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Article

Deep-sea crustaceans (400–3600 m) biodiversity in the northwestern Gulf of Mexico

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Abstract: Between 2016 and 2017, four oceanographic cruises were carried out in the Perdido Fold Belt area, in the northeastern province of the Gulf of Mexico. Benthic fauna was collected by bottom trawling with a benthic sled at 27 sampling sites, ranging from shallow to abyssal depths. The results obtained with the group of crustaceans are presented, selecting only the trawls representative of the bathyal benthic provinces (200–2000 m) and the abyssal plains (2000–6000 m) for analysis. Thus, 31 trawls with depths of 470 to 3600 m were recorded. The group was represented by 35 families, 72 genera, and 95 species. The lowest abundance/biomass recorded at the sampling sites was 2 org·ha^{-1}/17.67 g·ha^{-1}, while the highest was 400 org·ha^{-1}/5042.62 g·ha^{-1}. The highest species richness (16 species) was found at depths of 470 m, and the lowest (1 species) at 950–1000 m. Consequently, the lowest diversity (0.0 bits·ind^{-1}) was recorded at 950–1000 m and the highest (2.943 bits·ind^{-1}) at 470 m. The dominance of the top 5 species on each cruise reaches more than 50% for each, with 3 species remaining in this classification across all 4 cruises. The similarity given by the Bray-Curtis index associates similar depths. The NMDS (Non-metric Multidimensional Scaling) was used for the species ordinations because it is suitable for non-normal data or data that is discontinuous in scale, and shows most of the species close to the origin of the axes, only the most abundant species or those with the greatest weight are separated at the first crossing, in the rest there is no defined pattern. The sea bottom, as it presents physical conditions of great stability, presents a reduced biodiversity where biotic variables, such as competitive exclusion, resource division, and predation, are essential factors that define the structure and functioning of the communities of mega crustaceans in this area.

Keywords: megafauna; diversity; malacostraca; deep waters; Gulf of Mexico

1. Introduction

Since the Perdido Fold Belt region was included in the Block Allocation Rounds promoted by the Mexican Federal Government for oil exploitation by national and international oil companies [1], it was found that there was no previous information published for the region on the condition of the most important environmental components (water column, sediments, and organisms). In this context, the multidisciplinary project “Implementation of oceanographic observation networks (Physical, Geochemical, Ecological) for the generation of scenarios for possible contingencies related to the exploration and production of hydrocarbons in deep waters of the Gulf of Mexico” was approved, financed by the Hydrocarbons Sector account of the Ministry of Energy (SENER) and the National Council of Science and Technology (CONACyT) in Mexico. It was necessary to have a detailed environmental reference of the conditions in which the marine areas for exploitation would be handed over to the Oil Companies, and above all, the permanence within the limits established by national and international regulations for the compounds or elements (e.g., heavy metals and hydrocarbons) that could be extracted. The overall goal was to achieve an accurate understanding of the environmental conditions in that region.

Although the invertebrates of the benthic megafauna are one of the groups for which there is unquestionable information, this only corresponds to shallow conditions, especially in the southern part of the Gulf of Mexico, where there is an extraction platform. In the deep areas, there are methodological challenges that, together with the morphological differences of the different phyla that make up this fauna, restrict information substantially [2]. This lack of information makes it necessary to obtain quantitative and qualitative data on the community structure and biomass of the communities distributed in gas exploitation, oil exploitation, and fishing areas [3], to establish baselines that allow the creation of programs to protect area biodiversity [4]. The importance of marine benthic communities lies in the fact that they are the most affected by the expansion of fishing activities [5], oil and gas extraction [6–8], mining, and waste disposal [9,10]. Objectives are also diversified and may include conservation and stocking plans, assessments of fishing effort and efficiency (crustaceans and mollusks), as well as assessment of habitat damage due to fishing [11,12] and pollution [13–15].

Benthic mega invertebrates are multi-diverse and represent several phyla, [16–18], can modify the physicochemical characteristics of the sediment [19], and cause great heterogeneity in the ocean floor [20], which affects other smaller groups such as macrofauna and meiofauna [21–25]. Megafaunal invertebrates, particularly crustaceans, are distributed from intertidal to abyssal zones [26]. Despite their wide distribution, benthic deep-megafauna invertebrates are one of the least well-known groups [22], due to the methodological challenges involved in quantitative sampling [2], and, above all, the morphological differences of the different phyla that make up the group. Even though many of the members of these communities are of substantial ecological or economic importance, they are subject to high fishing efforts [3,12,27,28] both locally and nationally [29].

Crustaceans are the most in-demand of this group, and their fisheries provide considerable economic resources. It is generally caught by trawling, despite the inconveniences it causes to the habitat and other invertebrates [30–32]. This generates losses of around 70% of the fauna in an area subjected to trawling, with a negative effect of 97% on the total taxa present [33].

Although the distribution, size designation, feeding, etc. of representatives of this group has been studied in shallow and some deep areas, the variability in abundance and biomass in the deep sea is unknown [3,26,34,35]. The objective of this work is to present the distribution of the crustacean group in the deep bathyal zones (200–2000 m) to the abyssal plains (2000–6000 m) of the Perdido Fold Belt Polygon in the northwest of the Gulf of Mexico.

2. Material and methods

Study location. Sampling was carried out on the coast adjacent to the Perdido Fold Belt in the Northeastern Province of the Gulf of Mexico [36]. It has an accumulated coastline of low sandy beaches of rectilinear configuration, with a long barrier of approximately 454 km in length [37]. The great importance of this area lies in its enormous oil potential [38]. The area is formed by the strip of folds with north-northeast to south-southwest orientation armed in a sedimentary package from the Upper Jurassic to the Neogeno (140–5.2 million years ago) [38,39]. At these abyssal depths, bathymetry exhibits two main levels at the bottom. The upper one is characterized by rugged topography and winding valleys and the lower one has a flatter topography. Between the two levels, there is an escarpment ranging from approximately 1950 to 2850 m at its highest point [40,41].

In this area, 27 sampling sites were considered. However, for this study, only sites with depths greater than 400 m in the benthic province were selected and where crustacean collection was successful (**Figure 1**). The total number of samples was 31 (7 on the first cruise, 5 on the second, 10 on the third, and 9 on the last).

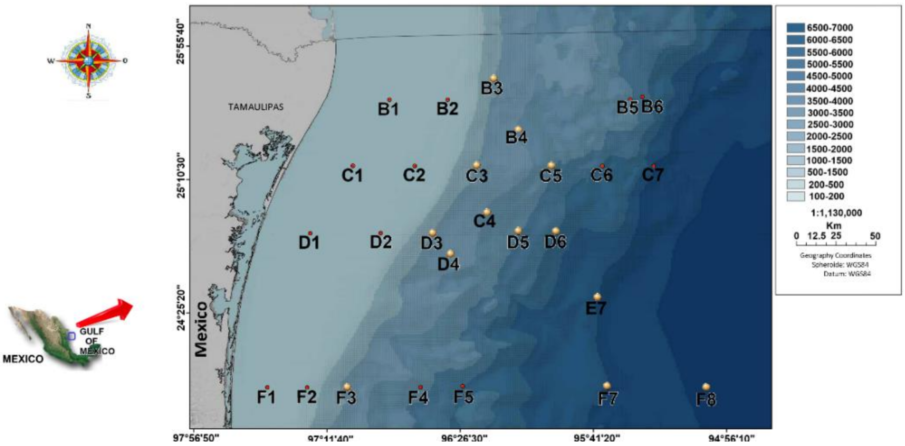

Figure 1. Location of sampling sites in the lost fold belt area of the northwestern Gulf of Mexico.

Sampling Sites. The samples were collected on 4 oceanographic cruises aboard the oceanographic ship Justo Sierra of the National Autonomous University of Mexico between 2016 and 2017. The fishing gear was trawled with a benthic sled 2.4 m wide and 1 m high at the mouth, 2 m long, and a mesh span of 2 1/4 inches in the body of the net and 1 1/2 inches in the collector coded. The duration of the trawls was approximately 30 min, at a speed of 2–3 knots$\cdot$h^{-1}, covering a total area of about 1 nautical mile.

The crustaceans were separated from the different groups and then frozen for subsequent transfer to the laboratory for counting, weighing, and identification with specialized literature [42–46]. Thus, abundance and wet biomass matrices were obtained and used for statistical analyses.

Statistical analysis. To obtain a robust quantitative descriptive synthesis: species dominance was determined using the Importance Value index [47], and biological diversity was quantified using the Shannon-Wiener index [48]. The sites were classified through multivariate statistics with the Bray-Curtis similarity index, using the flexible criterion [49,50] with a $\beta = 0.25$. A non-metric multidimensional scaling analysis (NMDS) was used for the spatial position of the species, as it is suitable for ordering non-normal data or data that are on a discontinuous scale [51]. All indices were calculated with the ANACOM software [52].

3. Results

In the oceanographic campaigns, crustaceans were represented by 1 class, 2 orders, 35 families, 72 genera, and 95 species (Appendix **Table A1**). The depth range was from 400 to 3600 m. The trawls area was 128,975 m^2, in 14 h 50 min. The overall data of the trawls and their number for each cruise are presented in **Table 1**.

Table 1. Trawl data of the crustacean megafauna for Perdido Fold Belt region.

Attributes	**Perdido_1 (May-2016)**	**Perdido_2 (Sep-2016)**	**Perdido_3 (Jun-2017)**	**Perdido_4 (Sep-2017)**	**Totals**
Trawl	7	5	10	9	31
Surface Trawl (m^2)	18,203.53	24,737.02	43,892.4	41,624.38	128,975.54
Time trawls (Hrs)	3.36	2.20	5.0	4.26	14.82
Deep (m)	470–2200	200–1400	470–3500	500–3600	470–3600

The abundance of organisms and their biomass was variable in all cruises, both between sites and in their values (**Table 2**), reaching from 2 to 401 org·ha^{-1} and from 0.91 to 5042.62 gr·ha^{-1} respectively. Species richness ranged from 1 to 16 species and the range of ecological diversity was from 0.0 to 2.94 bits·ind^{-1}. The geographical position of each trawl on the 4 cruises and the values for crustaceans are shown in **Table 2**.

Table 2. Abundance (org·ha^{-1}), biomass (g·ha^{-1}), species richness (S) and diversity (H’, shannon-wiener index) of crustaceans in the 4 perdido cruises in the Gulf of Mexico. The depth (m) of the trawl sites is displayed.

Sites	**Coordinates**		**Abundance**	**Biomass**	**Richness**	**Diversity**	**Depth**
	LN	LW	Perdido 1 (May 2016)				
B4	25°7'12″	96°25'12″	9	5.04	1	0	1000
C3	27°6'0″	96°13'48″	161	684.78	10	1.997	503.8
C4	24°33'36″	96°11'24″	62	746.94	6	2.099	1065.7
D3	24°29'24″	96°21'36″	36	315.25	4	1.549	473.4
D4	24°30'0″	96°21'36″	47	96.87	3	0.906	826
D5	24°32'24″	95°35'24″	32	45	2	0.918	1280
D6	24°4'30″	97°18'36″	26	23.7	3	1.557	2215
			Perdido 2 (September 2016)				
C3	25°22'54″	96°22'53″	108	610.9474	9	2.08	499
C4	25°57'32″	96°18'48″	25	294.6336	8	2.84	203.5
D3	24°49'53″	96°36'41″	109	457.2627	9	1.798	493
D4	24°49'9″	96°30'6″	25	64.285	8	2.914	826
D5	24°54'10″	96°5'40″	97	369.4404	11	2.609	1422.6
			Perdido 3 (June 2017)				
B3	25°49'33″	96°13'55″	249.7	530.3855	16	2.943	471.9
B4	25°35'48″	96°4'15″	10.11	3.8081	3	1.585	959.6
C3	25°14'23″	96°22'14″	65.72	4120.1988	5	1.503	503
C4	24°58'8″	96°19'21″	3.86	3.088	1	0	958
D3	24°49'56″	96°36'40″	9	50.4675	4	2	494.14

Table 2. (*Continued*).

Sites	Coordinates		Abundance	Biomass	Richness	Diversity	Depth
D4	24°55'46″	96°3'49″	4.74	2.844	2	1	1040
E7	24°34'57″	95°38'54″	102.5	188.95	7	2.472	3000
F3	23°44'23″	97°8'47″	400.77	5042.6283	8	1.341	553
F7	24°4'13″	95°40'20″	30	50.725	4	1.959	3235.3
F8	24°5'54″	95°14'4″	46.6	13.5373	3	0.922	3502
Perdido 4 (September 2017)							
B3	25°49'36″	96°13'56″	213	213.85	12	1.703	500
B4	25°35'55″	96°14'11″	2	17.67	1	0	987.7
C3	25°15'4″	96°21'56″	24	38.15	3	1.392	531
C4	24°58'2″	96°19'19″	9	57.07	4	2	986.5
D3	24°49'46″	96°36'38″	5	0.91	2	1	512
D5	24°54'54″	96°4'59″	47	109.64	7	2.499	1554
E7	24°34'58″	95°38'56″	20	23.22	4	1.868	3098
F7	24°5'26″	95°40'14″	26	20.25	4	1.522	3323
F8	25°6'45″	95°14'23″	9	38.47	2	0.811	3608

Ecological dominance, given by the Importance Value Index (IVI), shows the top 5 species on each cruise, the other species had lower values. Two shrimps (*Penaeus setiferus* (Linnaeus 1767) and *P. aztecus* (Ives 1891) were dominant in three cruises, and in one of them a crab (*Callinectes sapidus* Rathbun 1896). The dominance of these species never reached 30%; however, the sum of the 5 most dominant species was 50 to 70% of the total dominance in cruises (**Figure 2**). *Achelous spinicarpus* Stimpson 1871, *Raninoides laevis* (Latreille 1825) and *Callinectes sapidus* were present among the 5 most dominant species in all cruises, the other species were less frequent.

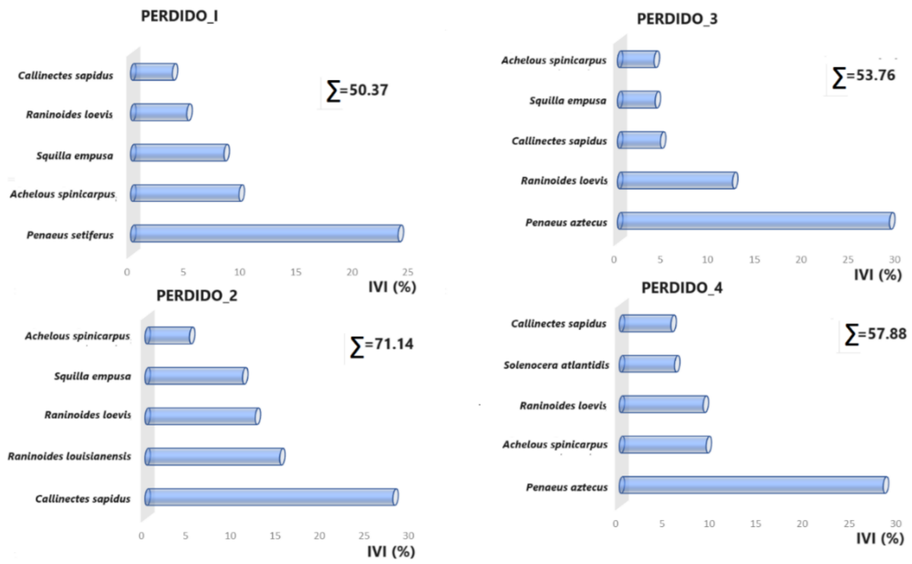

Figure 2. Crustaceans' dominance is given by the importance value index (IVI) from the deep zone of the northwestern Gulf of Mexico. The 5 most dominant species and their total dominance on each cruise are shown.

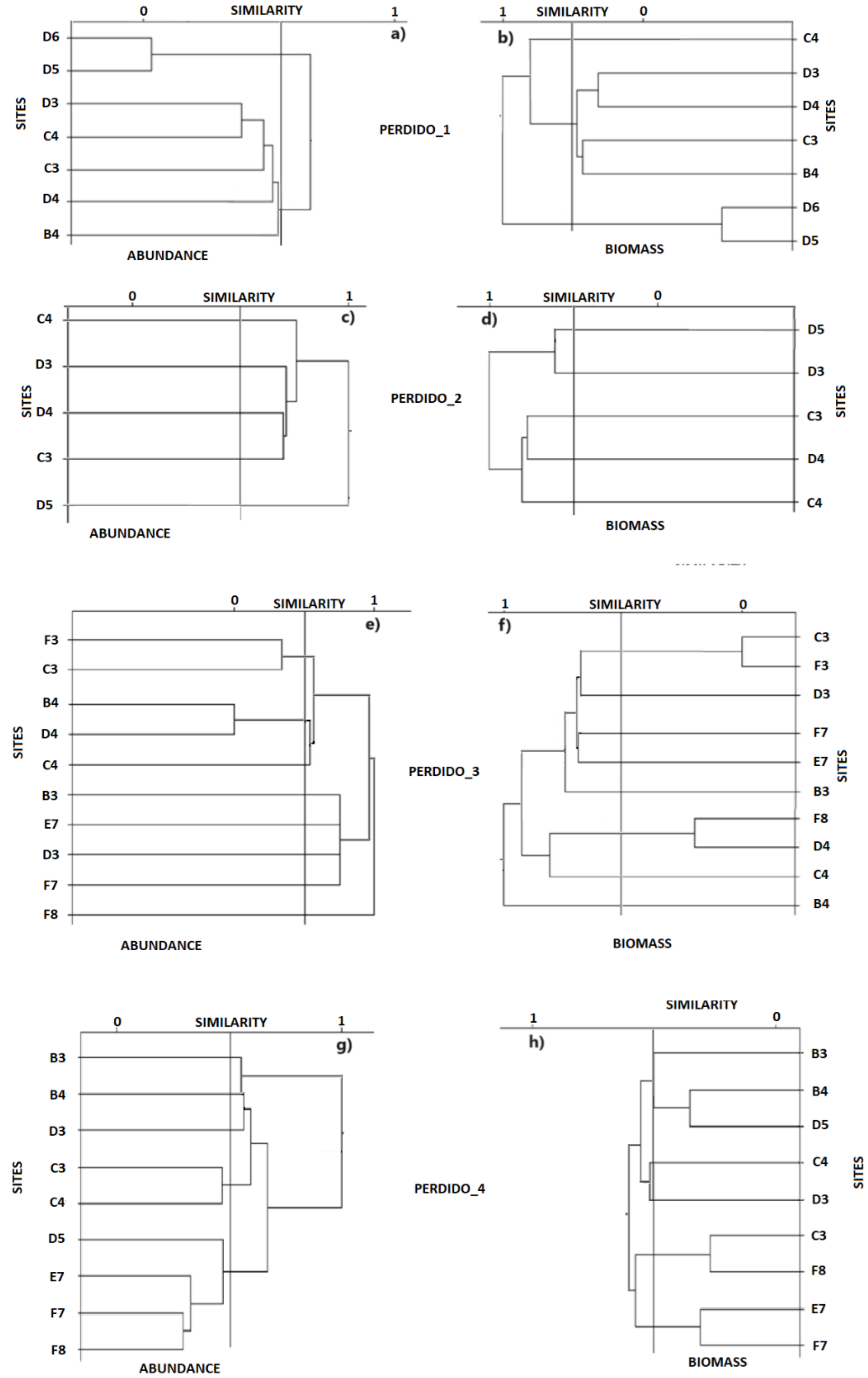

Figure 3. Sites similarity across different cruises in the perdido folded belt: **(a)** first cruise abundance; **(b)** first cruise biomass; **(c)** second cruise abundance; **(d)** second cruise biomass; **(e)** third cruise abundance; **(f)** third cruise biomass; **(g)** fourth cruise abundance; **(h)** fourth cruise biomass.

As for the similarity between the sites on the 4 cruises, the abundance of crustaceans shows the following scheme. In the first cruise two groups are formed, the first is given by sites D5 and D6 with abundances around 30 org·ha^{-1} at a depth between 1200 and 2200 m. The second is larger but lax, strongly linking localities C4 and D3 with 30 to 60 org·ha^{-1} later the other sites are integrated into this group (**Figure 3a**). The biomass of this cruise also shows two clusters, the first linking sites D3, D4, and the second sites C3 and B4, all of them with biomasses ranging from 5 g·ha^{-1} to 680 g·ha^{-1}. The second group is more homogeneous and joins sites D5 and D6 with biomasses of 23 to 45 g·ha^{-1} (**Figure 3b**).

In the second cruise, the abundances of all localities are separated without forming any group at this cut-off level (**Figure 3c**). Biomass follows the same pattern (**Figure 3d**).

In the third cruise with abundance, two groups are formed, the first joins sites F3 and C3 with abundances ranging from 65 to 400 org·ha^{-1}, which have a depth of about 500 m. The second group linking localities B4 and D4 has low values of 4 to 10 org·ha^{-1}, and its depths are around 1000 m (**Figure 3e**). The biomass also forms 2 groups. The first one joins localities C3 and F3 with values between 4 and 5000 g·ha^{-1}, and its depth is around 500 m. The second joins sites F8 and D4, with small biomass values of 3 to 13 g·ha^{-1}, and its depth varies from 1000 to 3500 m (**Figure 3f**).

The abundance of the fourth cruise shows 2 groups. The first joins sites C3 and C4 with low values of 9 to 24 org·ha^{-1}, and its depths are around 500 and 1000 m. The second group is larger at this shear level, strongly linking localities F8 and F7 which have low values of 9 to 26 org·ha^{-1} (their depths are between 3300 and 3600 m) and then joined by sites E7 (20 org·ha^{-1} and 3098 m depth) and D5 (5 org·ha^{-1} and 1500 m depth) (**Figure 3g**). The biomass has 3 groups. The first one joins localities B4 and D5 with values from 10 to 110 g·ha^{-1} and depths around 1000 m, later it joins site B3 (214 g·ha^{-1} with a depth of 500 m). The second group joins localities C3 and F8 with similar biomass values (38 g·ha^{-1}) and 500 to 3600 m depths. The third group joins sites E7 and F7 with values around 20 g·ha^{-1}, both at a depth between 3000 and 3300 m (**Figure 3h**).

The following results are obtained regarding the spatial position of the species given by the non-metric multidimensional scaling analysis (NMDS). The first cruise shows that with the abundance of crustaceans, there was a large group near the origin, leaving *Achelous spinicarpus* and *Callinectes sapidus*, very frequent crabs, as solitary species (**Figure 4a**). The biomass diagram also presents both crustacean species along with *Calappa sulcata* Rathbun 1898, while the other species form a very tight group near the origin of the coordinate system. Stress in both cases exceeds 0.7 (**Figure 4b**).

The spatial position of the species, given by their abundance obtained in the second cruise, shows three groupings: the first includes *Acanthilia intermedia* (Miers 1886), *Anosimus latus* Rathbun 1894 and *Cancellus ornatus* Benedict 1901, all of which have low abundance (maximum 13 org·ha^{-1}), the second group is the largest, very close to the origin of the axes; the third is very small and compact, which approximates the species *Mesopenaeus tropicalis* (Bouvier 1905) (9 org·ha^{-1}), the other species are isolated from these groups; the stress value is 0.43 (**Figure 4c**). The biomass of the species shows 3 clusters, a huge one that starts near the origin of the axes and moves to the right of the plane, to this large group belongs the species *Achelous spinicarpus and Oplophorus gracilirostris* A. Milne-Edwards 1881 (low to medium abundance: 4 to 120 org·ha^{-1}). The species *Calappa sulcata* and *Ranilia mulleri* Stimpson, 1898 (species with low abundance (maximum 7 org·ha^{-1}) delimit its apical end. The second group is small and very compact, *Penaeus aztecus* (medium abundance (120 org·ha^{-1}) is close to this group. The third group is the smallest, most compact, and closest to the origin. The species *Squilla empusa* Say 1818 and

Exhippolysmata oplophoroides (Holthuis 1948) (species with abundance between 270 and 47 org·ha^{-1}) are isolated possibly due to their high frequency. The stress obtained from the analysis is 0.43 (**Figure 4d**).

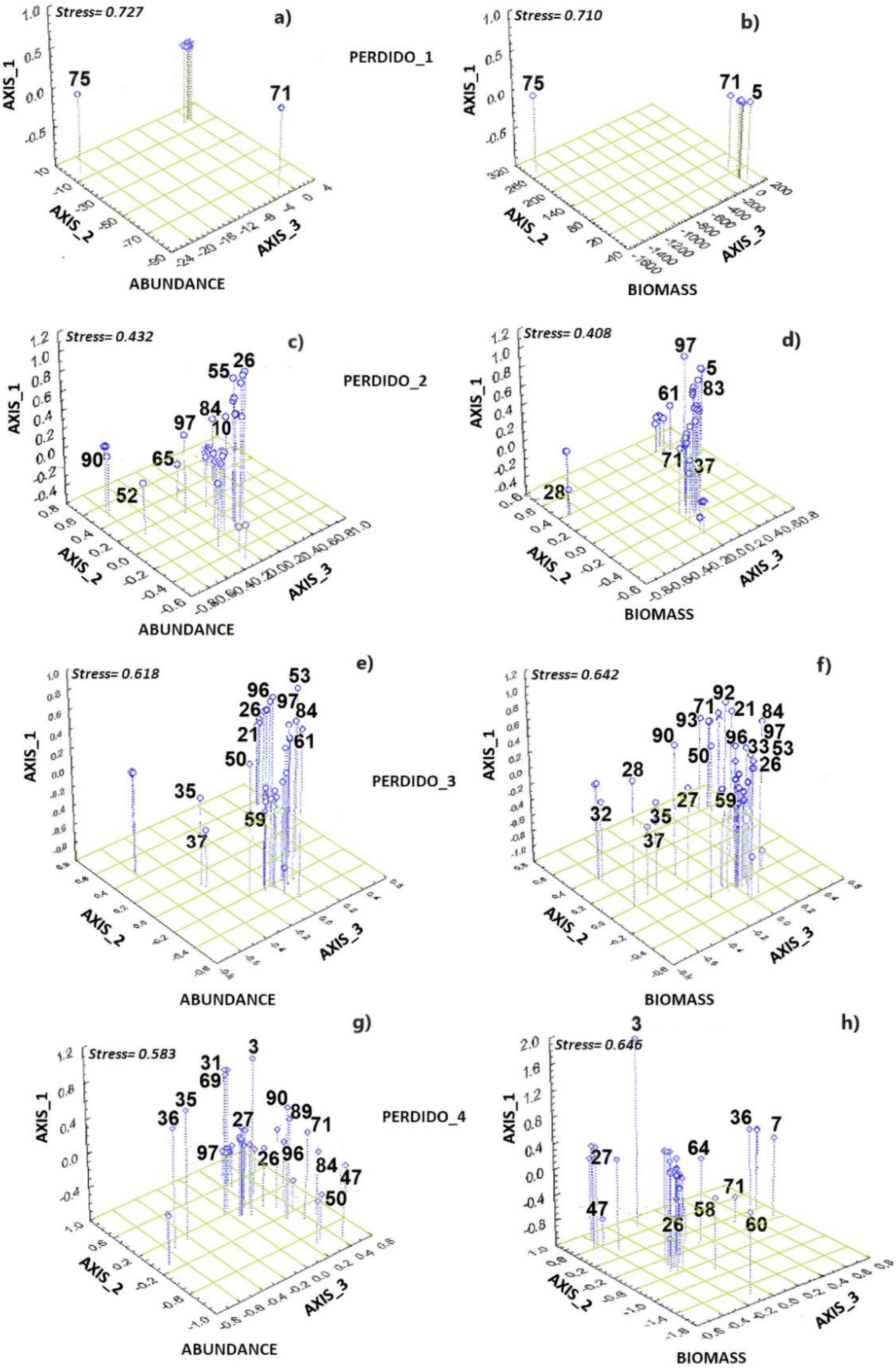

Figure 4. Species multidimensional position given by: **(a)** abundance obtained in the first cruise; **(b)** biomass obtained in the first cruise; **(c)** abundance obtained in the second cruise; **(d)** biomass obtained in the second cruise; **(e)** abundance obtained in the third cruise; **(f)** biomass obtained in the third cruise; **(g)** abundance obtained in the fourth cruise; **(h)** biomass obtained in the fourth cruise. The identity of the species is presented in the appendix.

The abundance of species in the third cruise shows three groupings: the first includes *Squilla chydaea* Manning 1962, *Squilla empusa, Solenocera atlantidis* Burkenroad 1939 and *Raninoides laevis,* an abundant species (about 400 org·ha^{-1}); the second group consists of *Leptochela sp*. and *Penaeus aztecus* with medium abundances (around 100 org·ha^{-1}), but also frequent; and finally the third group, which has few components and many species that anastomoses each other. This group is heterogeneous both in abundance (with intervals of 4 to 300 org·ha^{-1}) and in frequency; the stress value is 0.618 (**Figure 4e**). The biomass shows three groups. *Iliacantha subglobosa* and *Leptochela* sp in the first identified with high biomasses (greater than 300 g·ha^{-1}). *Acanthilia intermedia*, *Squilla* spp and *Raninoides laevis* (the biomass of this group is medium-high: 3 to 300 g·ha^{-1}) form a second. *Munida irrasa, Ophlophorus gracilirostris* and *Exhippolysmata oplophoroides* are separated from the cluster and represent low biomasses (less than 3 g·ha^{-1}). The stress obtained from the analysis is 0.642 (**Figure 4f**).

On the last cruise, abundance shows three spatial groupings. The first includes *Iliacantha subglobosa* Stimpson 1871, and *Squilla empusa*, abundant species (about 200 org·ha^{-1})*;* the second group is formed by *Panopeus herbstii*, *Sycionia typica and Mesopenaeus tropicalis* with medium abundances (about 100 org·ha^{-1}). It is the largest with many species that anastomose each other but are frequent. And finally the third group has few components. This group is heterogeneous both in abundance (with intervals from 4 to 300 org·ha^{-1}) as in frequency *Aristeus antillensis, Neophropsis aculeata and Neophropsis rosea* separated from any cluster. The stress value is 0.583 (**Figure 4g**). The biomass shows two clusters. The first was a huge one that starts near the origin of the axes and moves to the left of the plane. The second was represented by *Iliacantha subglobosa*, and the other species are separated. The stress obtained from the analysis is 0.646 (**Figure 4h**). This particular cruise featured species with wide separation, but some with close relationships.

4. Discussion

In the Gulf of Mexico, knowledge about invertebrate benthic communities is focused on assessments made in the northern part, due to industrial development brought about by the discovery of oil fields in the 1930s in coastal Louisiana in Texas, Alabama, and Florida [53]. Christensen [54] reports that much of the productivity observed in the northern Gulf (four times lower than that of the northwest Atlantic [55]), is subsidized by coastal ecosystems (e.g., estuaries, mangroves, estuaries) which favors commercial shrimp fishing (*Penaeus aztecus*). However, there are a greater number of deep-sea species in the interior of the Gulf than those observed in the Atlantic Ocean, due to the presence of the loop current that acts as a transport system for larvae, fish, plants, and heat to the eastern Gulf, and into the Mississippi River system [56].

Due to this enormous potential, it is important to have a complete registry, which characterizes the area before intensive hydrocarbon exploitation is carried out. In terms of megafauna, there are records from the northern Gulf that mention between 4 and 6 times more invertebrates than fish at all depths [57], with the decapod being the most abundant and diverse. Pequegnat et al. [55] recorded 129 species. In our case, there were 95. They attribute it mainly to the succession process associated with the change in depth that produces a decrease in the abundance values of invertebrates except holoturoids and ophiuroids, which begin to be more abundant [58,59]. Other studies [60,61] partly confirm these claims, as crustaceans are more frequent and abundant in shallow areas (50–200 m) and close to the coast, while echinoderms are more frequent and abundant in deep areas (> 500 m). However, when considering the averages of crustacean abundance for each cruise about depth, it is shown that at depths less than 1000 m it shoots up, but between 1500–1999 and between 3000–3499 there are peaks of abundance. With biomass, the scheme is similar, except that the curve is a little smoother (**Figure 5**).

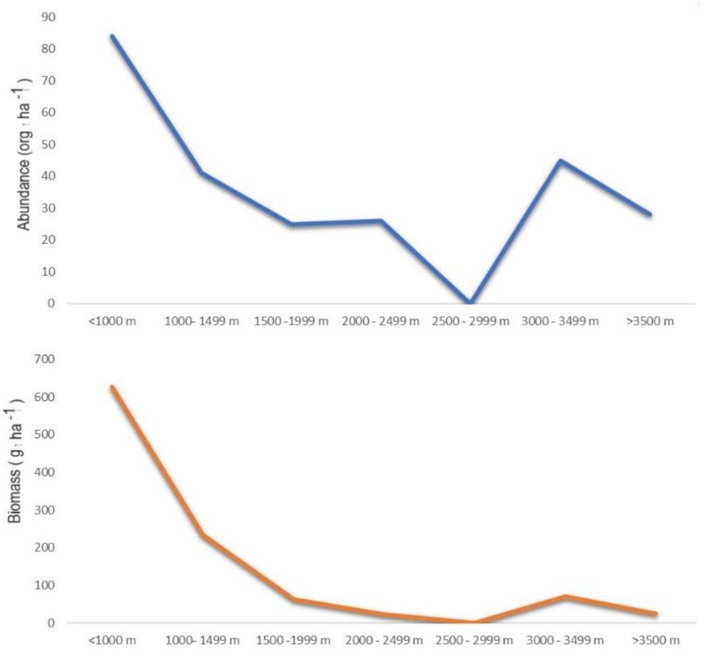

Figure 5. Crustaceans abundance and biomass in relationships to deep.

In our analysis, the only class among crustaceans was Malacostraca. Only two taxonomic orders were presented: the decapods, which showed greater diversification in their families and genera and consequently had greater relevance, and the stomatopods, with a single family; Even so, 95 species were recorded from the bathyal plain to the abyssal plain. Species richness in this depth range fluctuates; However, the highest and lowest values were recorded between 200–1000 m, in the deepest areas the richness of this group is low (between 2 and 6 species). Although fluctuating values continue to be recorded at depths between 400–1000 m, around 3000 m, there is a peak of diversity, very close to the highest values in the shallower areas (**Figure 6**). Ruiz et al. [3] report that crustacean richness and diversity do not vary across seasons or years in Campeche Sound. In our case, diversity values fluctuate in and between cruises. The Mediterranean decapod crustaceans were one of the dominant megafaunal groups in biomass and abundance. 32 species were collected and abundance and biomass decreased with depth [62] a pattern that does not occur in our area.

Rotlland et al. [63] define bathymetric ranges in their clustering analysis for Uruguay, from areas of 250 to 1100 m, from 1100 to 2000, from 2000 to 3000, and greater than 3000. Pajuelo et al. [64] report discontinuities at 300, 800, and 2000 m, mentioning that they are caused by the transition between the shelf and the slope and that it is likely that these discontinuities are due to environmental conditions and food resources. Only those less than 500, from 1200 to 2200, and greater than 3000 are identified, consistent in abundance and biomass. Still, no sharp discontinuities were obtained; there is no evidence of a strong transition zone in this case.

Conditions at the local scale of each site, and the regional scale (perhaps by transects or areas limited by coastal proximity) are likely to be reflected in the results obtained. It is also possible that the conditions in this area are reflected in the metrics used, as diversity did not reach high levels. In addition, only on the first cruise was there a high numerical and biomass dominance by very few species that could channel the greatest amount of energy for their development [63], as corroborated by spatial analysis by species. However, in later cruises, there is no such pattern, which could have been caused by the sampling and its conditions (lack of knowledge of the area, season, etc.).

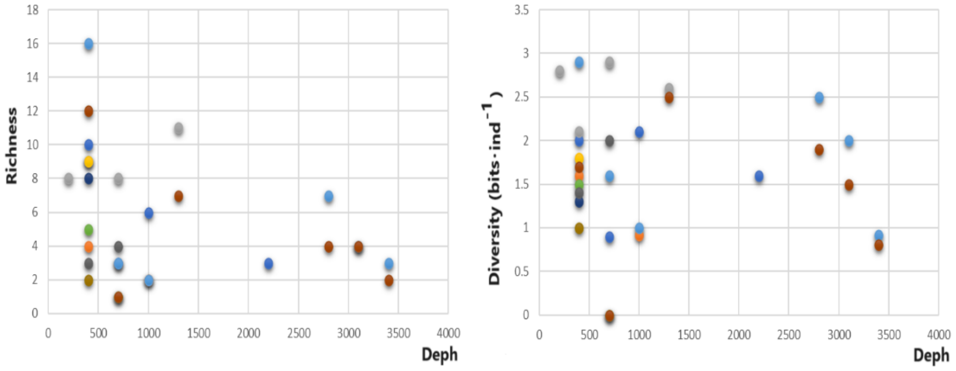

Figure 6. Richness and diversity of crustaceans concerning depth.

Some authors have reported that crustaceans dominate both in biomass and in number compared to other shallow-water invertebrate groups. In this work, the species *Penaeus aztecus*, *Callinectes sapidus*, *Raninoides loevis*, and *Squilla empusa*, have a high dominance in cruisers. Although the IVI integrates abundance, biomass, and relative frequency of species, these should be considered permanent resident organisms with strong adaptive capacities, with their dominance potentially regulated by the trophic spectrum. These species are mainly detritivorous and scavengers as reported by other authors [65,66].

Some authors mention that these organisms have distribution patterns determined by sedimentation [67], quantity and quality of organic matter in the water column, and depth [68,69]. They may also show a significant decrease in their density and species richness values as distance to shore increases [69–71]. In our case, we do not have data on sedimentation, nor on the quantity and quality of organic matter in the water column throughout the trawl, but there was a certain decrease in species richness and density as we moved away from the coast, but always associated with greater depth.

The seabed presents physical conditions of greater stability than shallow and coastal environments, exposed to complex hydrodynamic processes that give them a high variability [72,73]. Consequently, it is suspected that the biodiversity of deep-sea megafauna is generally low, and biotic variables, such as competitive exclusion, resource division, and predation, are essential factors defining the structure and functioning of benthic invertebrates, under the limited nutrient input [9,74]. However, in our case, there are high-diversity peaks in deep areas.

Multivariate analyses showed a high correspondence between the cruise ships, linking similar sites forming a pattern of assemblages maintained throughout both years. The species, in their arrangement in n-dimensional space, also showed some correspondence between the cruisers. Most formed overlapping groupings near the origin, so it is thought that stenoic species form them and that only some can be considered adaptable, hence the presence of locally abundant and rare species can coexist in the same time interval [74,75]. Proof of this is the values close to the center of the axes for most species. The degree of stress reflects how well the calculated distances align with the observed distances for this species. In this case, all values are above 0.5, indicating a strong correspondence between the results obtained. This may also show that this group, having reduced mobility, must strongly depend on the substrate and, consequently, on the depth [76,77].

It cannot be ruled out that the causal factors in this study are the result of concatenated tensions, since with both descriptors (abundance and biomass), in addition to depth, the characteristics of the substrate seem to influence the structure presented by the groups. This, although Torruco et al. [76] mention that the invertebrates of the trawl fauna respond uniquely to the stimulus imposed by the depth gradient.

The characterization of the biota in this area is urgent and of greater relevance since these communities have little information. Some authors [17,57,78] mention that sampling carried out in unexplored areas could provide up to 75% of organisms of possible new species, adding to the existence of new geographic records of species already reported in the Gulf of Mexico [79–81]. For crustaceans, no new species were found in our case, although several of them expanded their geographical trait.

Formulating effective conservation plans requires an understanding of habitat structure and processes that influence biodiversity [16,25,82]. In the case of the Perdido Fold Belt, where there are important oil deposits, the structure of benthic megafauna communities is unknown, so this type of study is indispensable [83] as they could serve as monitors in cases of alterations caused by exploitation. In addition, these communities are responsible for biomass production, bioturbation, bio-irrigation, sediment stabilization, organic matter decomposition, secondary production, and energy flux at higher trophic levels [84,85]. Swan et al. [67] mention that the maximum depth of decapods may be caused by temperature, oxygen, and hydrostatic pressure, an aspect that should be considered in future research. Although this work tried to characterize deep-sea crustaceans, many questions remain, especially in their relationship with other groups of deep-sea megafauna, which makes it inevitable to carry out more research that involves a higher frequency of sampling and that involves the general conditions of the region, to have a baseline of knowledge that allows us to discern the natural fluctuations of this fauna from those that could be caused for other activities in the area.

5. Conclusions

The richness and diversity of species fluctuate from 400 to around 1000 m, in the deeper areas the richness of this group is low. However, the pattern of diversity changes, around 3000 m, there are peaks of diversity, very close to the highest values of the shallower areas.

The similarities between the sites are quite pronounced. Associations identified assemblages of sites with strong interrelationships and identified with depth. The spatial arrangement of the species also showed some correspondence between cruises, as evidenced by the stress close to 0.5.

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Appendix

Table A1. Taxonomic list of deep-water crustaceans in the perdido fold belt area.

Phylum	Class	Orders	Families	Genera/Species	No.
Arthropoda	Malacostraca	Decapoda	Sergestidae	*Acetes americanus* Ortmann, 1893)	1
			Aristeidae	*Aristaeomorpha foliace*a Risso, 1827	2
			Aristeidae	*Aristeus antillensis* A. Milne-Edwards y Bouvier, 1909	3
			Calappidae	*Acanthocarpus alexandri* Stimpson, 1871	4
				Calappa sulcata, 1898	5
				Hepatus pudibundus Herbst, 1785	6
			Ceryonidae	*Raymanninus schmitti* , 1931	7
			Crangonidae	*Philocheras gorei* Dardeau, 1980	8
				Pontophilus brevirostris Smith, 1881	9
			Diogenidae	*Cancellus ornatus* Benedict, 1901	10
				Clibanarius vittatus Bosc, 1802	11
				Paguristes triangulatus A. Milne-Edwards y Bouvier, 1893	12
				Petrochirus diogenes (Linnaeus, 1758	13
			Epialtidae	*Macrocoeloma trispinosum* Latreille, 1825	14
				Nibilia antilocapra Stimpson, 1871	14
				Rochinia tanneri Smith, 1883	16
				Stenocionops spinimanus , 1892	16
			Galatheidae	*Galathea rostrata* A. Milne Edwads, 1880	18
			Inachidae	*Coryrhynchus sidneyi* , 1924	19
				Coryrhynchus vestitus Stimpson, 1871	20
				Coryrhynchus riisei Stimpson, 1860	21
			Inachoididae	*Batrachonotus fragosus* Stimpson, 1871	22
				Inachoides forceps A. Milne-Edwards, 1879	23
				Pyromaia cuspidata Stimpson, 1871	24
				Stenorynchus seticornis Herbst, 1788	25
			Leucosiidae	*Acanthilia intermedia* (Miers, 1886)	26
				Iliacantha subglobosa Stimpson, 1871	27
			Lysmatidae	*Exhippolysmata oplophoroides* Holthuis, 1948	28
				Lysmata ae Chace, 1970	29
			Munididae	*Garymunida longipes* A. Milne-Edwards, 1880	30
				Iridonida iris A. Milne-Edwards, 1880	31
				Iridonida irrasa (A. Milne-Edwards, 1880)	32
				Iridonida pusilla Benedict, 1902	33
				Typhlonida valida (Smith, 1883)	34
			Nephropidae	*Nephropsis aculeata* Smith, 1881	35
				Nephropsis rosea Spence Bate, 1888	35
			Oplophoridae	*Oplophorus gracilirostris A* . Milne-Edwads, 1881	37

Table A1. (*Continued*).

Phylum	**Class**	**Orders**	**Families**	**Genera/Species**	**No.**
Arthropoda	Malacostraca	Decapoda	Ovalipidae	*Ovalipes floridanus* Hay & Shore, 1918	38
				Ovalipes ocellatus Herbst, 1799	39
				Ovalipes stephensoni Williams, 1976	40
			Paguridae	*Pagurus longicarpus* Say, 1817	41
				Pagurus politus Smith, 1882	42
			Palaemonidae	*Macrobrachium olfersii* Wiegmann, 1836	43
				Urocaris longicaudata Stimpson, 1860	44
			Pandalidae	*Heterocarpus ensifer* A. Milne-Edwards.1881	45
				Plesionika edwardsii Brandt, 1851	46
			Panopeidae	*Dyspanopeus sayi* Smith, 1869	46
				Eurypanopeus abbreviatus Stimpson, 1860	48
				Eurytium sp. Stimpson, 1859	48
				Panopeus herbstii H. Milne-Edwards, 1834	50
				Rhithropanopeus harrisii Gould, 1841	51
			Parthenopidae	*Agolambrus agonus* Stimpson, 1871	52
				Platylambrus granulatus Kingsley, 1879	53
				Solenolambrus typicus Stimpson, 1871	54
			Pasiphaeidae	*Anasimus latus* , 1894	55
				Leptochela carinata Ortmann, 1893	56
				Leptochela papulata Chace, 1976	57
				Leptochela serratorbita Spence Bate, 1888	58
				Leptochela sp. Stimpson, 1860	59
			Penaeidae	*Parapenaeus politus* Smith, 1881	60
				Penaeus aztecus Ives, 1891	61
				Penaeus setiferus Linnaeus, 1767	63
				Penaeus sp Fabricius, 1798	63
				Rimapenaeus similis Smith, 1885	64
				Rimapenaeus constrictus Stimpson, 1871	65
				Xiphopenaeus kroyeri Heller, 1862	66
			Pilumnidae	*Pilumnus dasypodus* Kingsley, 1879	67
				Pilumnus floridanus Stimpson, 1871	68
			Polychelidae	*Polycheles typhlops* Heller, 1862	69
			Porcellanidae	*Porcellana sigsbeiana* A, Milne-Edwards, 1880	70

Table A1. (*Continued*).

Phylum	Class	Orders	Families	Genera/Species	No.
Arthropoda	Malacostraca	Decapoda	Portunidae	*Achelous spinicarpus* Stimpson, 1871	71
				Achelous spinimanus Latreille, 1819	72
				Callinectes bocourti A. Milne-Edwards, 1879	73
				Callinectes danae Smith, 1869	74
				Callincetes sapidus, 1896	75
				Callinectes similis Williams, 1966	76
				Portunus sayi Gibbes, 1850	77
			Processidae	*Processa* sp. Leach, 1815	78
			Pseudorhombilidae	*Nanoplax xanthiformis* A. Milne-Edwards, 1880	79
				Speocarcinus carolinensis Stimpson, 1859	80
				Tetraxanthus ae Chace, 1939	81
			Raninidae	*Ranilia constricta* A. Milne-Edwards, 1880	82
				Ranilia mulleri Stimpson, 1860	83
				Raninoides laevis Latreille, 1825	84
				Raninoides louisianensis , 1933	85
			Scyllaridae	*Scyllarus depressus* Smith, 1881	86
			Sicyoniidae	*Sicyonia brevirostris* Stimpson, 1871	87
				Sicyonia dorsalis Kingsley, 1878	88
				Sicyononia típica (Boeck, 1864)	89
			Solenoceridae	*Mesopenaeus tropicalis* Bouvier, 1905	90
				Pleoticus robustus Smith, 1885	91
				Solenocera atlantidis Burkenroad, 1939	92
				Solenocera vioscai Burkenroad, 1934	93
		Stomatopoda	Squillidae	*Meiosquilla quadridens* Bigelow, 1893	94
				Meiosquilla schmitti (Lemos de Castro, 1955)	95
				Squilla chydaea Manning, 1962	96
				Squilla empusa Say, 1818	97