

Fish communities in high-latitude mangrove in north-western Mexico

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Abstract

Studying fish communities in extreme habitats is important to better understand the variation in their ranges under climatic scenarios or anthropogenic pressure. In particular, the mangroves in Baja California Sur occupy the northernmost distribution range under two extreme conditions (temperate waters and arid weather). In this context, the aim of the presently reported study was to analyze the functional characteristics of ichthyofauna in two localities, La Paz Bay (BP) and Almejas Bay (BA), which are also located in different ecoregions. For both bays, the composition and frequency values were compiled from monthly samples and the literature. Eleven functional traits were assessed from the morphology of every fish species. Functional indices (Richness, Evenness, Divergence, and Originality) were used to evaluate different aspects of the community structure. A total of 83 species were found at both sites, with 54 in BP and 50 in BA. In BP, six species were residents, eight were temporal visitors, and 36 were occasional visitors. In BA, six species were residents, 15 species were temporal visitors, and 33 were occasional visitors. At both sites, 12% of the species were permanent residents; BA had a higher percentage of temporal residents (27%), while BP had a higher percentage of occasional visitors (72%). The functional analysis detected communities with specialized traits, but in comparison to BP, BA had higher evenness in the community structure. Although greater structural complexity was expected in the community during the warm months, because of the increase in richness and attributes, BA had higher values during the cold months, which was probably because the area is a transition zone and the fish communities are adapted to colder climates. In comparison to BA, BP had higher originality values, and colder months presented higher values than warmer months. Although the mangrove sites had the same northernmost latitudinal limits and both had extreme conditions compared to those in mangroves in tropical environments, the fish communities differed in their composition, frequency, and functionality with more extreme functional traits in colder weather than in warmer weather.

Keywords

arid, frequency, functional attributes, functional diversity, temperate

Introduction

Mangrove fish communities are distributed worldwide (30°N–30°S) on sheltered tropical and subtropical coastlines (Ellison 2002). Due to the importance of these communities from economic, ecological, and social perspectives (Costanza et al. 1997), the number of studies

has increased, especially in tropical distribution zones (Faunce and Serafy 2006). However, only a few studies have focused on higher latitudes around circumtropical boundaries (Quisthoudt et al. 2013). An analysis of habitats at latitudinal boundaries (which usually have extreme conditions) requires special attention (Ong et al. 2018), because environmental characteristics influence

the distribution, physiology, and survival of marine populations. In addition, the migration of fishes from the tropics to higher latitudes has started to become more frequent (Tedesco et al. 2017; Ford and Roberts 2018), which indicates that the changes in the community dynamics of the newly invaded habitats need to be understood.

Two kinds of mangrove environments have been defined at higher latitudes according to habitat characteristics: (1) temperate mangroves, which tolerate low water temperatures, with an average of 20°C in the coldest month (water and weather temperature combined; Cavanaugh et al. 2014), and (2) arid mangroves, which are in areas with low rainfall (<300 mm · year⁻¹), no riverine input, and high evaporation rates (Schaeffer-Novelli and Cintron-Molero 1993; Arreola-Lizárraga et al. 2004). Under both conditions, the trees are dwarfed with average heights of less than 3 m (Flores-Verdugo et al. 1993; Millán-Aguilar et al. 2019). In Baja California Sur (BCS), north-western Mexico, there are examples of mangroves that experience a combination of both conditions.

Although mangrove fish communities in BCS live under extreme weather conditions, few studies have been performed in this area. In this context, it is important to use the information available, which includes sampling performed at different time periods, and to implement the appropriate analytical tools to describe the characteristics of the community. In particular, functional ecological analyses have proven to be useful because they use species traits that are linked to ecosystem processes. These analyses focus on the difference between unique species characteristics (e.g., physiological, feeding, locomotion, and reproduction) and explain the functions performed by species in the environment from another perspective (Niche, Costa-Azevedo et al. 2017).

In the presently reported study, the main aim was to explore the arid and temperate mangrove fish communities and describe the functional aspects that may provide insights on broader ecological processes in high-latitude regions. We expected that the functional traits at the selected sites would be more specialized than those reported in tropical mangrove fish communities. However, based on the extreme weather conditions in BCS, the functional composition of the fish communities would likely be affected in a similar way (loss/gain of species) despite the original condition of the mangrove (arid/temperate) during the seasonal changes, as the temperature has been reported to guide local migration of fish to other near environments.

Methods

Study area

Two areas in the Baja California Peninsula, México, were selected: Bahía de La Paz (BP) and Bahía Almejas (BA). Both are strictly marine, without riverine inputs, and present arid and temperate environments (rainfall of 180 mm · yr⁻¹ in BP and approximately 80 mm · yr⁻¹ in BA with an evaporation rate of 1800 mm · yr⁻¹), as-

pects that create close to hypersaline suboptimal conditions. As a consequence, dwarf mangrove forest trees are common, with a maximum height of approximately 3 m (González-Zamorano et al. 2013). In contrast, the sites belong to two separate ecoregions (sensu Spalding et al. 2007), which implies different oceanographic characteristics. BP is the largest protected bay on the eastern coast of the peninsula inside the Cortezian ecoregion (24°07'39"N and 24°21'41"N, and 110°17'23"W and 110°40'23"W), as it includes the Gulf of California. It is characterized by warm climates, upwelling systems, and high levels of primary productivity. BA is located in the southern part of Bahía Magdalena on the western coast of Baja California Sur inside the Magdalena Transition ecoregion (24°17'18"N and 24°20'51"N, and 111°20'30"W and 111°27'47"W), which is a transitional zone for cold and warm waters located below San Ignacio to the southernmost tip of Cabo San Lucas. This ecoregion has moderate productivity with higher peaks in upwelling systems (Spalding et al. 2007; Wilkinson et al. 2010; Fig. 1).

Sampling and database

In BP, monthly trawling occurred at four sites (with a repetition on each, for a total of eight sampling events) from July 2010 to June 2011, and all events occurred at the same hour, with the highest possible reproducibility. The fishing device was an experimental seine net (a length of 50 m, depth of 2 m, and mesh size of 1 cm). The BA data were published by Rodríguez-Romero et al. (2011) from monthly sampling at ten sites (one sampling event per site) from October 1993 to September 1994 using an experimental shrimp seine net (6 m length, 4 m depth, and mesh size of 1 cm at the codend). BP identification

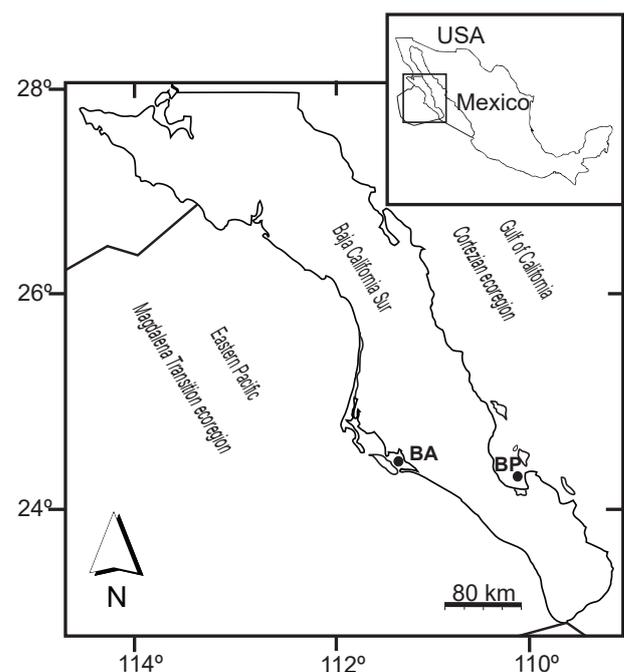


Figure 1. Sample sites location in the Baja California Peninsula. The two ecoregions are also represented in the map.

was carried out to the species level following the criteria of Fischer et al. (1995). All voucher specimens collected in BP were deposited in the Ichthyological Collection at CICIMAR, Instituto Politécnico Nacional, La Paz, BCS, Mexico. The list of species from Rodríguez-Romero et al. (2011) was reviewed using the FishBase *match name* tool (Froese and Pauly 2019). One species reported by Rodríguez-Romero et al. (2011) was detected out of its distribution range for *Sphaeroides angusticeps* (Jenyns, 1842); as a result, it was excluded from the analysis.

Frequency of the species

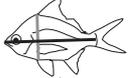
To identify the affinity and permanence time of the species in the environment, the percentage frequency throughout the year for each species was considered. The classification was modified from the proposal of Amezcua-Linares and Yáñez-Arancibia (1980): Resident species (frequency > 75%), Temporal visitors (75% > frequency > 25%), and Occasional visitor (frequency < 25%).

Functional diversity

One adult organism was selected to describe the morphology of the species, the photograph was taken following standard ichthyological guidelines, and the mouth of the organism was pointing to the left side with its fins extended. In the case where organisms were too damaged to follow this procedure, scientific photographs were gathered from available public web repositories such as FishBase (www.fishbase.org), Naturalista (www.naturalista.mx), and scientific fish collections (Ichthyological Collection of CICIMAR). Eleven body lengths were measured from the photographs using ImageJ software ver. 1.51j8 (Wayne Rasband, National Institutes of Health, Bethesda, MD, USA), and using these measures, proportions of the body were calculated describing nine functional traits (Table 1, modified from Toussaint et al. 2016). These functional traits were selected after a rigorous screening process from several potential descriptors (defining feeding and locomotion processes), and the correlation between the variables was considered to identify collinearity (cutoff variation inflation factor > 3; Zuur et al. 2010) as well as the explained variance in a PCA (which is not included here) to determine the traits that had relatively high explanatory power to describe the morpho-functional variation in the species.

Functional indices that could be calculated with the presence/absence of the species were selected, to avoid the introduction of bias in the community structure interpretation due to dominance aspects: Species abundance values could be related to external conditions (biotic and abiotic) present during the different years when the studies were carried out. Because abundance was not considered in the analysis, the interpretation of the functional indices was adjusted; instead of weighing the species by the number of individuals, each species was considered to have 1/S (Species) abundance (Villéger et al. 2008).

Table 1. Formulas and description for calculating functional attributes.

Attribute	Formula	Measures
Body elongation	$\frac{\text{Maximum body height}}{\text{Standard length}}$	
Body form	$\frac{\text{Head length}}{\text{Standard length}}$	
Body height	$\frac{\text{Head height}}{\text{Maximum body height}}$	
Oral gape position	$\frac{\text{Mouth position}}{\text{Head height}}$	
Mouth length	$\frac{\text{Jaw length}}{\text{Head length}}$	
Eye size	$\frac{\text{Eye diameter}}{\text{Head height}}$	
Eye orientation	$\frac{\text{Eye position}}{\text{Head height}}$	
Pectoral fin size	$\frac{\text{Pectoral fin length}}{\text{Standard length}}$	
Pectoral fin position	$\frac{\text{Pectoral fin insertion}}{\text{Maximum body height}}$	
Caudal peduncle throttling	$\frac{\text{Caudal peduncle height}}{\text{Caudal fin height}}$	
Caudal peduncle aspect	$\frac{\text{Caudal peduncle height}}{\text{Caudal peduncle length}}$	

The selected functional indices focused on four facets of functional diversity: functional richness (FRic), which is the functional space occupied by the species in the community represented by the multivariate set of 11 traits and, was calculated using a convex hull volume in an ordination space; functional evenness (FEve), which describes the regularity of the distribution of species in the functional space using a minimum spanning tree to be measured; functional divergence (FDiv), which describes how far highly frequent species are from the center (the median focus point that is at the same distance from each species) of the functional space (Villéger et al. 2008; Laliberté and Legendre 2010); and finally, functional originality (FOri), which describes how species modify redundancy between the species, where the lower the value, the closer species are together, and the larger the value, the more separated species tend to be from one another in the functional space (Mouillot et al. 2013). The indices were calculated with the multidimFD package (Villéger 2017). Due to low sample sizes for some months (extreme cold and warm water temperature), the indices FEve and FDiv could not be calculated in BP in December, January, February, and July.

Results

Fish community

A total of 83 species were recorded in this study: 54 were in Bahía de La Paz and 50 were in Bahía Almejas (Appendix 1–3). In both localities, Haemulidae was the most diverse family, with 10 species at each site, followed by Paralichthyidae and Gerreidae, with seven and five species in BP and seven and eight species in BA, respectively.

For BA, two species (*Orthopristis reddingi* Jordan et Richardson, 1895 and *Prionotus ruscarius* Gilbert et Starks, 1904) were found with a relatively small distribution range (from Bahía Magdalena to the Gulf of California), six species had a cosmopolitan range, whereas 42 species had a Tropical Eastern Pacific (TEP) distribution. For BP, we found one – *Exerpes asper* (Jenkins et Evermann, 1889) – with a restricted distribution range inside the Gulf of California, nine species with a cosmopolitan range and 43 species with a TEP distribution.

For BP, six species were defined as residents – *Diapterus brevirostris* (Sauvage, 1879); *Eucinostomus currani* Zahuranec, 1980; *Eucinostomus dowii* (Gill, 1863); *Eucinostomus entomelas* Zahuranec, 1980; *Mugil curema* Valenciennes, 1836; and *Paralabrax maculatofasciatus* (Steindachner, 1868); eight species as temporal visitors, and 36 as occasional visitors. For BA, six species were recognized as residents – *Achirus mazatlanus* (Steindachner, 1869); *Etropus crossotus* Jordan et Gilbert, 1882; *Paralabrax maculatofasciatus*; *Paralichthys cali-*

formicus (Ayes, 1859); *Spherooides annulatus* (Jenyns, 1842); and *Synodus lucioceps* (Ayes, 1855); 15 species as temporal visitors and 33 as occasional visitors. According to the proportions in each residence category, at both sites, 12% of the species were permanent residents, BA had more temporal residents (27%), and BP had more occasional visitors (72%).

Functional indices

Three similar morphologies were identified in the functional space: flatfish were on the right, tubular/elongated fish were on the left, and the remaining morphologies, mainly perch-like, were around the center (Fig. 2). Higher values of functional richness occurred during the months with more species, which were June, July, September, and October (warm season months), than during the other months, and these months had wider coverage areas in the convex hull (Appendix 4). The FEve did not show a general pattern among the seasons, but Bahía Almejas presented higher values than Bahía de la Paz and the posteriori test showed a significant difference ($t = 4.82$, $P = 0.0005$).

The FDiv plots for BP showed high value results (more than 70 to a total of 100), indicating specialized functional community composition. In comparison to other months, months with higher temperatures had species with extreme morphologies (i.e., *Mugil curema* and *Etropus crossotus*) that occur more frequently, each

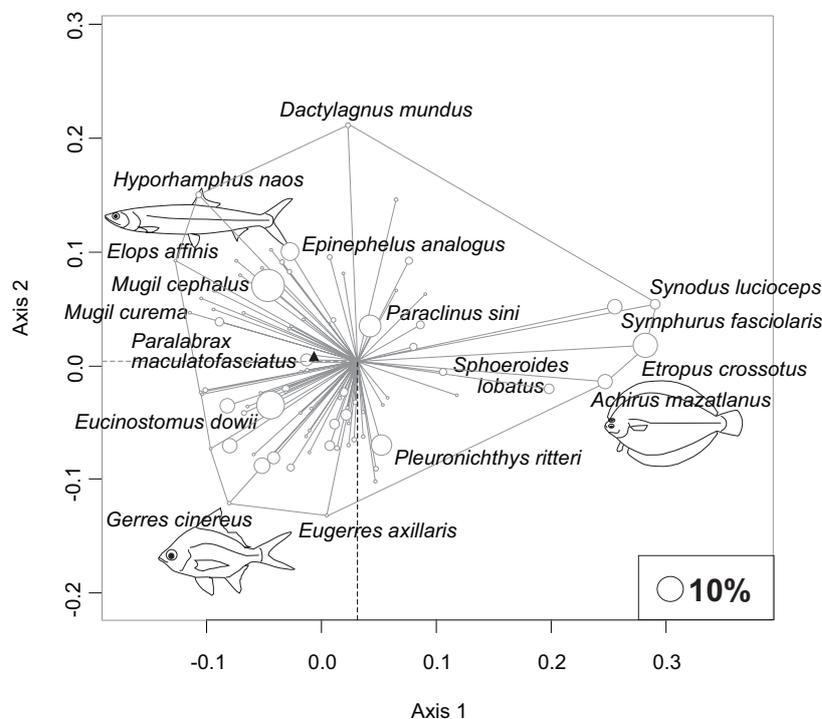


Figure 2. Functional space of the Baja California peninsula. Names describe the species position that is found to be of importance in the community, *Paralabrax maculatofasciatus* (black triangle) represent the point where most common morphological traits converge in the community.

month extending the border of the total functional space. On the other hand, in comparison to BP, BA presented a higher frequency of species presence with extreme morphologies (as indicated by the FEve high values), but the monthly functional space did not cover the whole functional space.

The species that seemed to have the highest frequency throughout the year in terms of functional divergence were those located farthest from the functional center of gravity, such as *Etropus crossotus*, *Mugil curema*, and *Symphurus fasciolaris* Gilbert, 1892, with the exception of *Paralabrax maculatofasciatus*, which was close to the center of gravity and represented a good example of the predominant fish morphotype (perc shaped) around this area. Statistical differences were found between sites ($t = 98.179$, $P < 2.2e-16$) for the months that were available. In comparison to BA, BP presented higher FOr values throughout the year, while BA showed wider variability in high and low values during different months. In general, months with lower temperatures presented higher FOr values, and warmer months presented lower FOr values.

Discussion

As expected from our first hypothesis, fish communities in strictly marine arid mangroves present highly functional specialized traits, as they are present throughout the year in both localities. Some studies in estuaries have identified communities with short functional spatial coverage in temporal analyses (months and seasons, Villeger et al. 2010; Pease et al. 2012), probably due to the physiological constraints required to overcome more dynamic and adverse environments than those of marine arid mangroves (Payán-Alcacio et al. 2020). Because functional analyses must be uniform in the selection of attributes (Violle et al. 2007) and although maximum biodiversity (1/S) was used instead of abundance data (both provides different results, but they reached the same conclusion; Villéger et al. 2008), we carefully examined our comparison.

Functional analyses confirmed the previously proposed regionalization (Spalding et al. 2007). It seemed that individual participation in the structuring and dynamic processing of the community in terms of its biological, morphological, and physiological traits was more related to oceanographic and biogeographic factors at a larger spatial scale than to similar habitat characteristics and the expected functional redundancy at a more local scale (Stuart-Smith et al. 2013; Frainer et al. 2017). According to the richness and frequency, we identified the families Haemulidae, Paralichthyidae, Gerreidae, Mugilidae, Tetraodontidae, and Serranidae as the most representative in the two mangrove localities on the Baja California Peninsula. Our finding agreed with the results of Castellanos-Galindo et al. (2013) in terms of the most important fish families in mangroves in the Eastern Tropical Pacific.

Although both localities had six resident species, only one (*Paralabrax maculatofasciatus*) occurred at both

sites. Based on the permanent resident species, BP seems more centrally structured with benthopelagic fishes (especially members of the Gerreidae family), while BA had a higher number of resident flatfish. Both groups are strong representatives of mangrove fish species in the Pacific (Yáñez-Arancibia et al. 1983; Castellanos-Galindo et al. 2013).

Regarding resident proportion, in comparison to BA, BP had a higher proportion of occasional visitors, and the results suggested a more open and dynamic environment. This scenario could be related to the geomorphology of the site; BP opens into two large channels connected to the Gulf of California, while BA is an enclosed cove with only one opening (Fig. 1).

Another similarity in the structural composition of these high-latitude mangroves with those in other areas of the Americas was the presence of the family Carangidae. Such fish have a preference for warmer temperatures (Sivakami 1996), and we found carangids at both sites from August to November. The temporal use of mangroves by this fish family could be related to the high availability of prey items, such as juveniles (mean total length <10 cm) of *E. dowii* and *M. curema*, as well as some species of Engraulidae and Clupeidae found during the same months at both sites. Although we found a low number of carangid species, as is usually reported for carangids in the mangroves of the Americas (Castellanos-Galindo et al. 2013), the low species diversity in this study could be related to the higher nocturnal feeding activity of the family (Sivakami 1996) and the lack of sampling during that time.

In general, season appeared to be the most important aspect determining the structural and functional characterization of the fish community at both locations. Species richness and organism abundance increased as the temperature increased at both sites, and the opposite effect occurred during the cold months. Similar results were obtained in other studies on the region (González-Acosta et al. 2005; López-Rasgado et al. 2012). The higher species richness during the warm months than during the cold months could be associated with higher temperature values, longer days, maximum litterfall rates, and the presence of nutrients that promote primary production (Félix-Pico et al. 2006; Bizzaro 2008). These characteristics result in food availability for the species inhabiting mangroves (López-Rasgado et al. 2012) and by default increase the range of available functional traits.

For our second hypothesis, the results showed a difference in the functional composition at both sites. Consequently, the results are consistent with the fish biogeography proposal for the Baja California Peninsula that separates BA within the transitional zone (considering the clash the sea currents temperatures, cold and warm from the northern and southern part of the peninsula respectively) and BP within the warmer zone (due to the degree of endemism and isotherms coming from the tropics preventing migration of genetic flow; Briggs and Bowen 2012).

For both localities, the FDiv results indicated specialized community composition. In BP, all extreme-mor-

phology species were present throughout the year, meaning that those specialized species were residents at the site. On the other hand, BA presented changes in the different extreme morphologies according to seasonality (i.e., from benthic flatfish to pelagic species such as *Hyporhamphus naos* Banford et Collette, 2001 to benthopelagic species such as *E. dowii*), indicating strong fragmentation in the community.

Although the community was more specialized, the most common morphological features indicated that the community contained *generalists*, as perch-shaped fish accounted for approximately 50% of the composition. Generalist traits are related to a greater swimming maneuvering capacity (due to the proportion of fins to the body and caudal peduncle; Villéger et al. 2010), allowing them to be efficient at competing for resources under a range of different circumstances (Bridge et al. 2016). In addition, generalists are less sensitive than specialists to alterations in the environment because they occupy a broader niche space (Villéger et al. 2010; da Silva et al. 2018).

The greater functional complexity of the fish community (higher presence of different traits) was related to the months with warm temperatures (August to November), mainly because higher FRic values were positively correlated with species richness (Schleuter et al. 2010). However, if the trade-off between species presence and the number of traits present are considered, greater complexity occurred in BA than in BP, regardless of the different mean temperatures present in the bays (Colder in BA and warmer in BP). This result could reflect a high degree of niche differentiation (Mason et al. 2013) rather than a high number of fish species. As BA is a transition zone between temperate and warm temperatures (Bizarro 2008), the functional traits could be more regularly distributed among species, as shown by the FEve results, and this scenario generates high differentiation of resources

and promotes distinct mechanisms for using the available resources per species (Dolbeth et al. 2016).

Functional originality differed between localities during warmer months (July to November). Although at both sites, an increase in the species occurred, and in comparison to BA, BP presented higher values of FOr due to the occurrence of species with extreme traits (e.g., opportunistic predators). In contrast, the FOr values in BA decreased because more generalist species entered the bay in the warmer months, which lowered community uniqueness, and the resident fishes had the extreme traits. The results suggest that mangrove fish communities in colder waters present a more complex set of traits than those in warmer waters, and this complex set of traits is also found in the functional life strategies of river fish in temperate water (Keck et al. 2014).

Both hypotheses were accepted. The first hypothesis indicated that due to extreme weather conditions (arid and temperate climate) mangrove fish communities at high latitudes present more specialized traits, and the second hypothesis indicated that biogeographic barriers and weather conditions alter the functional composition of the communities despite being found at similar latitudes in the same landmass. Future studies should focus on changes in the functional composition of fish communities in the same ecoregion with different environmental conditions at mangrove sites to validate our findings.

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Appendices

Appendix 1. List of fish species (Actinopterygii) in Baja California Peninsula and their geographic distribution.

Class	Family	Species	Author	Distribution
Pleuronectiformes	Achiridae	<i>Achirus mazatlanus</i>	(Steindachner, 1869)	Eastern Pacific
Perciformes	Scombridae	<i>Auxis thazard</i>	(Lacepède, 1800)	Eastern Pacific
Tetraodontiformes	Balistidae	<i>Balistes polylepis</i>	Steindachner, 1876	Eastern Pacific
Pleuronectiformes	Bothidae	<i>Bothus constellatus</i>	(Jordan, 1889)	Eastern Pacific and Gulf of California
Perciformes	Sparidae	<i>Calamus brachysomus</i>	(Lockington, 1880)	Eastern Pacific
Perciformes	Carangidae	<i>Caranx caninus</i>	Günther, 1867	Eastern Pacific and Gulf of California
Perciformes	Centropomidae	<i>Centropomus medius</i>	Günther, 1864	Eastern Pacific and Gulf of California
Perciformes	Ephippidae	<i>Chaetodipterus zonatus</i>	(Girard, 1858)	Eastern Pacific
Perciformes	Chaetodontidae	<i>Chaetodon humeralis</i>	Günther, 1860	Eastern Pacific
Pleuronectiformes	Paralichthyidae	<i>Citharichthys gilberti</i>	Jenkins et Evermann, 1889	Eastern Pacific
Pleuronectiformes	Paralichthyidae	<i>Citharichthys platophrys</i>	Gilbert, 1891	Eastern Pacific
Perciformes	Gobiidae	<i>Ctenogobius mangicola</i>	(Jordan et Starks, 1985)	Eastern Pacific
Perciformes	Gobiidae	<i>Ctenogobius sagittula</i>	(Günther, 1862)	Eastern Pacific
Pleuronectiformes	Paralichthyidae	<i>Cyclopsetta panamensis</i>	(Steindachner, 1876)	Eastern Pacific
Perciformes	Sciaenidae	<i>Cynoscion parvipinnis</i>	Ayres, 1861	Eastern Pacific
Perciformes	Sciaenidae	<i>Cynoscion stolzmanni</i>	(Steindachner, 1879)	Eastern Pacific
Perciformes	Sciaenidae	<i>Cynoscion xanthulus</i>	Jordan et Gilbert, 1882	Eastern Pacific
Perciformes	Dactyloscopidae	<i>Dactylagnus mundus</i>	Gill, 1863	Eastern Central Pacific
Perciformes	Gerreidae	<i>Diapterus brevirostris</i>	(Sauvage, 1879)	Eastern Pacific
Tetraodontiformes	Diodontidae	<i>Diodon holocanthus</i>	Linnaeus, 1758	Circumtropical distribution
Tetraodontiformes	Diodontidae	<i>Diodon hystrix</i>	Linnaeus, 1758	Circumtropical distribution
Perciformes	Serranidae	<i>Diplectrum pacificum</i>	Meek et Hildebrand, 1925	Eastern Pacific
Elopiformes	Elopidae	<i>Elops affinis</i>	Regan, 1909	Eastern Pacific
Perciformes	Serranidae	<i>Epinephelus analogus</i>	Gill, 1863	Eastern Pacific
Pleuronectiformes	Paralichthyidae	<i>Etropus crossotus</i>	Jordan et Gilbert, 1882	Eastern Pacific
Perciformes	Gerreidae	<i>Eucinostomus currani</i>	Zahuranec, 1980	Eastern Pacific
Perciformes	Gerreidae	<i>Gerres simillimus</i>	Regan, 1907	Eastern Pacific
Perciformes	Gerreidae	<i>Eucinostomus entomelas</i>	Zahuranec, 1980	Eastern Pacific
Perciformes	Gerreidae	<i>Eucinostomus gracilis</i>	(Gill, 1862)	Eastern Pacific
Perciformes	Gerreidae	<i>Eugerres axillaris</i>	(Günther, 1864)	Eastern Central Pacific
Perciformes	Gerreidae	<i>Eugerres lineatus</i>	(Humboldt, 1821)	Eastern Pacific
Perciformes	Labrisomidae	<i>Exerpes asper</i>	(Jenkins et Evermann, 1889)	Eastern Pacific
Syngnathiformes	Fistulariidae	<i>Fistularia commersonii</i>	Rüppell, 1838	Circumtropical distribution
Perciformes	Gerreidae	<i>Gerres cinereus</i>	(Walbaum, 1792)	American distribution
Perciformes	Haemulidae	<i>Haemulopsis elongatus</i>	(Steindachner, 1879)	Eastern Pacific
Perciformes	Haemulidae	<i>Haemulon sexfasciatum</i>	Gill, 1862	Eastern Central Pacific
Perciformes	Haemulidae	<i>Haemulon steindachneri</i>	(Jordan et Gilbert, 1882)	Eastern Pacific
Perciformes	Haemulidae	<i>Haemulopsis leuciscus</i>	(Günther, 1864)	Eastern Pacific

Appendix 1 continues on next page.

Appendix 1. cont.

Class	Family	Species	Author	Distribution
Perciformes	Haemulidae	<i>Haemulopsis nitidus</i>	(Steindachner, 1869)	Eastern Pacific
Clupeiformes	Clupeidae	<i>Harengula thrissina</i>	(Jordan et Gilbert, 1882)	Eastern Pacific
Perciformes	Carangidae	<i>Hemicarax zelotes</i>	Gilbert, 1898	Eastern Central Pacific
Perciformes	Lutjanidae	<i>Hoplopogrus guentherii</i>	Gill, 1862	Eastern Pacific
Beloniformes	Hemiramphidae	<i>Hyporhamphus naos</i>	Banford et Collette, 2001	Eastern Pacific
Perciformes	Blenniidae	<i>Hypsoblennius gentilis</i>	(Girard, 1854)	Eastern Central Pacific
Pleuronectiformes	Pleuronectidae	<i>Hypsopsetta guttulata</i>	(Girard, 1856)	Eastern Pacific
Perciformes	Lutjanidae	<i>Lutjanus aratus</i>	(Günther, 1864)	Eastern Pacific
Perciformes	Lutjanidae	<i>Lutjanus argentiventris</i>	(Peters, 1869)	Eastern Pacific
Perciformes	Lutjanidae	<i>Lutjanus colorado</i>	Jordan et Gilbert, 1882	Eastern Pacific
Perciformes	Lutjanidae	<i>Lutjanus novemfasciatus</i>	Gill, 1862	Eastern Pacific
Perciformes	Sciaenidae	<i>Menticirrhus undulatus</i>	(Girard, 1854)	Eastern Pacific
Perciformes	Haemulidae	<i>Microlepidotus inornatus</i>	Gill, 1862	Eastern Central Pacific
Perciformes	Sciaenidae	<i>Micropogonias ectenes</i>	(Jordan et Gilbert, 1882)	Eastern Central Pacific
Mugiliformes	Mugilidae	<i>Mugil cephalus</i>	Linnaeus, 1758	Circumtropical distribution
Mugiliformes	Mugilidae	<i>Mugil curema</i>	Valenciennes, 1836	American distribution
Siluriformes	Ariidae	<i>Occidentarius platypogon</i>	(Günther, 1864)	Eastern Pacific
Perciformes	Carangidae	<i>Oligoplites altus</i>	(Günther, 1868)	Eastern Pacific
Perciformes	Carangidae	<i>Oligoplites saurus</i>	(Bloch et Schneider, 1801)	American distribution
Clupeiformes	Clupeidae	<i>Opisthonema libertate</i>	(Günther, 1867)	Eastern Pacific
Perciformes	Haemulidae	<i>Orthopristis reddingi</i>	Jordan et Richardson, 1895	Eastern Central Pacific
Perciformes	Labrisomidae	<i>Paraclinus mexicanus</i>	(Gilbert, 1904)	Punta Concepción BCS
Perciformes	Labrisomidae	<i>Paraclinus sini</i>	Hubbs, 1952	Eastern Central Pacific
Perciformes	Serranidae	<i>Paralabrax maculatofasciatus</i>	(Steindachner, 1868)	Eastern Central Pacific
Perciformes	Serranidae	<i>Paralabrax nebulifer</i>	(Girard, 1854)	Eastern Pacific
Pleuronectiformes	Paralichthyidae	<i>Paralichthys californicus</i>	(Ayres, 1859)	Eastern Pacific and Gulf of California
Pleuronectiformes	Paralichthyidae	<i>Paralichthys woolmani</i>	Jordan et Williams, 1897	Eastern Pacific
Pleuronectiformes	Pleuronectidae	<i>Pleuronichthys ritteri</i>	Starks et Morris, 1907	Eastern Pacific
Perciformes	Haemulidae	<i>Pomadasyx branickii</i>	(Steindachner, 1879)	Eastern Pacific
Perciformes	Haemulidae	<i>Pomadasyx panamensis</i>	(Steindachner, 1876)	Eastern Pacific
Scorpaeniformes	Triglidae	<i>Prionotus ruscarius</i>	Gilbert et Starks, 1904	Gulf of California and Magdalena Bay
Perciformes	Mullidae	<i>Pseudupeneus grandisquamis</i>	(Gill, 1863)	Eastern Pacific
Perciformes	Gobiidae	<i>Quietula y-cauda</i>	(Jenkins et Evermann, 1889)	Eastern Pacific and Gulf of California
Perciformes	Haemulidae	<i>Rhonciscus bayanus</i>	(Jordan et Evermann, 1898)	Eastern Pacific
Clupeiformes	Clupeidae	<i>Sardinops sagax</i>	(Jenyns, 1842)	Circumtropical distribution
Perciformes	Scaridae	<i>Scarus perrico</i>	Jordan et Gilbert, 1882	Eastern Pacific
Scorpaeniformes	Scorpaenidae	<i>Scorpaena russula</i>	Jordan et Bollman, 1890	Eastern Pacific
Tetraodontiformes	Tetraodontidae	<i>Sphoeroides annulatus</i>	(Jenyns, 1842)	Eastern Pacific
Tetraodontiformes	Tetraodontidae	<i>Sphoeroides lobatus</i>	(Steindachner, 1870)	Eastern Pacific
Pleuronectiformes	Paralichthyidae	<i>Syacium ovale</i>	(Günther, 1864)	Eastern Pacific
Pleuronectiformes	Cynoglossidae	<i>Symphurus atramentatus</i>	Jordan et Bollman, 1890	Gulf of California and Magdalena Bay
Pleuronectiformes	Cynoglossidae	<i>Symphurus fasciolaris</i>	Gilbert, 1892	Gulf of California and Magdalena Bay
Aulopiformes	Synodontidae	<i>Synodus lucioceps</i>	(Ayres, 1855)	Eastern Pacific
Perciformes	Haemulidae	<i>Haemulon californiensis</i>	(Steindachner, 1876)	Eastern Pacific

Appendix 2. Presence of the species in Bahía Almejas.

Species	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
<i>A. mazatlanus</i>	1	1	1	1	1	1	1	1	1	1	1	1
<i>B. polylepis</i>	1	1	1	1	0	0	1	0	0	1	1	1
<i>B. constellatus</i>	0	1	1	1	0	1	0	0	1	1	1	0
<i>B. californiensis</i>	0	0	0	0	0	0	0	0	0	1	0	0
<i>C. brachysomus</i>	1	1	0	0	0	0	0	0	0	1	1	1
<i>C. caninus</i>	1	0	0	0	0	0	0	0	0	0	0	1
<i>C. medius</i>	0	0	0	0	0	0	0	0	0	0	1	0
<i>C. zonatus</i>	1	0	0	1	0	0	0	0	0	0	1	0
<i>C. humeralis</i>	0	0	0	0	0	0	0	0	0	0	1	0
<i>C. panamensis</i>	1	0	0	1	1	0	0	0	0	0	1	1
<i>C. parvipinnis</i>	0	0	0	0	0	0	0	0	0	0	1	1
<i>D. mundus</i>	0	0	0	0	0	0	0	1	0	1	1	0
<i>D. brevirostris</i>	1	1	0	0	0	1	0	0	0	1	1	1
<i>D. holocanthus</i>	0	0	0	1	0	0	1	0	0	0	1	0
<i>D. hystrix</i>	1	0	0	1	0	0	0	0	1	0	0	0
<i>D. pacificum</i>	1	0	0	0	0	0	0	0	0	0	1	0
<i>E. analogus</i>	0	0	1	0	0	0	0	0	0	0	1	1
<i>E. crossotus</i>	1	1	1	1	1	1	1	1	1	1	1	1
<i>E. dowii</i>	0	1	1	1	1	1	1	0	0	1	1	1

Appendix 2 continues on next page.

Appendix 2. cont.

Species	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
<i>E. gracilis</i>	1	1	0	0	0	0	0	1	1	1	1	1
<i>E. axillaris</i>	0	0	0	0	0	0	0	0	0	0	1	0
<i>F. commersonii</i>	0	0	0	0	0	0	0	1	0	0	0	0
<i>G. cinereus</i>	0	0	0	0	0	0	0	0	0	0	1	0
<i>H. steindachneri</i>	0	0	0	0	0	0	1	0	1	1	0	0
<i>H. leuciscus</i>	1	0	0	0	1	1	1	0	0	1	0	1
<i>H. nitidus</i>	0	0	0	0	0	0	0	0	0	1	0	0
<i>H. guentherii</i>	0	0	0	0	0	0	0	1	0	1	0	1
<i>H. gentilis</i>	0	0	0	0	0	0	1	1	1	0	1	0
<i>H. guttulata</i>	0	1	0	0	0	0	0	0	0	0	0	0
<i>L. aratus</i>	0	0	0	0	0	1	0	0	1	1	0	0
<i>L. argentiventris</i>	1	1	0	0	0	1	0	1	0	1	1	1
<i>L. colorado</i>	0	0	0	0	0	0	0	0	0	0	1	0
<i>L. novemfasciatus</i>	0	0	0	0	0	0	0	0	0	0	1	0
<i>M. undulatus</i>	0	0	0	0	0	0	0	0	1	0	0	0
<i>M. inornatus</i>	0	0	0	0	0	0	0	0	0	1	0	0
<i>M. ectenes</i>	0	0	0	1	0	0	1	0	0	0	0	0
<i>O. reddingi</i>	1	1	0	1	0	0	0	0	0	1	1	1
<i>O. platypogon</i>	0	0	0	0	0	0	1	0	0	0	0	0
<i>P. maculatofasciatus</i>	1	1	1	1	1	1	1	1	1	1	1	1
<i>P. nebulifer</i>	0	1	0	0	0	0	0	0	0	0	0	0
<i>P. californicus</i>	1	1	1	1	1	1	1	1	1	0	1	1
<i>P. woolmani</i>	0	0	1	0	0	0	0	1	1	0	1	0
<i>P. ritteri</i>	0	0	0	1	0	1	0	0	0	0	0	0
<i>P. panamensis</i>	1	0	0	0	0	0	0	0	0	1	0	0
<i>P. ruscarius</i>	0	1	0	1	1	1	1	0	0	0	1	1
<i>P. grandisquamis</i>	1	1	0	1	1	0	1	0	0	0	0	1
<i>R. bayanus</i>	0	1	0	0	0	0	0	0	0	1	1	0
<i>S. perrico</i>	0	0	0	0	0	0	1	0	0	0	0	0
<i>S. russula</i>	1	0	0	0	1	0	0	0	0	1	0	0
<i>S. annulatus</i>	1	1	1	1	1	1	1	1	1	1	1	1
<i>S. ovale</i>	0	1	0	1	0	0	0	0	0	0	1	0
<i>S. atramentatus</i>	0	0	1	1	1	1	1	1	1	0	1	0
<i>S. fasciolaris</i>	0	0	0	0	0	0	1	0	0	0	0	0
<i>S. lucioceps</i>	1	1	1	1	1	1	1	1	0	1	0	1

Appendix 3. Presence of the species in Bahía de La Paz.

Species	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
<i>A. mazatlanus</i>	0	0	1	0	0	0	0	1	0	0	1	0
<i>A. thazard</i>	0	0	0	0	0	0	1	0	0	0	0	0
<i>C. zonatus</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>C. gilberti</i>	0	0	0	1	0	0	0	0	0	0	0	0
<i>C. platophrys</i>	0	0	0	0	0	0	0	0	0	0	1	1
<i>C. mangicola</i>	0	0	0	0	0	0	0	0	1	0	0	0
<i>C. sagittula</i>	0	0	1	1	1	1	0	0	0	1	1	1
<i>C. stolzmanni</i>	0	0	0	0	0	0	0	0	0	1	0	0
<i>C. xanthulus</i>	0	0	0	0	0	0	0	0	0	0	1	1
<i>D. brevirostris</i>	1	1	0	1	1	1	1	1	1	1	1	1
<i>D. hystrix</i>	1	0	0	1	1	0	1	0	1	1	1	0
<i>E. affinis</i>	0	0	1	0	0	0	0	0	0	0	0	0
<i>E. crossotus</i>	0	0	0	0	1	1	0	0	1	1	1	1
<i>E. currani</i>	1	1	1	1	1	1	1	1	1	1	1	1
<i>E. dowii</i>	1	1	1	1	1	1	1	1	1	1	1	1
<i>E. entomelas</i>	1	1	1	1	1	1	1	1	1	1	1	1
<i>E. gracilis</i>	0	0	0	0	1	0	1	1	0	0	0	1
<i>E. lineatus</i>	0	0	0	0	0	0	1	0	0	1	0	0
<i>E. asper</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>F. commersonii</i>	0	0	0	0	0	1	0	1	0	0	0	0
<i>G. cinereus</i>	0	0	0	0	0	0	0	0	0	1	0	1
<i>H. sexfasciatum</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>H. steindachneri</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>H. elongatus</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>H. leuciscus</i>	0	0	0	0	0	0	1	0	1	0	0	0
<i>H. thrissina</i>	0	0	0	0	0	0	1	0	0	0	0	0
<i>H. zelotes</i>	0	0	0	0	0	0	0	0	0	1	0	0
<i>H. guentherii</i>	0	0	0	0	1	0	0	0	0	0	1	0
<i>H. naos</i>	0	0	1	0	0	1	1	1	1	1	1	1
<i>H. gentilis</i>	0	0	0	0	1	0	0	0	0	0	0	0

Appendix 3 continues on next page.

Appendix 3. cont.

Species	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
<i>L. aratus</i>	0	0	0	0	0	0	1	0	0	0	0	0
<i>L. argentiventris</i>	0	0	0	0	1	0	1	1	1	1	1	1
<i>L. colorado</i>	0	0	0	0	0	0	0	0	1	0	1	0
<i>L. novemfasciatus</i>	0	0	0	0	1	0	0	0	0	1	0	1
<i>M. cephalus</i>	0	0	0	0	0	0	0	0	1	0	0	0
<i>M. curema</i>	1	1	1	1	1	1	1	1	1	1	1	1
<i>O. altus</i>	0	0	0	0	0	0	0	0	0	1	0	1
<i>O. saurus</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>O. libertate</i>	0	0	0	0	0	0	1	0	0	0	0	0
<i>O. reddingi</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>P. mexicanus</i>	0	0	0	0	1	1	0	0	0	0	0	0
<i>P. sini</i>	0	0	0	0	0	0	0	0	0	0	1	0
<i>P. maculatofasciatus</i>	1	1	1	1	1	1	1	0	1	1	1	1
<i>P. branickii</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>P. macracanthus</i>	0	0	0	0	0	1	0	0	0	1	0	0
<i>R. bayanus</i>	0	0	0	1	0	1	1	0	0	1	1	0
<i>Q. ycauda</i>	0	0	0	1	1	1	0	0	0	0	0	0
<i>S. sagax</i>	0	0	0	0	0	0	0	0	0	1	0	0
<i>S. annulatus</i>	1	0	1	1	1	1	0	0	0	1	0	1
<i>S. lobatus</i>	0	0	0	0	0	0	0	0	0	0	0	1

Appendix 4. Values of the different functional indexes in the Baja California Peninsula and between the two bays (Bahía de la Paz and Bahía Almejas); bold numbers represent higher values and different trends between sites.

	Peninsula				Magdalena Transition				Cortezian			
	FRic	FDiv	FEve	FOri	FRic	FDiv	FEve	FOri	FRic	FDiv	FEve	FOri
Jan	0.0011	0.7755	0.7345	0.0982	0.0007	0.7455	0.8203	0.0990	0.0088	—	—	0.1416
Feb	0.0007	0.7082	0.5709	0.1030	0.00001	0.7945	0.8872	0.1231	0.0140	—	—	0.1807
Mar	0.0087	0.8789	0.6951	0.1082	0.0040	0.7856	0.8844	0.1159	0.0059	0.000001	0.7660	0.1574
Apr	0.0019	0.7989	0.5890	0.1055	0.00004	0.7533	0.8488	0.1116	0.0078	0.0004	0.7559	0.1617
May	0.0038	0.7776	0.7178	0.1044	0.00004	0.7440	0.8121	0.1068	0.0014	0.0001	0.7402	0.1813
Jun	0.0207	0.8030	0.6197	0.1104	0.0027	0.7662	0.8567	0.1091	0.0025	0.0001	0.7477	0.1497
Jul	0.0059	0.7804	0.7153	0.1095	0.0006	0.7463	0.8014	0.1231	0.0124	—	—	0.1928
Aug	0.0033	0.8320	0.6905	0.1072	0.00003	0.7756	0.8241	0.1113	0.0022	0.00001	0.7393	0.1674
Sep	0.0321	0.7787	0.5059	0.1063	0.0006	0.6992	0.7485	0.0848	0.0042	0.0024	0.7573	0.1630
Oct	0.1136	0.7653	0.4876	0.1007	0.0573	0.7733	0.8580	0.1086	0.0034	0.0004	0.7330	0.1709
Nov	0.0096	0.7926	0.6739	0.0964	0.0007	0.7358	0.8150	0.0908	0.0005	0.0054	0.7512	0.1530
Dec	0.0022	0.8026	0.6347	0.0963	0.0003	0.7423	0.8154	0.0873	0.0130	—	—	0.1487