SCIREA Journal of Biology
ISSN: 2995-388X
http://www.scirea.org/journal/Biology
October 8, 2024
Volume 9, Issue 2, April 2024
https://doi.org/10.54647/biology180373

THE SOUTH GULF OF MEXICO: MOLLUSKS AND THEIR RELATIONSHIP WITH ENVIRONMENTAL VARIABLES.

Daniel Torruco[1,*] & M. Alicia González-Solis [1]

[1] Center for Research and Advanced Studies of the IPN Mérida Unit, Km 6 Old road to Progreso. Merida, Yucatan, Mexico.

*Correspondence author: dantor@cinvestav.mx

Email: dantor@cinvestav.mx (Daniel Torruco); aligonzsol@gmail.com (M. Alicia González-Solis)

Orcid: 0000-0001-9133-8514; 0000-0002-4989-1129

Abstract

Because of the importance of the natural resources of the Gulf of Mexico that provide a diversified production, this work describes the relations presented by the mollusks with environmental factors. Under the context of a characterization, were carried out 5 cruise oceans, and coastal, obtaining spatial schemas of mollusks and ecological aspects. The results expressed the importance of the mouth of the rivers, the nearby reef areas, and oil platforms for the high abundance of mollusks; these habitats and structures, originate a refuge effect. Multifactorial analyses show strong relationships in sites with depth and habitat affinities. Mollusks recognize two strata: deep water and shallow water. The group presents positive relationships with the oxide reduction process. Even when relationships exist positive statistically with polluting derivatives of hydrocarbons and pesticides, these effects are less obvious than ecological interactions where processes and habitat preferences are still important since they routed the community structure. At the local level, the parameters of the

environment can be typified by a few indicator species; however, for the whole area, it is preferable to characterize it by applying different measures with different species and groups.

Keywords: Mollusks, distribution, indicator species, Gulf of Mexico, Mexico.

Introduction

The coasts of the Gulf of Mexico are characterized by their high productivity, especially of species of high commercial interest such as shrimp and pink snail, and several species of scale. There is also a strong exploitation of hydrocarbons, where the state-owned Petróleos Mexicanos (PEMEX) has more than 200 platforms for extracting crude oil and natural gas (Mendoza *et al.* 2004). In this area, ecological studies of marine benthic communities have been used from the point of view of fishing and environmental diagnosis, since they are organisms closely related to secondary production (Rubio-Polania *et al.* 2018). They are faithful indicators of problems of contamination and alteration of the environment due to their close relationship with the substrate, either in a sessile or pivoting way. Among them, the mollusks group has been one of the most widely used to indicate the health conditions of marine environments and has therefore defined its close relationship with pollutants and with exogenous elements that disturb these systems (Franco *et al.* 2002, Tripp-Quezada *et al.* 2009, Cabral *et al*. 2014, BOEM 2016).

Ecological analyses with this group can give us valuable information about the impact that fisheries and the exploitation of hydrocarbons have on the marine environment and distinguish them from those caused by nature itself (Conti and Cechett 2003, Ramírez-Cañada 2009, Escobar-Briones 2014); especially in environmental contingencies such as oil spills such as the spills from the Ixtoc-I well (Guzmán *et al*. 1986, Felder and Camps 2009) and Deep-Horizon (Baqueiro-Cárdenas *et al.* 2007).

With the main objective of presenting a solid baseline for a long-term monitoring program, this work presents the natural distribution of mollusks in the southeastern Gulf of Mexico and intends it to serve as an important fraction in the design and implementation of such monitoring of conditions in that area of the Gulf of Mexico.

Material and Methods

The study area is located between 22°30' and 18°26' LN and 95°44' and 90°00' LW. It is a polygon that covers the coastal and oceanic zone from Alvarado, Veracruz, and the continental shelf of the states of Tabasco and Campeche to the area of Celestún in Yucatan. The research is based on oceanic and coastal sampling campaigns in the 2005-2009 rainy season. Fish and invertebrate samples were taken with a commercial shrimp net in both oceanographic and coastal campaigns (1.5" mesh span) at 47 sites (Fig. 1). The duration of each trawl was 30 minutes at an average ship speed of 5 knots, representing a trawl distance of 1 nautical mile. After separation, the frozen invertebrate samples were taken to the laboratory for further analysis. The analysis procedures generally involve separating the different groups of mollusks, and the identification and counting of the densities of the species. Records and interpretation were performed to the highest possible taxonomic definition (Warmke and Abbot 1962, Abbot 1974, Rehder 1981, Vokes and Vokes 1985).

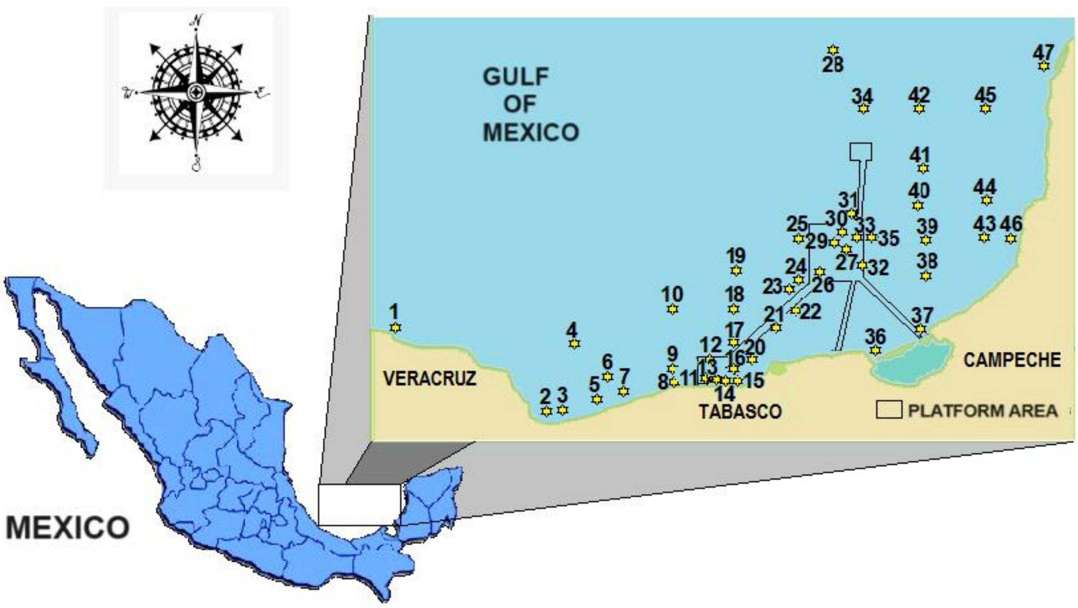

Figure 1. Location of sampling sites.

With the data obtained for the mollusks, species-density matrices were elaborated for each trawl, to obtain later images of diversity (Shannon-Wiener index), a non-parametric classification (Bray-Curtis index), and community ordination (Biplot Analysis), with which the relationships between the community structure were obtained, as well as the interactions that this group presents that allow the structural comparison between this community and the conditions (Pielou 1977, Orlocí 1978, Ter Braak 1995).

Given that one of the purposes was to know the influence of environmental factors especially in the sense of a monitoring program, which aims to detect changes in the biota *versus* concentrations of elements present in the environment, a step-by-step multiple regression analysis was used, under the following consideration: Identify if any community macro descriptor is related to any of the determined variables. To this end, it was considered that the weights **β** of the regression measure the average change in the community component being analyzed when variable ***X*** increases by one unit while the other variables remain immutable. This leads us to consider that first, there is no interdependence between the variables, and second, they meet normal conditions.

The selected community macro descriptors were Species Richness (S), Diversity (H'), Abundance (A), and Biomass (B). Independent variables were selected from 134; Hydrocarbon values, granulometry, physical and chemical parameters of the sediment, sediment bromatology, and pesticides. Of these, the 19 most relevant for this type of fauna were chosen, with which the corresponding correlations were made. The criterion used to analyze the relationship of the parameter with the community components was statistical significance.

Results

During the sampling, 7430 specimens with a biomass of 83,898 kg were captured. This group is characterized by 66 genera, representing 85 species of mollusks. Most of the specimens collected belong to the phylum biocenosis, although part of the thanatocenosis was also recorded when it was possible to identify it, it was not considered for the statistical analysis.

Two species obtained an abundance of more than 1000 specimens: *Amusium papyraceum* (Gabb, 1873) (1573 specimens) and *Argopecten gibbus* (Linnaeus, 1758) (1821 specimens). Although numerous works talk about the benefits of river mouths to maintain a great diversity and abundance of benthic organisms, in this work the high abundance of mollusks is also confined to specific localities, a station near oil activities, and an oceanic station. The cephalopod *Doryteuthis pealeii* (Lesueur, 1821) (36.08 kg) and the gastropod *Strombus pugilis* Linnaeus, 1758 (14.337 kg) are the heaviest.

The squid, *D. pealeii*, came in different sizes, even in the same season. The highest and lowest species richness for mollusks is shown in Table 1 of all the samples obtained. The other parameters of ecological diversity found are shown in Table 1. Mollusks have the highest value of ecological diversity at site 31 (3.69 bits·ind^{-1}.), this station is considered close to oil activities; The minimum values were presented at 11 sites, whose value was zero (bits·ind^{-1}.), represented by a single species. The highest evenness was obtained at sites 14 and 40, the lower near river mouths and lagoons, and the latter oceanic. As in the previous case, the lowest evenness were presented in the same 11 stations of zero diversity (Table 1).

Table 1. Richness (S), Ecological diversity (H'), maximum (Dmax), minimum(Dmin) diversity and evenness (J') of mollusks in the southeastern Gulf of Mexico.

SITES	S	H'	Dmax	Dmin	J'
1	3	1.500	1.585	1.500	0.946
2	4	1.535	2.000	0.306	0.768
3	5	2.252	2.322	2.252	0.970
4	5	2.042	2.322	0.507	0.879
5	3	0.492	1.585	0.013	0.310
6	10	0.664	3.322	0.098	0.200
7	3	1.322	1.585	0.866	0.834
8	2	0.918	1.000	0.650	0.918
9	14	1.678	3.807	0.283	0.441
10	9	2.427	3.170	0.761	0.766
11	5	2.059	2.322	1.880	0.887
12	2	0.918	1.000	0.918	0.918
13	1	0.000	0.000	0.000	0.000
14	2	1.000	1.000	1.000	1.000
15	2	0.811	1.000	0.811	0.811
16	1	0.000	0.000	0.000	0.000
17	1	0.000	0.000	0.000	0.000
18	2	0.918	1.000	0.503	0.918
19	1	0.000	0.000	0.000	0.000
20	1	0.000	0.000	0.000	0.000
21	1	0.000	0.000	0.000	0.000
22	3	0.748	1.585	0.244	0.472
23	1	0.000	0.000	0.000	0.000
24	2	0.310	1.000	0.133	0.310
25	6	2.087	2.585	0.690	0.808
26	1	0.000	0.000	0.000	0.000
27	10	2.755	3.322	1.673	0.829
28	7	2.725	2.807	1.339	0.971

29	1	0.000	0.000	0.000	0.000
30	12	2.492	3.585	0.797	0.695
31	20	3.699	4.322	1.123	0.856
32	1	0.000	0.000	0.000	0.000
33	10	1.519	3.322	0.779	0.457
34	5	1.443	2.322	0.243	0.621
35	9	0.374	3.170	0.098	0.118
36	2	0.722	1.000	0.722	0.722
37	4	1.341	2.000	0.339	0.671
38	1	0.000	0.000	0.000	0.000
39	2	0.469	1.000	0.211	0.469
40	2	1.000	1.000	0.650	1.000
41	3	0.331	1.585	0.034	0.209
42	11	1.404	3.459	0.174	0.406
43	9	2.658	3.170	0.810	0.838
44	4	1.378	2.000	0.352	0.689
45	3	1.149	1.585	0.549	0.725
46	8	1.492	3.000	0.333	0.497
47	2	0.918	1.000	0.650	0.918

The abundance of the mollusks, according to the analysis of the grouping of the sites and at the same cut-off level in their dissimilarity, formed only 2 groups with multiple sub-assemblies that typify the magnitude of the abundance and with high heterogeneity in terms of the characteristics of the site: Group **I** is made up of 28 stations that correspond to all areas. The second group involves 19 stations with two sub-clusters with a higher level of dissimilarity (Fig. 2a).

The biomass presents an assemblage of sites that make up three groups with very differentiable sub-assemblages: Group **I** present more than 50% of the stations (26 of 47) with two sub-groups, the first with more stations and the second with only 5 (of 26), most of them located in the oceanic part with two exceptions that correspond to coastal areas. Group **II** has strong assemblages, all of them from the oceanic zone. Group **III** has two groupings, the first of which is typified by coastal stations and the second by oceanic stations (2b).

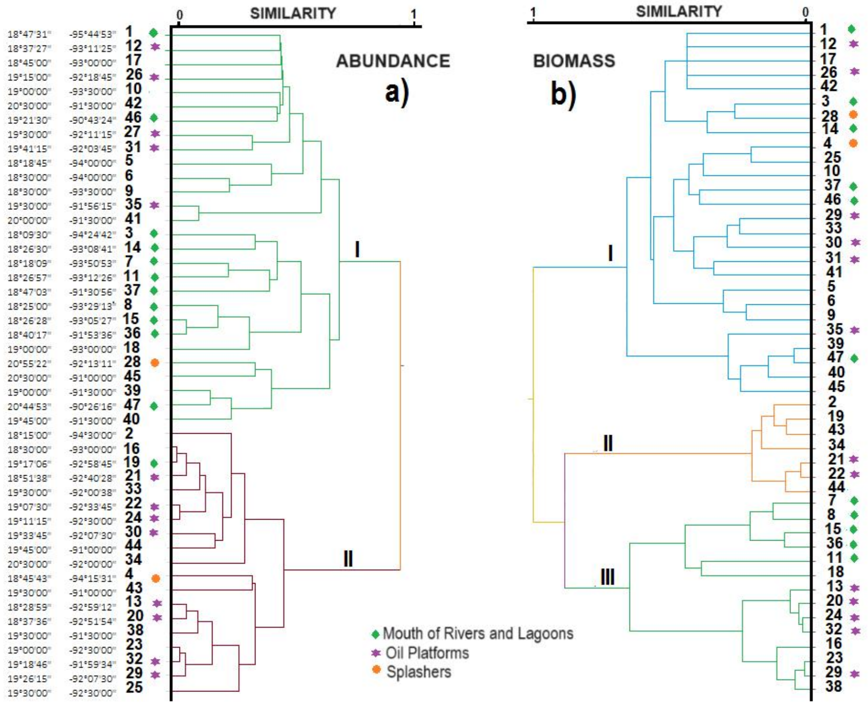

Figure 2. Cluster the sampling sites according to the Bray-Curtis criterion, taking as a descriptor the abundance (a) and biomass (b) of the mollusks. The groupings obtained and the geographic location of each site is shown.

The spatial arrangement of the sites with the abundance of mollusks as a descriptor, presents a large conglomerate intimately related to the axes origin, five sites are separated from this general pattern, the most distant are: 5 and 25, the first in the near of the coastal zone and the last close to oil activities, both with high abundance values and very frequent in the sampling; On another plane, station 6 is placed at a similar distance, also with values above 1000 organisms, also corresponding to the coastal part. Sites 41, 42, and 9 are closer to the axes origin, all of them oceanic, but with medium densities (around 500 organisms) (Fig. 3a).

The abundance of mollusks species forms a large conglomerate with little spatial variation, the most abundant and frequent species are separated from it: *Doryteuthis pealeii, Argopecten gibbus* and *Amusium papyraceum* (Fig. 3b), the variance explained with this attribute is 95.20 on the three axes, the first being the most important.

In terms of biomass, mollusks have a gradient pattern ranging from 3 kg (station 31) at one end to 12 kg (station 9), leaving site 42 (11 kg) far from any association, as in the previous cases, most of the stations occur in a conglomerate very close to the axes origin (Fig. 3c). The species also form a compact group close to the axes origin, with two associated species: *Antillipecten antillarum* Récluz, 1853 and *Euvola ravenelli* (Dall, 1898) and two distant species: *Argopecten gibbus* and *Doryteuthis pealeii*, the latter two being the ones with the highest biomass, while the first two have medium biomasses but their frequency is scarce in the network of stations analyzed (Fig. 3d).

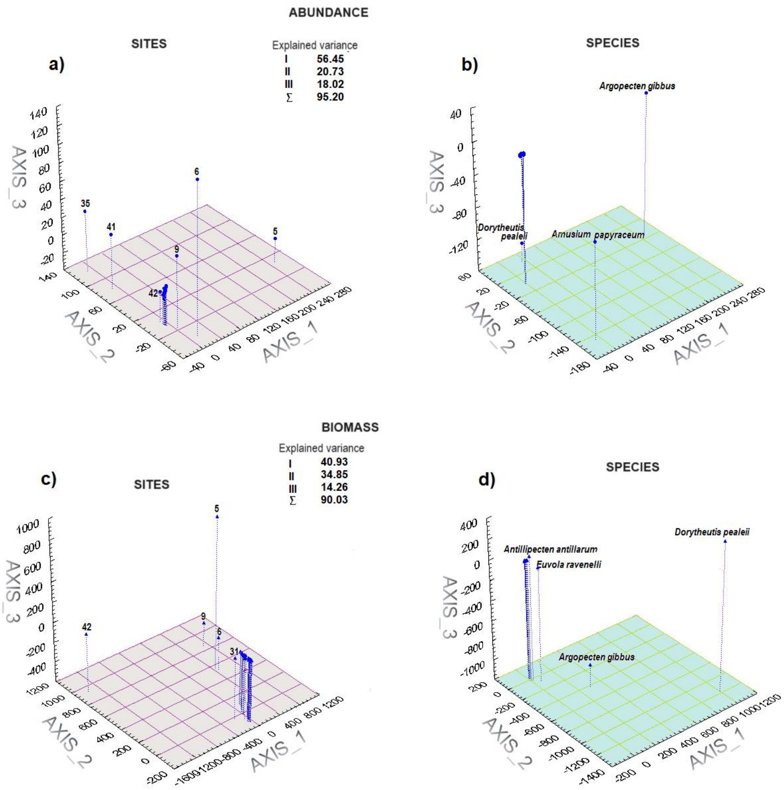

Figure 3. Spatial distribution of mollusk sites and species about abundance (a, b) and biomass (c, d) as descriptors.

This group is the only one whose 2 main axes have a similar weight in the explained variance (41% and 35% respectively), which shows that mollusks are a group that can respond in at least two ways to the conditions of the environment.

Table 3 shows the relationship between the macro descriptors and the variables analyzed. Only the most important relationships are shown, highlighting statistically significant ones and β weights assigned. The abundance of the mollusks group shows 6 important variables, three of them (abundance of fish, proportion of silt in the sediment, and total Polycyclic Aromatic Hydrocarbons), were statistically significant, the observed values *versus* calculated and residual values are shown in Figure 4a.

Biomass only shows four important variables, of which only fish abundance is statistically significant, observed values *versus* calculated and residual values are shown in Figure 4b. Species richness shows three important variables, of which organic carbon and fish abundance are statistically significant, the observed values *versus* calculated and residual values are shown in Figure 4c. The diversity of this group shows 5 important variables, the proportion of silt in the sediment and the REDOX, were statistically significant, and the observed values *versus* calculated and residual values are shown in Figure 4d.

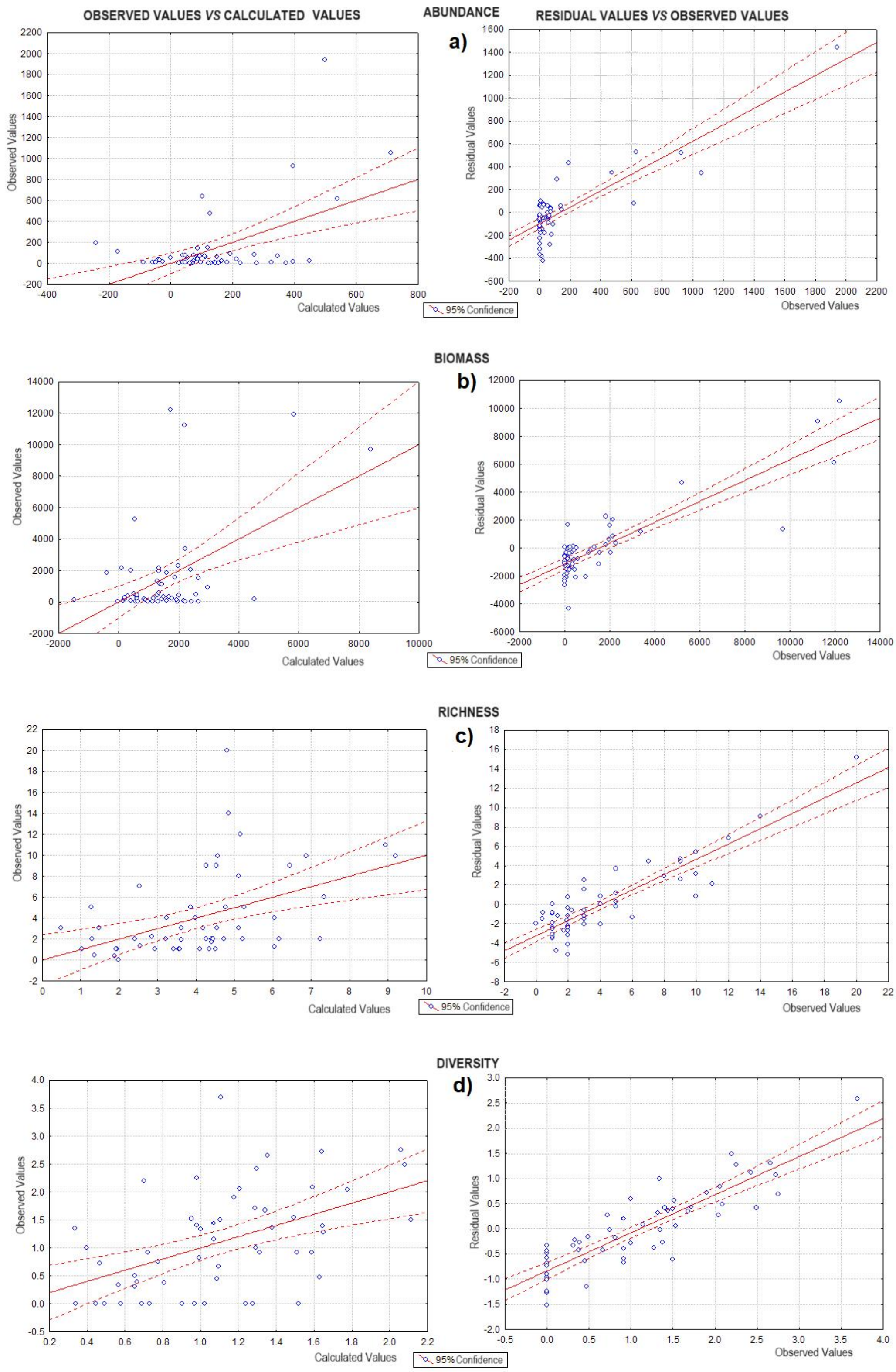

Figure 4. Observed *versus* calculated and residual values between the community parameters of molluscs: a) Abundance, b) Biomass, c) Species richness and d) Diversity, in relation to environmental conditions.

Discussion

Human activities that take place in the coastal zone or in the basins that drain into it, such as agriculture, livestock, exploitation of fossil fuels, and urban development, can alter the nature of the marine and coastal environment, almost always in a negative way, affecting the well-being of marine organisms and finally, among other components, the sectors that affect it (Committee on Effective Approaches for Monitoring and Assessing Gulf of Mexico Restoration Activities 2001). The impact not only affects local but can also affect regionally and to an increasingly acute degree (Flint, 1981, García-Cuellar *et al.* 2004, ITOPF 2005, García-Cuellar 2006).

Given this problem, inherent to development in the coastal zone, it is essential to take action to reverse the negative effects and ensure that both the use of resources and their conservation for future generations are allowed. One of the first activities is both the assessment of the current state of an ecosystem and the periodic monitoring of its resources and the communities that inhabit it (Flint and Rabalais 1981). Hence a need for indicators that reflect the state of the ecosystem or its communities with other factors in the system (González and Torruco 2001, Ramírez-Cañada 2009, Tripp-Quezada *et al*. 2009, Torruco *et al*. 2018a).

One of these indicators is the benthic fauna, since the relative ease of sampling due to its sessile or scarcely vagile way of life, and identification of organisms, makes it an attractive environment, however, given the wide diversity of species that make it up and their different responses to the local and temporal variability of physical and chemical factors, it is pertinent to limit the usefulness of some groups as bioindicators of natural or anthropogenic changes or alterations in marine systems (García-Valencia and Díaz 2000, García-Cuellar *et al*. 2004, Sabatini and Calcagno 2015, Torruco *et al.* 2018).

Historically, the study of benthic communities in the Gulf of Mexico has followed two patterns: 1) the identification of factors that determine benthic community structure and 2) the assessment of benthic community health as an indicator of environmental disturbance (Shepard *et al.* 2013, Murawski *et al.* 2018). Likewise, these types of organisms have been used extensively as indicators of the status and trend of marine and estuarine environments, as numerous studies have shown that benthic fauna responds predictably to many types of environmental disturbances, natural or anthropogenic (Grall and Glénmerc 1997, Morys *et al.* 2017).

Invertebrates in general and the dominance of different groups respond to the enrichment of organic matter and oxygen gradients and other environmental factors, which can define stages of degradation of different communities (Grall and Glénmerc 1997). Flint & Kalke (1986), Manino & Montagna (1997), and Riba *et al.* (2004), have found that sediment characteristics such as sand or organic matter content across a gradient can influence the distribution of benthic fauna. In our case, the differences in the mosaic of sediment types found at the bottom of the Gulf of Mexico are shown in two aspects: a sharp division in the Campeche Sounding with two types of sediment (one rocky and the other silt-clay) and a gradient of organic matter content, sediment composition, oxygen, and salinities. caused by the mouths of rivers into the sea. The distribution patterns found in the malacofauna are likely due to the point sources of spatial variation of other environmental factors such as salinity and sediments with the contribution of water from the rivers since this modifies the contents of sand and organic matter and generates a gradual variation along the mouths. that fades away from the coast. However, these patterns will likely change as the year progresses, as river discharge is different in dry and rainy periods, in addition to the effect that cyclones and tropical storms can have.

The assemblages of benthic organisms reflect local environmental conditions, as due to their low mobility they cannot avoid adverse conditions, which is an advantage for environmental assessments (Weisberg *et al.*1997). However, the structure of these assemblages can respond to several types of environmental disturbance because they include organisms with a wide range of physiological tolerances, feeding patterns, and trophic interactions; However, some of them can characterize a site and be stable over time if the disturbance is periodic and predictable (Engle *et al.* 1994, Huidobro *et al.* 2018). On the other hand, in some regions of the Gulf of Mexico, there is an alternation of species and changes in their assemblages, which it is not possible to detect even annually because their change is very subtle since they are bi- or three-year cycles (Torruco 1988, García-Valencia and Díaz 2000, Clare *et al.* 2015).

The synthetic table formed with the results of the multiple regression (Table 3) shows that no element is statistically significant for all the descriptors analysed since some represent a relationship with a particular one; However, some elements have positive or negative relationships with one or two descriptors. An interesting aspect is the presence of variables that are specific to only a single descriptor, which provides evidence that the responses to each of the environmental variables are different and that the tolerance threshold is also different for each class of mollusks, this influences the results of the different trophic strategies. of competencies for resources and habitats possessed by each of the classes that make up the group. An important relationship is that of mollusks with fish abundances, which can corroborate the trophic interaction of both groups, where fish make horizontal migrations in search of food in the great mosaic of habitats used by benthic invertebrates.

Table 3. Step-by-step multiple regression values of the community parameters of the different groups as dependent variables *versus* environmental parameters as independent variables.

# of Cases	# of Steps	Dependent variable	Independent Variables and Beta Weights	Multiple R	R^2	F	p	Intercept	Standard Error
55	6	Abundance	**Fish Abundance = 0.342** **Silt = -0.33** **Total PAHs = 0.355** DDTs = -0.18 PCBs = -0.18 Depth = -0.14	0,52	0,28	3,11	0,011	479,01	180,75
55	4	Biomass	**Fish Abundance = 0.460** Silt = -0.22 Organic Carbon = 0.259 REDOX = 0.141	0,50	0,25	4,27	0,004	1716,52	1715,24
55	3	Species Richness	**Organic Carbon = 0.466** **Fish Abundance = 0.314** REDOX = 0.227	0,45	0,21	40,52	0,006	-1,20	1,71
55	5	Diversity	**Silt = 0.380** **REDOX = 0.309** Organic Carbon = 0.298 APM PAHs = -1.3 Total PAHs = 1.12	0,49	0,24	3,15	0,015	-0,74	0,58

Statistically significant variables

Some relationships may be caused by a direct effect between the environmental factor and a macro descriptor, such as REDOX or total Polycyclic Aromatic Hydrocarbons (PAHs). On the other hand, it is important to mention that some variables have high relationships with each other and that possibly concatenates the effect on the mollusks.

From the relationship between environmental factors and community macro descriptors, it can be inferred that even when there are pollutants derived from hydrocarbons or pesticides, the effect of these is less evident than the effect of ecological interactions where the processes of competition for resources, predation, and habitat preferences continue to be for this fraction. They are very important, as they direct the structure of the malacological community. To know how the macro descriptors of the mollusk community are presented with the environmental variables, the BIPLOT analysis shows a layout in the n-dimensional space that corroborates what was obtained with the multiple regression, highlighting the importance of fish abundance and the fraction of silt and organic carbon (Fig. 5)

Even when the development of the activities of the oil and fishing industry results in a long-term deteriorating impact on the communities of the continental shelf (Flint 1981, García-Cuellar 2006), this is not easily shown. Therefore, limited field and laboratory studies should be established to establish the natural fluctuations of key organisms to differentiate them from those caused by oil activities, this means that it is necessary to have the time component in these natural fluctuations, which is not available with this type of analysis. However, it is understandable that this component is more difficult to please, given the magnitude of the study and the high sampling costs.

Conclusions

The conclusions that can be drawn from this work can be summarized as follows: Molluscs have greater magnitudes both in richness and density (abundance and biomass) in areas near the mouth of rivers, which are probably breeding and growth areas according to size sizes. The area of oil platforms causes a refuge effect that leads to high abundances of intermediate sizes; However, some oil-producing stations have the lowest densities. Classification and sorting analyses show clusters of related stations in both space and characteristics. At least two strata are present: deep water and shallow water in a mosaic of habitats. Mollusks interact with fish, which can mean a feeding relationship. Areas close to reef conditions show high densities, especially with gastropod mollusks. All groups have positive relationships with redox.

Acknowledgements. The author acknowledges PEMEX for funding the project.

Authors' Participation:

DT: Sample Separation and Analysis, Data Collection, Document Writing

MAGS: Data Processing & Analysis, Document Writing

References

[1] Abbot RT. 1974. American Seashells. The marine Mollusca of the Atlantic and Pacific coasts of North America. New York, USA: Van Nostrand Reinhold Co.

[2] Baqueiro-Cárdenas ER, Borabe L, Goldaracea-Islas CG and Rodríguez-Navarro J. 2007. Molluscs and pollution. A review. Rev. Mex. Biod. 78:1f-7s

[3] BOEM. 2016. Gulf or Mexico OCS Oil and Gas Lease Sales: 2017-2022. Draft Environmental Impact Statement. Vol II: Chapter 5-6, Appendices, and Keyword index. New Orleans, USA: U.S. Department of the Interior. Bureau of Ocean Energy Management. Gulf of Mexico OCS Region.

[4] Cabral-Oliveira J, Bevilacqua S, Terlizzi A and Pardal MA. 2014. Are eulittoral assemblages suitable for detecting the effects of sewage discharges in Atlantic and Mediterranean coastal areas?, Ital. Jour. Zool. 81(4): 584-592. doi: 10.1080/11250003.2014.947336

[5] Committee on Effective Approaches for Monitoring and Assessing Gulf of Mexico Restoration Activities. 2001. Effective Monitoring to evaluate Ecological Restoration in the Gulf of Mexico. The Washington, D.C., USA: National Academies Press.

[6] Clare DS, Robinson LA and Frid CLJ. 2015. Community variability and ecological functioning: 40 years of change in the North Sea bentos. Sea. Environ. Res. 107: 24-34. doi.org/10.1016/j.marenvres.2015.03.012

[7] Conti, ME, and Cechette, G., 2003. A biomonitoring study: Trace metals in algae and molluscs from Tyrrehenian coastal areas. Environ. Res. 93:99-112

[8] Engle DV, Summers KJ and Gaston RG. 1994. A benthic index of environmental condition of Gulf of Mexico estuaries. estuaries. 17(2): 372-384.

[9] Escobar-Briones, E., 2014. The Final Frontier: The Deep Ocean. In: Low Pfeng A and Peters Recagno EM, editors. Effects of Human Activities on the Deep Sea: Global Trends and Current State of Knowledge in Mexico's Exclusive Economic Zone (EEZ). Mexico City, Mexico: Semarnat-INECC. p. 287-304.

[10] Felder DL, Camp DK. 2009. Gulf of Mexico Origin, waters, and Biota. Vol. I, Biodiversity. Corpus Chriti, USA: Harte Research Institute for Gulf of Mexico Studies Series, Texas A&M University.

[11] Flint, RW. 1981. Gulf of Mexico outer continental shelf benthos: macroinfaunal environmental relationships. Biol. Ocean. 1:135-145

[12] Flint, RW. and Rabalais N. 1981. Environmental studies of a marine system: South Texas outer continental shelf. Galveston, USA: Texas University Press.

[13] Flint RW and Kalke RD. 1986. Niche characterization of dominant estuarine benthic species. Est. Coast. Shelf Sci. 22:657-674

[14] Franco J, Borja A, Solaun O and Pérez V. 2002. Heavy metals in molluscs from the Basque coast (Northern Spain): results from an 11-years monitoring program. Sea. Pollut. Bull. 44:956-976

[15] García-Cuellar JA, Arreguín-Sánchez F, Hernández SV and Lluch-Cota B. 2004. Ecological impact of the oil industry in the Campeche Sound, Mexico, after three decades of activity: a review. Interciencia 29(6):311-319.

[16] García-Cuellar JA. 2006. Analysis of the impact of the oil industry on the ecosystem and its relationship with the fisheries of the Campeche Sound, Mexico. [PhD Thesis]. Centro de Investigaciones Biológicas del Noreste, S.C. La Paz BCS, Mexico.

[17] García-Valencia C and Díaz JM. 2000. Molluscs and their taxocenosis in the shallow bottoms of the southern sector of the continental shelf of the Colombian Caribbean. Bowl. Invest. Sea. Cost. 29:73-80.

[18] González-Solis MA and Torruco, D. 2001. The benthic fauna of the Sabancuy estuary, Campeche, Mexico. Rev. Biol. Trop. 49 (1): 31-45.

[19] Gull, J and Glénmerec, M. 1997. Using biotic indices to estimate macro benthic community perturbations in the Bay of Brest. Est. Coast. Shelf Sci. 44 (Supplement A): 43-53

[20] Guzmán del Próo SA, Chávez EA, Alatriste FM, de la Campa S, de la Cruz G, Gómez L, Guadarrama R, Guerra A, Millé S and Torruco D. 1986. The impact of the Ixtoc-1 oil spill on zooplankton. Jour. Plankton Res. 8(3): 557- 581.

[21] Huidobro-Campos L, Vallarta-Zárate JRF, Izábal-Martínez JD, Martínez-Magaña VH, del Campo-Hernández D, Romero-Fernández O, Pérez-Flores EV, López-López L, Altamirano-López L, and Hernández-Cruz D. 2018. Benthic Ecosystem in the Campeche Sound: Bathymetry, Oceanography and Biology. Gulf of Mexico and Caribbean Sea Campaign, 2018. Technical Report. Campeche, Mexico: INAPESCA.

[22] ITOPF. 2005. Effects of oil pollution on the marine environment. Technical Information Document 13. London, UK: The International Tanker Owners Pollution Federation Limited. United Kingdom.

[23] Manino, A, and Montanna, AP. 1997. Small-scale spatial variation of macrobenthic community structure. Estuaries 20(1): 159-173

[24] Mendoza-Quintero A, Herrera-Rodríguez M and Olguín-Pascualli G. 2004. Coastal Management in Mexico. In: Rivera-Arriaga E, Villalobos GJ, Azuz-Adeath I and Rosado-May F, editors. Environmental monitoring of oil activity in the southern Gulf of Mexico. Campeche, Mexico: Universidad Autónoma de Campeche, SEMARNAT, CETYS-Universidad, Universidad de Quintana Roo. Mexico. p 589-610.

[25] Morys C, Poweilleit M and Forsher S. 2017. Bioturbation in relation to depth distribution of macrozoobenthos in the southwestern Baltic Sea. Sea. Ecol. Prog. Be. 579: 19-36

[26] Murawski SA, Peebles EB, Gracia A, Tunnell JW, Armenteros M. 2018. Comparative abundance, species composition, and demographics of Continental shelf fish Assemblages throughout the Gulf of Mexico. Marine and Coastal Fisheries: Dynamics, Management, and Ecosys. Sc. 10:325-246. doi: 10.1002/mcf2.10033

[27] Orlocí L. 1978. Multivariate analysis in vegetation research. Netherlands, The Hague: Ed. Dr. W. Junk B.V.

[28] Pielou EC. 1977. Mathematical ecology. 2nd. Ed. New York, USA: John Wiley and Sons.

[29] Ramírez-Cañada, R. 2009. Gastropod molluscs as bioindicators in the Canary archipelago: From natural processes to anthropogenic causes. Doctoral Thesis. University of Las Palmas de Gran Canaria, Spain.

[30] Rehder HA. 1981. The Audubon Society. Field Guide to North American Seashells. New York USA: Alfred A. Knopf Series.

[31] Riba I, Conradi M, Forja JM and DelValls TA. 2004. Sediment quality in the Guadalquivir estuary: Sublethal effects associated with the Aznalcoller mining spill. Sea. Pollut. Bull. 48:153-163.

[32] Rubio-Polania JC, Torruco D, González-Solis MA, Ordaz-Bencomo JF and Caamal-Jiménez CY. 2018. Megafauna benthic of outer margins of the continental shelf of Yucatan Peninsula. Reg. Stu. Sea. Sci. 24: 184-195

[33] Sabatini SE. and Calcagno JA. 2015. Marine Invertebrates. In: Calcagno JA, editor. Molluscs as bioindicators, Ch. 18. La Plata, Argentina: Vázquez Mazzini Editores. p. 193-196.

[34] Shepard AN, Valentine JF, D'Elia Ch, Yoskowitz DW and Dismukes DE. 2013. Economic impact of Gulf of Mexico ecosystem goods and services and integration into restoration decision-making. Gulf Mex. Sci. 201 5(1-2): 10-27. Doi: goms-31-01-03.3d

[35] Ter Braak CJF. 1995. Data analysis in community and landscape ecology. In: Jongman RHG, Ter Braak CJF, van Tongeren OFR, editors. Ordination. Cambridge, United Kingdom: Cambridge University Press. p. 91-173.

[36] Torruco, D. 1988. Structure of the necrobenthic fauna of the sublittoral of Laguna Verde, Veracruz. [M.C. Thesis]. [Merida] Center for Research and Advanced Studies of the National Polytechnic Institute. Merida Unit, Mexico.

[37] Torruco D., González-Solís M. A., Torruco-González Á. D. and Rubio-Polania, J. C., 2018. Invertebrate Megafauna in the Perdido Fold Belt Polygon, Gulf of Mexico, Mexico. Ocean. Fish. 8(1):1-6

[38] Torruco D, González-Solis MA and Torruco-González AD. 2018. Diversity and distribution of fishes and their relationship with environmental variables, in the southern Gulf of Mexico. Rev. Biol. Trop. 66(1): 438-456.

[39] Tripp-Quezada A, Borges-Souza JM, Cruz-Vizcaino M and Tripp-Valdez A. 2009. Environmental indicator mollusks in the Espiritu Santo archipelago, Mexico. PCTI 42.

[40] Vokes HE and Vokes EH. 1983. Distribution of shallow-water marine mollusca, Yucatan Peninsula, Mexico. New Orleans, USA: Tulane University.

[41] Warmke, LG and Abbott RT. 1962. Caribbean Seashells. A guide to the marine mollusks of Puerto Rico and other West Indian Islands. Bermuda to the lower Florida Keys. Pennsylvania, USA: Livingstone Publisher.

[42] Weisberg, B.S., A. J. Ranasinghe, M.D. Dauer, C.L. Shaffner, and B.J. Frithsen.1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. Estuaries 20(1): 149-158