Chapter 6

Biodiversity of Gastropod in the Southeastern Gulf of California, Mexico

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Abstract

Currently, studying the environment is important because of the phenomena that take place on the earth every day. That is why it is a priority to carry out studies that relate environmental changes to the biology of organisms. This allows us to know the interactions with the environment, and in this way solve, reduce or prevent ecological and economic problems, if they are organisms with a commercial value. The objective of this investigation is to determine ecological parameters of the gastropod community from the intertidal zone on five islands from the Gulf of California, México, to model the diversity, distribution and abundance of malacological fauna. We considered to evaluate the Shannon-Wiener diversity (H'), Pielou's of evenness (J) and the Margalef species richness indexes, in order to evaluate through an analysis from biotic and abiotic factors, the species status that was collected from the exposed and non-exposed zone tidal. The generated data were contemplated from a year-based biodiversity project (2016–2017) on the following islands: Patos, Bledos, Bleditos, Tunosa, and Mazocahui which belong to the Ohuira lagoon in Ahome, Sinaloa, southeast of the Gulf of California, México. Likewise a status about the importance of gastropods is mentioned for the study area.

Keywords: mollusks, Gulf of California, Muricidae, Melongenidae, tourism, fisheries, aquaculture

1. Introduction

The Gulf of California is one of the most important marine ecosystems in Mexico and one of the most productive and biodiverse in the planet, as well as being one of the least disturbed. There we find 922 islands [1] that stand out for their high diversity in species, its high level of endemic species and a great biological richness, features that have allowed these places to be considered as natural evolutionary laboratories [2]. Mollusks within the marine ecosystem play a big role in the energy flux and community structure, due to the fact that many of them work as ecological regulators [3, 4] and indicators of disruptions that take place in these systems [5]. Besides, they constitute an abundant and ecological important group due to the functions performed by each one of their members within the food web, nutrient recirculation and energy flux [6].

Mollusks are mainly used in benthic studies to relate their presence/absence and/or dominance, with the aim to set their relationship with types of seabed and substrate [7]. Furthermore, they help to establish a baseline for future follow-up and evaluation programs [8]. Life cycles, a high level of stress tolerance [7], an intimate relationship with the sediment and a high response toward disturbances [9] make them ideal organisms to study natural and anthropogenic environmental changes [10, 11].

As a framework, most of the published research about Mollusks in the Mexican Pacific has to do with faunistic studies and taxonomy, whereas others talk about diversity aspects and variation through time [12–17]. Additional studies relate to distribution and abundance [18–24] and ecology [25–27]. Based on these previous studies, there is a lack of current information about the biology and ecology of the community of Mollusks in the intertidal zone from the islands of the Gulf of California; henceforth, it is necessary to do research that can increase and deepen the knowledge about the composition, abundance, and diversity of Mollusks.

1.1. Geography and oceanography in the Gulf of California

The Baja California Peninsula encloses the Gulf of California and is one of the most remote peninsular areas of the world. The gulf is a big semi-enclosed sea with more than 1100 km in length, 100–200 km in width, and with 258,593 km (99,843 mi^2) of surface which comprises more than 9° of latitude which cross the Tropic of Cancer in its southern part, extending to Cabo Corrientes (Jalisco, Mexico). It is the home of more of 900 islands and islets; it gives place to a highly rich and diverse habitat region for the evolutionary forces which in turn shape its flora and fauna. The northeast part of the gulf covers around 60,000 km^2 (24,000 mi^2) of sea surface, it extends to 3° latitude, and it is a unique water body in many ways. The weather is very dry, with an annual rainfall of less than 100 mm. The array of average monthly air temperatures in the northern gulf is of 18°C. The northern gulf presents some of the biggest tides in the world. The annual tide (amplitude) in San Felipe and Puerto Peñasco comprises around 7 m and in the Delta of the Colorado River, at the highest part of the gulf reaches almost 10 m [28].

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1.2. Geography and oceanography of the Ohuira lagoon

The Ohuira lagoon connects itself with a 700-m-width cannel at Topolobampo Port. The Ohuira lagoon, with 125 km^2 (12,500 has) of surface, was the river basin of an ancient canal of the Fuerte River, which extended through the Topolobampo Bay, discharging its waters into this port. It is an area of shallows that during the rain period presents a deep zone of variable location depending on the tides and sediment dragging and presents a branch system that connects it with Navachiste Bay. In total, the system has eight islands: five within the Ohuira lagoon: Patos, Bledos, Bleditos, Tunosa, and Mazocahui (I and II) [29]. The circulation of the maximum currents in the lagoon's mouth is of 1.15 m s^{-1}, and in the channels of 1.10 m s^{-1} [30].

1.3. Biodiversity of mollusks

1.3.1. Current status

Mollusks are one of the zoological groups with more biological success, as much for its number of living species as for the habitat diversity they colonize [31]. Within the marine ecosystem, Mollusks play an important role in the energy flux and the community structure, due to the fact that many of them work as ecological regulators [32] and as disturbance indicators inside these systems [5]. In addition, they constitute an abundant and ecologically important group because of the role that each member performs within the food web, nutrient recycling and energy flux [6]. Inside this group, there are primary consumers, both herbivores and detritivores, second-level predators and specialized parasites, as well as opportunistic species, which indicates different answers to habitat modifications and pollution [33]. These organisms possess one of the most widespread distributions in the planet, ranging from the coastline to great sea depths [34]. The highest ability of Mollusks to adapt has given them a huge success along their evolution, and they have colonized terrestrial, damp and freshwater habitats [35], as far as deserts and polar areas, as well as the tropics and great sea depths [36], being widely studied due to their social and economic importance, as well as their commercial and nutritional values [37].

Many diverse studies about Mollusks have been undertaken in the Gulf of California. Nevertheless, the available information regarding the community structure of the group is scarce. Such investigations contribute important information because density variations from specific populations can be known in a specific period of time and locality, as well as the abundance and composition of a community within a natural gradient or when pollution or illness problems exist in the environment [38, 39]. In 2008, in the Guasave municipality, Sinaloa, Mexico, a Mollusk census was performed in the intertidal zone from La Mapachera, Tesobiate, La Huitussera, San Lucas, Guasayeye, Nescoco, El Metate and Las Chivas islands from the lagoon system known as Navachiste, in order to elaborate taxonomic lists and an intertidal species diagnosis. The collected Mollusks were located systematically in four classes (Gastropod, Bivalvia, Polyplacophora and Cephalopoda), 40 families and 81 species. Gastropods represented 59% with 24 families and 46 species, bivalves constituted 43% with 14 families and 34 species, polyplacophora comprised 3% with 2 families and 2 species and the remaining 1% corresponded to cephalopods with 1 family and 1 species [40].

In previous studies held in 2014 in the intertidal rocky zone (beach and mangrove area) from the Ohuira and Topolobampo Bays (Ahome), Sinaloa, the collected organisms represented a highly important trophic phase. The biodiversity and distribution of the community of epibenthic invertebrates was composed by a specific richness (S) of 168 species, divided in 10 taxonomic groups: 3 porífera, 2 cnidarians, 2 platyhelminths, 35 annelids, 2 sipunculids, 74 mollusks, 46 crustaceans, 1 pycnogonida, 1 ectoprocta, and 2 echinoderms, where Mollusks were the most predominant group with 74 species. The dominant Mollusks species were *Neritina* sp., and *Cerithium stercusmuscarum*. The epibenthic distribution was influenced by salinity and organic matter, enhancing the differences in the Ohuira lagoon [41].

1.3.2. Biodiversity of gastropods

The interest in studying biodiversity is linked to the lack of knowledge that exists over its magnitude, the processes that determine it and the constant loss due to human actions or climate change effects; thus, it is important to know and understand the processes that determine the abundance and distribution of biodiversity under different spatial and temporal scales in the gastropod species, as well as their transformation due to the environment [42–45].

2. Biodiversity of gastropods in Ohuira lagoon

Considering the period between October 2016 and 2017, organisms were collected by some of the authors from this present chapter in order to evaluate the biodiversity of Mollusks within the project named “Community structure of the Mollusks found in the islands of the north of Sinaloa, México” (Register number DSA/103.5/16/10277). Sampling stations were established in Patos (25°20′450″ N, 109°00′531″ W), Bledos (25°18¨350″ N, 109°00′458″ W), Bleditos (25°14′566″ N, 109°00′664″ W), Tunosa (25°15′785″ N, 109°00′924″ W) and Mazocahui (25°34′154″ N, 109°00′855″ W) islands in the Ohuira lagoon. To collect gastropod Mollusks we took as reference six quadrants of 1 m^2 dimension in the zone exposed to the waves and three quadrants in the area not exposed to the tides. The organisms were collected from the sand, mud, silt-clay and rocky soil, which were representative from the study area. Thereupon, in soft substrates the harvest was made manually, and those organisms that were found adhered to rocky substrates were removed with a scraper, chisel or hammer. In addition, those organisms that were found at a greater depth were collected by snorkeling. The collected Mollusks were stored in plastic bags with their corresponding label, according to the type of sample method. The organisms were conserved in ice to be transferred to the biology lab at the Universidad de Occidente Unidad Los Mochis, Ahome, Sinaloa, Mexico. Taxonomic keys were used to identify the gastropod Mollusks [46–53].

2.1. Alpha diversity measurement

The analysis of the community structure of gastropod Mollusks was based on ecological indexes that quantified the information given by the lagoon system, which were applied based on each island and whether the organisms were exposed or not to the tide. To represent the biodiversity of gastropods we used the following indexes:

The species richness (S) was estimated by counting the number of species because it is the easiest way to measure biodiversity, since it is based on the number of species that are present without considering their importance. The abundance (A) was estimated by counting the number of organisms that were registered in each sampling station. The relative abundance (Pi) represented the existing relation between the organisms of a single species and the total number of organisms from all the species encountered, by using the following equation (Eq. (1)):

$$Pi = \frac{\mathrm{ni}}{N} \tag{1}$$

where ni is the number of organisms from the "i" species and N is the total number of organisms from all gastropod species.

To identify the dominant species from the community we used the community dominance index (ID) (Eq. (2)) [27, 54]:

$$\mathrm{ID} = \frac{\mathrm{Y1} - \mathrm{Y2}}{\mathrm{N}} * 100 \tag{2}$$

where Y1 is the abundance of the most common species, Y2 is the abundance of the species that occupied the second place in abundance, and N is sum of the abundance of all species.

In accordance with the estimators, Pi, ID, H′, as well as with the dominance level, the main species for each island was determined. To represent the sui generis characteristic from the community, we analyzed jointly the abundance (A) and frequency (F) to establish four categories of species which are cataloged as (AF)—highly abundant and very frequent, (aF)—less abundant and highly frequent, (Af)—highly abundant and less frequent, and (af)—less abundant and less frequent [27].

The Shannon-Wiener diversity ecology index measured the average uncertainty degree to predict to which species a randomly chosen individual could belong to within a collection (Eq. (3)) [27, 38, 55, 56]:

$$\mathrm{H}' = \Sigma Pi^{*} \ln Pi \tag{3}$$

where Pi is proportional abundance of the "i" species.

Pielou's equity measured the proportion of the observed diversity from the maximum expected diversity. Its value ranges from 0 to 1, where 1 corresponds to those situations in which all species are equally abundant (Eq. (4)) [38]:

$$\mathrm{J}' = \frac{\mathrm{H}'}{H'\,max} \tag{4}$$

where H′: Shannon-Wiener's diversity and H′max: maximum diversity.

Species diversity under conditions of maximum equity, in other words, the species diversity from a sample if all the species (S) had the same abundance equity (Eq. (5)):

$$H' \, max = ln S \tag{5}$$

The diversity index or Margalef's richness (D_{mg}), transformed the number of species per sample into a proportion in which species are added by the expansion of the sample. This index assumes that there is a functional relation between the number of species and the total number of organisms [38]:

$$S = k\sqrt{N} \tag{6}$$

where k is the constant.

If the constant is not maintained, then the index varies with the sample size in an unknown manner. By using s-1 instead of S, we get $D_{mg} = 0$, when there is only one single species (Eq. (7)):

$$Dmg = \frac{S-1}{lnN} \tag{7}$$

where S: number of species; and N: total number of organisms.

In order to calculate these indexes the abundance data were transformed into a natural algorithm [27].

2.1.1. Richness (S), abundance (A), and relative abundance (Pi)

At the Ohuira lagoon we collected a total of 5431 gastropods, being Patos Island the one with the highest abundance of 2135 organisms (39.35%), followed by Bleditos Island with 1471 (27.12%), Tunosa Island with 768 (14.14%), Bledos Island with 649 (11.95%), and Mazocahui Island with 408 organisms, representing 7.44%.

In general, within all the islands that were studied in Ohuira lagoon a total of 22 species of gastropods were collected. In those areas where there was nonexposure to tides, the species that were found were: *Cerithium stercusmuscarum* (n = 333, Pi = 0.0613), *Neritina* sp. (n = 208, Pi = 0.0383), *Nerita scabricosta* (n = 301, Pi = 0.0554), *Nerita funiculata* (n = 207, Pi = 0.0381), *Nassarius luteostoma* (n = 22, Pi = 0.0041), *Nassarius gallegosi* (n = 20, Pi = 0.0037), *Crucibulum spinosum* (n = 217, Pi = 0.040), *Eupleura* sp. (n = 5, Pi = 0.000921), *Crepidula onix* (n = 1, Pi = 0.000184), *Crepidula rostrata* (n = 6, Pi = 0.001105), *Fisurella* sp. (n = 1, Pi = 0.000184), *Littorina aspera* (n = 5, Pi = 0.000921), *Littorina modesta* (n = 14, Pi = 0.0026), *Crepidula lessoni* (n = 10, Pi = 0.00184), *Tegula corteziana* (n = 5, Pi = 0.000921), *Diodora* sp. (n = 3, Pi = 0.00055), *Scurria mesoleuca* (n = 3, Pi = 0.00055), *Diodora digueti* (n = 3, Pi = 0.00055), *Crucibulum scutellarum* (n = 7, Pi = 0.00130), *Murex (Recurvirostris) lividus* (n = 3, Pi = 0.00055), *Terebra* sp. (n = 10, Pi = 0.00184), and *Hexaplex (Muricanthus) nigritus* (n = 10, Pi = 0.00184).

In the areas where there was tidal exposure a total of 19 gastropod species were found: *Cerithium stercusmuscarum* (n = 704, Pi = 0.130), *Neritina* sp. (n = 271, Pi = 0.050), *Nerita scabricosta* (n = 319, Pi = 0.059), *Nerita funiculata* (n = 505, Pi = 0.0930), *Nassarius luteostoma* (n = 11, Pi = 0.0021), *Crucibulum spinosum* (n = 14, Pi = 0.0026), *Crepidula onix* (n = 10, Pi = 0.00184), *Crepidula rostrata* (n = 8, Pi = 0.0015), *Littorina aspera* (n = 1, Pi = 0.000184), *Littorina modesta* (n = 50, Pi = 0.0092), *Crepidula lessoni* (n = 69, Pi = 0.0127), *Diodora digueti* (n = 4, Pi = 0.00074), *Murex (Recurvirostris) lividus* (n = 11, Pi = 0.0021), *Turritella gnostoma* (n = 1, Pi = 0.000184), *Thais biceralis* (n = 1, Pi = 0.000184), *Hexaplex (Muricanthus) nigritus* (n = 557, Pi = 0.1030), *Hexaplex eristrosthomus* (n = 76, Pi = 0.0140), *Phyllonotus brassica* (n = 15, Pi = 0.0028), and *Melongena patula* (n = 10, Pi = 0.00184).

2.1.2. Biodiversity in Patos Island

A total of 11 gastropod species were registered in Patos Island, where *Cerithium stercusmuscarum* showed the highest abundance with 214 organisms in the zone that was not exposed to the tide, whereas a total of 395 organisms were found in the area exposed to the tide. The least abundant species were *Crepidula onyx*, *Crucibulum scutellatum*, *Nassarius gallegosi*, *Nassarius luteostoma*, *Littorina modesta*, and *Murex (recurvirostris) lividus*, which were present with one single organism collected, both in the area exposed to the tide and the one not exposed to it (**Figure 1**).

2.1.3. Biodiversity in Bledos Island

Bledos Island was the one that showed a higher mollusk diversity with 13 species in which *Cerithium stercusmuscarum* was the most abundant with 41 organisms, whereas *Nerita funiculata* was the least abundant, being represented by only one collected individual (**Figure 1**).

2.1.3.1. Biodiversity in Bleditos Island

Bleditos Island had a gastropod diversity of 12 recorded species. *Cerithium stercusmuscarum* and *Nerita scabricosta* were the most abundant species in the intertidal area, being represented by 130 organisms. *Crucibulum spinosum* had 180 organisms in the area not exposed to the tide (**Figure 1**).

2.1.3.2. Biodiversity in Mazocahui Island

On Mazocahui Island a total of 9 species were registered from which *Nerita funiculata*, and *Neritina* sp. had the highest abundance with 109 and 124 organisms, respectively in the intertidal area. On the other hand, *Nassarius gallegosi* (17 organisms) and *Cerithium stercusmuscarum* (26 organisms) had the highest abundance in the area not exposed to the waves (**Figure 1**).

2.1.4. Biodiversity in Tunosa Island

Tunosa Island had a diversity of 10 species, from which *Nerita funiculata*, *Nerita scabricosta*, and *Hexaplex (Muricanthus) nigritus* were the most abundant in both zones, the one exposed

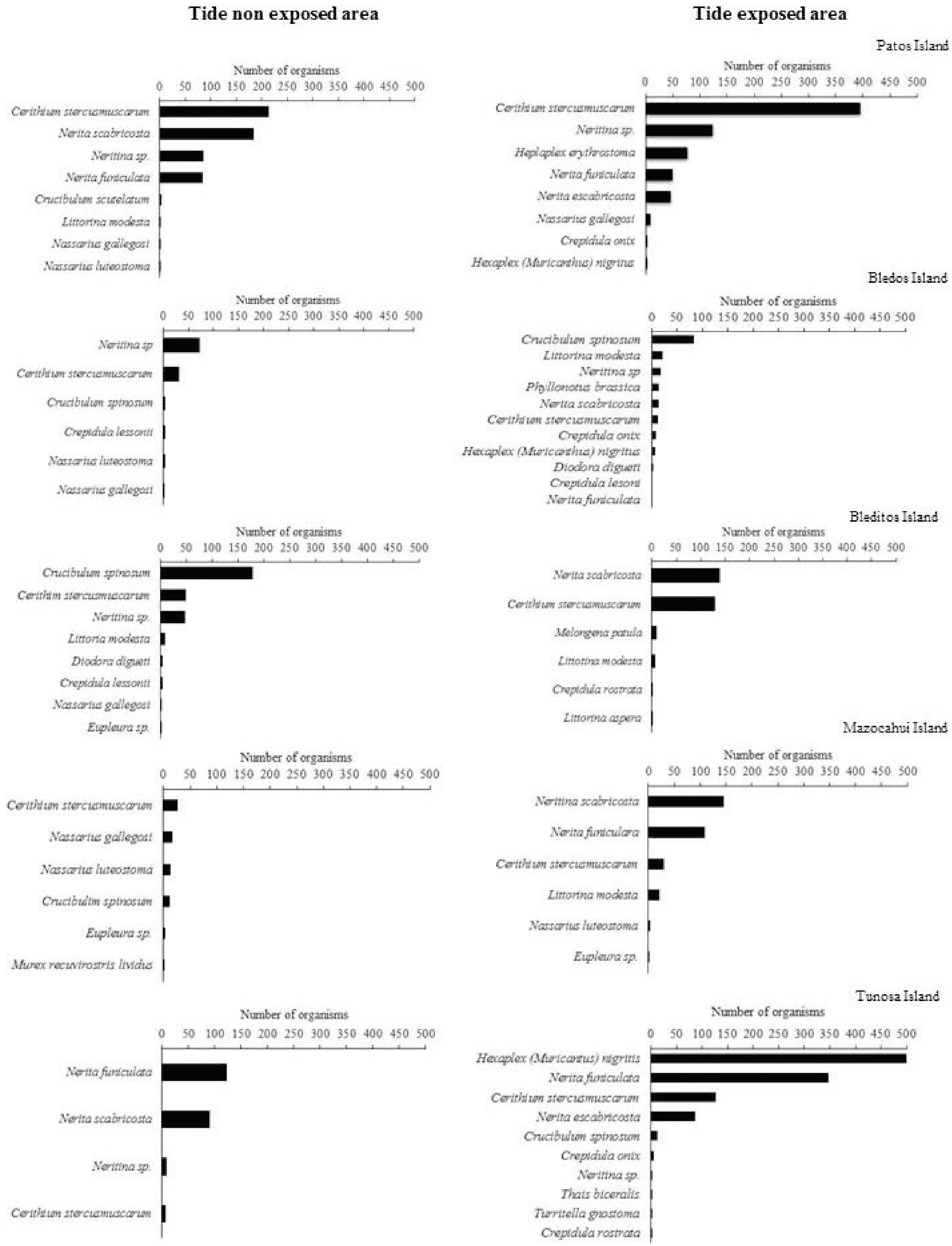

Figure 1. Diversity and abundance of gastropod mollusks on islands of Ohuira lagoon.

to the tide and the one not exposed to it, while *Turritellla gnostoma*, *Thais biceralis*, *Hexaplex (Muricantus) nigritus*, *Crepidula onix*, *Crucibulum spinosum* and *Neritina* sp. were the least abundant species in the area exposed to the tide (**Figure 1**).

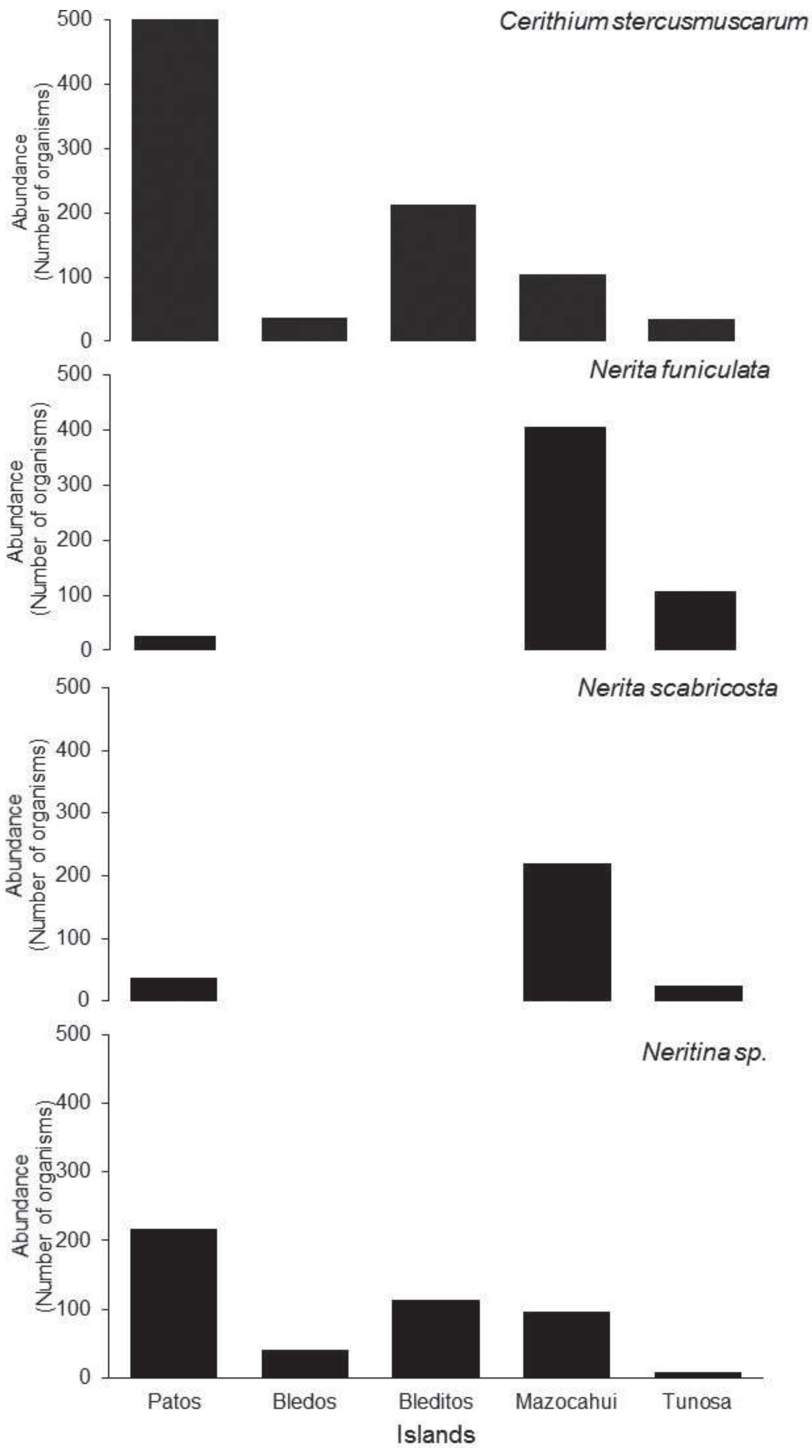

Figure 2. Dominance of *Cerathium stercusmuscarum*, *Nerita funiculata*, *Nerita scabricosta*, and *Neritina* sp. on the islands of Ohuira lagoon, Ahome, Sinaloa, Mexico.

2.2. Ecological indexes

2.2.1. Dominant species (ID) and Shannon-Wiener's diversity (H´)

Cerithium stercusmuscarum (ID = 32.20%, AF, H´ = 0.3161) was found on five islands with 1037 collected organisms, being Isla Patos the island with the highest abundance and Mazocahui the one with the lowest abundance (35 organisms). *Nerita funiculata* and *Nerita scabricosta* were the most abundant species on Tunosa Island with 712 (ID = 24.53%, Af, H′ = 0.2662) and 620 (ID = 21.67%, Af, H′ = 0.2478) collected organisms, respectively, in the intertidal zone. *Neritina* sp. was the dominant species and presented the highest abundance on Patos Island with 479 collected organisms (ID = 13.07%, aF, H′ = 0.2142), the sum of the dominance of these species was of 91.47%, where 8.53% corresponds to the rest of the remaining gastropod species. The biometrics of the dominant species on the islands of the Ohuira lagoon, Ahome, Sinaloa, México were as follows: *Cerithium stercusmuscarum* with 26.65 ± 0.146 mm in length, *Nerita funiculata* with 16.03 ± 0.118 mm in length, *Nerita scabricosta* with 39.03 ± 1.46 mm in length, *Neritina* sp. with 8.9 ± 0.205 mm in length (**Figure 2**).

2.2.2. Pielou's equity

2.2.2.1. Comparison between dominant species in tide exposed areas (J'_1) and non-exposed areas (J'_2)

The gastropods *Cerithium stercusmuscarum* (J'_1 = 0.5413, J'_2 = 0.8390) was recorded on five islands with 1037 collected organisms, being Patos Island the one with the highest abundance and Mazocahui Island the one with the lowest (35 organisms), finding a higher tendency of the proportion of the observed diversity in those nonexposed areas. *Nerita funiculata* and *Nerita scabricosta* were the most abundant species on Tunosa Island with 712 (J'_1 = 0.4677, J'_2 = 0.8298) and 620 (J'_1 = 0.6469, J'_2 = 0.6739) respectively, recording the highest equity index in the areas exposed to the tides. *Neritina* sp. dominated with the highest abundance on Patos Island with 479 collected organisms (J'_1 = 0.5831, J'_2 = 0.6993) showing the same tendency of high equity in the nonexposed areas.

2.2.2.2. Diversity index or Margalef's richness (D_{mg})

On Patos Island we found D_{mg} = 1.80, on Bledos Island D_{mg} = 1.68, Bleditos Island D_{mg} = 1.53, Tunosa Island D_{mg} = 1.95, and on Mazocahui Island, D_{mg} = 1.81, which suggests that on Patos and Mazocahui Islands, the diversity or richness is similar, being higher on Tunosa Island and lower on Bleditos.

3. Importance of gastropod biodiversity in the study area

Due to the lack of biological information from the Gulf of California islands, specifically from the ones found in Ohuira lagoon and their ecological and economic importance, it is necessary to perform research to increase the knowledge about them and to contribute on the elaboration of management methods and alternatives for the sustainable use the marine resources found on the islands. While it is true that in the past years the number of investigations have increased, the marine studies that have been performed on the islands of the Ohuira lagoon do not provide enough information about the species that inhabit the area, such as their biology, ecology, reproduction, physiology and taxonomy. This is why this current research pretends to set a baseline for future studies of the gastropod mollusk community from these islands throughout time, in order to evaluate possible environmental changes whether they are natural or anthropogenic.

3.1. Importance in ecology, biology and taxonomy

In Ohuira lagoon, Ahome, Sinaloa, the ecological importance in particular of the species of gastropod Mollusks is related to trophic levels, since there are organisms that are of carnivorous feeding habits such as the black murex *Hexaplex (Muricanthus) nigritus*, the prince murex *Hexaplex (Muricanthus) princeps*, the cabbage murex *Phyllonotus brassica*, the pink-mouthed murex *Phyllonotus erythrostoma*, Regal murex *Phyllonotus regius*, the Pacific melongena *Melongena patula*, the giant Eastern Pacific conch *Strombus galeatus*, and the Pacific cask shell *Malea ringens*, which can feed on other smaller gastropods such as *Cerithium stercus-muscarum*, the onyx slipper shell *Crepidula onyx*, *Terebra armillata, Hormospira maculosa*, and *Fusinus (Barbarofusus) colpoicus*, to mention some species. It is important to emphasize that both gastropods, the black murex *Hexaplex (Muricanthus) nigritus* and the ambiguous murex *Hexaplex (Muricanthus) ambiguus*, are sometimes considered as northern subspecies of the species radish murex *Hexaplex (Muricanthus) radix* [52]. Considering the gastropod species with the greatest economic-commercial importance in the study area, the biology is described for each case [41, 52].

3.1.1. Gastropods black murex Hexaplex (Muricanthus) nigritus (Philippi, 1845)

The distinctive features of the gastropod *Hexaplex (Muricanthus) nigritus*, are that it belongs to the family Muricidae, it has a relation of synonymy with *Murex nigritus* and *Muricanthus nigritus*; it has a very large, robust, bulbous shell with a moderately prominent conical spiral and a wide body turn. It presents six to nine strong spinal mandibular varices in the back of the body, crossed by spiral ribs intermixed with smaller ribs. It has relative scarce thorny acute varices, and those located on the shoulder and on the basis of the longer shell. It has a wide oval opening with a small rear channel and a wide siphoned channel, fairly well developed and slightly curved. It presents a strongly crenulated outer lip and an internal lip with a columellar adherent callus and a spiral crest on its back, and the nucleus of the operculum presents an anterior position. The color of the outer surface is white opaque, with a blackish-brownish dye on the ribs, spirals and thorns, and the opening is porcelain white. The maximum size reported was 150 mm, although the most common size is 120 mm. The reported habitats of the species were reefs or sandy bottoms in the intertidal zone and subcoastal shallow waters [52].

3.1.2. Pink-mouthed murex gastropod Phyllonotus Erythrostoma (Swainson, 1831)

It belongs to the Muricidae family, the synonyms used are *Murex erythrostoma*, *Chicoreus erythrostoma,* and *Hexaplex erythrostoma*. The distinctive features are a large, robust, globose-oval shell, with a short conical spiral and a wide body turn; four or five thick axial varices around the body, alternating with tubercular axial ridges; six to seven spiral crests that form nodules in the intervarical ridges and become open and sharp spines on the varices, being stronger in the shoulder; oval opening with a small posterior canal and a wide siphonel canal, relatively short and curved; an external erect and crenulated lip; an internal lip with a thin, expanded columellar callus and the nucleus of the operculum with an anterior position. The outer surface is opaque white and it has a bright pink opening. The maximum size reported was 150 mm, while the most common size is up to 100 mm. The habitat of the species was reported in sandy and muddy bottoms, both at low levels of the intertidal zone and offshore, up to 50 m deep [52].

3.1.3. Pacific melongena gastropods Melongena Patula (Broderip and Sowerby, 1829)

With only a single species in the study area, it belongs to the Melongenidae family. It presents a large and heavy, piriformed shell, the most recent rounds gradually enveloping the oldest, forming an irregular and deeply grooved suture and a very small spiral coil. Young organisms (less than 60 mm in length) are therefore more fusiform. The sculpture consists of a single-spaced row of short spines (although this feature might be absent) on the rounded shoulder, as well as numerous fine spiral grooves, mainly in the lower part of the shell. It has a rather smooth and thick periostraco, a very large opening, with a short and wide channel, an internal smooth and satin lip and a simple outer lip. The corneum operculum has a claw-like shape, with a terminal nucleus. The color is dark brown with cream spiral bands, just below the widest part of the last lap. The opening's color is yellowish to pinkish. The families of gastropods with similar appearance present in the area are: Fasciolariidae, with more fusiform shells, longer and narrow siphon canals, with few folds sometimes present in the columella. The maximum reported size was 260 mm; nevertheless, the most common size was up to 160 mm. Its habitat is in sandbars and mud from the high levels of the intertidal zone. It is a carnivorous species that especially feeds on other gastropod Mollusks [52].

3.2. Elaboration of crafts (tourism)

Several gastropods are used to create crafts (Port of Mazatlán, Sinaloa) such as jewelry boxes, picture frames, key holders, reliquaries, candles, lithographs, among others, by using shells of the gastropods belonging to the genus *Hexaplex*, *Melongena*, *Phyllonotus*, *Strombus*, *Turritella*, *Crucibulum*, *Crepidula*, and *Cerathium*. Mentioned artisan products are acquired by domestic and foreign tourists in local sales outlets established in municipal markets and in touristic areas. The elaboration of handcrafts has been carried out for decades mainly in the port of Mazatlán, where in many cases it becomes the livelihood-sustaining asset for a large number of families that take advantage of a waste product (shells) once the organism has been extracted for consumption and commercial importance. The same situation takes place with the smaller gastropods whose shells are collected on beach areas for these same purposes [10] (**Figure 3a–d**).

3.3. Fisheries

3.3.1. Current status

Some organisms of the gastropod are a very important fishery resource worldwide and have a significant economic impact through the generation of resources at the level of artisanal fishermen, local trade and the export of fishery products of international value. The gastropod fishery destined for human consumption in the study area is based on the black murex *Hexaplex (Muricanthus) nigritus,* prince murex *Hexaplex (Muricanthus) princeps,* cabbage murex *Phyllonotus brassica,* pink-mouthed murex *Phyllonotus erythrostoma,* Regal murex *Phyllonotus regius,* Pacific melongena *Melongena patula,* giant Eastern Pacific conch *Strombus galeatus,* and the Pacific cask shell *Malea ringens* [52].

Figure 3. (a–c) Decorative articles made with shells of gastropods, simulating flowers; (d) jewelry boxes made with different species of gastropods; (e) capture of black murex *Hexaplex (Muricanthus) nigritus* by snorkeling on a working day in the lagoon Ohuira, Ahome, Sinaloa, and also the adhesion of masses of embryos (Me) on the shells of the organisms captured; (f) capture of gastropods *Melongena patula* (Mp), *Hexaplex (Muricanthus) nigritus* (HMn); and *Phyllonotus erythrostoma* in the study area; (g) "Chipped" processing of the capture of the gastropod *Hexaplex (Muricanthus) nigritus* in the study area.

3.3.1.1. Gastropods black murex Hexaplex (Muricanthus) nigritus (Philippi, 1845)

The fishery of the gastropods black murex *Hexaplex (Muricanthus) nigritus* (*H. M. nigritus*) is the one of greatest effort considering the abundance of the species, incidentally including another gastropod (prince murex *Hexaplex (Muricanthus) princeps*) of the family Muricidae which has similar morphometric characteristics that go unnoticed to fishermen. Current official data from the port of Topolobampo, Sinaloa, on *H. M. nigritus* catches in the study area, with reference to the year 2008 with a catch of 8000 kg, and by 2014 of 4063 kg in live weight, which represented an income of $21,196.35 Mexican pesos [57, 58]. The exploitation and effort applicable to this gastropod in each season requires previous evaluations for each season according to the availability of the resource for each catch zone, due to their eating habits, the evaluation method can be by marking and recapture of marked organisms. The fishing effort is very variable, since not every year the catches are recorded. A fisherman by snorkeling can capture approximately 700 organisms in 4 h of work (**Figure 3e**). A minimum size for catching 90 mm of the shell [52] is contemplated in the Mexican legislation (**Figure 3f–g**). The average shell length recorded during the period 2016–2017 was 100 ± 2.53 mm, with a total weight of 104.45 ± 19.34 g. With regard to fisheries, growth with respect to the length ratio of the shell (mm)-total weight (g) was evaluated in black murex *H. M. nigritus* in the Ohuira lagoon and was represented by the potential model $TW = 4E\text{-}06SL^{3.7956}$, with $R^2 = 0.8317$ (**Figure 4a**).

3.3.1.2. Pink-mouthed murex gastropod Phyllonotus erythrostoma (Swainson, 1831)

The pink-mouthed murex gastropod fisheries *Phyllonotus erythrostoma* (*P. erythrostoma*) in the study area is complemented by the gastropod cabbage murex *Phyllonotus brassica* and regal murex *Phyllonotus regius* which have similar morphometric characteristics that go unnoticed by fishermen [52]. There are currently no official data in the office of the Port of Topolobampo, Sinaloa on the catches of *P. erythrostoma* in the study area, the closest reference is to the year 2008, with a catch of 8000 kg, which represented an income of $ 11,096.21 Mexican pesos [57–59]. The exploitation and effort applicable to this gastropod in each season of capture, as in black murex *H. M. nigritus*, requires previous evaluations for each season according to the availability of the resource for each catch zone. Due to their eating habits the evaluation method can be made by labeling, and the recapture of marked organisms. The fishing effort is very variable, since not every year has a recorded catch. A fisherman by snorkeling can capture approximately 150 organisms during 4 h of work (**Figure 3f**). Growth with respect to the length ratio of the shell (mm)-total weight (g) was evaluated in pink-mouthed murex *Phyllonotus erythrostoma* in the Ohuira lagoon and was represented by the potential model $TW = 0.5596SL^{1.2287}$, with $R^2 = 0.4442$ (**Figure 4b**).

3.3.1.3. Pacific melongena gastropod Melongena patula (Broderip and Sowerby, 1829) and incidentals gastropods

Captures in the study area of the Pacific melongena gastropod *Melongena patula* (*M. patula*), considering the official records in the Port of Topolobampo, Sinaloa, amounted 21,695 kg for the year 2014 with a value of $ 130,432 Mexican pesos. In contrast, the black murex gastropod

H. M. nigritus has a lower abundance than *M. patula* but it is compensated with the longer shell length and total weight that also has its commercial value (**Figure 3f**). FAO in 1995 [52] reported a maximum shell length of 260 mm, with a common length of 160 mm. There are gastropods that have a shell length and total weight similar or superior to *H. M. nigritus*, *P. erythrostoma*, and *M. patula* like the giant eastern Pacific conch *Strombus galeatus* (Swainson, 1823) and the Pacific cask shell *Malea ringens* (Swainson, 1822). However, their catch is incidental because of their low abundance. For these species of gastropods, there are no official regulatory standards for their fisheries, it is only mentioned those non-updated catch volumes, as well as the recommended catch sizes in the national fisheries charter issued by the National Fisheries Institute, Mexico.

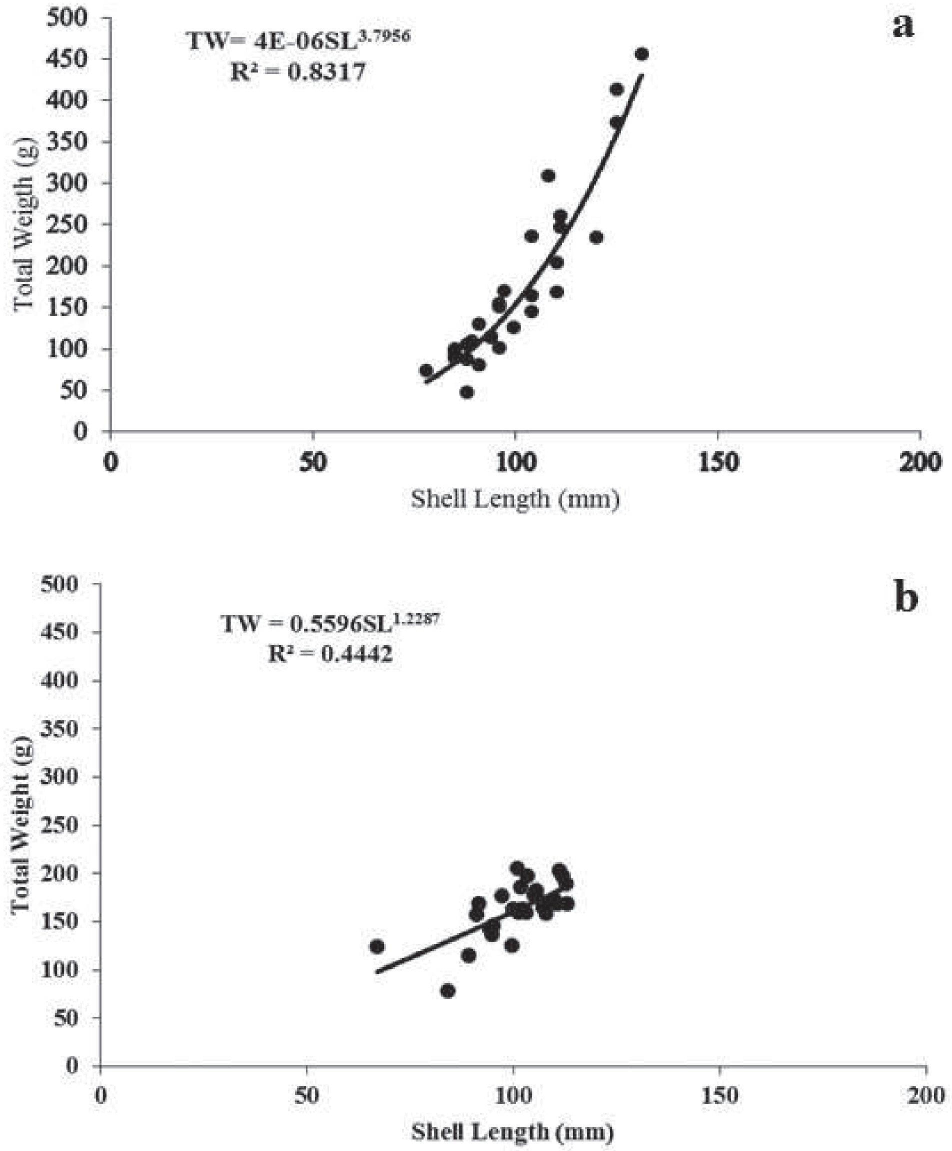

Figure 4. Growth in length of the total weight (g)-shell of the (a) black murex *Hexaplex (Muricanthus) nigritus* and (b) pink-mouthed murex gastropod *Phyllonotus erythrostoma* in Ohuira lagoon, Ahome, Sinaloa, Mexico.

3.4. Aquaculture

3.4.1. Current status

The reproductive cycle of the snail *Hexaplex (Muricanthus) nigritus*, was studied in 2011, under lab conditions. A total of three females and two males were collected in Macapule lagoon, Guasave, Sinaloa, Mexico. After being held at water exchange regimes a total of 24 eggs masses were collected. The average number of capsules found within an eggs mass was of 150.75 ± 37.23. The estimated height and width for the capsules averaged 15.05 ± 1.21 and 4.93 ± 0.58 cm, respectively; the average number of embryos found per capsule was of 1583 ± 149, obtaining a total of 238,626 ± 3457 embryos in the egg mass. The obtained results were considered as useful tools to estimate the reproductive potential of *H. M. nigritus* for commercial and repopulation purposes [60].

4. Discussion

A difference was found among the ecological indexes (H′, J′, D_{mg}) from the intertidal Mollusks community between the present study from the Ohuira lagoon, Ahome, Sinaloa (2016–2017 period) and previous studies undertaken at the Guasave municipality in Sinaloa (Navachiste lagoon) [15] and in the Topolobampo and Ohuira lagoons (mangrove zone) [16]. The abundance distribution of organisms and species on the collecting sites was heterogeneous. In the gastropod mollusk community in Ohuira lagoon, Ahome, there was a certain type of association with the type of substrate, which is composed of rocky and sandy zones (beach), zones with small rocks and in less proportion mangroves. The sampling methods showed that the gastropod *Littorina modesta* associates with the mangrove. In a previous study about epibenthic invertebrate communities associated with hard substrates in the intertidal zone in the Ohuira and Topolobampo lagoons, Sinaloa, the authors mentioned that the rocky intertidal zone and its organisms represent a very important trophic phase, and they recognize the importance of getting to know more about the biodiversity and distribution of the epibenthic invertebrate community of that study area. In their study, they performed 4 samplings with 50 × 50 cm quadrants at 5 stations from August 2011 to February 2012. The results showed that the community presented a specific richness (S) of 168 species, where 74 of them corresponded to Mollusks. The gastropod *Cerithium stercusmuscarum* was found within the dominant species, which matches with the results reported in the present study on the Ohuira islands [52]. The species *Cerithium stercusmuscarum, Neritina* sp., *Nerita funiculata, Nerita scabricosta, Crucibulum spinosum, Nassarius luteostoma* and *Crepidula onix* could be considered as representatives of the malacological fauna of the Ohuira lagoon, Ahome, Sinaloa, Mexico.

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