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Research Article

Base indexes for marine communities in the southern Gulf of Mexico derived from shrimp-fishery data

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ABSTRACT. In Mexico, shrimp is the most important fishing resource in terms of value, and second in production. Ten percent of the country's production comes from catches in the southern Gulf of Mexico. Several studies report the number of marine species recorded in this zone; however, few consider bycatch, and still fewer determine biodiversity indexes. This work identified the species captured in shrimp trawls from 22 commercial fishing trips from August 2016 to December 2017 in the south of the Gulf of Mexico. Four indexes of taxonomic diversity were determined: richness, evenness, average taxonomic distinctness, and variation. The indexes were calculated by season (dry, rainy, and northerly), spatial scale (terrigenous, carbonate, and Contoy zones), and depth interval: 1 (<10 m), 2 (10-20 m), 3 (20-40 m), and 4 (>40 m). The zones were separated according to the sedimentological characteristics described in the literature, and the depth ranges were arbitrarily defined considering the bathymetry of the zone. Nine classes, 51 orders, 121 families, 207 genera, and 334 species (152 terrigenous, 289 carbonates, and 76 Contoy) were recorded. Evenness index was highest in Contoy (0.75), followed by the terrigenous (0.54) and carbonate zones (0.35). Average taxonomic distinctness was greater in the carbonate (83.51) zone, followed by the Contoy (75.83) and terrigenous (74.55) zones. Contoy was identified as the most variable based on taxonomic distinctness (301.1). Also, the same index calculated by depth stratum and zone showed that the deeper zones generally have more phylogenetic relationships. The determinations of these indexes are proposed and can be used as points of reference to assess the variation and status of marine communities in the region.

Keywords: base line; bycatch; shrimp fishing, trawl; biodiversity index; Contoy zone; Campeche Sound

INTRODUCTION

Shrimp is one of the most important fishing products worldwide since it generates strong economic benefits, especially for developing countries, making a significant contribution to the livelihood of communities, particularly the poor and vulnerable (Gillet 2008), with an average annual catch of 84.6 million tons (Mt) from 2010-2014 (Eayrs & Fuentevilla 2021). However, in 2007, the FAO estimated that worldwide commercial fishing discarded around 7 Mt of fish annually. Of this, 27% is bycatch from shrimp fishing in tropical zones (Eayrs 2007), including a landed (or retained) catch of 75.5 Mt and discarded of 9.1 Mt (6.7-16.1). This discard rate of 10.8% (Pérez-Roda et al. 2019) suggests that shrimp-trawling gear is the most damaging

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to biodiversity, the seabed, and, consequently, to ecosystem health (Van Denderen et al. 2015, Eigaard et al. 2017). In Mexico, shrimp trawling, and aquaculture have placed the resource in second place in terms of volume, and first in commercial value, being exported mainly to the USA, Vietnam, and France. Of the 230,381 t reported in 2018, only 14.5% came from deep-sea capture, and of this, 10% (3341 t) were caught off the southern coast of the Gulf of Mexico (GM) (CONAPESCA 2018). The current situation of the relationship between the target species and the bycatch in the trawl fishery in the southern GM and Caribbean, as described by Quiroga et al. (2022), presents biological, ecological, socioeconomic, and technological indicators of incidental capture in this area.

The southern GM has a high biodiversity, supports diverse fisheries crucial for the local economy, and is considered strategic to Mexico's social and economic development (Soto et al. 2014, Alvarez et al. 2023). Furthermore, its complex and dynamic oceanic area is influenced by runoff from the country's largest river system (Grijalva-Usumacinta, Coatzacoalcos, and Papaloapan), which contributes nutrients, and dissolved organic matter, and interacts with coastal lagoons, and estuaries (Botello et al. 1998, Day et al. 2004, Rabalais 2004). The region has two geological provinces, each with distinct topographic and environmental charac-teristics: the terrigenous zone that runs along a continental shelf to the west and the carbonate zone to the east (Yáñez-Arancibia & Sánchez-Gil 1986, Hernández-Arana et al. 2005, Vallarta-Zárate et al. 2017). Similarly, the southern GM is influenced by the waters of the Lazo Current, which contributes to the development of coral reefs in the Caribbean region.

Few studies have compared the amount of bycatch to the amount of shrimp caught in the southern GM, and the number of species captured is virtually unknown. Grande-Vidal & Díaz-López (1981) reported ratios of bycatch to shrimp catch ranging from 1.45:1 to 5.4:1. These values are lower than 6:1 for the main fishing areas of the northern GM and much lower than 14.8:1 for catches along the entire Tamaulipas coast (Wakida-Kusunoki et al. 2013), where 131 species have been recorded in bycatch, including echinoderms, mollusks, crustaceans, and fishes. Parsons & Foster (2015) signaled for the north of GM a discard-to-landings ratio of 4.6:1.

In Campeche Sound, Carranza-Fraser & Grande (1982) reported a ratio of 3:1 and 72 species in bycatch. From six research cruises in Campeche Sound using trawl nets, Yáñez-Arancibia & Sánchez-Gil (1986) identified 152 fish species, of which 36% were bottom species, 41% calcareous bottoms and reefs species, 16% pelagic-coastal species, and 7% pelagic oceanic species. More recent studies of shrimp trawling in Campeche Sound by Ramírez et al. (2019) and Romero-Fernández (2020) reported 177 and 219 species of ichthyofauna, respectively.

Despite knowledge of fauna bycatch associated with shrimp capture in some zones of the GM, the impact caused by trawl nets on biodiversity still needs to be discovered. Nevertheless, bottom trawling may disorganize the seafloor, damage the biogenic structures, and kill benthic invertebrates, causing modifications in the structure and functioning of benthic ecosystems with the consequence damage in the trophic food (Kaiser 1998, 2019, Thrush & Dayton 2002).

Studies are needed to assess the current condition of the GM and measure changes. Earyrs (2007) notes that reducing bycatch in shrimp fishing operations would improve the environment's health, decrease the capture of juvenile shrimp, and protect the populations of various species. It is essential, therefore, to have indicators that serve as a baseline for the future monitoring of natural or anthropic impacts on communities.

Indicators of species diversity may be used to monitor alteration due to human activities (Maclaurin & Sterelny 2008) and, thus, ecosystem health. UNESCO (2009) mentions that several diversity estimates are needed to assess the conditions of the coastal marine ecosystem since these elements figure in the management and administration of ecosystems.

Ricotta (2004), indicates that Simpson and Shannon's entropy indexes summarize the information about the relative abundances of species in the community regardless of differences between species. However, other indexes can be used to obtain a general diversity trend, such as the richness index (Pielou 1975, Baltanás 1992), and the evenness index, since they provide species distribution and abundance (Smith & Wilson 1996). Other taxonomic indexes were proposed by Vane-Wright et al. (1991) as a taxonomic measure of species based on the phylogenic relationships to quantify the taxonomic value of different species, "taxonomic distinctness" and "average taxonomic distinctness": the first is based on the distinct character of a particular species compared to the rest of the community, and the second is a community indicator that can signal its "high" taxonomic value concerning another community in a different habitat or geographic zone (Warwick & Clarke 2001). Romero-Fernández (2020) recently conducted a study in the so-called "exclusion zone" in Campeche Sound, an area closed to protect the oil installations (DOF 2003), as a baseline used to quantify impacts from future fishing. The author used several diversity indexes, among them average taxonomic distinctness (Δ+), to determine that the zone had a high taxonomic diversity in 2017, compared to studies performed in 1980 by Yáñez-Arancibia & Sánchez-Gil (1986).

Quantifying these indexes based on trawl net capture in commercial shrimp fishing from Campeche Sound to the Contoy zone will provide data on the current diversity of the nektonic, and benthic communities, establishing them as complementary indicators to that described by Romero-Fernández (2020) for the region, and as a baseline for Contoy. Seasonal monitoring would show the effect of various impacts, i.e. not only from commercial fishing but also natural environmental impacts and those due to human activities (e.g. oil exploitation, and the damming of rivers).

During the study, the vessel monitoring system records show that 127 boats fished shrimp with trawl nets in Campeche Sound and the Contoy zone. In this study, catch data from this shrimp fishery are used to create indexes of taxonomic diversity that are evaluated at a spatial (terrigenous, carbonate, and Contoy zones) and seasonal (dry season, rainy, and northerly) level to obtain baseline indicators of the community structure that can be used to evaluate future ecological impacts to the region.

MATERIALS AND METHODS

Information on bycatch species and their biomasses was obtained from an "Analysis of the population of pink shrimp and bycatch in trawl fishing in Campeche Sound," produced by a program of scientific observers in the trawl fleet of Campeche Sound (southern GM) from August 2016 to December 2017, operating within the framework of the international project REBYC-II LAC (FAO-INAPESCA). All the fishing trips were commercial, except those in the Caribbean, which carried out research fishing in the closed season for shrimp fishing.

The monitoring was carried out in commercial fishing vessels with 21 to 24 m lengths and motors with power between 400 and 450 Hp. These had a shrimp trawl system of double rigs with two nets per band. The nets used for this fishery are 45 to 50 ft long. Headrope length, made with sapphire nylon thread, with mesh size according to the regulations, and turtle excluder devices according to the national regulations (Quiroga-Brahms et al. 2022). These boats carry out tows that generally last 3 h. In the case of the Contoy zone, where the samples come from research tows in the close period, these had 1 h of duration.

Catch information is from 22 fishing trips from 7 to 52 days. The geographic position of every tow was recorded (Fig 1).

A sample of 10 kg was taken randomly to know the catch species by trawling, where the shrimp was separated, and kept in a plastic bag for later analysis in the laboratory. On the other hand, the species of the incidental catch that was retained was identified and quantified. A sample of 10 kg was taken for the discarded incidental catch, which was identified by species on board.

The species were identified on board, and in CRIAP-Lerma, and EPOMEX-UAC Institute laboratories by applying the criteria of several key resources and websites (Cervigón et al. 1992, Robertson et al. 2015, Lavett-Smith 2016, Fishbase (Froese & Pauly 2019), Integrated Taxonomic Information System (ITIS) (Guala & Döring 2022), World Register of Marine Species (WoRMS 2022), Sea Life Base (Palomares & Pauly 2022), and the Global Biodiversity Information Facility (GBIF 2022)).

Study area

The Campeche Sound is characterized by river input and physicochemical properties. According to Yáñez-Arancibia & Sánchez-Gil (1986), the terrigenous zone to the west receives freshwater and nutrients from the San Pedro and San Pablo rivers, Palizada, and indirectly through the Terminos Lagoon from the Chumpán, Candelaria and Mamantel rivers (Fig. 1). It has 10-16% silty-clay sediments, with turbid waters (transparency of 7-42%), temperature of 25 to 28ºC, and salinity of 34-37. It lacks benthic vegetation, with a pH of 7.6 to 8.3 and dissolved oxygen >4 mL L^{-1} (Vázquez-Gutiérrez et al. 2005).

Carbonates geologically structure the carbonate zone to the east, are typically marine, and have sands with 70-90% $CaCO_3$ of low organic content (<10%). Although coastal circulation changes seasonally, no seasonal variation was observed in temperature or solar radiation received by Campeche Sound, giving rise to a semipermanent physicochemical pH gradient, dissolved oxygen, organic matter, and salinity. It has clear waters (transparency 53-99%), pH 7.7 to 8.9, dissolved oxygen >4 mL L^{-1}, temperature 26-29ºC, salinity 36-37, with abundant seagrasses and macroalgae (Vázquez-Gutiérrez et al. 2005). Given the region's characteristics, three climate seasons are recognized: dry from January to May, rainy from June to October, and

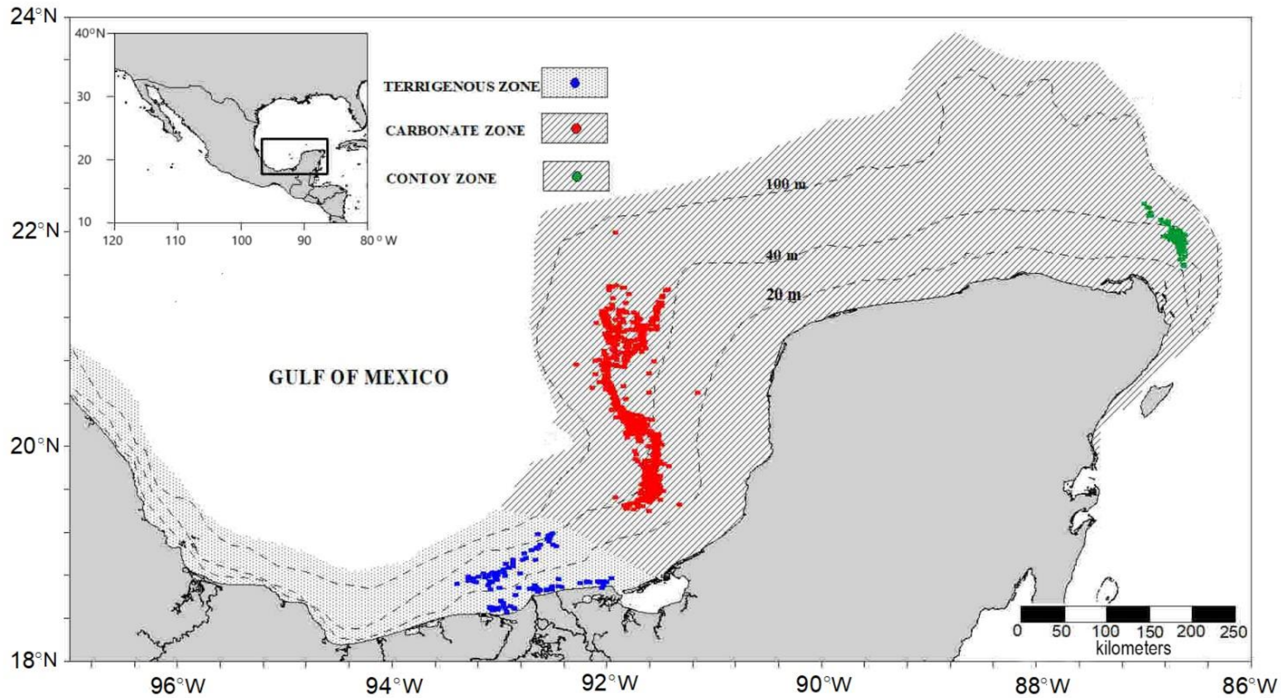

Figure 1. Tows made during the commercial pink shrimp trips. Blue shows those recorded in the terrigenous zone, red in the carbonate zone, and green in the Contoy zone. Differences in gray hue over depth isobaths show the terrigenous (left) and carbonate (right) zones.

northerly from November to February (Yáñez-Arancibia & Sánchez-Gil 1983). In the northerly season, masses of cold air bring winds from the north, resulting in annual minimal temperatures and winds from the country's southeast (Gómez-Hernández 2020).

Contoy Island is located 30 km north of Isla Mujeres and 12.8 km from the northeast coast of the Yucatan Peninsula. The substrate of the beaches of Contoy Island is made up of calcareous rock and coral reefs, with a predominance of lamellar algae, as well as large extensions of seagrass in areas with a sandy substrate (SEMARNAP 1997). The climate of this region is warm sub-humid with summer rains and an average annual temperature of 27.7°C. Due to its location on the border between the Caribbean sea, and the Gulf of Mexico, they are influenced by the Gulf Stream to the northwest and the Yucatan and Caribbean Sea currents to the southeast. A season of cold fronts runs from October to April of the following year. In March and April, there are winds from the southeast, and a period of calm between July and August (SEMARNAP 1997, CONANP 2016).

Data analysis

Four indices were used to characterize the community diversity, each related to different aspects of the biological community. Species richness (*S*) enumerates the total number of species in each collection since total richness cannot generally be estimated (Pielou 1975, Baltanás 1992). Comparisons of *S* between zones and climatic seasons were made using a non-parametric Kruskal-Wallis test, complemented by a pairwise multi-comparison test using the Steel-Dwass-Critchlow-Fligner/bilateral test procedure.

Evenness ($E_{1/D}$) evaluates the distribution of abundance between species, regardless of species richness; it is based on the species dominance index (*D*) (Simpson 1949) and was chosen according to the criteria of Smith & Wilson (1996). For its calculation, the biomass of the species present in each trawl of each trip is used. We adjust the species' weight to each tow's swept area to do this.

Average taxonomic distinctness (Δ^+, Clarke & Warwick 1998, Warwick & Clarke 2001) indicates the presence of a species, has a value between 0 and 100, and is independent of the number of individuals and species richness (Warwick & Clarke 2001, Magurran 2004). Average taxonomic distinctness adds information to the classic species richness and evenness indexes (Ramos-Miranda et al. 2005) while avoiding bias from differences in sampling effort (Magurran 2004).

Taxonomic distinctness (Λ+) considers the taxonomic tree structure (Clarke & Warwick 2001). This index may be biased for species with various orders if a single species represents some and others are represented by several species.

The indexes were calculated by season (dry, rainy, and northerly), spatial scale (terrigenous, carbonate, and Contoy), and depth interval: 1 (<10 m), 2 (10-20 m), 3 (20-40 m), and 4 (>40 m). The number of species in each of these groups (zone, climatic season, depth, zone-depth, and climatic season-zone-depth) was compared to the total number of species (334) in the study area. These comparisons were made by simulating 114 communities with 10,000 random iterations and calculating their confidence intervals with 5% type I error. SGBiodiv software (version 1.2.1, Gaillard 2002, UMR CNRS 5119 ECOLAG) was used to calculate the indexes.

RESULTS

From the 223 fishing tows analyzed, 120.92 kg of the catch was processed in the laboratory, representing 9 classes, 51 orders, 121 families, 207 genera, and 334 species. Teleost was the most predominant class with 203 species, followed by Malacostraca (42 species), Gastropoda (27 species), Chondrichthyes (22 species), and Bivalvia (19 species). Carangidae was the most represented family with 12 species; Haemulidae, Sciaenidae, and Lutjanidae each with 11 species; Triglidae and Sparidae each with 10 species, and Portunidae with 11 species.

In the terrigenous zone, 98 tows included 152 species. In the carbonate zone, 97 tows had 289 species, and 28 tows in the Contoy zone produced 76 species.

The Kruskal-Wallis test indicated significant differences in the catch weight between zones ($H_{2,0.05}$ = 154.7; P < 0.0001), and the Steel-Dwass-Critchlow-Fligner/bilateral test procedure showed that this was mainly between the terrigenous zone, and the three climatic seasons ($H_{2,0.05}$ = 220.0; P < 0.0001).

For each region and season, species that contributed more than 1% to the total catch were separated (Fig. 2). In the carbonate zone, despite having greater richness, eight species made up more than 1% of the catch, the pink shrimp *Penaeus duorarum* (77%), rock shrimp *Sicyonia brevirostris* (6%), red shrimp *P. brasiliensis* (5%), inshore lizardfish *Synodus foetens* (4%); red snapper *Lutjanus campechenus* (3%), and Mexican flounder *Cyclopsetta chittendeni*, southern stingray *Hypanus americanus*, and grey triggerfish *Balistes capriscus* (2% each). In the terrigenous zone, 14 species amounted to more than 1% of the catches, including brown shrimp *P. aztecus* (39%), inshore lizardfish *S. foetens* and white shrimp *P. setiferus* (11% each), and longfin inshore squid *Loligo pealeii* (7%). In the Contoy zone, nine species contributed more than 1% of the total catch, including rock shrimp *S. brevirostris* (42%), red shrimp *P. brasiliensis* (37%), inshore lizardfish *S. foetens* (5%), and shoal flounder *Syacium gunteri* (4%).

Regarding climatic season, 247 species were recorded in the dry season, 129 in the rainy season, and 214 in the northerly season. During the dry season, 11 species contributed more than 1% to the catch, including pink shrimp *P. duorarum* (59%), brown shrimp *P. aztecus* (11%), and inshore lizardfish *S. foetens* (7%) (Fig. 3). In the northerly season, seven species were the highest contributors to the catch, notably pink shrimp *P. duorarum* (85%), and red snapper *L. campechanus* (4%). In the rainy season, 14 species were the most representative: rock shrimp *S. brevirostris* (29%), red shrimp *P. brasiliensis* (25%), brown shrimp *P. aztecus* (14%), and lizardfish *S. foetens* (7%) and *S. intermedius* (5%).

The evenness index was highest in the Contoy ($E_{1/D}$ = 0.75), followed by the terrigenous (0.54), and carbonate (0.35) zones. The Contoy zone produced few species but was well distributed. The carbonate zone had the most (298) species, but they were not well distributed, some rare and others frequent. The terrigenous zone had 152 species that were more evenly distributed than the carbonate zone (Fig. 4).

The northerly season presented the highest evenness index ($E_{1/D}$ = 0.57; Fig. 4b), followed by the dry (0.42) and rainy (0.39) seasons.

Figures 5-8 show the values of Δ+ and Λ+ for each zone, climatic season, zone-depth and climatic season-zone-depth, and the corresponding confidence intervals (95%). Figure 5 shows significant differences (P < 0.05) in Δ+ for each zone regarding the confidence intervals. The carbonate zone presented the highest value (83.51), followed by Contoy (75.83) and finally, the terrigenous zone (74.35), suggesting that the length of steps from class to order, from order to family, from family to genus, and from genus to species are the longest. The carbonate zone included 9 classes, 40 orders, 111 families, 191 genera, and 289 species. In the terrigenous zone, Δ+ is the lowest (74.35), recording only 27 orders, 65 families, 103 genera, and 152 species (Fig. 5). Only the Contoy zone (Λ+ = 301.1) showed significant differences (P < 0.05) in the

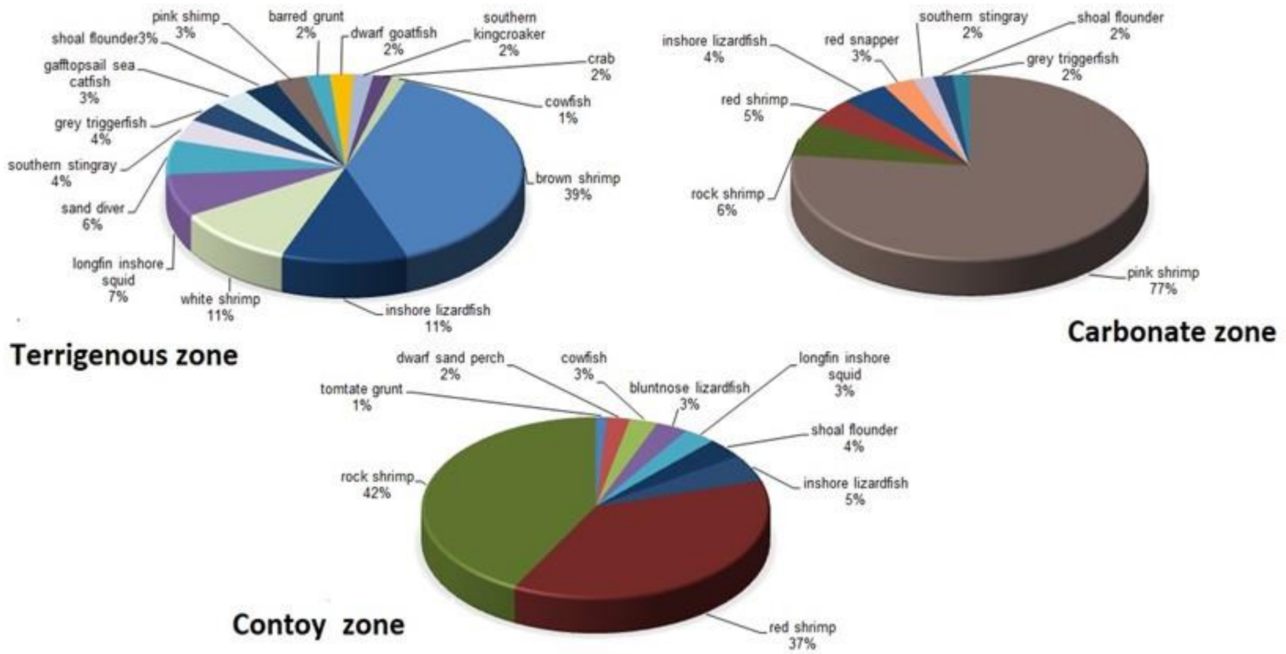

Figure 2. Most representative species for each zone recorded on the commercial shrimp fishing trips in the study zone.

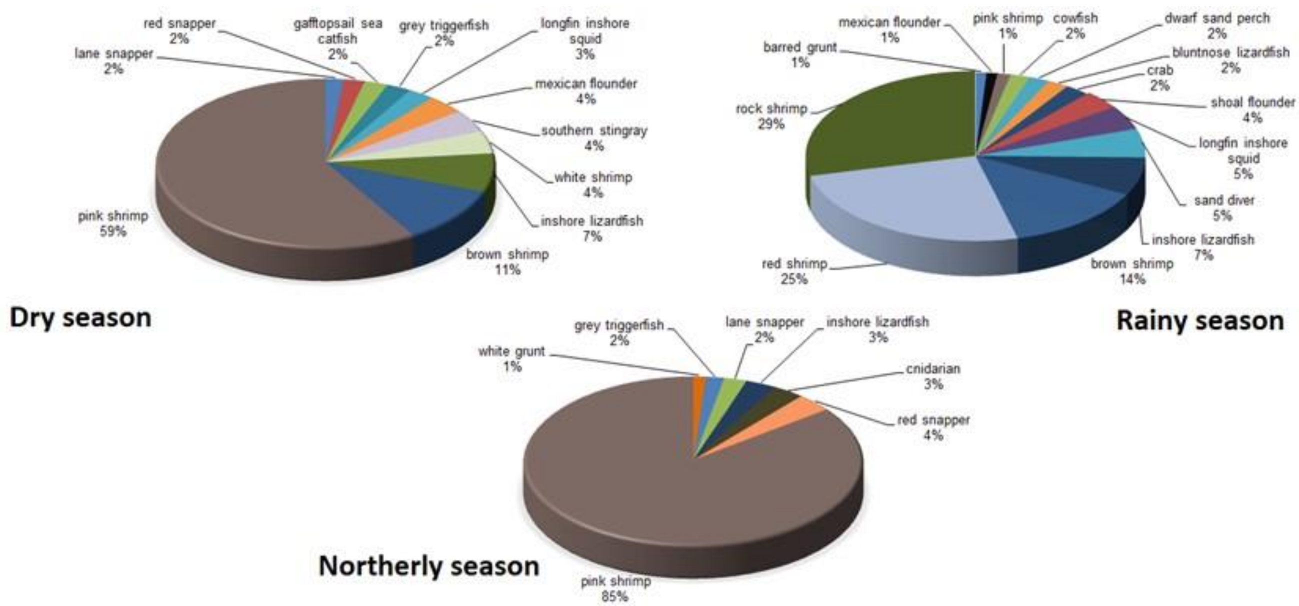

Figure 3. Most representative species for each climatic season recorded on the commercial shrimp fishing trips in the study zone.

model, which indicates strong variability, i.e. 53 genera and 76 species, many genera having only one species.

The values of both indexes obtained by climatic season (Fig. 6) showed that during the dry season (S), $\Delta+$ and $\Lambda+$ presented significant differences ($P < 0.05$) compared to the theoretical models; both presented the lowest values ($\Delta+ = 74.97$ and $\Lambda+ = 328.65$); 9 classes, 35 orders, 105 families, 171 genera and 247 species were recorded. A long step is observed from class to order, from order to family, family to genus, and genus to species. Only slight variation ($\Lambda+$) was observed in this season, above all in the Teleost class, which presented eight Lutjanidae species and six Triglidae species.

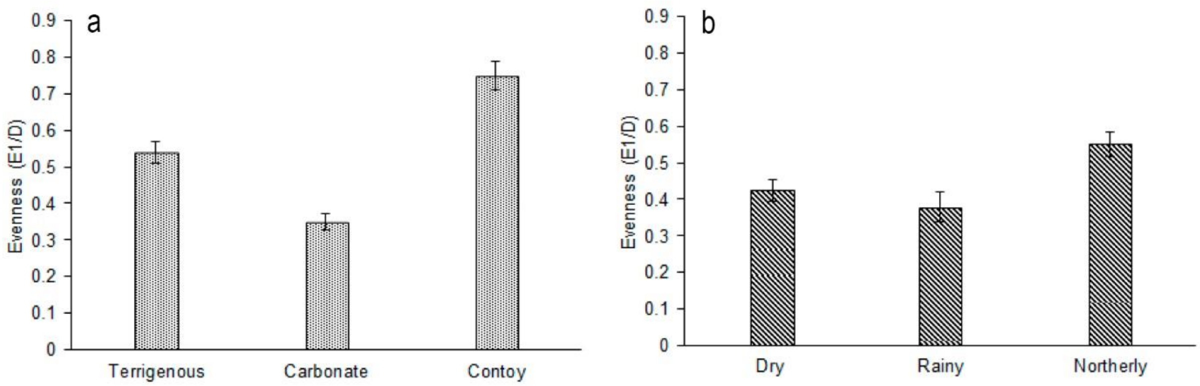

Figure 4. a) Equity index obtained by a) zone, and b) climatic season of the diversity obtained from the commercial shrimp trawls. Bars correspond to standard error.

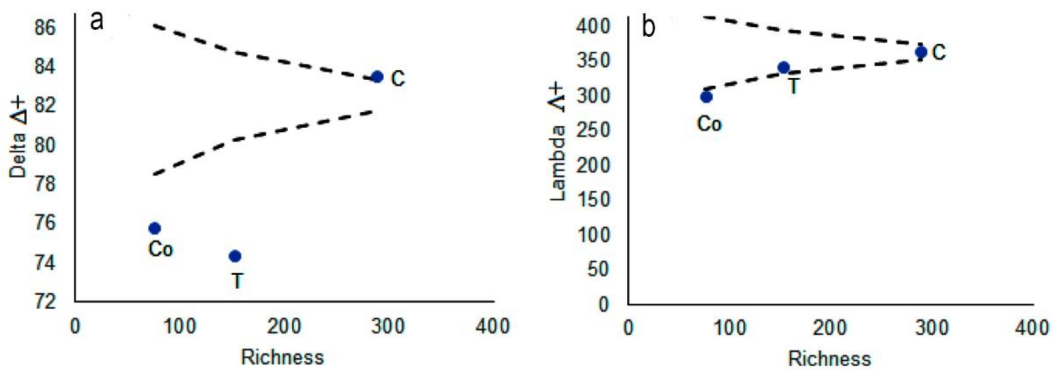

Figure 5. a) Average taxonomic distinctness (Δ+), and b) variation in taxonomic distinctness (Λ+) values and confidence intervals (95%) for fauna observed in shrimp trawls for each zone (T: terrigenous, C: carbonate, Co: Contoy) graphed against observed richness in the southern Gulf of Mexico.

By depth stratum and zone, a change is noted in the pattern of Δ+, the values obtained at depth 4 of the three regions, depths 2-4 of the terrigenous zone, and depth 1 of the carbonate zone being significantly different (Fig. 7). In general, in the deeper zone more steps or ways in its phylogenetic relationships are found. The carbonate zone at depth 1 indicates a few steps from genus to species (same number of genera as species). Regarding the variance of the index (Λ+), only depths 3 and 4 in the Contoy zone and depth 1 in the terrigenous zone presented significant differences ($P < 0.05$), showing greater variability within the taxonomic composition in these areas.

The pattern of the indexes by climatic season-zone-depth is shown (Fig. 8). In the dry season-terrigenous zone-depth 1, Δ+ was significantly different ($P < 0.05$) from all zones and depths in that season, and the lowest (73.15). The four Phyla recorded were Arthropoda, Chordate, Echinodermata, and Mollusca. Several species of crustaceans were recorded, along with many fish and a few echinoderms and mollusks. Hence, the steps to species are shorter, although the greatest variability (Λ+ = 321.12) was within the taxonomic group. A similar pattern is observed in the northerly season-carbonate zone-depths 1 and 3 since the model obtained only showed significant differences in Δ+. The greatest differences were seen in the rainy season-terrigenous zone-depths 1, 3, and 4, and in the Contoy zone-depths 3 and 4. The taxonomic groups that occurred in this season-zone-depth are regulated by the disturbance caused by freshwater to the ecosystem, as it rearranges the groups by moving the species inside and outside these sites, allowing a more complex structure of the taxonomic groups that define the values of Δ+ and Λ+.

DISCUSSION

The southern GM is highly productive, and its biodiversity is well documented (García-Cuellar et al. 2004, Torruco et al. 2018). It is also an important area for oil exploitation and coastal development, such as

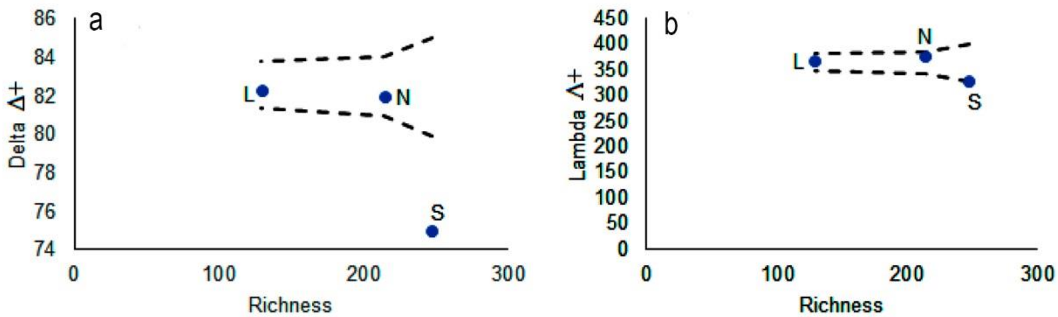

Figure 6. a) Average taxonomic distinctness (Δ+) and b) variation in taxonomic distinctness (Λ+) values and confidence intervals (95%) for fauna observed in shrimp trawls for each climatic season (L: rainy, N: northerly, S: dry) in the southern Gulf of Mexico.

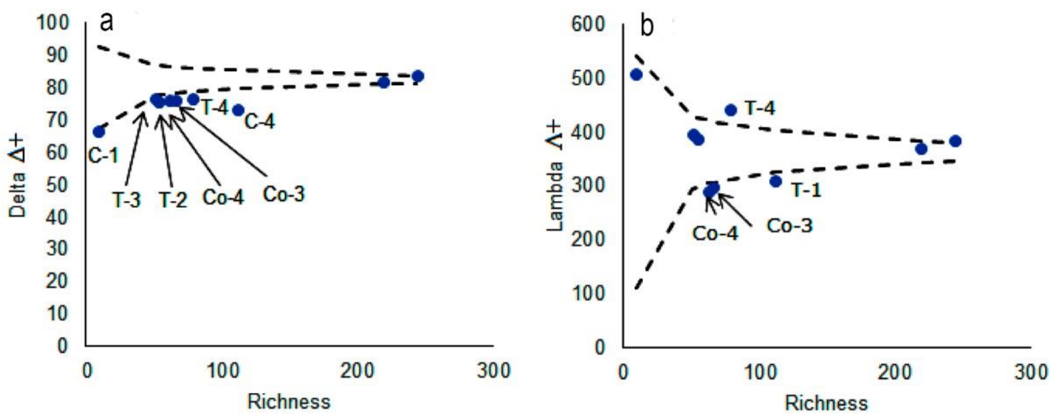

Figure 7. a) Average taxonomic distinctness (Δ+) and b) variation in taxonomic distinctness (Λ+) values and confidence intervals (95%) for fauna observed in shrimp trawls for each zone-depth stratum in the southern Gulf of Mexico. T: terrigenous, C: carbonate, Co: Contoy, numbers 1 to 4 correspond at different depth intervals: 1 (<10 m), 2 (10-20 m), 3 (20-40 m), and 4 (>40 m).

fishing, livestock, and agriculture, and is affected by frequent hurricanes, and storms.

Regarding species richness, for the Campeche Sound in the southern GM in 2010, Torruco et al. (2018) reported 193 species of fish captured with commercial trawl nets. Yáñez-Arancibia et al. (1985) and Yáñez-Arancibia & Sánchez-Gil (1986) reported 149, and 152 species, respectively, for the same area. Between 2011, and 2013, Ramírez et al. (2019) captured 177 fish species in the northern and southern portions of the GM. Romero-Fernández (2020) reported 219 species of ichthyofauna in the fishing exclusion zone in Campeche Sound in 2017. Here, we report 203 fish species, showing the difference between the three study zones, and identifying all the fauna present in the commercial shrimp trawls (Malacostraca with 42 species, Gastropoda with 27, Chondrichthyes with 22, and Bivalvia with 19), a total of 334 species. These data illustrate the region's richness, and the impact of trawling on specific species, and taxonomic groups in the zone. The different numbers of species reported in these studies could result from several factors, including the sampling zones, years, seasons, and even times of day.

The interactions of coastal inputs (Terminos Lagoon, and river inputs) with the coastal-marine waters have been widely studied (Soto et al. 2014). The southern GM has heterogeneous habitat, available food, and interactive processes involved in reproduction, and the life cycles (Yáñez-Arancibia et al. 1985, Yáñez-Arancibia & Sánchez-Gil 1986, Zetina-Rejón 2004, Abascal-Monroy et al. 2016). For Campeche Sound (zones A and B), Yáñez-Arancibia & Sánchez-Gil (1986) discuss the effects of Terminos Lagoon on multiple species. These environmental associations affect life cycles, behavior, and probably the compositions of communities in each zone, which may explain the difference in evenness with a greater imbalance in the distribution of abundance in the carbonate region, followed by the terrigenous region,

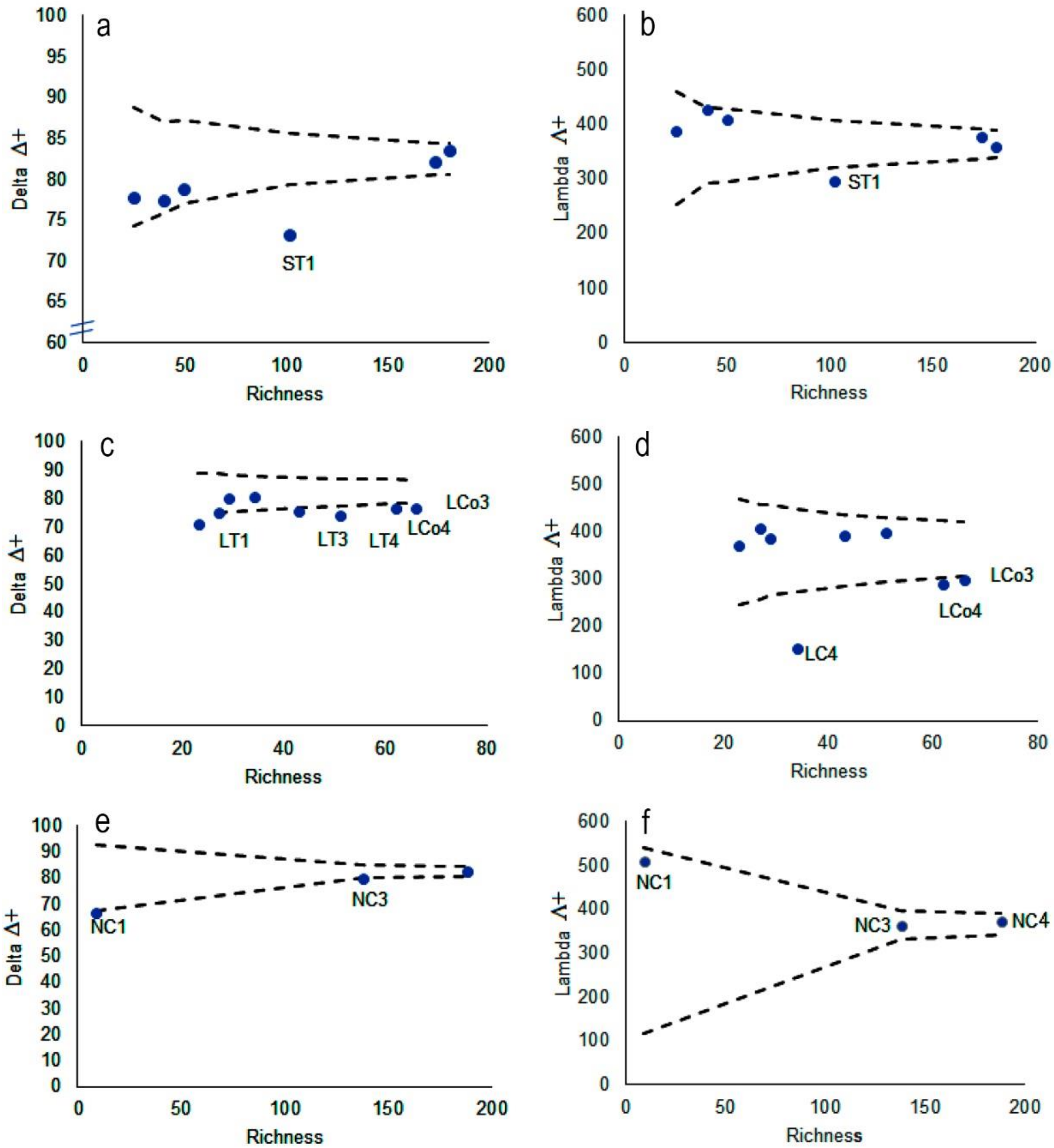

Figure 8. Average taxonomic distinctness (Δ+) and variation in taxonomic distinctness (Λ+) values and confidence intervals (95%) for fauna observed in shrimp trawls for each season-zone-depth stratum in the southern Gulf of Mexico. a-b) Dry (L) *vs*. terrigenous (T) and different deep intervals; c-d) rainy (L) *vs*. different zones and different depth intervals; e-f) northerly *vs*. carbonate (C) and different depth intervals. Climatic season (S: dry, L: rainy, N: northerly), zones (T: terrigenous, C: carbonate, Co: Contoy), numbers 1 to 4 correspond at different depth intervals: 1 (<10 m), 2 (10-20 m), 3 (20-40 m), and 4 (>40 m).

although with the highest observed richness, and homogeneity of abundance and least richness in the Contoy zone. It may also explain the evenness observed in the different climatic seasons, with the highest value recorded in the northerly season (Fig. 4). The climatic influence in the area causes a movement and changes of the water masses, which modify the distribution and abundance of species, since they obey a time-space pattern determined by their physiological, and nutritional needs (Yáñez-Arancibia & Sánchez-Gil 1986).

Average taxonomic distinctness (Δ+) and variation in taxonomic distinctness (Λ+) have the peculiarity of being robust to variation in the sampling effort, making them very useful for comparing studies with different methods or sampling periods (Clarke & Warwick 1999, 2001, Hardy & Senterre 2007) allowing them to be used as base indexes of biodiversity in the face of environmental impact, not only by trawling but also by other anthropic and natural impacts. In this study, 114 communities of different sizes were simulated (species richness) from a broad list of species, enabling the independence of Δ+ and Λ+ to the sample size to be determined (Figs. 6, 8). Additionally, both indexes, and the differences obtained for each zone, season, and depth allow them to be used as a baseline for a wide area of the southern GM. Some authors have pointed out that these indexes can be used as predictors of the functional diversity of assemblage groups (here called communities); thus, the most phylogenetically distant species could have different or exclusive functional traits (Warwick & Clarke 1995, Winter et al. 2013). This knowledge could be used to protect zones with high distinctness values, as they can pinpoint the communities with greater evolutionary history (Maciel 2013, Pérez-Hernández 2019). We propose that these diversity indexes are necessary for managing bycatch in shrimp trawling and assessing improvements in fishing gear towards more efficient and selective methods, as well as for designing and evaluating natural reserves, and fishing refuge zones.

For Campeche Sound, in an area known as the "Fishing Exclusion Zone" due to its importance for oil exploitation, Romero-Fernández (2020) found a high diversity using the Δ+ index, which he compared with the same indicator estimated from studies conducted in 1980; the values were lower than those obtained in the equivalent zone (carbonate) in our study (Δ+ = 79, and 84, respectively). The differences may be associated primarily with the author working in a fishing exclusion zone. At the same time, this study was based mainly on commercial catches in shrimp fishing areas. Another factor might be the difference in capture times since many species exhibit different behaviors during the day or night while feeding or reproducing (Blaber 1997), affecting their vulnerability to fishing.

These indexes, therefore, would allow the evaluation of any differences in the taxonomic distinctness between zones or depths and the potential changes due to the decrease in species or colonization (Tucker et al. 2017, Pérez-Hernández 2019). Likewise, the variation in taxonomic distinctness (Λ+) allows the observation of whether any ecological, anthropic, or environmental process could modify the communities when there is an over-representation of taxa (Tucker et al. 2017).

It has been shown that these indexes can be used due to their ability to discriminate environmental influence. Mouillot et al. (2005) used the indexes to study macrophytes in three lagoons in France, finding that Λ+ may be associated with salinity gradients. In this study, the environmental characteristics of the terrigenous, carbonate, and Contoy zones and the influence of the climatic seasons, and depth strata are determining factors in these indexes. However, the impact of trawl nets on the ecosystem, causing disturbance of the seabed, not only affects the physical medium but possibly also alters the taxonomic composition of the communities through the fishing of large species, which are often the most important predators in trophic networks; this has been discussed by Pauly et al. (1998). Kelleher (2005) pointed out that this fishing gear captures almost half of all fish and marine organisms worldwide.

Likewise, in addition to the macrofauna on the seabed, trawling also affects organisms that inhabit the sediments (meiofauna), and the bacteria, phytoplankton, and zooplankton that are important to mineralization, and bioturbation processes in the marine ecosystem, since they maintain the ecological balance and participate in the flow of matter and energy (Kelleher 2005). We recommend conducting studies to find the diversity index, and possible baselines to determine the potential impact of trawl fishing on these groups in the study zone.

The indexes obtained could form the basis of the current taxonomic composition of communities. They may be used as benchmarks in the future against possible environmental changes due to overfishing from trawling or potential improvements due to introducing more efficient gear with greater selectivity (Eayrs & Fuentevilla 2021). Warwick & Clarke (1995) showed a continued reduction in the taxonomic distinction of a marine assemblage along a gradient of growing environmental contamination in a situation where species diversity remains constant, demonstrating that stress factors are influential in biodiversity decline, and are reflected as a decrease in this index.

The future monitoring of fauna associated with shrimp capture in the southern GM, and biodiversity studies are needed to observe changes in community structure, and take relevant measures toward the sustainable management of fishing and other industries that can impact biodiversity.

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