Fernández et al. 2009; Páez-Osuna et al. 2010).

We start by defining marine pollution, biomarkers and sentinel species. Many of these terms can refer to several concepts, however, use the more accepted. Marine pollution is the introduction of substances and energy by the entry of water used for cooling industrial plants in the marine environment, which is harmful to live resources, it constitutes a risk to human health, harm marine activities as fishing damages the quality of sea water and reduces recreational activities (definition proposed by the experts of the United Nations (GESAMP 1980). The biomarkers are living organisms that are exposed to contaminants, or that may be useful for predict future damage and even may themselves present harmful effects. The context in which a biomarker falls to be interpreted in the biochemical, physiological, morphological or behavioral level (Badii-Zabeh et al. 2005, Cajaraville et al. 2000). The

species bioindicators used to detect environmental changes through a stress response that can be extended to other groups. They are used to reflect the biotic or abiotic state of the environment, reveal evidence of impacts caused by environmental changes or to indicate the diversity of other species, groups or communities in an area (Tabor and Aguirre 2004; Badii-Zabeh et al. 2005, Rendon 2005). Tabor and Aguirre said in 2004 that the use of biomarkers in the diagnosis of alteration of ecosystems has several advantages: a) the response of biomarkers can indicate the presence of pollutants biologically available, b) with a suitable battery set or biomarkers You can ascertain the presence of pollutants that had not been considered, c) can detect intermittent pollution events and integrate in time and space exposure, d) they can detect induced by complex mixtures of pollutants effects. In many cases, the use of biomarkers is much easier and cheaper to implement than other options, such as chemical analysis (Handy et al. 2003). Mayer et al. 1992 states that it is necessary to know the biochemistry and physiology of the organism, set the size and reproductive status, which is simple sampling, which is available in sufficient number and ages, know their trophic level and mainly delivering social and ecological importance. This is necessary to give a complete diagnosis of the condition of the body, and that serves to monitor environmental problems.

They can give examples of sea turtles as sentinels, so we have the leatherback turtle that may be a biomarker of changes in the short and long term food networks and the availability of resources in the overexploited marine ecosystems (Saba et al. 2008; Fossette et al. 2010). They are used to monitor the effects of dredging (McRae 2014).

Sea turtles: Sentinels of Climate Change: Temperature determines the sex of the turtles. An increase in the average temperature could cause a bias in the sex ratio that could be used as evidence of climate change. The increase of air temperature will advance the date of nesting (Weishampel et al. 2004). The use of stable isotopes to identify the foraging area for turtles. Changes of places to eat in conjunction with the measurement of other variables can be indicators of climate change (Rodriguez Baron 2010; Strang et al., 2012.).

Sea turtles: Sentinels of pollution contaminants Biocumulan (Jakimska et al. 2011a, 2011b.). Since a correlation was found between fibropapilloma tumors and highly polluted areas, it has been proposed to the disease as contamination indicator (Aguirre et al. 2004). The fibro papilloma tumors can cause weakening and eventually death of turtles green (*C. mydas*). From the 1980s, the incidence increased and has become the biggest threat to the green turtle (Gamache and Horrocks 1991) and has already been detected in other species.

There is evidence for maternal transfer of persistent organic pollutants into the eggs so that they can be used as indicators of pollution (Alava et al. 2011; Sakai et al., 1995).

Perfluorinated compounds (PFCs) are water-repellent properties oil are hardly degraded in the environment and can bio Cuma arse. They pose a threat to many organisms because they are toxic and endocrine disruptors. Evidence of their presence in turtles (Guerranti et al. 2013). Vitellogenin as a biomarker of endocrine disruption in turtles (Zaccaroni et al. 2010). Gonadal development partnership between the turtle and the concentration of the herbicide atrazine (De Solla et al. 2006).

Sea turtles are considered as potential indicators of the health of the marine, coastal habitats and local environments in which they live in temporary, annual or even decadal scales (Aguirre and Lutz 2004; Wallace et al., 2004). The longevity of individuals of sea turtles, the residence time on land or water, and the variety of marine habitats by traversing along his life story, return to these organisms susceptible to exposure to multiple stressors and Pollutants (Milton and Lutz 2003). Several studies have explored the vulnerability of the

turtles to these two factors, being that this will depend directly on their longevity (Milton and Lutz 2003; Aguirre et al. 2006), Ecological niche, including diet and feeding strategy (Gardner et al. 2006; Kampalath et al. 2006), concentration and duration of exposure (Talavera-Saenz et al. 2007) and metabolic processes and homeostatic (Gardner et al. 2003;... Sakai et al. 2000).

Sea turtles are becoming one of the most popular icons of the environment. Taking advantage of his charismatic image, a remarkable variety of stakeholders including scientists, conservationists, community-based organizations, corporations and governments have sought to use sea turtles to motivate people to consider issues surrounding the health of the marine ecosystem, warning while a potential danger situation as demonstrating the presence of contaminants in the environment in which they live and the degree of exposure, the sustainability of fisheries, the potential benefits of protected areas, indigenous cultural value (often involving nationalism and cultural) pride, biodiversity and the desirability of cooperation and the multilateral management of shared marine and terrestrial species (Eckert and Hemphill 2005). In the context of the use of sea turtles as sentinel species it has been proposed to generate databases on parameters for: how to make environmental monitoring using sea turtles using data and analysis eggs in search of contaminants, and which it is an effective technique that causes little damage to the populations studied (Alava et al. 2011, Schneider et al. 2011). Use of tissue carapace has proven useful in the study of pollutants (Komoroske et al. 2011). Analysis of blood samples to detect contaminants such as lead, selenium and mercury (Burger et al. 2009) and has the advantage of being a minimally invasive technique (Labrada et al. 2011, Lara-Uc et al. 2011). Tissue analysis of recently dead turtles can be useful (da Silva et al. 2014.) To make the following analysis: in vitro culture of stem cells, for example, liver cells green turtle has potential in monitoring and evaluation of mercury contamination (Wang et al. 2013). Determining the affinity trophic by stable isotopes (Rodriguez Baron 2010; Strang et al., 2012). Antioxidant enzyme activity. This may be a good biomarker of contamination in turtles (Labrada-Martagón et al. 2011). The search for biomarkers that reveal the exposure of organisms to endocrine disruptors, for example, the presence of vitellogenin in males. Satellite tracking to monitor populations (Schofield et l. 2013), and the unborn tracking (Mansfield et al. 2014).

Advantages and disadvantages of using turtles as bioindicators. Is it easy sampling? A collecting permit is required; this is handled with the undersecretary for environmental protection management (Directorate General of Wildlife) specifying the objectives of the study and whether it is a research project or teaching purposes. They should have experience in sampling either blood, tissue, etc. Because if you do not have to experience results that are issued are be as reliable, on the material used, the shape of the blood collection, in which means of transport the fabrics are, as time has shown to the analysis from which the sample was drawn until delivery to the laboratory. A feature is a sentinel species that react very quickly to environmental disturbances. However, to be ancient turtles, the impact of these disturbances on the size of the populations occurs slowly so it does not reflect the effects of the unrest on short-lived species (disadvantage). At the same time a long-lived species can bioaccumulate more polluting than short-lived species, the latter exacerbated by being the top predators turtles.

Challenges

Develop a reliable method for sexing turtles and to estimate the proportions of sexes. As very long-lived, the impact of environmental stressors on the population size may be delayed. Such delay would cause the indirect environmental stressor effects could not be detected on time in species with a short life.

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Chapter 9

SIMILARITY IN MOLLUSK ASSEMBLAGES ASSOCIATED WITH CONSPICUOUS HABITAT FORMERS IN NORTHWEST MÉXICO

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ABSTRACT

Mollusks mesograzers are an important ecological factor in subtidal environments. We analyzed conspicuous habitats from Gulf of California and Mexican Pacific littoral in northwest to answer: 1) How are formed the associated mollusks assemblages? 2) Is taxocenosis structure maintained over time and space inside habitats? 3) How does biodiversity change between habitats? Mollusks were found in critical habitats *Zostera marina*, rhodoliths and *Sargassum* forest, and invasive red seaweed *Acanthophora spicifera*. We made clusters about their presence in different geographical sectors and surveys using qualitative and quantitative data. 75 small species were recorded. Rhodoliths was the habitat with higher richness (25) and diversity, as well eelgrass beds (24). The grouping shows one assemblage that contains localities with eelgrass, the second rhodoliths, and the third seaweeds. Small gastropods *Acteocina*, *Alabama*, and *Barleeia* were essential components in all hosts. The structure changed over time and between habitats. Results suggest similar assemblages in eelgrasses and distant regards brown/red seaweeds as well rhodolith beds. This study highlights the importance of *Zostera marina* beds by evidence of similarity even localities inside and outside gulf; coralline beds by preserving atypical diversity and brown/red seaweeds as transitional microhabitats and temporary corridors subject to further change. These interactions are more complex than estimated, but this contribution helps to understand these critical habitats as biological corridors and implications on mollusk distribution.

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INTRODUCTION

Eelgrass and seaweed constitute a sort of biodiversity as micro-habitats, are significant for recruitment, settlement, and development of fishes and invertebrates (Morse 1992; Russo 1999; Christie 2009), in which mollusks are part of mesograzers inhabiting and one of the major groups interest of them. In addition to the structure complexity for shelter, another reason is food availability (Albano and Sabelli 2012). Sometimes mesograzers enhance host condition by removing epiphytes or redirecting nutrients to the sediments (Fong et al. 2000; Rakocinski et al. 2008), another reason to highlight its importance is because they are contributors to secondary production. Despite this, studies remain poor in assessed spatial composition and variation of this group on subtidal habitats (Wernberg et al. 2008).

In the Gulf of California and Pacific Coast, researchers have documented marine and brackish-water molluscan biodiversity in geographical scaling using the whole of the substrates (Hendrickx et al. 2007), another, in particular, localities but overall fauna (Quiroz-Vazquez et al. 2005; Hinojosa-Arango y Riosmena-Rodríguez et al. 2004; Foster et al. 2007). This region contain several relevant ecosystems: *Sargassum* forest, rhodolith and eelgrass beds actually are considered as critical habitats (Steller et al. 2003; Riosmena-Rodríguez 2009; Ávila et al. 2010; López-Calderón et al. 2013; Hinojosa-Arango et al. 2014) by establishment and development for abundant associated fauna and their ecosystemic services (Hinojosa-Arango and Riosmena-Rodríguez 2004; Foster et al. 2007; Riosmena-Rodríguez and Medina-López 2010; Suarez-Castillo 2014), therefore, arises the need to analyze predominantly these ecosystems.

Recently, in addition to the historical or natural process of colonization (Muñiz-Salazar et al. 2005), the anthropogenic factor (shipping and contamination) is influencing the species presence and dispersal around the world, as the actual situation of the invasive seaweed *Acanthophora spicifera* (Russell 1992; Schaffelke and Hewitt 2007), which was observed inside the gulf in 2006 by first time (Ávila et al. 2012) and has since then spread and established throughout Bahía de La Paz, making it one of the most conspicuous ecosystems and potentially invasive along the gulf.

We observed that one of the most significant and fluctuant taxa associated whit this conspicuous habitat in Mexican Pacific Northwest is Mollusca, however, recently beginning to be studied. The aim of this study analyzes if there a similarity in mollusk assemblages between the most distinct habitats recorded in northwest Mexican Pacific by the response: 1) How are formed the mollusk assemblages each habitat? 2) Is taxocenosis structure maintained over time and space inside habitats? 3) How does biodiversity change between habitats? This research is to understand the mollusk taxocenosis dynamic inside the distinct habitats recorded, which involve critical habitats and the most invasive seaweed by the moment.

STUDY SITE

Peninsula coast and the Gulf of California maintain the border of geographical distribution of *Zostera marina* along northeast Pacific (Muñiz-Salazar et al. 2005; Riosmena-Rodriguez et al. 2012), as well *Sargassum* (Suarez-Castillo et al. 2013) and the major rhodolith beds (Steller et al. 2003; Ávila and Riosmena et al. 2011). The invasive seaweed

Acanthophora spicifera by the moment is distributed in Bahía de La Paz (Ávila et al. 2012). Pacific Coast communities are not only separated geographically from communities in the Gulf of California but are also exposed to different environmental conditions (Cabello-Pasini et al. 2003). The Gulf of California is a semi-enclosed sea where the exchange with Pacific waters occurs only in the south of the gulf via cyclonic circulation (Castro et al. 2000). We analyzed localities at these critical habitats, as well the invasive species *A. spicifera*. Sampling was conducted at different sites each locality, from 1-5 m depth by SCUBA, to collect most of the mobile organisms for concurrent studies.

Samples were taken from *Zostera marina* in San Ignacio (SI): 26°55' N; 113°10' W North (N), 26°49' N; 113°15' W, Media (M), 26°42' N; 113°60' W, Pitahaya (P). Bahía Magdalena in *Zostera* (BMZ): CFE, Las Tijeras (T1), Cancún (C1), El Muerto (EM1), Punta de Gato (PG1). Sonora in *Zostera* (SZ): Punta Arenas (PA1), Coniic (C1), Bajo Callero (M1), Punta Xpanams (PX), Punta Chueca (SR), Punta Tormenta (PT), Palo Fierro (PP), Estero San Miguel (SM), Punta Ohna (PO), El Álamo (BA), Bajo Media Luna (ML), Bajo Canal (MC). Rhodolith beds from Bahía Magdalena (BMR) 24°15' N; 111°30' W (CFE) and 25°20' N; 112°15' W (PED). *Sargassum* forest throughout Bahía de La Paz (BLP): L1 (24°45'37"N; 110°40'24" W), L2 (24°35'52" N; 110°44'48" W), L3 (24°28'29" N; 110°41'37" W), L4 (24°18'59" N; 110°38'24" W) and L5 (24°12'15" N; 110°32'6" W) in June 2011 and May 2012. Invasive seaweed *Acanthophora spicifera* in Ensenada de La Paz (ELP) 24°12'07" N; 110°17'59" W.

Field Sampling

Samples were taken every two months from April to August. 2010 in *A. spicifera* from holdfast using a sampling square of 0.00625 m² over three beds, nine replicates each one. June 2011 and May 2012 from *Sargassum* in 5 beds, sampling 15 replicates each site from the holdfast. June 2011 in two rhodolith beds, 20 replicates each one using a square of 0.0625 m² (same for the next three localities). October 2009, March, April and August 2010 from *Z. marina*, Sonora in 12 sites, sampling three replicates each one from the rhizome and the sediment surface (same for the next two localities). June, April, and September 2009 and December 2010 from *Z. marina*, San Ignacio in 4 sites, three replicates each. June 2011 from *Z. marina*, Bahía Magdalena in 5 locations, three replicates each.

Laboratory Analyses

The samples were separated by sieved through a 0.5 mm mesh and preserved in ethyl alcohol (70%). Each sample were examined for the record and counted all organisms possible. Mollusks were sorted quantitatively and identified as a group possible using particular references. Some species required further identification.

Feeding Habits and Feeding Guilds

The next feeding habits and guilds were considered: carnivores (C) herbivorous (H) Omnivorous (O). Deposit feeders (D) feeding on organic particles contained in the sediment, filter feeders (F) intercepting nutrient particles with their gills and/or mucous strings, Suctorial parasite (Sp), Grazer (Gr) feeds by scraping, either on algae or sessile animals, and

Browsing (feeds by tearing or gathering particular items (Br), we selected sorts of Rueda et al. (2009). Trophic information was mined from the literature for each species wherever possible. If the feeding behavior of a particular species was unknown, it was assumed to feed in a similar manner to species within the same major group.

Data Analysis

Mollusk taxocenosis structure and dynamics were analyzed by the number of specimens (N), the number of species (S), the Shannon index (H' , using the log formula) and Pielou's evenness index (J'). Before all data were converted to m^2 for comparison. After were tested for KS normality and homogeneity of variances by Cochran's test, and log-transformed as necessary. Component Principal Analyses (CPA) were made each habitat to detect and compare the most variable data corresponding with the species. We performed a cluster analyzes and non-metric multidimensional scaling (MDS) in different geographical sectors and surveys using qualitative and quantitative data (presence/absence and Ind m^{-2}) and the Jaccard similarity index. Before analysis, data were the fourth root transformed abundance data, to minimize the effect of extremely abundant species. The SIMPER routine was then used to locate which species contribute most to the differences between habitats or, conversely, which species contribute most to the similarities within the same group. Multivariate analyzes were performed using R software and PRIMER.

RESULTS

Fauna Composition

An almost total of assemblages were dominated by mollusks in most of the surveys (Figure 2), except in *Sargassum*, the transitional habitat in BLP, which usually is occupying by crustaceans, and the next abundant group is polychaetes. We recorded 42 families and 73 species of mollusks across all sites and time surveys (Appendix 1). The material was identified as level possible. Species abundance was different between sites inside habitat along time, due to the location, but we chose the total abundance all surveys for the show the principal components and abundant species each locality (Figure 3). In most of the habitats dominated the carnivorous guild, except in Sonora due to the high abundance of the detritus feeder *Caecum* in soil (Figure 2).

Similarity and Taxocenosis Structure

Main species contribution consistently accounted for greater than 70% of the total dissimilarity among the different habitats and localities (Table 1). The taxocenosis in eelgrass beds and brown/red seaweed is characterized by high abundance of less dominant species than rhodolith beds (Figure 3).

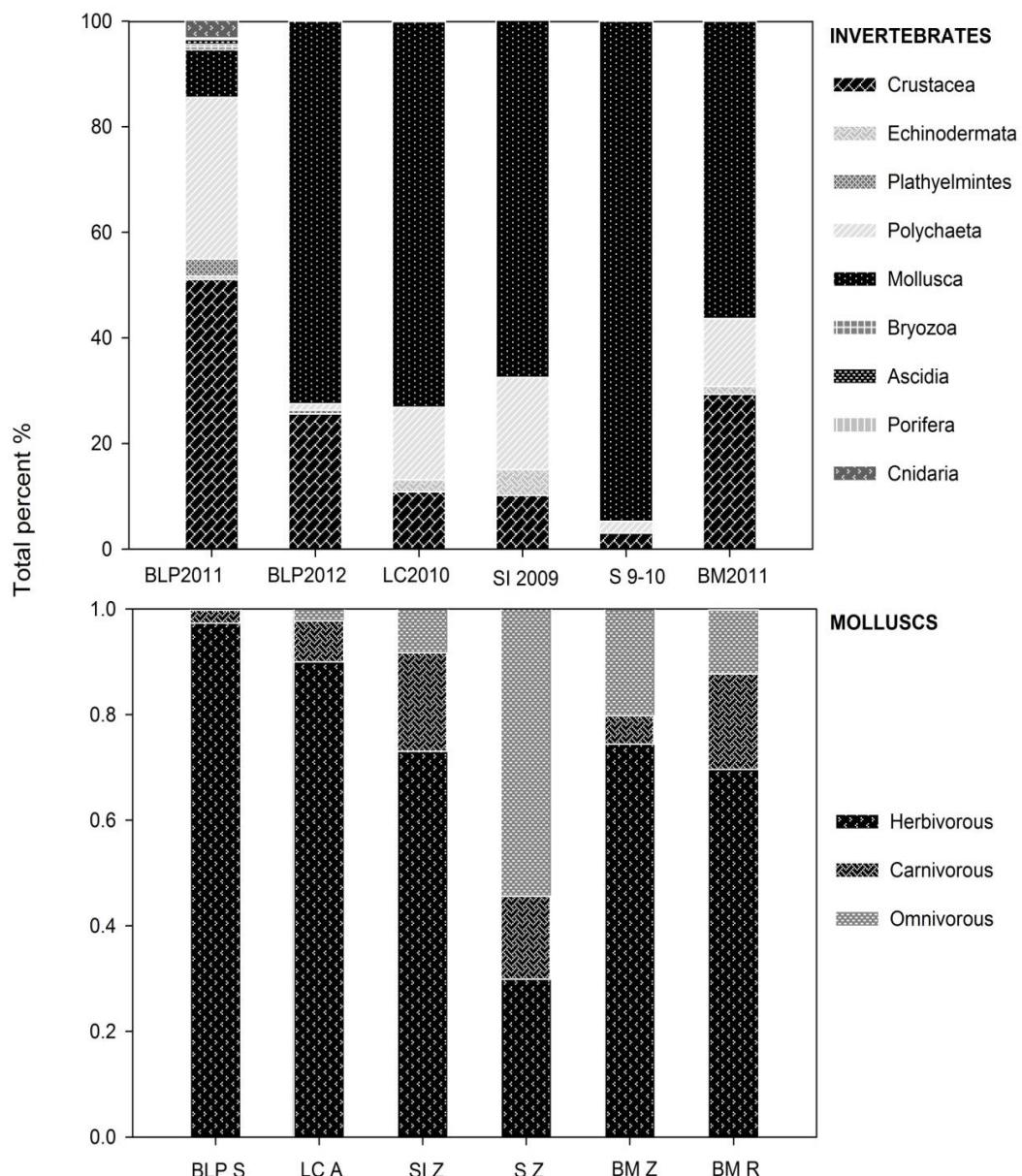


Figure 2. Contribution of Invertebrates in the different habitats: Bahía de La Paz *Sargassum* (BLP S), Roca Caimancito *Acanthophora* (LC A), San Ignacio *Z. marina* (SI Z), Sonora (S Z) and Bahía Magdalena in *Z. marina* (BM Z) and Bahía Magdalena in rhodolith beds (BMR).

Taxocenosis structure in *Acanthophora* was relatively consistent over time but differ between sites, the greatest abundances were found to in this invasive seaweed (Figure 3), *Assiminea* were the most abundant species in this habitat. Rhodolith bed shows less abundance but greatest S, J' and H'; the species recorded in this habitat were entirely different to eelgrass taken the same date and lagoon, only three species share both. BLP contains fewer species and only the dominant *Alaba supra lira ta* (Figure 3). *Alabimia*, *Barleeia*, *Acteocina*, *Caecum* and *Alaba* were the most related taxa in almost all habitats. Several particular taxa

less abundant were found only inhabiting eelgrass beds, even one locality inside gulf and two outside as well (Figure 1): *Alabina*, *Nassarius*, *Anachis*, *Neopilina*, *Cerithiopsis*, *Mitrella*, *Turbanilla*, *Elephantelum*, *Hipponix*, *Calyptrea*, and *Biv 1* (Table A1).

The mollusk assemblages grouped among similar habitats represent by eelgrass and distant respect to seaweed beds (Figure 4). Taxocenosis composition in *Sargassum* was near to *Acanthophora* group; these localities are cited in Bahía de La Paz both. Clustering in rhodolith beds was far to the other groups since most of the species were only found in these habitats. A significant nMDS ordination is detected; stress values for the analyzes were 0.146, the plots show some clustering of habitats (Figure 5). SZ is near to SIZ and BMZ, even if these last is situated outside gulf.

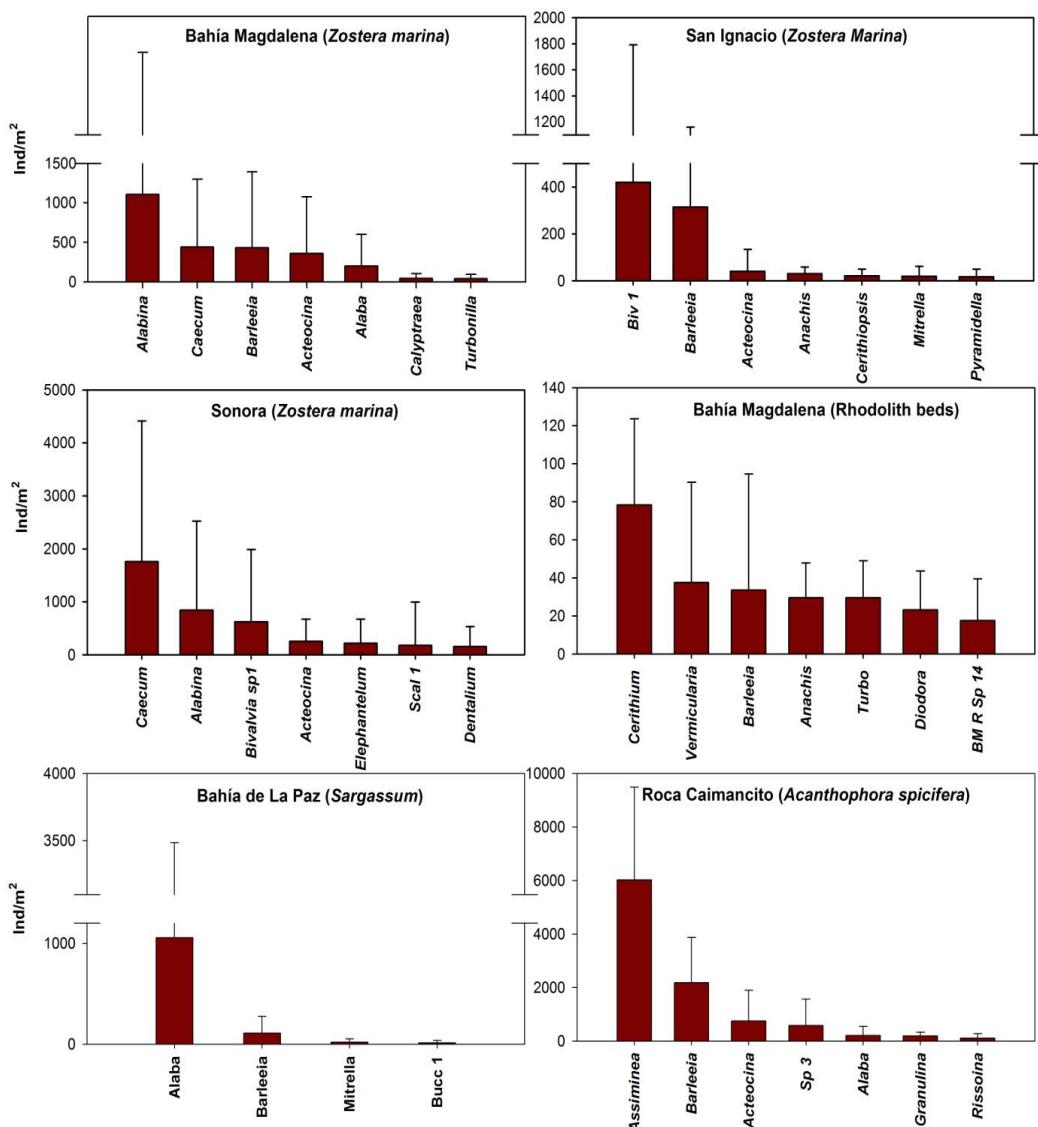


Figure 3. Representative species each habitat, selected by high abundance and principal components after Component Principal Analyses each habitat.

Table 1. Results of SIMPER analysis on the percent contribution of benthic categories, testing dissimilarity between zones

Category	Contribution %	Cumulative %	Category	Contribution %	Cumulative %
Groups: BM Z and SI Z					
Average dissimilarity = 88.14					
<i>Alabina</i>	20.95	20.95	<i>Alabina</i>	19.28	19.28
<i>Barleeia</i>	16.05	46.92	<i>Alaba</i>	16.78	36.05
<i>Calyptraea</i>	9.92	56.42	<i>Caecum</i>	8.42	44.47
<i>Acteocina</i>	9.5	64.27	<i>Barleeia</i>	7.68	52.16
Groups: BM Z and S Z					
Average dissimilarity = 87.49					
<i>Caecum</i>	26.85	26.85	<i>Assiminea</i>	48.52	48.52
<i>Alabina</i>	22.63	49.48	<i>Barleeia</i>	17.28	65.8
<i>Biv 1</i>	10.14	59.63	<i>Alaba</i>	9.86	75.66
<i>Acteocina</i>	7.2	66.83	<i>Acteocina</i>	4.79	80.46
Groups: S Z and SI Z					
Average dissimilarity = 92.73					
<i>Caecum</i>	30.4	30.4	<i>Caecum</i>	29.39	29.39
<i>Alabina</i>	16.57	46.97	<i>Alabina</i>	14.8	57.88
<i>Biv 1</i>	15.44	62.4	<i>Alaba</i>	13.68	68.57
<i>Barleeia</i>	5.83	68.24	<i>Biv 1</i>	10.69	73.8
Groups: BLP S and LC A					
Average dissimilarity = 93.31					
Groups: BLP S and S Z					
Average dissimilarity = 95.11					

DISCUSSION

Olds et al. (2012) have shown that connectivity is essential in conservation planning and this is extremely difficult to find in many planning process in marine protected areas. Also is a consideration lacking in environmental impact reports who needs to evaluate the synergic impacts of assemblages in any given project. Strong differences were found among the major habitats studied in relation to feeding habits (Figure 1) and in relation to diversity (Figure 2). Steller et al. (2003) have found strong differences between Rhodolith beds and sandy areas, our analysis extend this observations to other habitats. Seagrasses meadows and Rhodolith beds seems to be the most diverse areas but less abundant (Figure 6) comparing among them.

Foster et al. (2007) have found rich and diverse biota associated to *Sargassum* forest in Bahia Concepcion and our results are contrasting with less species and less abundant. This situation might be related to geographical position because our sampling is from Bahia de La Paz. However, when comparisons with the *Zostera marina* meadows are made strong similarities among sites are clearly present. In the case of Rhodolith beds it is clear that no significant differences have been found in the associated species from what we know. Our study is unique because no one has compare this ecosystems before, we have found indicators for further analysis with the whole invertebrate community.

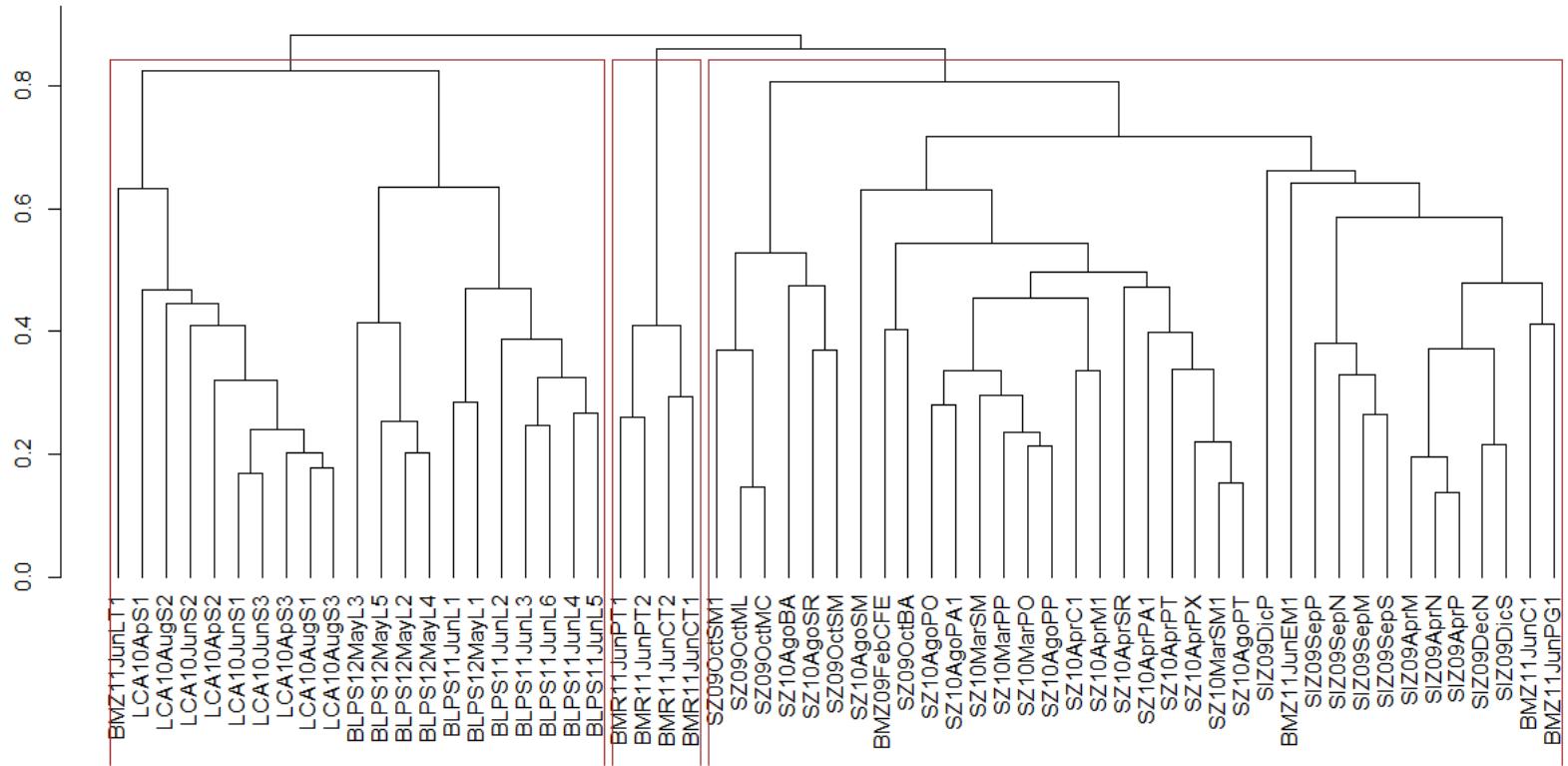


Figure 4. Cluster analyzes. The key is arrangement in the next order: localities: BLP (Bahía de La Paz), Roca Caimancito (LC), Bahía Magdalena (BM), Sonora (S) and San Ignacio (SI); hosts: *Zostera marina* (Z), *Acanthophora spicifera* (A), *Sargassum* (S) and rhodolith beds (R); year, month and sites inside each locality.

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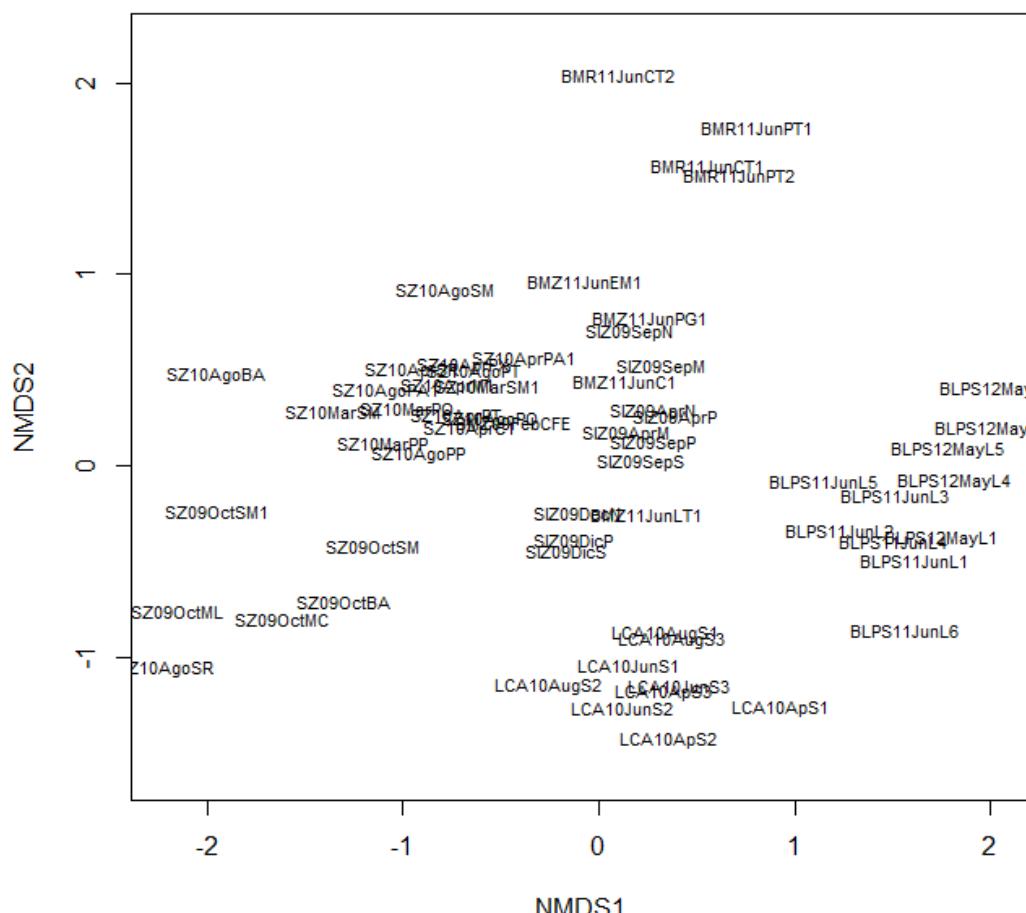


Figure 5. Nonmetric Multidimensional Scaling (nMDS) biplot on the Jaccard similarity matrix of transformed benthic taxocenosis data (the fourth root transformed abundance data) showing physical means for all habitats and sites. Bahía Magdalena *Zostera marina* (BM Z), San Ignacio *Zostera marina*, Sonora *Zoster Mariana* (S-Z), Bahía de La Paz *Sargassum* (BLP A), Bahía Magdalena rhodolith beds (BM-R) and Roca Caimancito *Acanthophora spicifera* (LC A).

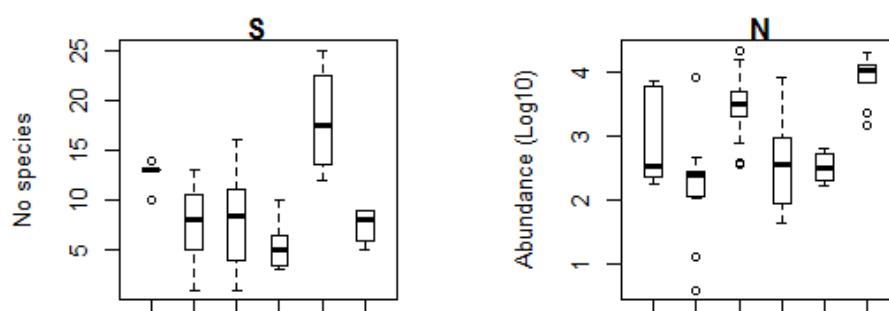


Figure 6. (Continued).

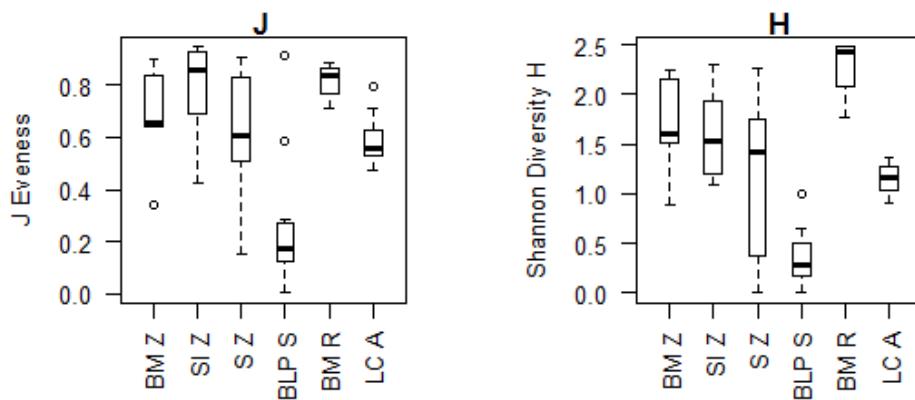


Figure 6. Ecological attributes. Bahía Magdalena *Zostera marina* (BM Z), San Ignacio *Z. marina*, Sonora *Z. marina* (S-Z), Bahía de La Paz *Sargassum* (BLP A), Bahía Magdalena rhodolith beds (BM-R) and Roca Caimancito *Acanthophora spicifera* (LC A).

APPENDIX

**Table A1. Mean abundance (Desvest) by m² of species associated with different habitats.
Bahía Magdalena (BM), San Ignacio (SI), Bahía de La Paz (BLP)
and Roca Caimancito (LC)**

Genus	BM		SI		Sonora		BM Rod		BLP		LC	
	Zostera	Zostera	Zostera	Zostera			(0)	(0)	(0)	(0)	(0)	(0)
<i>Dentalium</i>	13	(20)	0	(0)	157	(377)	0	(0)	0	(0)	0	(0)
<i>Neopilina</i>	4	(10)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
<i>Alabina</i>	1,105	(2,165)	6	(14)	843	(1,682)	0	(0)	0	(0)	0	(0)
<i>Cerithium stercusmuscarum</i>	0	(0)	0	(0)	0	(0)	78	(45)	0	(0)	0	(0)
<i>Cerithiopsis</i>	7	(14)	22	(28)	81	(146)	0	(0)	0	(0)	21	(46)
<i>Epitonium</i>	4	(5)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
<i>Alaba</i>	199	(402)	1	(4)	103	(318)	3	(5)	1,055	(2,429)	212	(340)
Buccinidae 1	0	(0)	0	(0)	182	(813)	0	(0)	0	(0)	0	(0)
<i>Vermicularia</i>	0	(0)	0	(0)	0	(0)	38	(53)	0	(0)	0	(0)
<i>Turritella</i>	0	(0)	0	(0)	0	(0)	10	(7)	0	(0)	0	(0)
<i>Assiminea</i>	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	6,022	(3,470)
<i>Caecum</i>	442	(857)	0	(0)	1,763	(2,647)	5	(10)	0	(0)	54	(110)
<i>Elephantelum</i>	14	(25)	0	(0)	220	(452)	0	(0)	0	(0)	0	(0)
<i>Crucibulum</i>	0	(0)	0	(0)	0	(0)	8	(7)	0	(0)	0	(0)
<i>Calyptraea</i>	43	(58)	3	(5)	0	(0)	0	(0)	0	(0)	0	(0)
<i>Hipponix</i>	0	(0)	3	(8)	50	(218)	0	(0)	0	(0)	0	(0)
<i>Rissoina</i>	0	(0)	0	(0)	0	(0)	17	(18)	0	(0)	110	(168)
	0	(0)	0	(0)	0	(0)	0	(0)	13	(23)	0	(0)
<i>Anachis</i>	16	(14)	31	(29)	127	(258)	30	(18)	0	(0)	0	(0)
<i>Mitrella</i>	32	(56)	20	(42)	0	(0)	4	(6)	20	(34)	0	(0)
<i>Granulina</i>	20	(45)	17	(46)	0	(0)	0	(0)	0	(0)	190	(143)
<i>Nassarius</i>	22	(26)	17	(15)	36	(100)	8	(8)	0	(0)	0	(0)
<i>Oliva</i>	0	(0)	0	(0)	3	(14)	0	(0)	0	(0)	9	(27)
<i>Pilsbryspira nymphia</i>	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)

Genus	BM	SI	Sonora	BM Rod	BLP	LC
	Zostera	Zostera				
<i>Acteocina</i>	359	(718)	41 (93)	255 (421)	0 (0)	0 (0)
<i>Haminoea</i>	0 (0)	0 (0)	0 (0)	0 (0)	3 (11)	0 (0)
<i>Haminoea sp2</i>	2 (3)	0 (0)	28 (51)	0 (0)	0 (0)	0 (0)
<i>Turbonilla</i>	39 (56)	6 (8)	8 (22)	0 (0)	0 (0)	6 (17)
<i>Pyramidella</i>	2 (5)	17 (32)	0 (0)	0 (0)	0 (0)	0 (0)
<i>Theodoxus</i>	1 (2)	0 (0)	0 (0)	6 (6)	0 (0)	0 (0)
<i>Diodora inaequalis</i>	0 (0)	0 (0)	0 (0)	23 (20)	0 (0)	0 (0)
<i>Tricolia</i>	0 (0)	0 (0)	0 (0)	0 (0)	6 (10)	0 (0)
Fissurellidae sp1	6 (7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
<i>Tegula</i>	14 3(2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
<i>Turbo funiculosus</i>	0 (0)	0 (0)	0 (0)	30 (19)	0 (0)	0 (0)
<i>Turbo</i>	0 (0)	0 (0)	0 (0)	10 (12)	0 (0)	0 (0)
<i>Barleeia</i>	432 (963)	314 (846)	0 (0)	34 (61)	110 (166)	2,183 (1,687)
BLP Sp 4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
BLP Sp 5	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
BLP Sp 6	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
BLP Sp 7	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
BLP Sp 8	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	0 (3)
BLP Sp 9	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
BM R Sp 8	0 (0)	0 (0)	0 (0)	2 (3)	0 (0)	0 (0)
BM R Sp 15	0 (0)	0 (0)	0 (0)	7 (12)	0 (0)	0 (0)
BM R Sp 10	0 (0)	0 (0)	0 (0)	2 (3)	0 (0)	0 (0)
BM R Chione	0 (0)	0 (0)	0 (0)	2 (3)	0 (0)	0 (0)
BM R Sp 14	0 (0)	0 (0)	0 (0)	18 (22)	0 (0)	0 (0)
BM R Sp 9	0 (0)	0 (0)	0 (0)	9 (11)	0 (0)	0 (0)
BM R Sp 21	0 (0)	0 (0)	0 (0)	10 (21)	0 (0)	0 (0)
BM R Sp 22	0 (0)	0 (0)	0 (0)	1 (2)	0 (0)	0 (0)
BM R Sp 23	0 (0)	0 (0)	0 (0)	1 (2)	0 (0)	0 (0)
BM R Sp 24	0 (0)	0 (0)	0 (0)	2 (3)	0 (0)	0 (0)
BM R Sp 25	0 (0)	0 (0)	0 (0)	1 (2)	0 (0)	0 (0)
LC Sp 5	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	79 (104)
LC Sp 6	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	47 (114)
LC Sp 7	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
LC Biv 1	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	22 (34)
Sp 3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	581 (990)
Gast 4	0 (0)	0 (0)	47 (218)	0 (0)	0 (0)	0 (0)
Gast 8	0 (0)	0 (0)	3 (14)	0 (0)	0 (0)	0 (0)
Gast 11	0 (0)	0 (0)	1 (5)	0 (0)	0 (0)	0 (0)
Gast 12	0 (0)	0 (0)	19 3(2)	0 (0)	0 (0)	0 (0)
<i>Cardita</i>	0 (0)	0 (0)	0 (0)	6 (5)	0 (0)	0 (0)
<i>Tagelus</i>	0 (0)	0 (0)	1 (5)	0 (0)	0 (0)	0 (0)
<i>Tellina</i>	1 (2)	2 (5)	0 (0)	3 (5)	0 (0)	0 (0)
<i>Chione</i>	6 (14)	0 (0)	59 (96)	6 (6)	0 (0)	0 (0)
<i>Arca</i>	0 (0)	0 (0)	3 (14)	0 (0)	0 (0)	0 (0)
<i>Pecten</i>	4 (8)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Bivalvia sp1	0 (0)	420 (1,372)	624 (13,64)	0 (0)	0 (0)	0 (0)
Bivalvia sp2	0 (0)	9 (16)	6 (27)	0 (0)	0 (0)	0 (0)
Biv 3	0 (0)	0 (0)	4 (18)	0 (0)	0 (0)	0 (0)
Biv 13	0 (0)	0 (0)	99 (328)	0 (0)	0 (0)	0 (0)

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Chapter 10

A CRITIQUE OF THE ENVIRONMENTAL IMPACT STUDIES IN MÉXICO BASED ON TWO STUDY CASES

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ABSTRACT

By means of behavioral studies it has been determined for the first time in Mexico the critical habitat of a semi-resident group of coastal dolphin *Tursiops truncatus* (bottlenose dolphin) in Ensenada de La Paz and the south-southeast of Bahía de La Paz. In this zone it is more frequent to observe small groups of mothers with calves and juvenile dolphins. Through the years it has been recorded a habitat shift of these cetaceans induced by environmental and anthropogenic factors: loss of southwest basin in Ensenada de La Paz due to silting, dredging and tropical cyclones; similarly a reduction of the feeding activity has been observed in the northwest basin due to fisheries and the increase of nautical traffic which overlaps with the main transit route of bottlenose dolphins near El Mogote, thus affecting their conduct. The disturbance could increase because of dredging realized in 2012 by the touristic development Paraíso del Mar to build a dock for a marina in El Mogote, affecting particularly zones where females teach juvenile dolphins to feed next to mangroves. Unfortunately, the ecological, social and economic importance of these coastal wetlands it is not considered, subject to a stress and risk increase in the last decades due to non-regulated deforestation and dredging, as a consequence of the mentioned touristic development for the construction of a golf course, and affecting the mangrove zone. It is imperative a decree by SEMARNAT stating Ensenada de La Paz and south of Bahía de La Paz as a critical habitat for dolphins, based on the scientific information available; given the current threats on this Ramsar site and its communities, the lack of acknowledgement as a critical zone, and the need to be included in the environmental impact evaluation for coastal developments. By including

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them as part of the environmental policy other species will be protected too, establishing general management plans for its conservation, building agreements with environmental authorities, researchers, government agencies, society organizations, fishermen, and general public.

Keywords: bottlenose dolphin, critical habitat, mangrove, Ensenada de La Paz, conservation

INTRODUCTION

The Article 2 of the Mexican Constitution ensures that natural resources are owned by the nation (and its citizens) have developed concessions to the implementation of productive projects (whether public or private) where it could impact the ambient. Based on this constitutional mandate the General Law of Ecological Balance seeks to preserve ecosystems and their processes to human actions. These processes are extracting water from wells, rivers and lakes through land use for different purposes to the way we use the oceans with its highly productive ecosystems. When a country assumes a model of sustainable development you are able to meet current needs without putting at risk the resources continue to be used long term for the same population. To this end, they require environmental instruments to support us in order to determine whether the activity to be developed could have an impact on ecosystems or significantly affect its processes. This is key, you can use the environment but what you intend to do has to be friendly to the future development and not necessarily destroy the natural capital that exploits.

Although its origins are in the 70's, the instrument used in Mexico to assess the potential impacts of human activities began to be used effectively in 2000 arising from both changes in environmental policy and the commitments the country signing international treaties. It is when it is proposed that all development projects will have to submit an Environmental Impact Statement taking two forms: private or regional which is related to the size of the project. There is also what is called Preventive Report being used in very specific cases. Although it seems that these manifestations seem to name only assess potential impacts on the environment which would also have to consider are social, economic, cultural and even political aspects (since the project in question could cause some instability). It is also necessary to consider that even developed in two modes have to keep in mind the potential synergistic impacts both the quantity and the size of other nearby projects that can be generated.

To give an award to a particular is very necessary that the Environmental Impact Statement develop a detailed description of the environment or ecosystems in the area of interest. This is a key point for any project since being a concession to a certain time what could hope for is that development does not cause a drastic change in the environment where the grant is completed changes are as small as possible. However, there is no classification of terrestrial ecosystems consistent between different secretariats in the SEMARNAT (i.e., that each agency secretariat terrestrial ecosystems are recognized differently). However, the seriousness of the matter is that on aquatic ecosystems seems to be marine or freshwater is the biggest difference possible. There is an inclusive classification of all marine ecosystems leaving defenseless internationally recognized for any administrative or procedural protection of ecosystems in Mexico but we have not yet dared to protect (including seagrass beds, maerl

beds, kelp/Sargassum forests, marsh meadows, hydrothermal vents, gorgonian forests, etc ... among many others). This generates a lot of controversy of how to develop an environmental statement if you do not have a complete catalog of the “environment” of the country. Perhaps this is related to the number of professionals in the marine sciences have been trained and employed in different spheres of the productive life of the country.

But as it is assumed that the MIA will seek to assess whether the processes to be carried out to make an impact on these ecosystems should know some of its dynamic aspects. These should be at least biodiversity (species in the area), ecological processes (reproduction, recruitment, breeding or feeding, etc. ...) and participation in geological processes (stability of beaches, soil, sediment origin, etc. ...). Now if this is not well understood in developing the EIS then it is not possible to propose measures to compensate or mitigate the impacts making it impractical to say that a project is feasible or not, right? It is something that needs to be worked intensively gathering critical information that you have in the country on this issue both in research centers and universities, it is not possible that information of this nature is generated and is not used. Although there are very serious academic exercises like those made by the National Commission for the Use and Conservation of Biodiversity (CONABIO) to understand the Natural capital to understand their gaps or omissions not covered there are still some corners that need to be evaluated priority.

But consider that these deficiencies are already covered in these fundamental inputs that the process requires. The next thing to ask for this instrument to fulfill its roles is: who makes the demonstrations and who evaluates them. It is disturbing to know that is supposed to be to draw up a register of providers of this service are properly credited to the demonstrations but this one is at the state level (where differences to be accredited are evident), in some cases to levels City (counted) but we could not find a single federal standard or features should have this provider. Subsequently, although SEMARNAT you have a direction to make assessments of these studies it seems that they must have a wide range of professionals to cover the topic of each and every one of the evaluations. However, it does not seem to be the case and has not touched me that these offices require advice or support from academics who might have information on the project or subject knowledge to support decision making. This would be necessary to conduct some sort of survey data verification so as to delineate dispute that projects might have. The figure of the expert is not well defined at both the federal and state levels. It requires a profile of each position to ensure that the process will be well qualified professionals who achieve the goal of having fewer disputes arising in these processes.

Within this instrument it has been considered that the public consultation and the reports are objective elements where you can clarify any doubts regarding the project. But experience with public consultations in Baja California Sur (and we are sure in other parts of the Republic) tell us that this has been a media circus than an exercise of reflection on the true intentions of the petitioner. We think there should be other elements from previous assessment that the petitioner could use to assess the chances of their proposal well before starting to invest in studies that did not represent support decision making. Then you end up with the wrong idea about the interest in the protection and conservation of the environment losing sight of the nuances that this may have on the approaches of each organization. In this area at country level absent the professional associations in Marine Sciences (perhaps with the honorable exception of Oceanographers organizations in the North state) that could be guarantors in the process of evaluation. Perhaps the key point is that it has not properly stimulated private organizations environmental assessment (like has happened with Civil

Society Organizations) profiles which are desirable for the development of the EIS. This would stimulate the development of professionals in the area of knowledge and would provide with the necessary feedback to professional associations, removing the temptation to involve public institutions that, through your profile, may have conflicts of interest to develop these demonstrations.

A well implemented MIA monitoring may be evaluated to assess the observed impacts against the predicted and to adjust or modify the planned mitigation in each process. Clearly this represents an additional cost that often do not want to pay but if you want to know the state of the ecosystems as a project (or several projects) is necessary to have this ongoing assessment. That is why in other countries environmental monitoring program that measures are developed, registers and makes available to the public a series of crucial data in the development environment in the region. These are also used by insurance companies working with large companies assuring its activities related compensation and any potential impact.

Thus, the paradigm of sustainable development are not the windows of opportunity that should have different organizations or companies. But the way they achieve, or not accredit an environmental impact study due to lack of renovation of processes and the limited view of its scope. It would be important that the permanent dialogue that should have all sectors in the country could discuss adjustments to existing procedures. They may implement alternative assessment systems that represent relative cost differentials and the size of the project but at the same time give certainty to investors, CSOs and government processes that will achieve the objectives of environmental policy. The experience gained in these collective processes might achieve that decisions are at least controversial and politicized that current net profit for the ecosystem. Because of that we are presenting here 2 study cases in La Paz Bay who serve as examples to show how the actual model is not working and the urgent need of a review.

DOLPHINS, MANGROVES AND EL MOGOTE

Mangrove structure, functioning and permanence are singular, given that it is an ecosystem located at the threshold between marine and terrestrial environments. On one hand it is dominated by oceanic factors like tidal regime, marine currents, salinity, temperature, and nutrient availability; on the other hand atmospheric factors like humidity, wind, temperature and irradiance determine its physiological status and survival. From an anthropocentric point of view, mangroves experience significant changes due to land use modifications, deforestation, and pollution (1). Unfortunately, anthropogenic agents have had a determinant effect on this coastal ecosystem, reducing its spatial coverage. It is estimated that in the last two decades, approximately 50% of the mangroves of the world have been lost (Santamaría-Gallegos et al., 2011). FAO (2007) determined that the worldwide coverage of mangrove was 150,000 km² between 1980 and 2005. A recent assessment by Giri et al. (2011) states that worldwide mangrove coverage in year 2000 was 137,360 km², 12% less than estimated by FAO.

From an ecologic and economic point of view, mangrove of the Baja California Peninsula are acknowledge as valuable ecosystems, and protected by the Mexican legal framework. Despite of this, currently they are highly threatened by the construction of real estate development with urban and tourist purposes: golf facilities, marinas and roads. In order to

carry out mangrove conservation in Mexico it is required that they are considered in management plans, that authorities enforced the law strictly during the inspection and authorization of building activities along the coastal zone, and that public policies at the federal, state, and municipal level acknowledge the economic value of the environmental services provided by mangrove forests.

The municipality of La Paz, Ensenada de La Paz, and Bahía de La Paz in its Eastern portion have 14 wetlands with mangrove forests (Mendoza-Salgado et al., 2011). Inside Ensenada de La Paz the sandy bar known as El Mogote has two wetlands with mangrove forests: Zacatecas and El Mogote. Zacatecas mangrove has been subject to a management proposal by federal authorities to be preserved for being the habitat of least tern (*Sternula antillarum*) an endangered migratory bird species that uses this habitat as reproductive area (Amador and Mendoza, unpublished data; Mendoza 1994; Mendoza-Salgado et al., 2011). While mangrove El Mogote has a series of mangrove forests separated by dune zones, the total length along the shore of these mangroves is 6 km. Mangrove El Mogote constitutes the central subject of this chapter, given that mangroves along El Mogote form a fundamental ecological connection with a population of coastal dolphins known as tursiones (*Tursiops truncatus*) in Ensenada de La Paz.

It is known that between 1973 and 1981 Ensenada de La Paz lost more than 44 ha of mangrove, 21.5% of its total coverage (Mendoza-Salgado et al., 1984), the purpose of this deforestation was to obtain firewood, build roads to access the coast by mangrove-oyster fishermen, and to develop recreational areas (Mendoza-Salgado et al., 2011). Mendoza-Arrambídez et al. (2007) developed and applied a Coastal Environmental Quality Index (ICAC) at Bahía de La Paz, which shows that a wide spectrum exists in terms of conservation status of coastal wetlands with mangrove forests. These values go from good environmental quality (ICAC = 58%) to an environmental alert status (ICAC = 31%) (Mendoza-Salgado et al., 2011). Unfortunately, more than 30% of the surveyed sites show environmental alert indexes, thus mangrove forest at those sites have ecophysiological problems in its remineralization capacity of organic matter (Mendoza-Salgado et al., 2011).

Lack of community awareness is another serious problem for the preservation of mangrove forests, because a large sector of the population thinks of this coastal ecosystem as illegal dumps, breeding ground for mosquitoes, free source of firewood, and bad odor. It is necessary to strengthen a dissemination campaign in all levels of society so that people know that these forests are fragile ecosystems on which hundreds of resident and migratory species rely on, and where key biogeochemical processes take place that have an important role in the recycling of carbon, nitrogen, and phosphorous through the terrestrial-marine system. This promotion of environmental culture will bring a new approach to social conscience: healthy mangrove forests mean a reduction of CO₂ in the atmosphere, healthy fisheries, biodiversity preservation and a higher environmental quality for Bahía de La Paz.

Dolphins (*Tursiops truncatus*) are known as bottlenose dolphins or toninas, they distribute in almost every ocean, except at higher latitudes (Leatherwood and Reeves, 1983), they are gregarious animals that form herds (Walker, 1981; Leatherwood and Reeves, 1982; Mead and Potter, 1990). Females reach maturity between 5 and 12 years old, while male does it between 10 and 15 years old (Sergeant et al., 1973; Mead and Potter, 1990; Wells, 1991). Gestation in these animals last approximately 12 months (McBride and Kritzler, 1951; Hansen, 1990; Wells, 1991; Mann and Smuts, 1999), females give birth in any season of the year, with one calf every 2 or 3 years (Shane et al., 1982). A strong binding forms between

mother and calf that lasts 3 to 10 years; calves do not interact with males (Shane et al., 1986; Wells et al., 1987; Buckstaff, 2004). Social organization in dolphins is based on age and sex and the association mother - calf and between adult males is very stable. Size and composition of groups it is related with different parameters, characteristics, requirements and attributes of each animal *per se*, intra- and inter-specific relationships, availability and use of resources. It also varies seasonally, according to the structure of habitat, activity patterns, food availability, reproductive stage, and protection against predators (Caldwell, 1955; Wells et al., 1980, 1987; Shane et al., 1986; Ballance, 1990; 1992; Wells, 1991; Mann and Smuts, 1999; Connor et al., 2000; Bearzi, 2005).

Coastal zone is the home range for bottlenose dolphins, reaching permanent social groups (Wells et al., 1980; Ballance, 1985). The preference for this zone could be a result of prey abundance supported by coastal systems and the protection offered by this zone against predators. In this zone bottlenose dolphins reproduce, breed, and feed their offspring, therefore their presence in the coastal zone can be used as an indirect indicator of productivity. Bottlenose dolphin distribution is also related to other factor such as bathymetry, tidal regime, type of bottom, and prey diversity, thus they can be found in a wide range of environments (Wells et al., 1980; Irving et al., 1981; Shane et al., 1986; Ballance, 1992; Wilson et al., 1997; Hastie et al., 2004). They feed on fish of 5 to 30cm in length; their diet includes individuals of the families Mugilidae, Scianidae, Clupeidae, Scombridae, Batrachoidae and Haemulidae, among others. Also octopus, squid, shrimp, crab, and in some cases sharks can be present in their diet (Gunter, 1942; Barros and Odell, 1990; Corkeron et al., 1990; Corkeron and Ross, 1990; Mead and Potter, 1990).

Human impact has increased on coastal ecosystems in the last decades, mainly because of anthropogenic activities and settlement developments such as fisheries, tourism, marine traffic (Wells et al., 1980; Shane et al., 1986; Wilson et al., 1997; Barco et al., 1999; Bristow and Rees 2001; Nowacek et al., 2001; Prideaux, 2003; Lemon et al., 2006). As a consequence of these worldwide impacts a measure adopted for the protection and conservation of bottlenose dolphins is the declaration of critical habitats, formed by regions of high presence of bottlenose dolphins where feeding, socializing, and resting activities take place (Higham and Lusseau, 2004; Hoyt, 2005). This declaration promotes protection of core areas to preserve critical habitat for the species as well as their prey and marine ecosystems; establishing that only non-invasive research and periodic environmental surveys are allowed, conducted by specialist in the species studied or under their supervision (Hoyt, 2005). Habitat use pattern is different between localities, so it is important to know species behavior and its relation with environmental and anthropogenic factors in order to establish a critical habitat as a function of feeding, socializing, resting, and breeding areas (Wells and Scott, 1997; Nowacek et al., 2001; Ingram and Rogan, 2002; Higham and Lusseau, 2004; Pierpoint and Allan, 2004).

For northwest Mexico, research focused on bottlenose dolphins in the Gulf of California and Pacific Ocean has focused on subjects like community structure, distribution, abundance, morphology, genetics, feeding, home range, movements, behavior, group organization, distribution, size and population structure, photoidentification, residence patterns, reproduction and birth, human impacts and strandings. In Ensenada de La Paz and south of Bahía de La Paz there is a semiresident population of bottlenose dolphins that can be observed almost the whole year and that has been one of the populations most studied in Mexico since 1987 through 2006 (Acevedo-Gutiérrez, 1989; Marcín-Medina, 1997; 2010;

Díaz-Gamboa, 2001; Rojo-Arreola, 2002; Valadéz-Suárez, 2002; Salinas-Zacarías, 2005). In 2005 and 2006 a survey was conducted regarding its behavior (Figure 1) and it was determined that this region represents a portion of its critical habitat (Figure 2). Several of their activities take place near the coastline of El Mogote (feeding, breeding, reproduction, socialization, resting), including the outer margin to the Bahía as well as the inner margin to the Ensenada. It is worth mentioning that this is the first time in Mexico that a critical habitat is determined for coastal dolphins. These cetaceans can be observed in groups from 2 to 40 individuals, however small groups (2 to 10 animals) predominate, formed by females with calves and juvenile dolphins which are the ones observed inside the Ensenada; constituting a breeding lagoon (Figures 3 and 4). Its distribution range goes from 1 to 5 m from the coastline and from 1 to 7 m depth, shallow waters where they protect their offspring. Mothers teach their calves to hunt by playing, the mother and the calf throw a fish several in the air until the calf learns to eat it. It is important to mention that juvenile dolphins do not have an innate hunting instinct, it is an acquired trait taught only by its mother. Such a conduct has been frequently observed in the Ensenada channel and in shallow waters near the El Mogote mangrove; small fishes inhabit this area and represent an easy prey. It should also be highlighted that reproductive activity has been observed mainly in the Ensenada channel and in Ensenada mouth (Marcín-Medina, 2010).

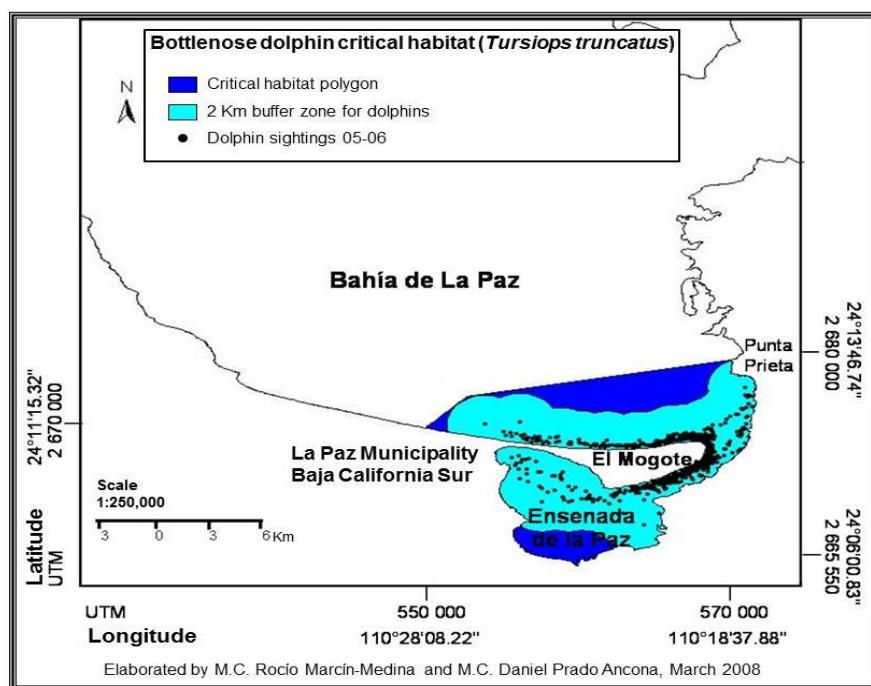


Figure 1. Critical habitat polygon and buffer zone base on bottlenose dolphins (*Tursiops truncatus*) sightings and behavioral studies during 2005 and 2006 in Ensenada La Paz and southeast of Bahía de La Paz (Marcín-Medina, 2010).



Figure 2. Mother and calf traveling in the Ensenada de La Paz channel. Picture by Alberto León-Gómez-Villacorta.



Figure 3. Juvenile dolphins near to El Mogote in Ensenada channel. Picture by Rocío Marcín-Medina.

This behavioral study was compared with a previous one made on 1995-1996 using the same methodology in Ensenada La Paz (Marcín-Medina, 1997; 2010), finding a habitat shift in 2005-2006 induced by environmental factors and anthropogenic disturbances (Figure 4). Southeast basin was lost (zone 1) due to sedimentation associated with tropical storms, hurricanes and dredging; reduced feeding activity in the northwest basin (zone 2) as a consequence of fisheries and increase in marine traffic superimposed on bottlenose dolphins main route near El Mogote; this affects dolphins' behavior particularly the mothers. This species is very sensitive to noise, in July 2005 it was recorded that a group of females with their calves were feeding when dredging activities of marina Singlair in Fidepaz began (zone 1). Dolphins were scared by sound and never returned to the zone, at least during the whole

year that the survey continued; it is an example of negative effects caused by noise pollution which implies loss of habitat (Marcín-Medina, 2010).

In La Paz city there has been an increase in mega-projects to create more touristic facilities (hotels, marinas) in the last 12 years. Among them there are the “Costa Baja” development in Bahía de La Paz, and the “Paraiso del Mar” development in Ensenada de La Paz; the latter was planned to occupy an area of 504.31 ha with 3,922 residential units, 2,050 hotel rooms in a 6 stories building, two 18-holes golf courses, a desalination plant, 5 wastewater plants, an outer marina with capacity for 535 docking stations, a pier with a building at the end, and a boardwalk (39 ha of marine development in a zone adjacent to Ensenada de La Paz). Clearly, this marina will obstruct the secondary navigation channel of the bottlenose dolphins, and the circulation of vessels will increase the noise pollution in their main transit route, specially where females teach their calves how to feed. Therefore, the construction of this marina poses a threat inside the critical habitat for this species protected by NOM-059-SEMARNAT-2001.

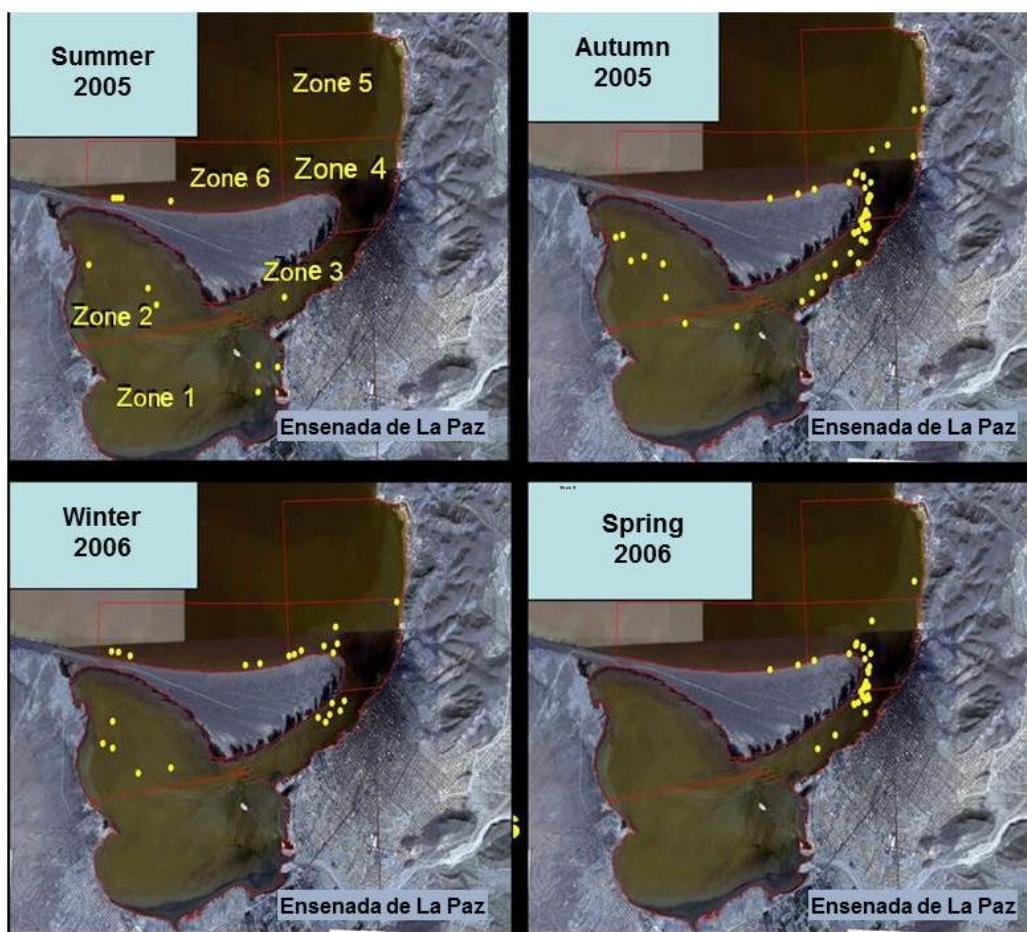


Figure 4. Bottlenose dolphin seasonal feeding zones in Ensenada and south of Bahía de La Paz in summer 2005 and spring 2006. Points represent dolphin feeding location (Marcín-Medina, 2010).

Grounds where this mega-project is planned (over 500 ha) were owned by the state, but in February 2004 a land use change was authorized from forests grounds and several vegetal species were removed from the area. In the written project it was stated that mangrove forest will be removed only in an area of 1.19 ha in order to build both the dry marina and the touristic marina, and that a buffer fringe 100 m wide will be established between the remaining mangrove forest and every construction made by this mega-project. This was not so, even when a group of scientific researchers (including some authors of this chapter) sent letters to the SEMARNAT delegacy (Secretary of Environment and Natural Resources) at La Paz and to the President of Mexico to denounce the damage on mangroves and probably dolphins as well, one month later DGIRA (General Directorate for Environmental Risk Impact) at SEMARNAT authorized the MIA (Environmental Impact Declaration) of this mega-project without the public consultation process required by law. In the resolution of the MIA it was consider that deforestation of 1.19 ha of mangrove forest did not put at risk the ecosystem and that petitioner's proposal for restoration of Enfermeria and El Grande estuaries (only the latter located at El Mogote, where the mega-project is planned) will be enough to mitigate the impact. As for the impact of vessel traffic on the feeding zone of dolphin community DGIRA only manifests that petitioner will be conditioned to develop a protection program for the environmental imbalance and a "survey program of the project's environmental performance" including: indicators for the incidence of nautical activity on main components of marine biota in the area with emphasis on the marine mammal population (*Tursiops truncatus*) present in Ensenada de La Paz, and to include as an indicator the results of the survey program for water quality. Include concrete preoperative actions to the activities of the touristic marina anticipating possible affectations that can occur due to nautical activities inherent to the mega-project to marine biota preservation. Emphasizing on transit routes, feeding and refuge zones for marine mammals, fishes like whale shark (*Rhincodon typus*) and manta (*Manta birostris*). All this created discontent among some researchers and civil society organizations (OSC), thus a decision to appeal on a long environmental litigation to impugn the authorization of the MIA, defending organisms, values, and ecosystem services of El Mogote was made.

The OSC "Ciudadanos Preocupados A.C." on July 2005 showed the review resource for the violation to the NOM-022-SEMARNAT-2003 for the mangrove affectation, violation to the NOM-059-SEMARNAT-2001 for the detriment to species like whale shark, breeding zones without mitigation measurements, and for considering that proposed measures by the petitioner of the MIA are insufficient to mitigate the damage to Enfermeria and El Grande estuaries. SEMARNAT resolution was unfavorable, stating that the arguments were unfounded without sustenance and insufficient to declare the nullity of the contested resolution. In October 2006 "Ciudadanos Preocupados A.C." replied recurring to an annulment of judgement before the TFJFA (Federal Court of Fiscal and Administrative Justice) where it was requested the impugnment of this development for the violations of NOM-059-SEMARNAT-2001 and NOM-022-SEMARNAT-2003 and because DGIRA did not considered the existence of a presidential mandate declaring protected forest zone the grounds surrounding the city and port of La Paz, publish on August 24, 1938 in the DOF (Federation Oficial Diary). The mandate includes El Mogote and forbids the use and extraction of live wood, only dead wood extraction is allowed. In February 2008 "Paraíso del Mar" realized without clearance dredging activities and installation of sewage pipelines on the shore of La Paz city where Reforma Street is located. In June of the same year they

repeated the operation, this time where Nayarit Street is located. Although official complaints were stated no authority took action nor penalized those actions in any way. In response, judges from S11M (Metropolitan Hall #11) of TFJFA emitted the record 32183/06-17-11-3 on April 3rd, 2010 which cancels the clearance granted by DGIRA to the real-estate mega-project “Paraiso del Mar” regarding environmental impact. They were no longer authorized to perform any operation or development including the marina and its environmental effects given that the permission previously granted violated protection regulations for mangrove forests (NOM-022-SEMARNAT-2003) ignoring that the 500 ha grounds for such project are located in a zone declared as a wetland of international importance by the Ramsar convention (site #1816). Petitioners presented two legal appeals which were both denied by PJF (Federal Judicial Power), meanwhile it was expected that SEMARNAT through DGIRA emitted a resolution against “Paraiso del Mar” thus denying any development to this mega-project. Surprisingly SEMARNAT disrespectfully ignored judges’ decision violating legal order, while real-estate enterprise continued working. Despite all above mentioned, during March 2011 Paraiso del Mar started illegally to dredg, construct and operate of the marina in the Ensenada de La Paz channel adjacent to the mangrove zone (Figures 5 and 6). Although organizations like CEMDA (Mexican Center of Environmental Right), AICMMARH, A.C. (Research and Conservation Association of Marine Mammals and their Habitat), and ConCiencia denounced this activities to SEMARNAT at local and federal level, as well as to PROFEPA (Federal Attorney for Environmental Protection), neither authority took action to stop such activities. One of PROFEPA’s guidelines established on June 1st, 2009 states that when an enterprise performs an activity that requires environmental clearance without authorization it will be closed. Nevertheless this development continued with the construction of a pier for 25 vessels. After several months the activities ceased because of the complaints; nowadays the hotels zone, and the golf course still operate; and the residential zone is inhabited. In March 2014 Guillermo Haro Belchez, head of PROFEPA, stated that this project will be reviewed and that if it does not comply with the required specifications it could be closed or even be demolished (2).

In October 2008 another mega-project named “Entremares” presented its MIA in the modality regional. This development was planned at El Mogote adjacent to “Paraiso del Mar,” with a property size of 390.76 ha to construct touristic, residential and hotels infrastructure. Development included construction of a system of tidal channels, a docking for 440 vessels, an 18-holes gulf course, shooting practice field, commercial and residential lots, hotels, duplex houses, single-family houses, villas, commercial areas, clubhouse, with a total of 3,420 housing units or its equivalent to 6,840 hotel rooms. Tidal channels will serve for vessels to circulate and dock inland. In order to develop this project, the petitioner required a deforested area of 285.99 ha, 73.2% of the total surface of its property. Tidal channel system would be formed by smaller channels in an area of 4.3 ha in the salitales zone and/or in the restriction zone specified in the numeral 4.16 of the NOM-022-SEMARNAT-2003 (minimum of 100 m to the mangrove fringe). The larger navigation channels forming the touristic-residential complex would cover an area of 37.68 ha, including two main flow channels inside Ensenada de La Paz 50 m wide on the sea, and 30-40 m wide on the land with a depth of 2-3m. In the adjacent lots to the tidal channels, floating docks is planned with 9 to 18 m long for a total of 440 docking facilities. For this mega-project DGIRA did make a public consultation and a public meeting in November. Different opinions were exposed against this development like damage to mangroves, Marcin-Medina delivered data regarding the critical habitat of

dolphins and the impact of vessels on its main transit route where frequent feeding and socializing activities take place. In November 2009 in the resolution made by DGIRA, 7 state and federal agencies opposed to this project, like CONANP (Natural Protected Areas Commision) in consideration of articles 3 and 4 of Ramsar Convention did not consider feasible any deforestation, digging, and dredging activities for the opening and construction of channels for the “Entremares” mega-project inside the Ramsar polygon wetlands Mogote-Ensenada de La Paz. In an unprecedented action, the DGVS (General Directorate for Wildlife) a branch of SEMARNAT, declares for the first time the damage to dolphins stating that the petitioner does not indicate the dates when the field surveys were realized, which could limit the identification of environmental impacts. For example, information about the presence of bottlenose dolphins and how they utilize the region was presented, but it was not considered which would be the impacts from vessel use over bottlenose dolphin’s populations, as well as for whale sharks, given the fact that the mega-project plans the construction of piers inside the navigation channels; thus it is to be expected that these vessels do not only use the projected channels but the whole Ensenada de La Paz region as well. Despite all these arguments, DGIRA approved the mega-project with some conditions; one of them was land use change, which was denied by the municipality of La Paz. Meanwhile organizations like AICMMARH, A.C., CEMDA, Tiburon Ballena Mexico, and ConCiencia pointed out the risks that this project represented to local species; these opinions where written in the annulment of judgment before the Federal Court of Fiscal and Administrative Justice. In September 2012 the TFJFA permanently nullify the Environmental Impact Authorization (AIA) of “Entremares” and determined that the petitioner did not consider in the project the possible damage caused to endangered species, like California sea lions, coyotes, gray foxes, and raccoons, all of them inhabitants of the forested protected zone El Mogote, located in front of La Paz city in Baja California Sur. Petitioner appealed legally but in November 2013, the Eleventh Collegiate Tribunal confirmed the nullity of the AIA, resolving to deny the appeal for considering that the 1938 decree that declares the port of La Paz area as a forested protected zone, is valid as a natural protected area (ANP) in the category “protection area for flora and fauna,” according to LGEEPA (Ecologic Equilibrium General Law).



Figures 5 and 6. Dredging for marina Paraíso del Mar (A) in March 2011. Already dredged zone and pier with docking for 25 vessels (B). Both pictures by R. Siddharta Velázquez Hernández.

CONCLUSION

The way in which Mexican environmental authorities like SEMARNAT have authorized touristic-nautical developments like Paraiso del Mar and Entremares in La Paz, B.C.S. shows a clear systematic violation of our environmental law (LGEEPA) resulting in the deforestation of mangrove forests, modification of the coastline and damage to protected species.

There are 5 wetlands inside Ensenada de La Paz with mangrove forests; El Mogote is one of them affected by deforestation, garbage, construction for touristic activities, and dredging of water channels. As it could be observed, main threat is the establishment of touristic facilities like Paraiso del Mar or Entremares, the potential impact of the latter was higher; because the petitioner pretended to remove the mangrove to build the inner channels so residents could board their vessels outside their houses. El Mogote is bordered by red and black mangrove, is considered a highly fragile environment, acknowledge as Ramsar site #1816 on February 2nd, 2008 (Wetlands Mogote-Ensenada de La Paz).

Ensenada de La Paz and south of Bahia de La Paz are part of the critical habitat for groups of female's bottlenose dolphins, which they use during most of the year for feeding as well as nursing, protect them against predators, socialize and rest. One potential threat that can affect this protected species is coastal touristic nautical development, with an increase in the number of constructions and marinas along the coast. The latter will influence habitat quality due to the increase in the number of vessels traveling in the zone, with a concomitant increase in marine noise; hearing system is the most important sense for the development of different biological activities in cetaceans.

In Mexico critical habitats are mentioned in articles 63 and 64 of the LGVS (General Law for Wildlife), those articles were reformed by the Commission of Environment, Natural Resources and Fish from the Republic Senate (DOF, 2010), stating that SEMARNAT has the authority to declare critical habitats by means of a secretariat agreement, based on scientific information of species. Critical habitats are specific areas in which organisms develop their essential biological processes (feeding, reproduction, socialization, and resting). Physic, chemical or acoustic pollution, as well as risk of collision with vessels can affect populations of coastal marine mammals. Therefore SEMARNAT with the aid of researchers specialized in such species and their behavior must decree zones as critical habitats and consider management measures for the conservation of species. Without a doubt, one of these zones is Ensenada de La Paz and south of Bahia de La Paz, that should be legally acknowledged as a critical habitat for dolphins; this will help for the protection and conservations of the whole ecosystem. By means of management programs, human activities that could impact the critical habitat of bottlenose dolphins must be regulated; this impact is higher for mothers with calves and juvenile dolphins, which according to the environmental laws of our country should be protected.

MARINA AZUL AND THE ACCUMULATIVE AND SYNERGIC IMPACTS

Another case is the fact that during the development of the Environmental Impact Study of the Project Marina Azul the consultant did not make a good evaluation because some relevant issues were not taking in consideration. Direct, synergistic, cumulative and residual ecological corridor in the southern Bay of La Paz impacts because we believe there are omissions, methodological faults, flaws and gaps in the Environmental Impact Statement filed. In the case of omissions, you can make a direct reference to the literature review of the relevant area as a list of species cannot be restricted to the exclusive area of the project and should be included in the zone of influence of the project as They focused on the development zone but not in the region. This project was categorized as REGIONAL so the information should be presented as part of the MIA. The document was presented with a list of some pretty grim and updated references.

It represents an omission the fact that there was a collection of diverse taxa marine, coastal and land that should be considered in the report. Within my count there are about 3000 species inhabit ecosystems corridor Bay La Paz-Bay Window (considering the Archipelago of Isla Espiritu Santo and Isla Cerralvo) where they have at least 50 endemic species and at least 500 species NOM ECOL are 059. There are at least 8 ecosystems (mangrove forests, rocky reefs, coral reefs, forests of seaweed, maerl beds, seagrass, sacrocaule scrub and marsh grasses) that did not show appropriate information distribution in the region. The project is located in the fishing 7 Bay of La Paz and represents an important area for fishermen in the region. The document does not present a single analysis of the situation of coastal fisheries. information relevant to the project are ignored as the winds relationship with respect to the movement of marine sediments pair raised. The Pleistocene terrace which covers almost 50% of the project was not considered. It is not considered the presence of invasive species in the project area (at least 2 species of invertebrates in the area and at least 4 of macroalgae in the vicinity) that could increase your coverage by leaks resulting nitrogen-rich water Golf Equestrian Club and pastures. So this project could well be causing direct impacts to ecologically and economically important populations.

The study data have methodological errors as the data collection were not raised using widely accepted standards in academia so that the data presented have presented interpretative vices. This is particularly evident in the methodology for determining the coverage of corals, macroalgae, density of vertebrates and fish for sea area but could set the same standard for the land area. The major mistakes I find in these data are in the design of sampling as no samples were statistically significant aftershocks in which clearly show that the project area is homogeneous in this biological corridor. Having no appropriate sampling design and not having a robust database we could not calculate the residual impact that could estarse generated as part of the development.

This Environmental Impact Statement has gaps in information and in the vicinity of this project there are 6 projects already approved and some of them already in operation shown in Figure 7: Maravia (adjacent), Punta Blanca (adjoining), El Judío (next), Azul del Cortés (next), The Saltito (next) and Vista Cerralvo (near and longer active). There is at least one mining concession adjacent and in addition to the desalination plant proposed in this project, there are two more: one in Maravia (adjacent) and another planned for the south of the CNA

project. This set of projects having at least 4 sea which would add to the already operational in 5 Peace and plan tourist Megacruceros input. In addition there are two thermal power projects in close and marine aquaculture area. All these projects will promote the increase in population along with the frequency of visitors to the ANP: Sloop Gulf Islands and ANP in a first stage but most certainly to other areas such as Cabo Pulmo ANP by increased traffic in the calculation boats least 2 thousand boats continuously circulating. This was not evaluated as part of the MIA and displayed synergistic and cumulative impacts that have not been evaluated or resolved herein. All these projects represents the increase in population which also put pressure on the aquifer of La Paz, La Ventana and Dam Buena Mujer.



Localidad

- ANP- Decreto: 30/11/2012
- Puerto Mexia-Clave:03B52007FD029-Oício:01/06/2007
- Azul del Córtez-Clave:3BS2006T0025-Resolutivo:19/04/2007
- El Saltito-Clave:03BS2010-Resolutivo: Abril/2010
- Proyecto Maravia-Clave 03B5200FD083-Resolutivo:16/01/2006

- Proyecto villas de Cerralvo- Concesión: 64 864/BCS/2008 03/JL-0059/01/08 Resolutivo 08/2008 21/07/2008

Figure 7. Overall view of Marina Azul project and related approved projects and desalinization plants.

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