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research paper

Classification and comparison of five estuaries in the southeast Gulf of California based on environmental variables and fish assemblages

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ABSTRACT.—Estuarine systems in subtropical and tropical areas of the Mexican Pacific are characterized by specific hydrological, biological, and anthropogenic conditions. Using multivariate analyses of geomorphic, biological, and anthropogenic variables, five of the largest estuarine systems of the southeastern Gulf of California were classified into estuary type using a similar classification method to that employed in New South Wales, Australia. Three estuary types were identified: tide-dominated, wave-dominated, and intermittently-closed. The characteristics of each estuary type were related to the fish assemblages from every system, using catch per unit effort to make results comparable among all estuaries. Our results demonstrated that intrinsic estuarine characteristics, such as geomorphologic, biological, physicochemical, anthropogenic, and biogeographical attributes, are likely to have a strong influence on the diversity and structure of fish assemblages, but more information is needed on the ecology and biology of the fish fauna to understand how these variables affect the different fish species.

Estuarine areas in tropical and subtropical regions are highly productive ecosystems that provide nursery, feeding, and spawning areas for many fish species, which supports small-scale fisheries (i.e., Barletta-Bergan et al. 2002, Barletta et al. 2003). The high productivity of an estuary is linked to its hydrologic attributes, depositional environments, and flora (Roy et al. 2001), which influence faunal species richness and diversity, and ultimately commercial fisheries production. For example, it has been demonstrated that in intermittent estuaries, opportunities for recruitment decrease due to the appearance of a physical barrier impeding the movement of fauna between the sea and the estuarine system (Pease 1999). Also, fluctuations in salinity can occur, which are detrimental to survival of many species. Therefore, the productivity of fisheries is directly linked to the hydrology and salinity of these systems (Saintilan 2004).

In the southeastern (SE) Gulf of California, estuarine systems are exploited by small-scale fisheries targeting more than 90 species of fishes, shrimps, sharks, rays, and swimming crabs (Ramírez-Rodríguez et al. 2014). Catches also include a large number of nontargeted species that inhabit these zones during either part or throughout their life cycle (Amezcua et al. 2006, 2009). There are reports of apparent overexploitation by the local fisheries (SAGARPA and FAO 2014) related to the rapid growth of recreational and small-scale fisheries. This can cause widespread degradation of the coastal and marine ecosystems and marine food webs (Sala et al. 2004).

Ramírez-Rodríguez et al. (2014), in their examination of small-scale fisheries of the SE Gulf of California, identified six fishing zones based on spatial and seasonal changes in the fishing operations. However, the possible relationships among the zones and the fish assemblages in individual lagoons have not yet been defined. From previous studies, it is known that the geomorphology and hydrology of estuaries have an influence on the biota (Saintilan 2004). Roy et al. (2001) demonstrated that ecological indicators, such as the diversity and richness of faunal species, in addition to commercial fishery production, are directly influenced by the estuary's physical and chemical characteristics, which are influenced by geological setting, inlets, and evolutionary history. Other studies have demonstrated that environmental factors, such as salinity, turbidity, water temperature, and dissolved oxygen, which are also influenced by the estuary's characteristics, influence fish species composition, and thus the quality of fisheries' landings in terms of biomass, density, and number of species (Barletta et al. 2005, 2008, 2016).

A suite of environmental, biological, geological, physical, and other characteristics have been measured in the estuarine systems of the SE Gulf of California (Flores-Verdugo et al. 1993, Páez Osuna et al. 2007, Amezcua 2014, SEMARNAT and CONAFOR 2015). Through the use of multivariate statistical techniques, the aims of the present study were to: (1) classify the estuarine systems in the region into different estuary types based on measurable geomorphology, hydrology, and other environmental characteristics, similar to the classification method proposed by Roy et al. (2001); (2) determine if the type of estuary has an influence on fish assemblages; and (3) identify which variables are most important for fish species composition within each system. The working hypothesis was that the fish assemblages differ according to the type of estuarine system, but there are specific characteristics of each system that influence the fish assemblages as well.

Materials and Methods

Area of Study.—The present study was conducted along the coast of Sinaloa in the SE Gulf of California. Five of the most important estuarine systems with respect to landed weight and economic value of the catch were sampled: Navachiste, Santa María La Reforma, Urias, Huizache-Caimanero, and Teacapán (Fig. 1). The marine fauna in this area is generally tropical, representative of the Mexican province, but with direct influence of the Californian Current, which brings fish species from the Cortez province (Ramírez-Rodríguez et al. 2014). This region is called the Sinaloan Gap and is a transition zone between the tropical Mexican province and the warm Cortez province (Hastings 2000). Navachiste and Santa Maria La Reforma systems are located north of the Tropic of Cancer. The rest of the systems are located to the south of this latitude (Fig. 1, Table 1).

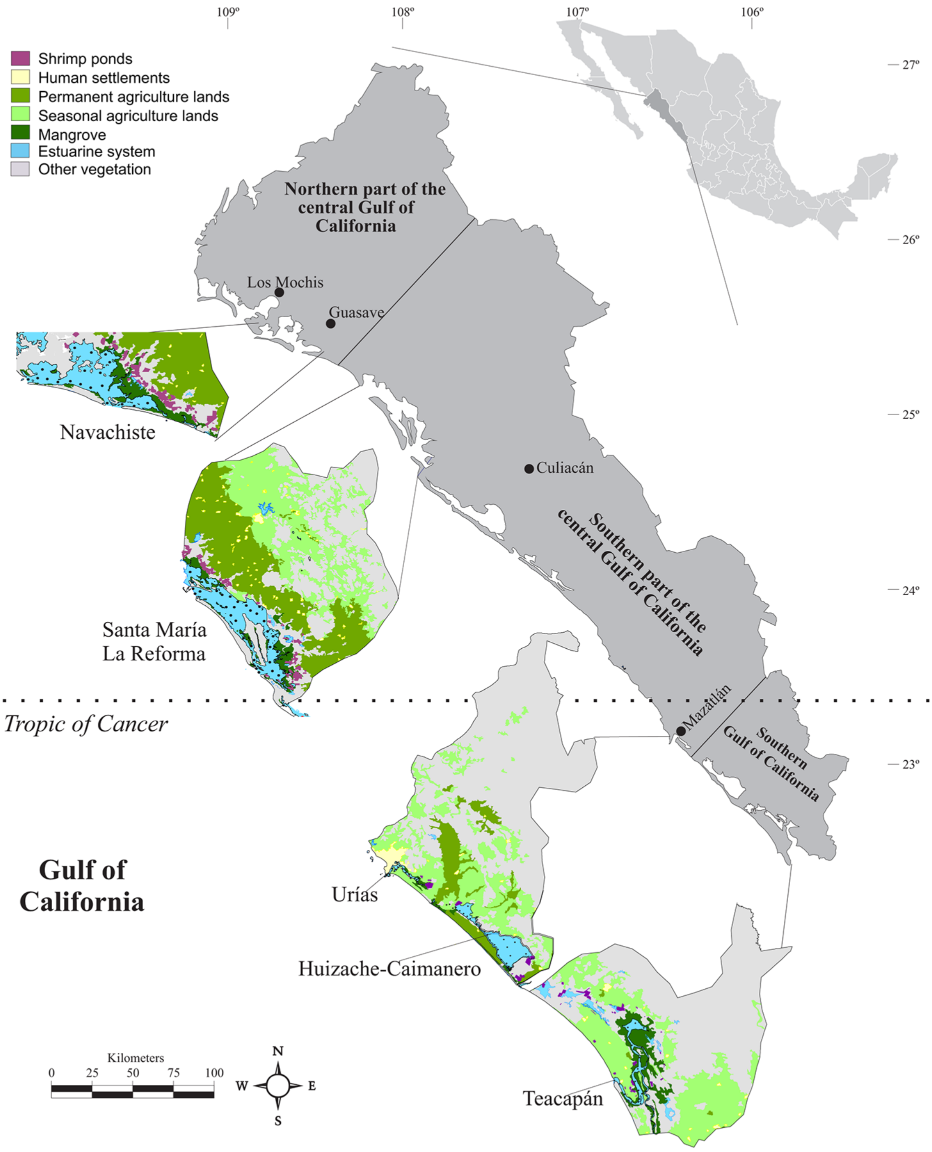

Figure 1. Studied systems in the southeast Gulf of California. Black dots within each system indicate sampling stations.

Sampling Procedures.—Sampling was performed in every estuarine system during the morning hours and at high tide every 4 mo from July 2009 to August 2011. Samples were grouped into three seasons based on the average water temperature, which was measured on site, and on rainfall information from the National Institute of Geography and Statistics of Mexico (http://www.inegi.org.mx/). The three seasons included: dry cool season (DCS, from December 1 to March 31), dry warm season (DWS, from April 1 to June 30), and humid warm season (HWS, from July 1 to November 30). Samples were taken using a 300 m long gill net with 88.9 mm (3.5 in) mesh and a 75 mm liner. This gear was the same as that used by the local

Table 1. Characteristics and classification of all the estuarine systems analyzed in this study. Estuary classification and type according to Roy et al. (2001).

Characteristic	Navachiste	Santa María la Reforma	Urias	Huizache-Caimanero	Teacapán
Latitude	25°45′N–25°17′N	25°17′N–24°41′N	23°55′N–23°07′N	23°07′ N–22°49′ N	22°49′N–22°32′N
Longitude	109°25′W–108°30′W	108°30′W– 108°01′W	106°58′W– 106°19′W	106°19′ W– 106°00′ W	106°00′W– 105°45′W
Ecoregion	Central Gulf of California-North	Central Gulf of California-South	Central Gulf of California-South	Southern Gulf of California	Southern Gulf of California
Classification	Wave-dominated estuary with barrier	Wave-dominated estuary with barrier	Tide-dominated estuary	Intermittent estuary	Tide-dominated estuary
Type	III5	III5	II	IV	II
Climate	Dry and arid	Dry and Arid	Semiarid	Semiarid	Subhumid

fishers to catch finfish. Sampling operations lasted 30 min onboard 7.5-m skiffs fitted with 75–90 hp outboard engines. In the Navachiste estuarine complex, 19 stations were sampled, 29 stations in Santa Maria la Reforma, 15 at Urias, 27 at Huizache-Caimanero, and 17 at Teacapan (Fig. 1).

The gill net was set and left adrift, and the initial and final positions were recorded with a GPS. Fish catches were placed in separately-labeled plastic bags and transported in an icebox to the laboratory. Fish were counted and identified to species according to Fischer et al. (1995).

Estuary Classification According to Environmental Data.—For each system, in situ environmental data were recorded at each sampling station [water temperature (°C), salinity, and depth (m)], and a mean value was obtained for every system per climatic season. Additionally, the following environmental data were obtained from previous studies for each system (Flores-Verdugo et al. 1993): mean annual precipitation (mm), mean annual evaporation (mm), and mean mangrove height (m).

Information on the geomorphic [area (m^2) of tidal sandbanks, intertidal flats, barrier sands], geometric [watershed area (m^2), estuary perimeter (m), estuary length, estuary greatest width, and inlet(s) width], vegetation (mangrove cover in m^2), and anthropogenic (area of shrimp ponds and area of agricultural lands in m^2) variables for each estuary were also made available through previous studies (Flores-Verdugo et al. 1993, Páez Osuna et al. 2007, Amezcua 2014, SEMARNAT and CONAFOR 2015). The values of each environmental variable were used to perform multivariate analyses and determine if the analyzed estuaries followed the classification of Roy et al. (2001). However, to adequately discern the effects of estuary type on fish assemblages, and while minimizing estuary size effects, the values used for the analyses were mean environmental values [annual precipitation (mm), annual evaporation (mm), water temperature (°C), salinity, depth (m), and mangrove height (m)], and relative measures in relation to the area of the human settlements (human population density, people m^{-2}), or in relation to the geometric variables of each estuarine system (relative inlet length, relative barrier sand cover, relative area of tidal sandbanks, relative area of intertidal flats, mangrove density, relative area of agricultural lands, relative shrimp pond area).

A matrix was constructed using the estuarine systems during different climatic seasons as columns and each environmental parameter constituted the rows. The data were normalized using PRIMER, given that the environmental data involves multiple variables measured with different scales (mean concentrations, mean lengths, relative values, etc.). The normalization routine transforms every variable, such that they each have a mean of 0 and a standard deviation of 1. Pearson's correlation coefficients were used to determine if a statistically significant correlation existed between the geomorphic, geometric, anthropogenic, and vegetation variables. When a significant correlation was found, data were square-root or fourth-root transformed, and the previous analysis was rerun until the correlation was not significant. We used Excel's regression tool to calculate the Pearson's correlation coefficients and their respective P-values. Subsequently, a similarity matrix of the standardized and transformed environmental data was constructed using Euclidian distance. To determine if the estuarine system and the climatic season, as well as the estuary type and the climatic season, were consistent or whether they influence the environmental variables, two permutational multivariate analyses of variance (PERMANOVAs) were made, one comparing the climatic season and estuarine system, and another comparing the climatic season and estuary type according to the classification proposed by Roy et al. (2001). Factors were assigned to each station: climatic season and estuarine system, and climatic season and estuary type.

A PERMANOVA (Anderson et al. 2008) was undertaken to test the H_0 that the estuarine systems and system types are not different based on the factors utilized, climatic seasons, or the interaction season/estuary and season/type. If a P-value was <0.05, then the H_0 was rejected. Pairwise-tests were performed to determine which estuarine systems differed from each other according to the analyzed factors. Due to the increased risk of inflated type I error, we applied a Bonferroni procedure by dividing α (0.05) by the number of comparisons being made.

Principal coordinates analysis (PCO) was performed to visualize how the different estuarine systems were grouped where the PERMANOVA revealed statistically different results, and also to determine which characteristics of the systems best explained group separation. This ordination method produces a two-dimensional scatter plot, and the characteristics of each system can be overlaid as a vector. The trajectory of the vector can be interpreted to indicate the importance of certain characteristics in the different systems. Both axes have a scale from $-n$ to n, in which the point 0,0 is the centroid—the location where all the points would be located if the null hypothesis was true (Anderson 2017).

Analysis of Fish Communities.—Mean catch per unit effort (CPUE, y) was computed for every station and was used for all analyses. This index was obtained according to the method proposed by Viana et al. (2010) by estimating the number of individuals captured in every haul (n) according to the equation: $y = 100\, n(AT_i)^{-1}$, where A is area and T_i is the time the gill net was left adrift. After the catch of every fishing operation was standardized using the CPUE, a two-way analysis of variance (ANOVA) was performed to determine if there was significant variation in CPUE across seasons, systems, and the interaction between season and system. Homoscedasticity of variance was tested using Cochran's C test, and a Tukey honestly significant difference (HSD) test was used to perform pairwise comparisons if significant differences were found.

Fish species diversity was estimated for every estuarine system and for every type of system at the different climatic seasons using the Shannon index of diversity (H'). The form of the index is: $H' = -\Sigma p_i \ln p_i$, where p_i is the proportion of individuals found in the i^{th} species (Magurran 2004). To determine statistical differences in diversity between estuarine systems or types of estuaries in the different climatic seasons, a two-way ANOVA was performed since this index follows a normal distribution (Magurran 2004). Homoscedasticity of variance was tested with Cochran's C test, and a Tukey HSD test was performed if statistical differences were found for subsequent pairwise comparisons. To determine if a statistically significant correlation existed between the watershed and the diversity, we performed a regression analysis.

A randomized cumulative species curve was constructed for every estuarine system sampled to determine if sample sizes were sufficient to describe the total number of species from our modeled samples (Flather 1996). The order in which samples were analyzed was randomized 1000 times for each new cumulative species sample using Chao's estimator of the absolute number of species in an assemblage. It is based upon the number of rare classes found in a sample (Chao 1984), and the notation is:

$$S_{est} = S_{obs} + \left(\frac{f_1^2}{2f_2} \right),$$

where S_{est} is the estimated number of species, S_{obs} is the observed number of species in the sample, f_1 is the number of singleton taxa (taxa represented by a single occurrence in the assemblage), and f_2 is the number of doubleton taxa (two or more occurrences in the assemblage). Further details of this method can be found in Magurran (2004).

Multivariate analyses were used to compare the fish assemblages between the different estuarine systems and types of system across all climatic seasons defined. A matrix containing the estuarine system per climatic season as columns and fish species as rows was created and from this a Bray-Curtis similarity matrix was generated. The same factors assigned to the environmental data were assigned to this matrix (climatic season, estuary type, and system). We used a PERMANOVA to test the H_0 that the fish assemblages did not differ according to these factors. Pairwise-tests were performed to determine which assemblages, types, or seasons differed from the others, and a Bonferroni procedure was applied to correct for multiple comparisons. If significant results were found, the data were graphically represented using a stepwise distance-based linear model permutation test (DistLM) (McArdle and Anderson 2001). This analysis identifies the environmental variables that predict the multivariate variation of the fish assemblages in the different estuarine systems in multivariate space. A similarity of percentages (SIMPER) analysis was used to determine which species accounted for most of the dissimilarities among the compositions in the different systems when significant differences were found (Collins and Williams 1982, Clarke and Warwick 1994), and thereby identified characteristic species for each system. The diversity index and all multivariate statistical analyses were completed using the PRIMER 6 statistical package with the PERMANOVA+ add-on (PRIMER-e, Plymouth Marine Laboratory, UK). All parametric statistical analyses were performed in STATISTICA 13 (TIBCO Software, Inc.) or Microsoft Excel.

Results

Environmental Data.—There were marked seasonal differences in both temperature and rainfall in the area of study, which were in accordance with the seasons established a pirori (DCS, DWS, RWS). The rainfall occurs from approximately mid-June to mid-November, with the remaining months almost completely dry. The water temperature also peaks between July and August, with temperatures close to those maxima in June, September, and October. There is a clear drop in the temperature in December, and then in late March it starts to increase again (Fig. 2).

After normalized—environmental data were fourth-root transformed—environmental variables were not significantly correlated (Online Appendix 1). PERMANOVA of environmental variables revealed no statistically significant interactions (season × estuarine system: pseudo-$F_{8,15}$ = 0.24, P = 0.99; season × estuary type: pseudo-$F_{4,21}$ = 0.41, P = 0.91). However, significant discrimination among estuarine systems and estuary types were evident (estuarine system: pseudo-$F_{4,15}$ = 3.62, P

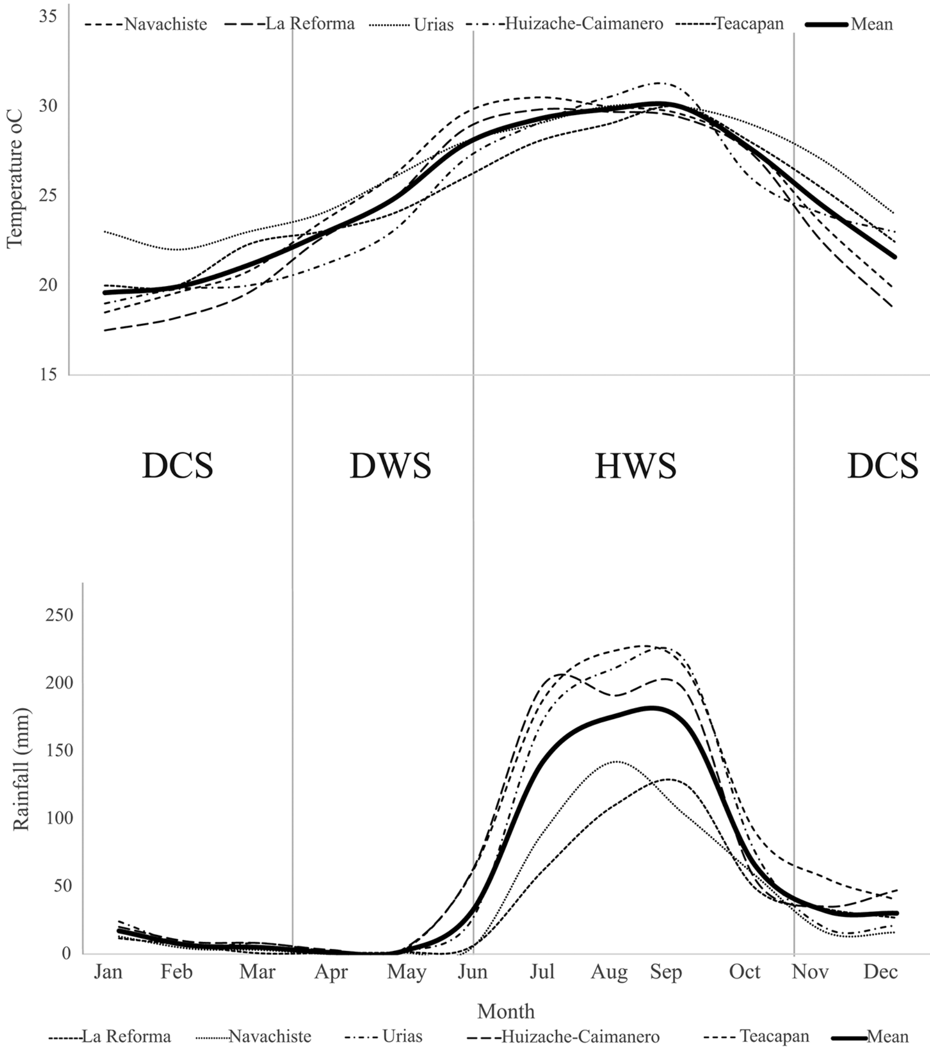

Figure 2. Seasonal fluctuation in mean water temperature and rainfall in the studied systems.

= 0.001; estuary type: pseudo-$F_{2,21}$ = 5.35, P = 0.001). Estuarine systems of the same type were statistically equivalent (Table 2). Differences were found according to climatic season (season $_{\text{when comparing estuarine systems}}$: pseudo-$F_{2,15}$ = 18.16, P = 0.001; season $_{\text{when comparing estuary types}}$: pseudo-$F_{2,21}$ = 4.28, P = 0.004), but these were related to the system or type of estuary, as no seasonal differences were found within the same estuarine systems or estuary types.

Relationships within and among estuaries can be visualized in the PCO plot (Fig. 3) with the overlaid vectors. Santa María La Reforma and Navachiste grouped closely together. Both systems were identified as Type III 5 (wave dominated estuaries with barrier). These estuarine systems are characterized by high values of mean evaporation, mean salinity; barrier and tidal sand areas, inlet width; and shrimp ponds and agricultural lands.

Table 2. Permutational multivariate analysis of variance results testing for differences according to estuary and estuary type. (A) Pairwise comparisons between estuarine systems, and (B) type of system. II = tide dominated estuaries, III5 = wave-dominated estuaries with barrier, IV = intermittent estuaries. * Significant result (after Bonferroni correction).

Comparison	*t*	*P*-value
(A) Estuarine system		
Navachiste, Santa María la Reforma	1.240	0.228
Navachiste, Urias	2.072	0.027*
Navachiste, Huizache-Caimanero	1.987	0.009*
Navachiste, Teacapan	2.246	0.007*
Reforma, Urias	1.769	0.026*
Reforma, Huizache-Caimanero	1.944	0.006*
Reforma, Teacapan	2.055	0.012*
Urias, Huizache-Caimanero	20.386	0.049*
Urias, Teacapan	1.782	0.095
Huizache-Caimanero, Teacapan	2.443	0.003*
(B) Estuary type		
III, II	2.145	0.010*
III, IV	2.443	0.008*
II, IV	2.373	0.002*

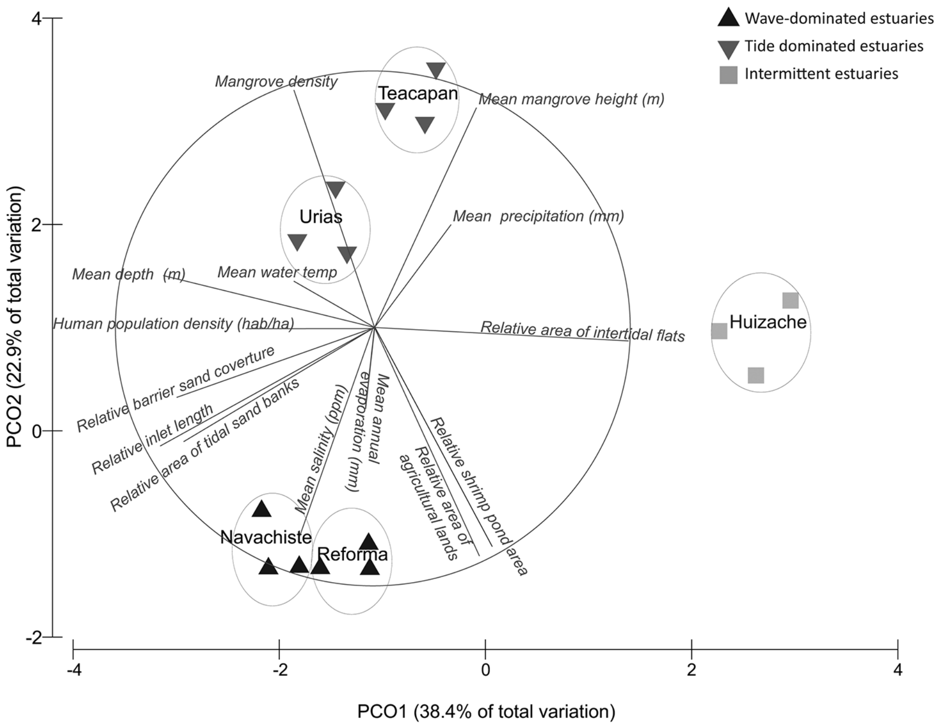

Figure 3. Principal coordinate analysis (PCO) of the geomorphologic, anthropogenic, environmental and biological features of each system.

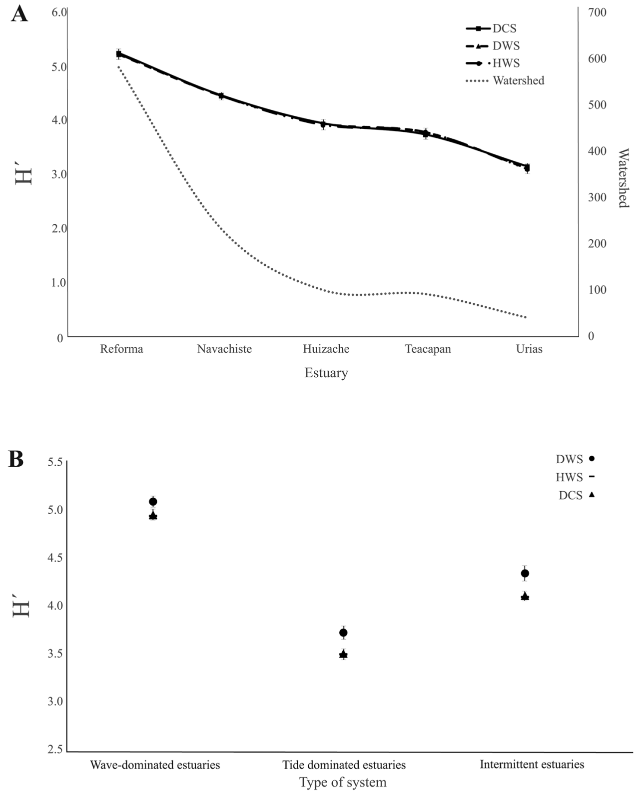

Figure 4. Values of the Shannon diversity index for (A) each estuary system in the different seasons compared to the watershed, and for (B) each type of system in the different seasons analyzed.

Teacapan and Urias, both identified as Type II (tide dominated estuaries), are also closely located in the plot, and the variables characterizing these systems were high values for mean mangrove density, mean mangrove height, and mean annual precipitation. Huizache-Caimanero, classified as Type IV estuary (intermittent estuary), was characterized by the large area of intertidal flats. High values of mean precipitation and mean mangrove height characterized this system.

Fish Assemblages.—A total of 33,479 individuals were captured over the course of this study. ANOVA results for CPUE revealed no significant season-estuary ($F_{(8,306)}$ = 1.53, P = 0.147), or season-type of estuary ($F_{(4,312)}$ = 1.74, P = 0.142) interaction, nor did CPUE vary by season ($F_{\text{when comparing estuarine systems }(2,306)}$ = 0.37, P = 0.694), ($F_{\text{when comparing system type }(2,312)}$ = 0.08, P = 0.927), estuary ($F_{(4,306)}$ = 2.36, P = 0.053) or estuary type ($F_{(2,312)}$ = 0.88, P = 0.417).

ANOVA results for fish diversity revealed no significant season-estuary interaction, nor did diversity vary by season. However, significant differences were found among estuarine systems ($F_{(4,20)}$= 740.7, P < 0.001). The diversity of fish species was positively correlated with system watershed size (Pearson's correlation coefficient = 0.9343, P = 0.02); Santa Maria la Reforma had the highest diversity, and Urias the lowest (Fig. 4A). Tukey HSD test results for the diversity of fish species indicated that all estuarine systems differed from each other.

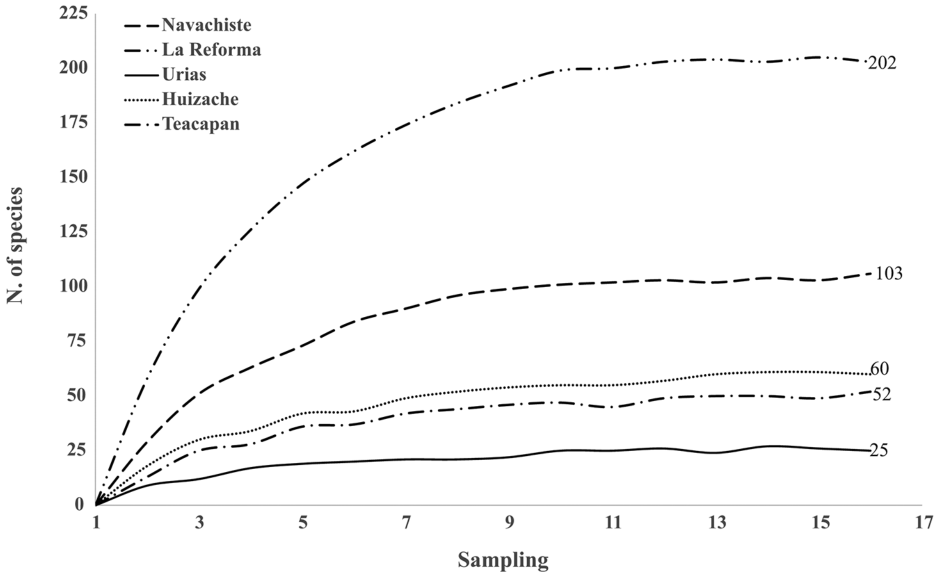

Figure 5. Fish species accumulation model for the different estuarine systems studied. The model used was Chao. The number at the end of each line indicates the total number of species found at each system.

Upon examining fish diversity among estuary types and seasons, the season-type interaction term emerged nonsignificant, as did the season term. However, statistical differences were found according to the type of estuary ($F_{(2, 26)} = 44.46$, $P < 0.001$). The diversity was higher in wave dominated estuaries, compared to the other two estuary types (Fig. 4B).

The total number of species varied considerably between all the studied systems: 204 in Santa María La Reforma, 104 in Navachiste, 61 in Huizache Caimanero, 51 in Teacapan, and 26 in Urias. These numbers were similar to those estimated with Chao's model when fitting the species accumulation curve: 204 for Santa María La Reforma, 103 for Navachiste, 60 for Huizache Caimanero, 54 for Teacapan, and 29 for Urias (Fig. 5). In the tide dominated estuaries, 60 fish species were recorded, 277 species in the wave-dominated estuaries, and 61 species in the intermittent estuaries.

PERMANOVA results indicated no significant season-estuary nor season-type interactions. Seasonal effects were also nonsignificant. However, differences were found among all estuarine systems, and also among all estuary types (Table 3).

Estuarine systems of the same type sharing common species grouped together in the distance based linear model (DistLM) plot of the fish assemblages (Fig. 6). This plot shows that the estuarine systems spanned: (1) a gradient from north to south according to the mangrove density, mean mangrove height, and to a lesser extent, the intertidal flats; and (2) from south to north according to the width of the inlets, and the area of shrimp ponds and agricultural lands, explaining 44.8% of fitted variation in the abscissa axis. Navachiste and Urias were associated with high human populations. Santa María La Reforma was associated with high sand barrier coverture and depth.

SIMPER analysis revealed characteristic species for each estuarine system, as well as species common to the different system types (Fig. 7). Navachiste was characterized

Table 3. Permutational multivariate analysis of variance results of the fish assemblages testing for differences according to estuarine system and estuary type. Pairwise comparisons between (A) estuarine systems, and (B) type of system. II = tide dominated estuaries; III5 = wave-dominated estuaries with barrier; IV = intermittent estuaries.

Comparison	*t*	*P*-value
(A) Estuarine system		
Navachiste, Santa María la Reforma	38.180	0.001
Navachiste, Urias	11.709	0.003
Navachiste, Huizache-Caimanero	20.732	0.001
Navachiste, Teacapan	19.022	0.001
Santa María la Reforma, Urias	11.836	0.007
Santa María la Reforma, Huizache-Caimanero	22.166	0.001
Santa María la Reforma, Teacapan	19.542	0.003
Urias, Huizache-Caimanero	77.886	0.004
Urias, Teacapan	74.845	0.013
Huizache-Caimanero, Teacapan	90.128	0.010
(B) Estuary type		
III, II	2.328	0.009
III, IV	1.999	0.049
II, IV	2.806	0.009

mainly by benthopelagic species such as the ribbon halfbeak, *Euleptorhamphus viridis* (*see* Online Appendix 2 for species authorities), and the skipper halfbeak, *Hyporhamphus snyderi*, but also demersal species such as the bearded banded croaker, *Paralonchurus rathbuni*, and gray bar grunt, *Haemulon sexfasciatum*. Santa Maria La Reforma was distinguished by the presence of typical demersal species, such as croakers (*Corvula* sp.), drums (*Umbrina* sp.), and batoid rays. These two systems (wave-dominated estuaries with barrier, Type III 5), were also characterized by demersal and benthic species, such as benthic rays, and demersal fishes, such as croakers, groupers (*Epinephelus* sp.), grunts, drums, and snappers (*Lutjanus* sp.).

Urias was characterized by demersal species, such as the spotted head sargo, *Genyatremus dovii*; Teacapan was distinguished by the presence of juvenile roosterfish, *Nematistius pectoralis*. These two systems as tide dominated estuaries (Type II) were characterized by benthopelagic species including lookdowns (*Selene* sp.), leatherjackets (*Oligoplites* sp.), milkfish (*Chanos chanos*), machete (*Elops affinis*), and several species of catfish (Arridae).

Huizache-Caimanero, an intermittent estuary (Type IV), was characterized by small demersal species with burying habits, such as flatfish and soles (Pleuronectoidei), sleepers and gobies (*Gobiomorus* sp. *and Gobionellus* sp.), and freshwater species, such as the Nile tilapia, *Oreochromis niloticus*, and the Pacific fat sleeper, *Dormitator latifrons*.

With the exception of a few species (sargo, gobies, halfbeaks, and sleepers), all the species found in this study have commercial importance for small scale fisheries (Ramírez-Rodríguez 2015).

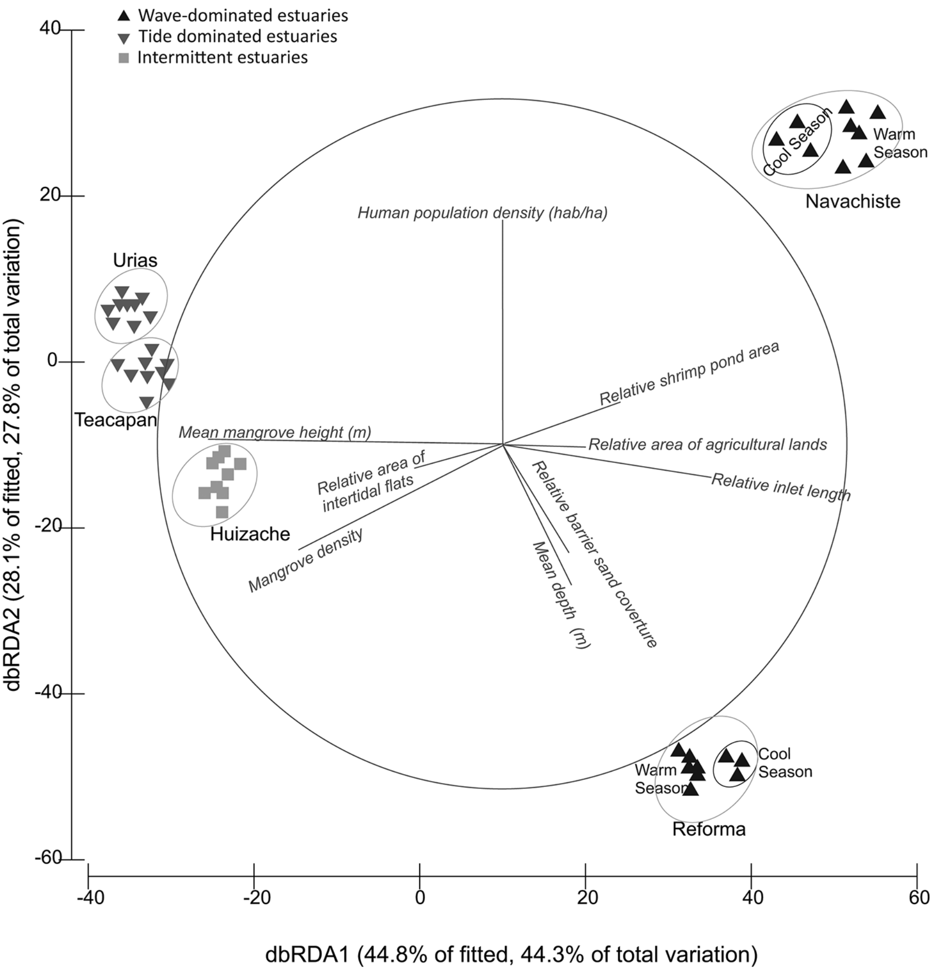

Figure 6. Distance-based linear model (DistLM) describing the patterns in the biota using the environmental variables analyzed in different seasons.

Discussion

Tropical and subtropical estuarine systems are highly diverse and productive ecosystems of considerable economic, biological, and aesthetic value (Harborne et al. 2006, Stone 2007). However, in the recent decades, these systems have been subjected to intense degradation and modification due to human activities (Short and Wyllie-Echeverria 1996, Alongi 2002). Particularly in the Gulf of California, estuarine ecosystems cover large areas of the region's coastline and are important fishing grounds for a large number of small-scale fisheries (Amezcua 2014). Therefore, the degradation of these ecosystems in the region can potentially affect fisheries productivity (Aburto-Oropeza et al. 2008). However, despite their importance, there is a lack of studies within the region examining the relationship between estuary form and characteristics of fish assemblages, although it has been recognized that the understanding of this relationship is essential for the proper management of these ecosystems (Saintilan 2004).

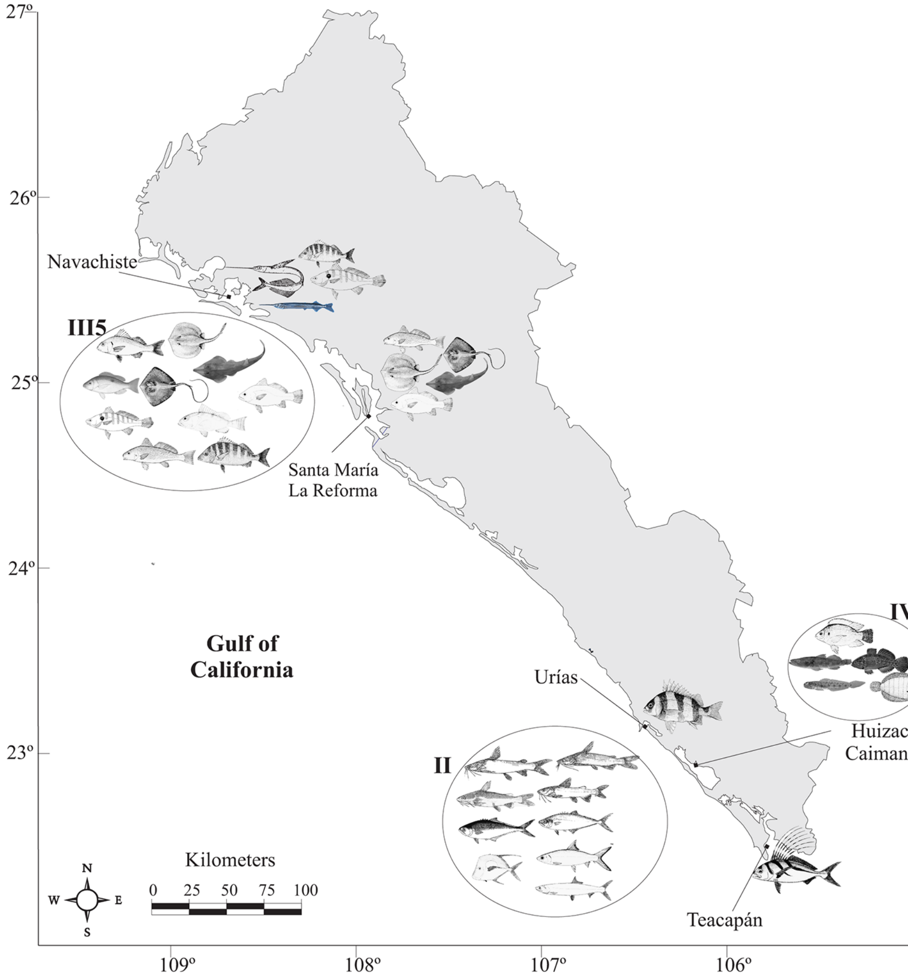

Figure 7. Distinctive species of each estuarine system and each type of estuary based on the results from SIMPER. II = Tide dominated estuaries. III5 = wave dominated estuaries with barrier, IV = intermittent estuaries.

In the studied area, the lack of proper management programs and poor knowledge of estuarine characteristics that are important to preserve biodiversity have contributed to the conversion of several mangrove and coastal lagoons areas for aquaculture, agriculture, livestock grazing, urbanization, and tourism development (Amezcua 2014). The effect that these modifications have on the fish assemblages has not been evaluated. The results from our study on five of the largest estuarine systems in the SE Gulf of California show that the features of each system have the potential to affect or influence abiotic or biotic factors, including the ecological distributions, mangrove density, fish species diversity, and the structure of fish assemblages.

Estuary Classification.—The relative area of the agricultural lands and human density surrounding the systems were used as proxies for the effect of sewage discharge and runoff from agricultural lands into the systems; the higher the human density and the relative area of cultivated lands, the greater the impact these will have. Mangrove height was used as a proxy for the state of the mangrove forests considering that in zones where the hydrology has been altered, salinity increases and mangroves in these areas tend to take the form of shrubs (Flores-de-Santiago et al. 2012). Although some studies suggest that nutrient limitation in the area has the same effect (Feller et al. 2003a,b), it is important to consider that the studies from Feller et al. (2003a) and (2003b) were carried out in salinities below 45 and 57, respectively. Moreover, a recent study found that the combination of high light and hypersaline conditions (salinity >60) was particularly stressful to developing seedlings of black mangrove, *Avicennia germinans* (L.) L. (Dangremond et al. 2015). The central Gulf of California is an arid to semiarid coast where red, *Rhizophora mangle* L., white, *Laguncularia racemosa* (L.) C.F. Gaertn., and black mangrove have inhabited areas with salinities below 40, compared to inland dwarf mangrove, *Conocarpus erectus* L., which grow in salinities from 70 to >90 in flood plains. It has been shown that hypersalinity in this region reduces the height of mangroves from 8 to 1.5 m (De-León-Herrera et al. 2015). The previous findings indicate that mean mangrove height is an adequate proxy for the state of the estuarine system, as a reduced mean mangrove height reflects perturbations that have increased the salinity in the system.

The use of a broad range of physical, geomorphic, geometric, biological, and environmental variables confirm the utility of the classification of estuaries into types developed by Roy et al. (2001), at least for the analyzed systems of the SE Gulf of California. We were able to classify the studied estuarine systems into discrete physical types with markedly different entrance conditions (opening to tidal exchange) and other features that impact salinity regimes, which also affect mean mangrove height and mangrove density (Flores-de-Santiago et al. 2012).

Wave dominated estuaries (Navachiste and Santa María La Reforma) have larger inlets and are located in an arid zone where the evaporation rate is high and the precipitation rate is low. This causes a deficit in the input of fresh water into the system, increasing the salinity. Also, anthropogenic alterations, such as shrimp ponds and agricultural lands, are an important characteristic in both systems, which cause modifications in the hydrology and soil of the system, contributing to areas where the mangroves are stressed and are prevented from reaching greater heights (Flores-de-Santiago et al. 2012). The combination of these two factors has likely led the mangroves in these two systems to grow as shrubs, with low mean height and lower density.

The systems to the south have higher rainfall than the evaporation rate; therefore, the salinity is lower and the mean mangrove height and mangrove density is higher (Flores-de-Santiago et al. 2012). The tallest and most dense mangroves are found in the Teacapan system. Although this system has similar conditions to the Urias estuarine system, there are no large human settlements nearby, as compared to Urias which borders on the city of Mazatlán, where there are human influences from navigation channels, a thermoelectric plant, and large sewage discharges (Amezcua 2014).

Huizache-Caimanero, the intermittent estuary, is a very shallow system with less mangrove coverage than the Type II systems, a higher influence of freshwater inputs (lower salinity), and an inlet that disappears for at least half of the year. In addition, because of the closure of the inlet, the area of intertidal flats is the largest among all the studied systems, which seem to constitute the factors that clearly separate this system from the others.

Fish Assemblages.—CPUE was similar among all estuary systems and types, which allowed us to make all results comparable, and eliminate estuary size related problems.

Fish species diversity was strongly correlated with the watershed area of each system. This correlation may be due to the fact that, as the watershed size increases, habitat diversity, and complexity also increase (Hugueny 1989, Gratwicke and Speight 2005). However, other factors may also be at play, such as the intrinsic characteristics of each system; e.g., the area of intertidal flats, mean depth, or inlet closure during a considerable part of the year, in the case of Huizache-Caimanero.

Regarding the type of system, the highest diversity was found in the Type III systems and the lowest in the Type II and IV systems. Although similar results were reported by Saintilan (2004), it is necessary to bear in mind that both Type III systems in our study were also the largest, and Urias, the system with the lowest watershed area, is a Type II. So, these results reflect what has already been previously discussed, that the size of the system effectively correlates with a higher fish diversity, and that this seems to be independent of the type of system.

An asymptote was reached in all systems, indicating that the sampling program was efficient in terms of the representation of the species in each system that were susceptible to being captured with the gillnet used.

Multivariate results indicate that each system has a characteristic fish fauna, but also that there are features related to the estuary type that support similar fish assemblages among estuaries of the same type. These results are an indication that the fish assemblages are positively related to some of the variables of the estuarine systems, a result similar to that reported by Saintilan (2004), and evidenced by the vectors in the DistLM test, such as the positive correlation of the fish fauna in the wave dominated estuaries with agricultural land area and shrimp ponds area, as well as to the width of the inlets, or the correlation of the fish fauna in the tide dominated estuaries with mangrove height, and mangrove density.

The way in which each of these variables shape the fish assemblages is difficult to determine because there is a lack of information about the habits of most of the fishes that were found during the course of this study in all five systems. Nevertheless, there are other features that, although not directly indicated by the DistLM analysis, may be directly related to the vectors of the analysis, and exert their influence on the focal fish assemblages. One of these features may be biogeographic province. According to Hastings (2000), the part of the Tropical Eastern Pacific Biogeographic Region that comprises the Mexican Pacific has two provinces based on the distribution of rocky shore fishes and marine invertebrates: the Cortez and the Mexican provinces. These two provinces are separated by a long stretch of coastline south of the city of Los Mochis, the "Sinaloan Gap," which extends to Mazatlán. Thus, the three analyzed systems in the south are located in the Mexican Province, while both Type III systems are located in the Sinaloan Gap, near the Cortez province. This feature clearly separates the fish assemblages of the systems in the north from those in the south; being at the northern limit of this gap, the fish assemblages in Navachiste and Santa María La Reforma may be more related to those from the Cortez province.

The other important feature that seems to have a direct influence on shaping the fish assemblages in the different systems, and which was suggested by the vectors in the DistLM test, is salinity, which, as previously indicated, is directly related to the mangrove height and density (higher salinity implies a lower mean height and lower mangrove density), the area of shrimp ponds, and the area of agricultural lands. Barletta et al. (2005) demonstrated the important role of salinity in shaping fish assemblages in tropical estuarine systems from many regions in the Americas and Australia. The results from our study suggest that the salinity is also a very important feature in structuring the fish assemblages in the region. In the intermittent estuary (Huizache-Caimanero, Type IV), the fish assemblage differentiates clearly from the other systems by the abundance of freshwater species, such as the Nile tilapia, the sleepers, and the goby. In this estuarine system, the connection to the sea is not permanent, but there are two large rivers that drain into the system, causing lower salinities, which are occasionally comparable to those found in freshwater systems during the year (Romero et al. 2014). In this particular case, the hydrology has an effect on the salinity, which in turn has an effect on the fish assemblage.

Both tide dominated estuaries are located to the south, near to each other, and are characterized by a higher precipitation and a salinity regime that fluctuates considerably between rainy and dry seasons (Romero et al. 2014). This type of system was characterized by a high presence of catfish species, which have been previously demonstrated to inhabit typical estuarine systems, where the salinity shows seasonal fluctuations (Dantas et al. 2012). The system is also characterized by the presence of other species that inhabit brackish environments, such as the machete and milkfish (Amezcua-Linares 2009).

However, wave dominated estuaries are both located in an arid zone with higher evaporation rates, and on the largest inlets compared to all the systems analyzed. As a consequence, these systems have a better water exchange with the sea; thus, conditions are similar to marine environments. In both of these systems, the alterations due to shrimp ponds and agriculture are much higher. Accordingly, the salinities in these systems are high, never reaching values <30, and with little seasonal fluctuation (Romero et al. 2014). The consequence of these characteristics is that the fish species in these systems are mainly of a marine affinity rather than estuarine. This observation needs to be treated with caution, because as previously indicated, there is a lack of knowledge of most of the species encountered in this study, although some studies have shown that most of the species observed in these systems inhabit the open sea (Amezcua et al. 2006, Madrid-Vera et al. 2007).

Regarding the large differences found within fish assemblages of the Type III systems, the fish fauna in Santa María La Reforma was positively correlated with mean depth, which is higher in this system, area of sand barriers, and to a lesser extent, mangrove density. Sand barriers are known to be an important factor in wave dissipation and are an associated buffer against extreme weather events (Defeo et al. 2009), which translates to a better-protected mangrove forest, and therefore a higher density, which in turn increases fish productivity (Aburto-Oropeza et al. 2008). Considering that Santa María La Reforma was the system with the highest richness and diversity among all the studied estuarine systems, it is possible that these parameters are also related to a higher mangrove density, besides being a larger system. Navachiste does not receive runoff from any river (Amezcua 2014), unlike Santa María La Reforma, and there is a high presence of halophytic vegetation. This might have an influence on the benthic fauna available as food, and hence the difference in species composition. For instance, in Santa María La Reforma, the abundance of organisms that consume benthic fauna, such as rays and flatfish, was much higher than in the other systems. Finally, it has been demonstrated that demersal fish assemblages vary with depth (Araújo et al. 2002), thus greater environmental depths can have a strong effect in shaping the fish species assemblage.

The classification of estuaries by Roy et al. (2001), but with the necessary modifications that consider the particular characteristics of the estuaries in the SE Gulf of California, proved to be an effective way to distinguishing between systems on the basis of geomorphic, geometric, environmental, biological, and anthropogenic characteristics. The most important features seem to be the size of the inlet, and the volume of the system and the salinity, which in turn have an effect on biological characteristics, such as the density and height of the mangrove forests; this is consistent with the notion that estuarine systems in subtropical and tropical zones are characterized by factors that strongly influence estuary hydrology and nutrient inputs (Flores-de-Santiago et al. 2012).

Using estuary type instead of solely using measures of water quality or species diversity may be more useful in linking ecological aspects, such as species diversity and commercial fisheries production to the habitat. Previous studies have found that using a holistic approach to understand estuaries allows managers to predict the biological and ecological effects of human interventions (reclamation, channel dredging, catchment disturbance, etc.), and to devise practical management responses for each system (Roy et al. 2001).

The estuarine systems in the SE Gulf of California can be classified using Roy's classification system. However, the influence of the type of system on the fish assemblages is difficult to ascertain. The geomorphology of the system together with biological characteristics, anthropogenic alterations, the salinity regime, as well as the biogeography component are likely to have a strong influence on the fish assemblages in this area of the world. However, adequate understanding of this influence requires further studies on the ecology and biology of the fish species inhabiting these systems to determine how these variables affect the occurrence and abundance of fish species or groups of species.

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