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Research Article

Community structure of rocky reef-associated fish in industrial and fishery areas in La Paz Bay, Mexico

José María Morales-Trejo[1], Jesús Rodríguez-Romero[1], María Ruth Ochoa-Díaz[1]
Leonardo Andrés Abitia-Cárdenas[2] & Juana López-Martínez[1]
[1]Centro de Investigaciones Biológicas del Noroeste, La Paz, Baja California Sur, México
[2]Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas
La Paz, Baja California Sur, México
Corresponding author: Jesús Rodríguez-Romero (jrodri04@cibnor.mx)

ABSTRACT. Rocky reefs show structures with great fissures that give place to site or habitat formation, benefiting organisms and serving as refuge and possible predator protection. La Paz Bay, located within the southern Gulf of California, has recently grown in population, increasing natural resource use. Creating an industrial area stands out with Grupo Acuícola Mexicano (GAM) shrimp farm and Roca Fosfórica Mexicana II (ROFOMEX II) mine reactivation. Thus, the present research aims to compare the fish community structure on rocky reefs close to these commercial and industrial fishing areas. It accounts for 27,561 organisms belonging to 110 species, 74 genera, and 36 families by visual census. The relative abundance showed that the most representative species were *Abudefduf troschelii*, *Haemulon maculicauda*, *Sardinops sagax*, *Thalassoma lucasanum*, *Haemulon steindachneri*, and *Stegastes rectifraenum*. The fishery areas (Paredones Verdes and El Portugues) had higher richness and abundance than the industrial zone (El Cobre) of Block I. In contrast, the fishery areas (Tarabillas and Las Pacas) in Block II showed greater diversity and equity concerning the industrial zone (El Muelle). In conclusion, industrial activity negatively affects fish species close to these areas with respect to fisheries.

Keywords: rocky reef; ichthyologic diversity; fishery-industrial zone; Gulf of California

INTRODUCTION

Rocky reefs are important and common marine environments in the rocky shores and many shallow sublittoral zones of islands (Figueroa-Pico et al. 2020). Rocky and insular environments provide a high diversity of substrate for fixation, protection, recruitment, feeding, breeding, and spaces for larval settlement for a great number of species and organisms (Booth & Brosnan 1995, Rodríguez-Romero et al. 2005, NOAA 2016). Thus, these species play an important role at the ecosystem level since, in these areas, efficient and effective trophic chains (Campos-Dávila et al. 2005, Aburto-Oropeza et al. 2015, Sánchez-Rodríguez et al. 2015) have protection and/or importance for commercial fishing (Lluch-Cota et al. 2007, Teixeira-Neves et al. 2015).

The previous sites are important sources of income for many countries; they constitute a barrier that protects the coastal zones from hurricane and storm effects and serve as a seasonal refuge along the life cycle of the species, which are key for the fishing sector (Teixeira-Neves et al. 2015, NOAA 2016). However, due to growth and population settlement in the neighboring coastal zones, these ecosystems have threatened their stability at the world level (Cudney-Bueno 2000, Vicente-Castro 2020). Among the anthropogenic factors most affected are fishing and excessive contamination caused by residual water waste from industrial, agricultural, and urban areas (Mumby et al. 2014, Vicente-Castro 2020). In the case of fishing, the decrease in fish biomass occurs from excessive capture, in addition to the negative effects of fishing gear (bottom longline and trawling nets) and incidental fishing (Vicente-Castro 2020).

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In the southern Gulf of California (GC) area, La Paz Bay (LPB) has shown greater urbanization and population growth in recent years. Additionally, increased tourism and recreational activities (López-Espinosa 2002) convey a greater use of natural resources, such as the marine environment, including fish, invertebrates, and marine mammals. Moreover, the creation of an industrial zone that includes Grupo Acuícula Mexicano (GAM) shrimp farm and the reactivation of Roca Fosfórica Mexicana II (ROFOMEX II) mining company both induce an additional agent of marine ecosystem impact. Wastewater discharge from the previously mentioned industrial activity has generated high metal concentrations in organism tissues and sediments (Hernández-Almaraz et al. 2016, Páez-Osuna et al. 2017). All of it has effects on both terrestrial and marine (rocky reefs).

Some studies within La Paz Bay by Abitia-Cárdenas et al. (1994), Aburto-Oropeza & Balart (2001), Galván-Piña et al. (2003), Rodríguez-Romero et al. (2005), Villegas-Sánchez et al. (2009), Barjau-González et al. (2012, 2013, 2023), Torres-Esparza (2016), González-Acosta et al. (2018) and Castillo-Rosas et al. (2020) have focused on ichthyological systematic lists present in the rocky reefs, as well as the characterization of ecological indices and its structural assemblage. However, the increased activity and discharge of wastewater from the shrimp farm and phosphorite mine over time, as well as the remains of nets, hooks, and other traps commonly used for artisanal fishing, and damage caused by natural effects have intensified in recent years. Therefore, it is necessary to evaluate the community structure and its state of disturbance. The objective of this work is to evaluate the state of the community structure and the degree of disturbance of the ichthyofauna associated with the rocky reefs near the La Paz Bay areas, providing information that allows the corresponding agencies to establish management strategies, helping to care for resident fish species and migratory species.

MATERIALS AND METHODS

Study area

La Paz Bay is on the GC western coast, between 24.1-24.8°N and 110.2-110.8°W (Fig. 1). It has an approximate dimension of 4,500 km^2 (80 km in length and 35 km in largest width). The climate is semi-desert (García 1973), with an average annual temperature of 23.8°C, which ranges from 8°C in winter to 37°C in summer.

Sampling

Four bi-monthly samplings were carried out in six sites in May (spring), July (beginning of summer), September (end of summer), and November (autumn) 2022. Visual census is a non-destructive method that provides quantitative descriptions of reef fish structure and is acceptable for studies related to reef management and assemblage patterns (Villegas-Sánchez et al. 2009). The visual transects were performed by free diving during the day (10 to 17 h), which were of 100×5 m (500 m^2) lineal parallel to the coast at two depths and allowed comparing shallower (1-2 m) and deeper (4-6 m) parts, where usually the reef substrate reaches its limit. All the fish species and their observed abundance were recorded in polyvinyl chloride (PVC) tables, and two replicates were performed for each site.

The work of Nelson et al. (2016) used specialized literature to arrange the species found taxonomic.

Separation was performed in two zones per block, taking the degree of the industrial and fishery activities as a reference (Barjau-Gonzalez et al. 2013),), in this way, the Paredones Verdes Block I is an area with less fishing activity (PV-LeFA); El Portugués has more fishing activity (EP-GrFA); and El Cobre is an area with industrial activity (EC-I). In Block II (replica), the area with the least fishing activity was Tarabillas (T-LeFA), while Las Pacas is located near the urban area and has the most fishing activity (LP-GrFA). Finally, El Muelle has high industrial activity (EM-I) (Fig. 1). According to the block selection, two replicates within LPB could be performed and corroborate if the same pattern exists in ichthyofauna or act differently.

Since the environmental variables (temperature, oxygen, and salinity) vary over time, they were measured in each sampling period with multiparametric brand YSI, model Pro-2030, YSI Incorporated, OH, USA

Ecological indices

For data analysis, the following ecological indices were used based on species abundance:

Relative abundance (RA) is the species-individual ratio of the species to the total individuals of all the species present in a determined area:

$$RA = n / Nt \times 100$$

where n is each species' abundance, and Nt is the total abundance of all the fish.

Shannon-Weaver (H') diversity index shows the heterogeneity of a community using two measures: number of species and relative abundance in a community

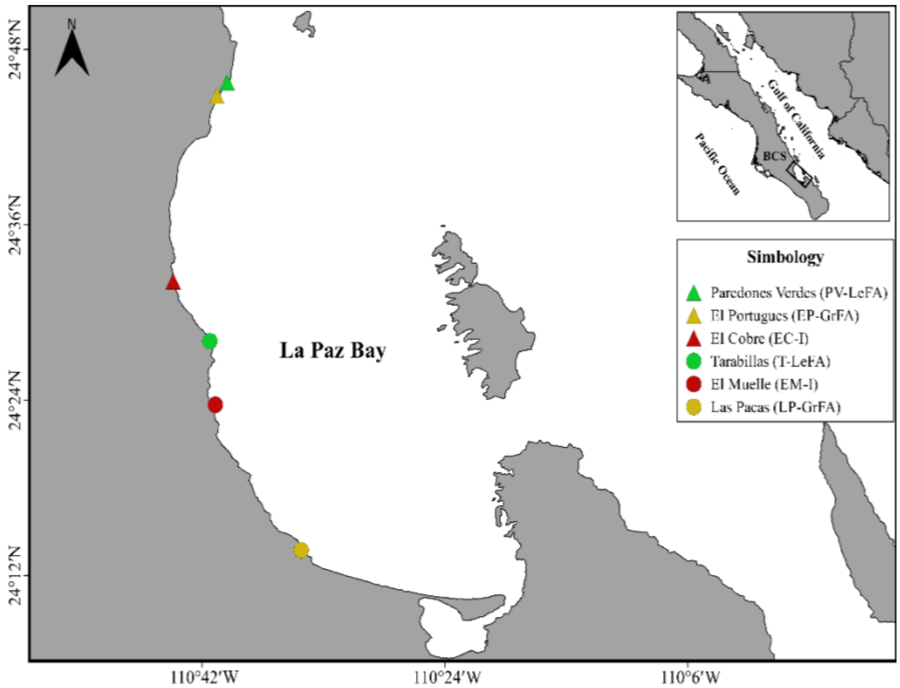

Figure 1. Geographic location of the study areas within La Paz Bay, Baja California Sur, Mexico.

$$H' = -\sum_{i=1}^{s} (p_i \times \log2(p_i))$$

where p_i is the proportion of species i, and s is the number of species (Shannon & Weaver 1949).

Pielou evenness index (J') (Pielou 1975) is a component of diversity and an indirect measure of relative abundance. It uses values from 0 to 1. Values closer to 1 indicate evenness, while values closer to 0 indicate dominance from a species:

$$J' = H' / \ln(S)$$

where H': Shannon-Weaver diversity index; S: number of species.

The level of dominance determines the dominant species and, in contrast, which are rare:

$$Fr = ni / N \times 100\ \%$$

where n_i: absolute frequency; N: sample size.

Subsequently, Olmstead Tukey's (Olmstead & Tukey 1947) diagram was performed to observe the dominant, frequent, occasional, and rare species.

Statistical analysis

To evaluate differences between areas, depths, and stations, we carried out different statistical tests for which normality and homogeneity of the data were tested. Since the ecological indices and temperature showed normality and homogeneity, a one-way ANOVA was used to compare zones and a *post-hoc* test. In contrast, a Student-*t* was used for depth and season. However, since salinity and dissolved oxygen showed neither homogeneity nor normality, a Kruskal-Wallis test was used to compare zones and months. All *P*-values were considered significant at $P < 0.05$. All statistical analyses were performed using R 4.2.2 (R Development Core Team 2022).

It also performed a principal component analysis (PCA) by hot and cold season, a technique for dimensionality reduction that identifies a set of orthogonal axes, called principal components, that capture the maximum variance in the data:

$$Cp_i = \sum_j \lambda_{ij}\left[\left(X_j - \bar{X}_j\right)\sigma_j^{-1}\right]$$

where X_j is the absolute value of each variable, and $\bar{x}$ is average of each measurement.

Bray-Curtis distances were used to test the overall association of fish structure with environmental conditions, which were calculated among sites based on species´ abundance and habitat variables. Subsequently, a Cluster analysis using the square-root transformed abundances from the six study zones was carried out following agglomerative techniques (Gauch 1982).

RESULTS

Physicochemical variables

The average water temperature was 27°C (min = 22.4°, max = 32.6°), with a seasonal difference ($F = 14.7$, $P < 0.05$), of which July and September are the hottest compared to May. The average dissolved oxygen was 1.14 mg L^{-1} (min = 0.1 mg L^{-1}, max = 4.52 mg L^{-1}), recording a significant ($P < 0.05$) seasonal difference, of which November recorded greater dissolved oxygen compared to May and July. The average salinity was 35.8 (min = 34.3, max = 36.8), finding spatial differences ($P < 0.05$) in the LP-GrFA area with greater salinity concentration concerning EC-I (Table 1).

Richness and abundance

A total of 27,561 individuals were counted, belonging to 110 species, 74 genera, and 36 families (Table S1). The families with the highest number of individuals were Carangidae (10 species), Serranidae (9 species), and Haemulidae (8 species).

On the other hand, the most abundant families were Pomacentridae species *A. troschelii* (7,044 ind), Haemulidae species *H. maculicauda* (3,034 ind), and Clupeidae species *S. sagax* (2,050 ind) (Figs. 2-3). Of the 110 species recorded, 40 occurred in all four sampling months, 12 occurred in three months, 23 species occurred in two months, and 35 species occurred in only one of the four bimonthly samples.

Abundance in fishery areas was PV-LeFA = 3,638 ± 145 ind and EP-GrFA = 2,875 ± 144 ind concerning the industrial area EC-I = 1,713 ± 44 ind in Block I ($F = 4.03$, $P < 0.05$). On the other hand, the industrial fishery area EM-I (10,691 ± 562 ind) recorded greater abundance concerning T-LeFA (5,710 ± 532 ind) and LP-GrFA (2,934 ± 244 ind) in Block II ($F = 4.3$, $P < 0.05$) (Fig. 4, Table 2). When the year's season was considered, no differences were found between the hot and cold seasons ($T = -1.3$, $P > 0.05$). However, the depth variable in Block II, EM-I (8,973 ± 526.2 ind) was significantly different ($F = 11.8$, $P < 0.05$) from T-LeFA (2,060 ± 125.7 ind) and LP-GrFA (919 ± 92 ind).

A total of 60 ± 2.6 species were recorded in PV-LeFA and 63 ± 1.4 species in EP-GrFA, of which both fishery areas were significantly higher ($F = 9.3$, $P < 0.05$) concerning EC-I, where 51 ± 1.3 species were recorded. Likewise, 58 ± 1.6 species were recorded in EM-I and 65 ± 1.3 species in T-LeFA, of which the last one is significantly higher ($F = 8.2$, $P < 0.05$) in LP-GrFA with 50 ± 2.7 species (Fig. 4, Table 2). No differences between seasons were found by climate period ($T = -0.1$, $P > 0.05$). On the other hand, in the shallow part, T-LeFA recorded 50 ± 2 species, which was significantly different ($F = 10.7$, $P < 0.05$) when compared with LP- GrFA and EM-I with 32 ± 1.4 and 40 ± 2 species, respectively.

Diversity and evenness

The PV-LeFA, EP-GrFA, and EC-I areas showed a spatial diversity (H') similar to 2.3, 2.4, and 2.1 bits ind^{-1}, respectively, without significant difference ($F = 2.5$, $P > 0.05$) (Fig. 5, Table 2). However, in the deepest part, PV-LeFA (2.16 bits ind^{-1}) and EP-GrFA (2.45 bits ind^{-1}) showed a greater H' ($F = 2$, $P < 0.05$) concerning EC-I (1.64 bits ind^{-1}). On the other hand, T-LeFA showed H' = 2.5 bits ind^{-1}, which was significantly higher ($F = 12.4$, $P < 0.05$) than LP-GrFA (1.8 bits ind^{-1}) and EM-I (1.5 bits ind^{-1}) (Table 2). Likewise, T-LeFA (2.43 bits ind^{-1}) once again showed greater H' ($F = 5$, $P < 0.05$) in the deepest part when compared to EM-I (1.42 bits ind^{-1}).

The PV-LeFA, EP-GrFA, and EC-I areas showed evenness (J') similar to 0.66, 0.70, and 0.67, respectively, but no significant difference ($F = 0.4$, $P > 0.05$) was found (Fig. 5, Table 2). Nevertheless, PV-LeFA (0.67) and EP-GrFA (0.77) showed greater evenness in the deepest part, of which the last one was significantly different ($F = 4.7$, $P < 0.05$) than EC-I (0.60). On the other hand, T-LeFA (0.71) and LP-GrFA (0.57) had greater evenness, and at the same time, T-LeFA was significantly different ($F = 6.1$, $P < 0.05$) than EM-I (0.46) (Table 2). Likewise, in the deepest part again, T-LeFA (0.77) showed greater evenness ($F = 4.4$, $P < 0.05$) when compared to EM-I (0.45).

Dominance and correlation

Of the 110 fish species censed associated with rocky reefs, Olmstead-Tukey's diagram (Figs. 6a,c) showed that 14 species are dominant, where those that stand out are *A. troschelii*, *H. maculicauda*, *T. lucasanum*, *S. rectifraenum*, and *B. polylepis* in LPB (Table S1).

When PCA was performed for the hot season, *A. troschelii* was correlated to variable abundance (0.80); *H. maculicauda* was correlated to salinity (0.78), whereas *S. suborbitales* correlated with temperature (0.65), which can be explained by components 1 and 2 (80.4%) (Fig. 5b). While in the cold season PCA, *A. troschelii* was correlated with abundance (0.83), *K. vaigiensis* with temperature (-0.51), which explain 70.1% of the components 1 and 2 (Fig. 5d).

Cluster analysis using the square-root transformed abundances from the six study zones revealed some similarity between zones: Group 1: T-LeFA, PV-LeFA, and EP-GrFA; Group 2: LP-GrFA and EM-I; Group 3: EC-I (Fig. 7).

Table 1. Variables parameters measured in the six areas within La Paz Bay, Baja California Sur, México in 2022. PV-LeFA: Paredones Verdes less fishery activity; EP-GrFA: El Portugués greater fishery activity; EC-I: El Cobre industry; T-LeFA: Tarabillas less fishery activity; LP-GrFA: Las Pacas greater fishery activity; EM-I: El Muelle industry.

Zone	May						July					
	PV-LeFA	EP-GrFA	EC-I	T- LeFA	LP- GrFA	EM-I	PV- LeFA	EP- GrFA	EC-I	T- LeFA	LP- GrFA	EM-I
Variable												
Oxygen	0.6	0.7	0.7	0.6	0.3	0.4	0.1	0.2	0.2	0.3	0.4	0.5
Temperature	24.7	23.6	23.2	22.9	28.2	25.5	28.4	28.7	27.6	28.5	29	27.5
Salinity	35.3	36.6	35.6	36.2	36.5	35.6	35.7	36	34.7	36	36.5	36.1
Zone	September						November					
	PV- LeFA	EP- GrFA	EC-I	T- LeFA	LP- GrFA	EM-I	PV- LeFA	EP- GrFA	EC-I	T- LeFA	LP- GrFA	EM-I
Variable												
Oxygen	-	-	-	-	-	-	1.06	1.31	0.98	3.38	4.52	4.3
Temperature	31.4	31	28.8	30.5	33.1	28.6	26.6	26.5	25.3	25.7	30.1	26.3
Salinity	35.7	35.7	35.7	36	36	36	35.8	35.8	34.3	35.9	36.8	36.3

Table 2. Ecological indices calculated in La Paz Bay, Baja California Sur, México. PV-LeFA: Paredones Verdes less fishery activity; EP-GrFA: El Portugués greater fishery activity; EC-I: El Cobre industry; T-LeFA: Tarabillas less fishery activity; LP-GrFA: Las Pacas greater fishery activity; EM-I: El Muelle industry; N: abundance; S': specific richness; H': Shannon-Weaver diversity; J': Pielou evenness.

Zone	May				July				September				November				Total			
	N	S'	H'	J'	N	S'	H'	J'	N	S'	H'	J'	N	S'	H'	J'	N	S'	H'	J'
PV-LeFA	961	28	2.06	0.61	510	31	2.51	0.73	963	36	2.64	0.73	1204	40	2.24	0.60	3638	60	2.74	0.67
EP- GrFA	625	32	2.31	0.66	736	33	2.53	0.72	413	30	2.64	0.77	1101	37	2.42	0.67	2875	63	2.84	0.68
EC-I	417	21	1.75	0.57	554	26	2.18	0.67	346	21	2.15	0.70	396	25	2.39	0.74	1713	51	2.89	0.73
T-LeFA	914	36	2.61	0.73	601	34	2.88	0.81	1215	40	2.70	0.73	2980	39	2.19	0.59	5710	64	2.83	0.68
LP- GrFA	237	19	1.88	0.64	400	26	2.18	0.67	1071	32	1.78	0.51	1226	28	1.65	0.49	2934	50	2.39	0.61
EM-I	3460	32	1.67	0.48	1091	25	1.92	0.59	2651	32	1.09	0.31	3489	31	1.67	0.48	10691	58	2.32	0.57

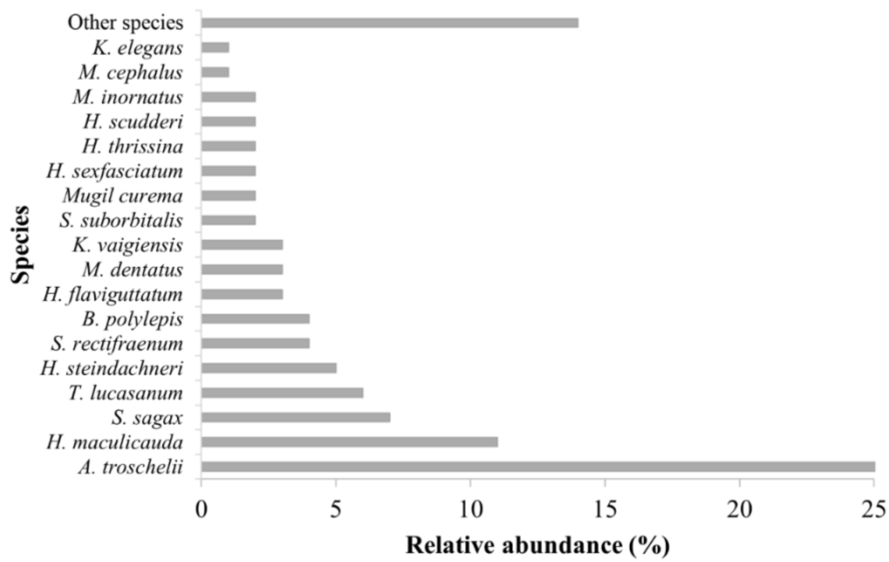

Figure 2. Relative species abundance within La Paz Bay, Baja California Sur, Mexico, during 2022.

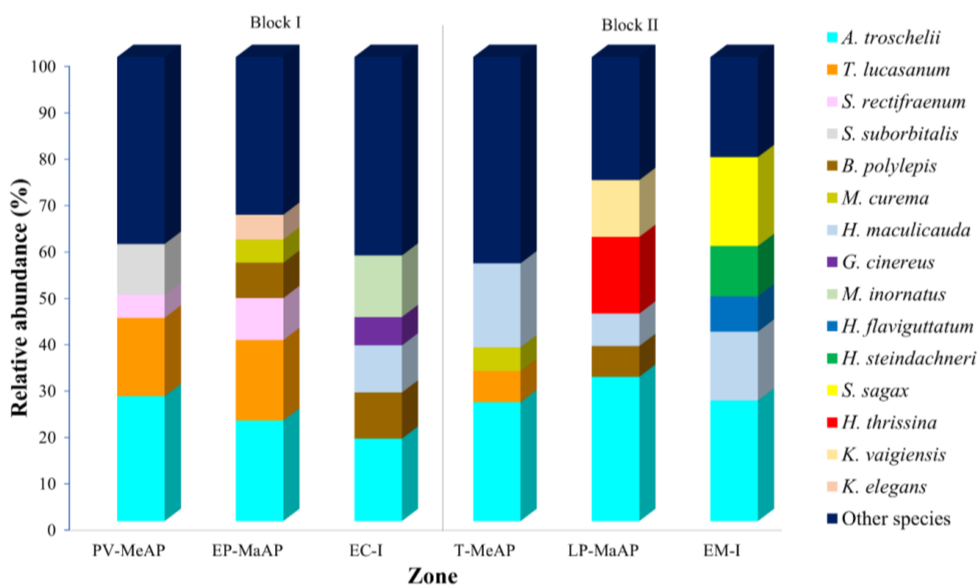

Figure 3. Relative abundance of species by zone within La Paz Bay, Baja California Sur, Mexico during 2022. PV-LeFA: Paredones Verdes less fishery activity; EP-GrFA: El Portugués greater fishery activity; EC-I: El Cobre industry; T-LeFA: Tarabillas less fishery activity; LP-GrFA: Las Pacas greater fishery activity; EM-I: El Muelle industry.

DISCUSSION

Anthropogenic activity is one of the main negative affectations on marine life, either infrastructure or industrial (Aburto-Ororpeza et al. 2015, Wang et al. 2021, Wang & Zhang 2023). At the world level, evidence has shown how affectation toward the coastal zones causes changes in chemical variables, such as salinity, oxygen, and pH, among others (Mazzola et al. 2000, Vita et al. 2002, Wang et al. 2021, Mancuso et al. 2023). Therefore, this study focused on the current issues of increasing phosphorite mine-activity, fishing activity, and the status of the fish communities associated with the rocky reefs near these areas in LPB.

The systematic list of ichthyofauna recorded in rocky reefs and analyzed within LPB were 110 species, representing 12% of the total species reported (911 spp.) for the GC by Hastings et al. (2010). Other studies performed in LPB and neighboring islands reported 120 species for Espíritu Santo Island (Rodríguez-Romero et al.

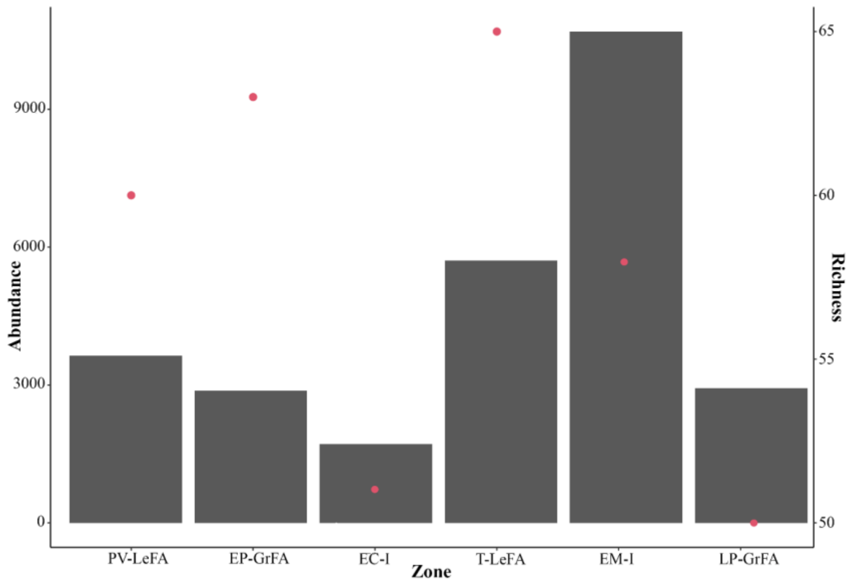

Figure 4. Abundance (bars) and richness (point) by zone in La Paz Bay during 2022. PV-LeFA: Paredones Verdes less fishery activity; EP-GrFA: El Portugués greater fishery activity; EC-I: El Cobre industry; T-LeFA: Tarabillas less fishery activity; EM-I: El Muelle industry; LP-GrFA: Las Pacas greater fishery activity.

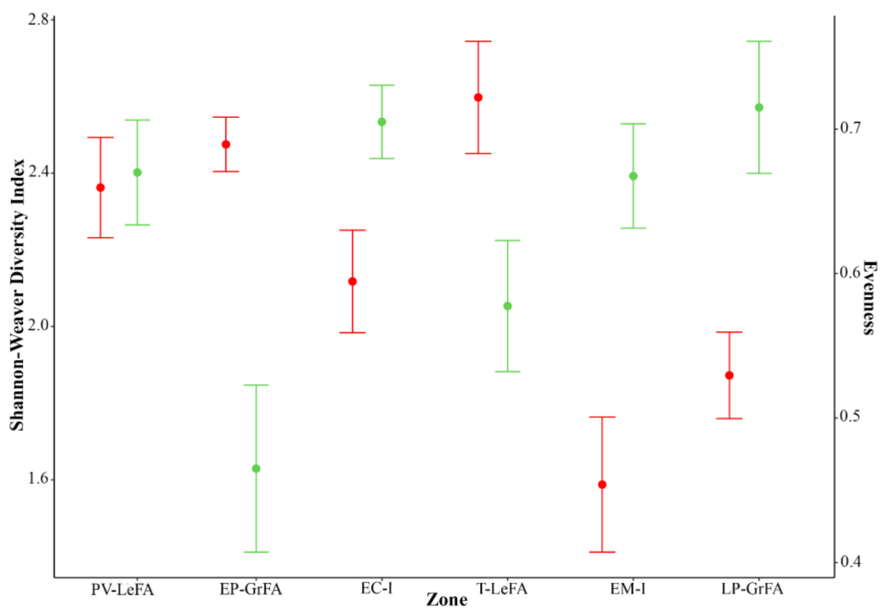

Figure 5. Diversity index (red line) and evenness (green line) by zone in La Paz Bay. PV-LeFA: Paredones Verdes less fishery activity; EP-GrFA: El Portugués greater fishery activity; EC-I: El Cobre industry; T-LeFA: Tarabillas less fishery activity; LP-GrFA: Las Pacas greater fishery activity; EM-I: El Muelle industry.

2005) and 112 for San José Island (Barjau-González et al. 2012), which are similar in numbers of species found here. Other studies carried out to determine fish species richness using the visual census method included those by Pérez-España et al. (1996), Arreola-Robles & Elorduy-Garay (2002), Galván-Piña et al. (2003), Villegas-Sánchez et al. (2009), Barjau-González et al. (2013) and Torres-Esparza (2016), recorded less than 95 species in LPB. Rocky substrate heterogeneity (sizes and shapes), as well as coral sargassum and sand corridors, have a positive effect on ichthyofauna (Aburto-Oropeza & Balart 2001, Rodríguez-Romero et al. 2005), a fact that explains the great influence exerted upon species composition, distribution, and abundance; for example, *A. troschelii*, *H. maculicauda*,

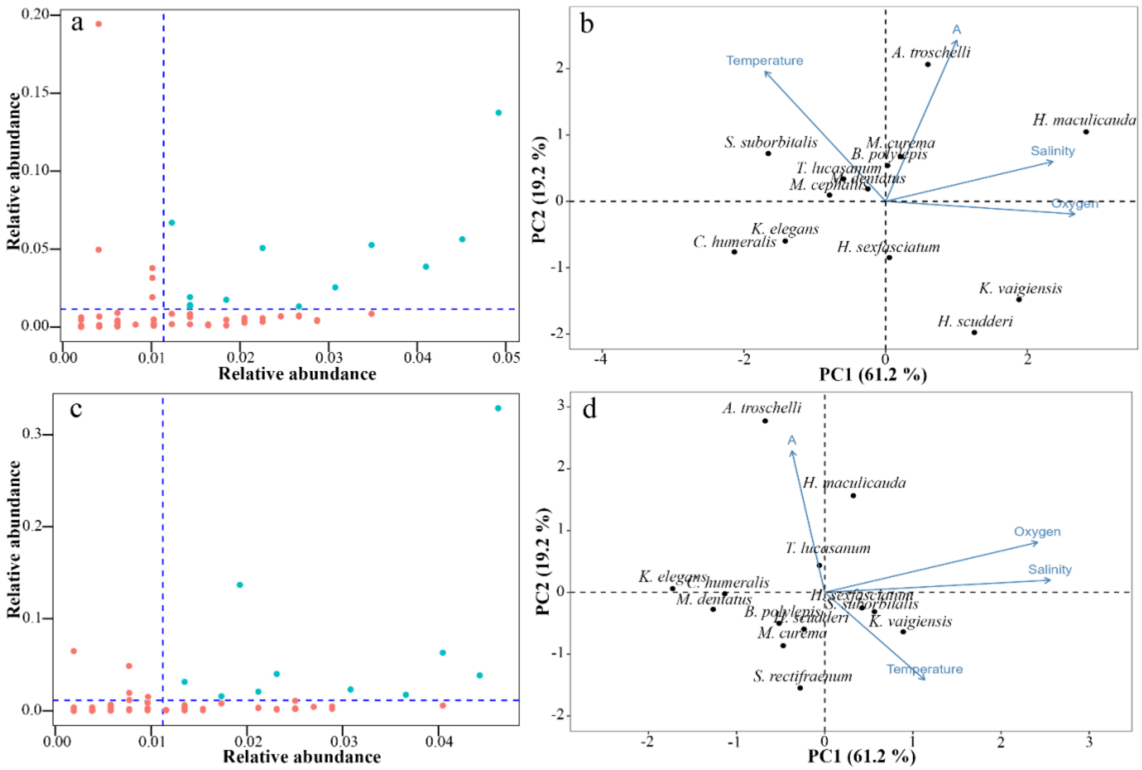

Figure 6. a) Olmstead-Tukey's diagram and b) principal component analysis in the warm season, and c) Olmstead-Tukey's diagram and d) principal component analysis in the cold season of the dominant fish species in La Paz Bay, Baja California Sur, Mexico.

T. lucasanum, and *S. rectifraenum*, among others have distribution in Cortez Province (CP) and Eastern Tropical Pacific (ETP) (Allen & Robertson 1994, Rodríguez-Romero et al. 2005, Moreno-Sánchez 2009, Torres-Esparza 2016). On the other hand, a latitudinal gradient or loss of richness from south to north may explain why studies in regions with latitudes above those found in LPB have reported lower species richness (Viesca-Lobatón et al. 2008).

Anthropogenic activity in coastal zones has a negative effect. Precisely, the GAM shrimp farm empties pond water into the sea without any previous process to decrease contaminants (residual organic matter and other pharmaceutic products) that alter water quality (turbidity, total suspended solids, chlorophyll-*a*, NO_2-, NO_3-, NH^4+) and sediment quality (Vita et al. 2002, Barraza-Guardado et al. 2014). These contaminants affect EC-I marine species, and the results have been reflected in fish richness and abundance, which was less when compared to PV-LeFA and EP-GrFA, which are within Block I. However, in Block II, the fishery areas (T-LeFA and LP-GrFA) recorded lower abundance than EM-I, where greater species abundance was found. This result is likely due to water discharge used by "ROFOMEX II" mining operations, which carries mainly fluorhydric acid, hexafluorsilic acid, and phosphorus -this last one is favorable in certain amounts for some trophic levels (Rueda-Jasso et al. 2014)- which may induce to believe there is no habitat disturbance.

Nevertheless, the fish's health and the rest of the biotic components of the ecosystem are still unknown. However, flora and fauna likely have high metal concentrations due to the mineral and metal extraction (Hernández-Almaraz et al. 2016, Páez-Osuna et al. 2017). Whereas in LP-GrFA, its low richness and abundance may be due to the shallow waters with a very smooth slope and a coastline far from the edge (~50 m), as well as the rock size, which is small and does not seem to be a secure refuge for fish of greater size (Viesca-Lobatón et al. 2008, Aburto-Oropeza et al. 2015).

H' and J' values differed from the fishery areas (T-LeFA and LP-GrFA) to the industrial zone EM-I. Although this area had high richness (58 species), it may be explained by the fact that there is a disparity of organisms by species since six species (*A. troschelii*, *S. sagax*, *H. maculicauda*, *H. steindachneri*, *H. flaviguttatum* and *M. dentatus*) represented 83.2% (7,847 ind) and 52 others concentrated 26.8% (1,480 ind) of abundance. Part of the behavior of the Haemulidae family is that during the

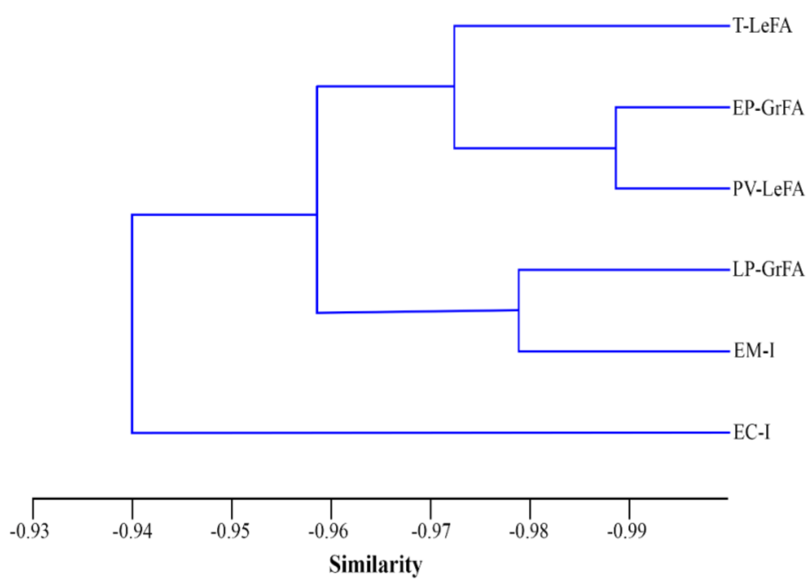

Figure 7. Cluster analysis based on square-root transformed data of numeric abundance of the rocky reef fish assemblage sampled in La Paz Bay. Groups of locations were delineated at the 94% level. PV-LeFA: Paredones Verdes less fishery activity; EP-GrFA: El Portugués greater fishery activity; EC-I: El Cobre industry; T-LeFA: Tarabillas less fishery activity; LP-GrFA: Las Pacas greater fishery activity; EM-I: El Muelle industry.

day, they hide on the reef and then disperse to feed after dark. They also form very large schools during the day to rest near the reefs (Robertson et al. 2024). Something that was observed in the EM-I zone. Although rocky substrate heterogeneity and extensive sand corridors exist, coral and sargassum presence is low (less than 20%), limiting its complexity as a refuge, feeding, resting, spawning, and nursery site, besides being species of minor segregation concerning the six already mentioned. (Aburto-Oropeza et al. 2015, Torres-Esparza 2016). Finally, the negative effect of the industry is that along the reef, the dock is found where phosphorite mineral is transported toward the cargo ships that arrive at the port of San Juan de la Costa. This situation generates an impact due to the ship propeller, which may raise sediment, including noise.

In the fishery and industrial LPB areas where the census was performed, 14 dominant species were recorded in the rocky reefs, of which those that stand out are *A. troschelii*, *T. lucassanum*, *B. polylepis*, and *S. rectifraenum*, which agrees with Rodríguez-Romero et al. (2005), Barjau-González et al. (2012) and Torres-Esparza (2016) who reported the same dominant species in different years. These species are along the ETP and are permanent residents in rocky and coral reefs and shallow water, looking for zooplankton and algae in groups over rocks. So, rocky reefs are ideal areas for spawning or feeding. However, some species are also at greater depth (Allen & Robertson 1994, Castro-Aguirre et al. 1995, Aguilar-Medrano 2012, Palacio-Salgado et al. 2012). In addition, the grouping of the zones by cluster analysis can be explained by the similarity of the habitat (variables factors), as observed in the samplings, the heterogeneity of the rocks, and the presence of sargassum and sand.

The correlation found in some species (*A. troschelii*, *H. maculicauda*, *K. vaigiensis*, and *S. suborbitalis*) with the physicochemical variables in the two climate seasons was low concerning the rest of the species. This result may be explained because, in their majority, they are eurythermal and euryhaline; that is, they may resist wide oscillatory temperature and salinity intervals due to their tropical affinity and biological characteristics, which allow adapting and performing short, medium, and long displacements to different habitats that are favorable for them (Castro-Aguirre et al. 1995, Villegas-Sánchez et al. 2009, Palacios-Salgados et al. 2012, Torres-Esparza 2016). However, dissolved oxygen values in this study were low, which could be due to the lack of rainfall in summer; in addition, the suspended particles absorb heat from sunlight, causing turbid waters to become warmer, and thus reducing the concentration of oxygen in the water (Obeso-Niebla & Gaviño-Rodríguez 2014). None of the species correlated with this physicochemical variable.

CONCLUSION

The results obtained from this study show that the fish communities that inhabit the rocky reefs adjacent to industrial areas are affected in their diversity and dominance due to the change in the physicochemical variables that cause there to be no homogeneity in abundance between the species caused by the anthropogenic disturbance product of the mining industry. This would limit habitat for some species more susceptible to gradient changes and allow only a few more resilient species to take advantage of the area. However, we observe that fish communities on rocky reefs adjacent to artisanal fishing areas are less affected, as the impact is minimal because large vessels are not used to destroy reefs (greater habitat viability) and seabeds, allowing for greater richness and greater diversity of species.

Credit author contribution

J.M. Morales-Trejo: conceptualization, validation, methodology, formal analysis, writing-original draft; J. Rodríguez-Romero: project administration, supervision, review, and editing; M.R. Ochoa-Díaz, L.A. Abitia-Cárdenas & J. López Martínez: supervision, review, and editing; All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare no potential conflict of interest in this manuscript.

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SUPPLEMENTARY MATERIAL

Table S1. Species that conform to the systematic list of fish associated with rocky reefs in La Paz Bay, BCS, Mexico sampling zone. D: dominant, F: frequent, O: occasional, R: rare. Species recorded by zone: LeFA: less fishery activity, GrFA: greater fishery activity, I: industry.

Chondrichthyes	Dominance	Zone
Urotrygonidae		
Urobatis concentricus Osburn & Nichols, 1916	R	LeFA, I
Urobatis halleri (Cooper, 1863)	R	GrFA, I
Urobatis maculatus Garman, 1913	R	GrFA
Actinopterygii		
Muraenidae		
Gymnomuraena zebra (Shaw, 1797)	R	GrFA
Gymnothorax castaneus (Jordan & Gilbert, 1883)	R	GrFA
*Gymnothorax.*spp	R	LeFA, I
Muraena lentiginosa Jenyns, 1842	R	GrFA
*Muraena.*spp	R	GrFA
Clupeidae		
Harengula thrissina (Jordan & Gilbert, 1882)	O	GrFA, I
Sardinops sagax (Jenyns, 1842)	O	I
Holocentridae		
Sargocentron suborbitalis (Gill, 1863)	D	LeFA, GrFA, I
Gobiidae		
Gobiosoma chiquita (Jenkins & Evermann, 1889)	R	GrFA
Pomacentridae		
Abudefduf troschelii (Gill, 1862)	D	LeFA, GrFA, I
Microspathodon bairdii (Gill, 1862)	R	LeFA
Microspathodon dorsalis (Gill, 1862)	F	LeFA, GrFA, I
Stegastes acapulcoensis (Fowler, 1944)	R	LeFA, GrFA, I
Stegastes flavilatus (Gill, 1862)	R	LeFA, I
Stegastes leucorus (Gilbert, 1892)	R	LeFA, GrFA, I
Stegastes rectifraenum (Gill, 1862)	D	LeFA, GrFA, I
Mugilidae		
Mugil cephalus Linnaeus, 1758	D	LeFA, GrFA, I
Mugil curema Valenciennes in Cuvier & Valenciennes, 1836	D	LeFA, GrFA, I
Blenniidae		
*Blennidae.*spp	R	I
Ophioblennius steindachneri Jordan & Evermann, 1898	F	LeFA, GrFA, I
Plagiotremus azaleus (Jordan & Bollman, 1890)	R	I
Labrisomidae		
Labrisomus xanti Gill, 1860	R	GrFA
Malacoctenus hubbsi Springer, 1959	R	GrFA
Malacoctenus tetranemus (Cope, 1877)	R	LeFA, GrFA
Malacoctenus zonifer (Jordan & Gilbert, 1882)	R	GrFA
Exocoetidae		
Fodiator acutus (Valenciennes, 1847)	R	LeFA, GrFA
Hemiramphidae		
Hemiramphus saltator Gilbert & Starks, 1904	O	LeFA, I
Belonidae		
Tylosurus crocodilus moderator Jordan & Gilbert, 1882	R	GrFA, I
Nematistiidae		
Nematistius pectoralis Gill, 1862	R	LeFA
Carangidae		
Alectis ciliaris (Bloch, 1787)	R	I
Caranx caballus Günther, 1868	R	LeFA, GrFA, I

Continuation

Chondrichthyes	Dominance	Zone
Caranx caninus Günther, 186	R	I
Caranx sexfasciatus Quoy & Gaimard, 1825	R	LeFA
Caranx vinctus Jordan & Gilbert, 1882	R	I
Gnathanodon speciosus (Forsskål, 1775)	R	LeFA, I
Oligoplites refulgens Gilbert & Starks, 1904	R	LeFA, GrFA
Oligoplites saurus (Bloch & Schneider, 1801)	R	GrFA
Selar crumenophthalmus (Bloch, 1793)	R	LeFA, I
Selene peruviana (Guichenot, 1866)	R	LeFA, GrFA
Sphyraenidae		
Sphyraena ensis Jordan & Gilbert, 1882	R	LeFA
Paralichthyidae		
Syacium ovale (Günther, 1864)	R	I
Fistulariidae		
Fistularia commersonii Rüppell, 1838	F	LeFA, GrFA, I
Labridae		
Bodianus diplotaenia (Gill, 1862)	R	LeFA, GrFA, I
Halichoeres chierchiae Di Caporiacco, 1947	R	LeFA, GrFA, I
Halichoeres dispilus (Günther, 1864)	F	LeFA, GrFA, I
Halichoeres nicholsi (Jordan & Gilbert, 1882)	F	LeFA, GrFA
Halichoeres notospilus (Günther, 1864)	F	LeFA, GrFA, I
Thalassoma grammaticum Gilbert, 1890	F	LeFA, GrFA
Thalassoma lucasanum (Gill, 1862)	D	LeFA, GrFA, I
Scaridae		
Nicholsina denticulata (Evermann & Radcliffe, 1917)	F	LeFA, GrFA, I
Scarus compressus (Osburn & Nichols, 1916)	R	LeFA, I
Scarus ghobban Forsskål, 1775	F	LeFA, GrFA, I
Scarus perrico Jordan & Gilbert, 1882	F	LeFA, GrFA, I
Scarus rubroviolaceus Bleeker, 1847	R	LeFA, I
Gerreidae		
Eucinostomus currani Zahuranec in Yáñez-Arancibia, 1980	R	LeFA, GrFA, I
Eucinostomus dowii (Gill, 1863)	R	GrFA, I
Eucinostomus gracilis (Gill, 1862)	R	GrFA
Gerres cinereus (Walbaum, 1792)	F	LeFA, GrFA, I
Mullidae		
Mulloidichthys dentatus (Gill, 1862)	D	LeFA, GrFA, I
Kyphosidae		
Girella simplicidens Osburn & Nichols, 1916	R	I
Kyphosus azureus (Jenkins & Evermann, 1889)	R	LeFA, I
Kyphosus vaigiensis (Quoy & GAimard, 1825)	D	LeFA, GrFA, I
Kyphosus elegans (Peters, 1869)	D	LeFA, GrFA, I
Serranidae		
Alphestes immaculatus Breder, 1936	R	GrFA, I
Cephalopholis panamensis (Steindachner, 1877)	F	LeFA, GrFA, I
Dermatolepis dermatolepis (Boulenger, 1895)	R	GrFA
Epinephelus analogus Gill, 1863	R	LeFA, I
Epinephelus itajara (Lichtenstein, 1822)	R	LeFA, GrFA
Epinephelus labriformis (Jenyns, 1840)	F	LeFA, GrFA, I
Mycteroperca rosacea (Streets, 1877)	F	LeFA, GrFA, I
Paralabrax maculatofasciatus (Steindachner, 1868)	R	LeFA, GrFA
Paranthias colonus (Valenciennes, 1846)	R	I
Chaetodontidae		
Chaetodon humeralis Günther, 1860	D	LeFA, GrFA, I
Johnrandallia nigrirostris (Gill, 1862)	R	LeFA

Continuation

Chondrichthyes	Dominance	Zone
Pomacanthidae		
Holacanthus passer Valenciennes, 1846	F	LeFA, GrFA, I
Pomacanthus zonipectus (Gill, 1862)	F	LeFA, GrFA, I
Haemulidae		
Anisotremus interruptus (Gill, 1862)	R	LeFA, I
Haemulon flaviguttatum Gill, 1862	O	LeFA, GrFA, I
Haemulon maculicauda (Gill, 1862)	D	LeFA, GrFA, I
Haemulon scudderii Gill, 1862	D	LeFA, GrFA, I
Haemulon sexfasciatum Gill, 1862	D	LeFA, GrFA, I
Haemulon steindachneri (Jordan & Gilbert, 1882)	O	LeFA, GrFA, I
Haemulopsis leuciscus (Günther, 1864)	R	LeFA, GrFA
Microlepidotus inornatus Gill, 1862	O	LeFA, GrFA, I
Lutjanidae		
Hoplopagrus guntherii Gill, 1862	F	LeFA, GrFA, I
Lutjanus argentiventris (Peters, 1869)	F	LeFA, GrFA, I
Lutjanus colorado Jordan & Gilbert, 1882	R	GrFA
Lutjanus guttatus (Steindachner, 1869)	R	LeFA
Lutjanus inermis (Peters, 1869)	R	LeFA
Lutjanus novemfasciatus Gill, 1862	R	LeFA, GrFA, I
Lutjanus viridis (Valenciennes, 1846)	R	LeFA, I
Cirrhitidae		
Cirrhitichthys oxycephalus (Bleeker, 1855)	R	LeFA, GrFA
Cirrhitus rivulatus Valenciennes, 1846	F	LeFA, GrFA, I
Scorpaenidae		
Scorpaena mystes Jordan & Starks in Jordan, 1895	R	I
Zanclidae		
Zanclus cornutus (Linnaeus, 1758)	R	LeFA, I
Acanthuridae		
Prionurus punctatus Gill, 1862	F	LeFA, I
Sparidae		
Calamus brachysomus (Lockington, 1880)	F	LeFA, GrFA, I
Balistidae		
Balistes polylepis Steindachner, 1876	D	LeFA, GrFA, I
Sufflamen verres (Gilbert & Starks, 1904)	R	LeFA
Monacanthidae		
*Monacanthidae.*spp	R	I
Tetraodontidae		
Arothron meleagris (Lacepède, 1798)	F	LeFA, GrFA, I
Canthigaster punctatissima (Günther, 1870)	F	LeFA, GrFA, I
Sphoeroides annulatus (Jenyns, 1842)	R	LeFA, GrFA
Sphoeroides lobatus (Steindachner, 1870)	R	GrFA
Diodontidae		
Chilomycterus reticulatus (Linnaeus, 1758)	R	GrFA
Diodon holocanthus Linnaeus, 1758	F	LeFA, GrFA, I
Diodon hystrix Linnaeus, 1758	R	LeFA, GrFA, I