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Variation in Taxonomic Diversity of the Fish Assemblage Associated with Soft Bottoms in San Ignacio Lagoon, Baja California Sur, Mexico

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Abstract

The San Ignacio Lagoon is one of the largest in the northwest area of Baja California Sur; it is characterized by high levels of commercial fish catch; however the number of investigations related to taxonomic diversity is low. The variation in taxonomic diversity was determined for the assemblage of fish associated with soft bottoms, at 11 locations in a period from spring of 1998 to winter of 1999. Variation in diversity of the soft bottom fish were evaluated considering the taxonomic distance between species, using the indices of alpha, average alpha, beta and gamma diversity, also the indices of taxonomic distinctness (Δ^*) and average taxonomic distinctness (Δ^+). Bottom trawls were performed using an experimental net to an average depth of 5 meters, between 9:00 to 17:00 hours. 1361 organisms were observed, belonging to 44 species on 35 genera. According to the average alpha, beta and gamma diversity indices, the season with higher value on average alpha diversity was summer, with 6.68 species followed by spring with 5.73 species. In beta´s case the highest value was observed during spring (21.27%) followed by summer (20.18%). Taking gamma in account, the highest values were observed during spring and summer, both seasons with 27 species each. The lowest values observed according to the average alpha beta and gamma indices, was observed during winter season (5.27, 20.18% and 20 species, respectively). In the spatial analysis, the average taxonomic distinctness index (Δ^+) show a significant difference ($p \leq 0.05$), while taxonomic distinctness index (Δ^*) showed no significant difference ($p \geq 0.05$). In the temporal analysis both indices showed no difference ($p \geq 0.05$).

Keywords: Taxonomic diversity; Ecological indices; Soft-bottom fish; San Ignacio Lagoon; Seasons

Introduction

Coastal lagoons and estuaries are physically unstable areas, characterized by spatial and temporal variations in temperature, salinity, oxygen concentration, turbidity and other factors [1,2]. In Baja California Sur, there are only coastal lagoons without fresh water input, because of the low rainfall; so, they are considered anti-estuarine type [2]. The coastal lagoons, estuaries and bays on the west coast of northwestern Mexico, are considered areas of particular interest within the Eastern Tropical Pacific Ocean (ETPO), due to its complex geological history and the confluence of the California current and the north equatorial current, which have produced a series of environmental and climatic conditions that result in a wide variety of habitats for marine organisms [3]. Laguna San Ignacio (SIL) is the second most important in the Pacific Ocean side of Baja California Sur (BCS). From the zoogeographical point of view, SIL is found in the Californian province [4], so it is geographically located in the temperate region. This lagoon is used during winter as breeding, rearing and refuge of the gray whale *Eschrichtius robustus* [5], as well as some species of migratory birds such as *Branta bernicla*, *Limosa fedoa y Numenius americanus* [6]; however, few ecological studies include fish fauna in this lagoon [2,7-9].

Coastal Lagoons and estuaries diversity have been studied worldwide [10-15]. One of the principal objectives of coastal management is to sustain the ability, of those ecosystems, to provide goods and services such as fisheries, tourism and cultural value, upon which people depends [13,16]. Coastal ecosystems are facing a continuous increase by human pressure through fisheries, recreational activities, demographic increase and even global change consequences [16]. These factors can cause alterations in diversity and structure of marine communities that can disrupt the ecological functions performed by species assemblages [13,17]. To ensure the possibility to contrast the biodiversity state in SIL, it´s important to state basal data for future studies. This study is aimed to determine variation in taxonomic diversity of fish associated with soft bottoms.

Materials and Methods

Study area

San Ignacio Lagoon is geographically located between 26°43´ and 26°58´ North and between 113° 08´ and 113°16´ West (Figure 1). It is a shallow lagoon with depths ranging from 2 to 4 meters for the most part, with a depth of 20 meters in the channels that communicate with the ocean [18]. The coast has sandy beaches, muddy bass, mangrove swamps, marshes and few rocky areas [18]. The northern part of the lagoon forms the main water body; a second arm extending eastwards includes most of the mangroves [2].

Fieldwork

Four campaigns were conducted during the seasons of spring, summer and fall of 1998 and winter of 1999. 44 trawls were conducted at 11 locations (Figure 1); trawls were conducted for 30 minutes, performing three replicates of 10 minutes each. For the selection of the sampling locations the physiographic aspects of the study area was considered. The geographical coordinates of each location were recorded with help of a Global Positioning Satellite (GPS). The fishing gear used to capture organisms was an experimental dragging net with a length of 9 meters with an opening of 4.5 meters and a mesh size of 1.5", with metal doors of 95×50 cm, towing speed was 3.5 km/h, using a boat of 22 feet and an outboard engine with 75 HP. Physicochemical measurements (bottom temperature and salinity) were measured with a termohaline (YSI model 33). Dissolved oxygen was measured with an oxymeter (YSI model 57). To obtain substrate type on each location, a substrate sample was taken and analyzed in the Geology laboratory of UABCS (Universidad Autónoma de Baja California). The methodology corresponds to that used by Barjau-González [2].

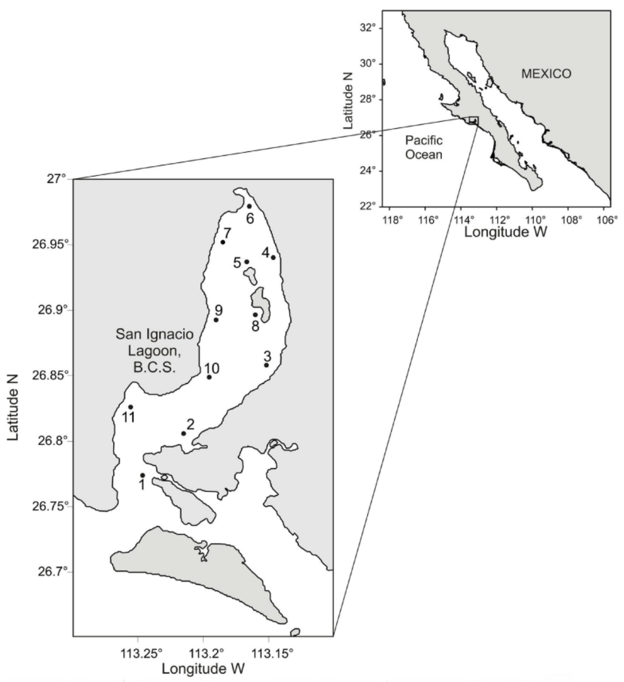

Figure 1: Location of the study area, San Ignacio Lagoon, Baja California Sur, Mexico.

Data treatment

Diversity was calculated through Fisher´s alpha, and indices of taxonomic distinctness (Δ^*), average taxonomic distinctness (Δ^+) and variation in taxonomic distinctness (Δ^+). Each one calculated for each location and season. These indices are described below:

Fisher´s alpha index; is a parametric index that assumes the abundance of species follows a logistic distribution. This analysis was considered more appropriate than Shannon and Simpson indices, considering that they are too dependable on the number of common species [19], so it can mask the importance of rare species.

Taxonomic distinctness index (Δ^*) [20] evaluates the considered taxonomic distance and species richness, in addition to the total abundance of them. One of the advantages of using this index it´s that it doesn't rely on the sample effort or size, and the presence of normality in data is not necessary. Likewise, it has been considered by Warwick and Clarke [20,21] as an accurate measure for diversity that incorporates qualitative and quantitative aspects of fauna.

Average taxonomic distinctness index (Δ^+) [22] evaluates richness along with taxonomic distance between each pair of species, defined trough a Linnean classification tree. It uses presence and absence data; each taxonomic hierarchy level receive a discrete proportional value within a range of 100 units, depending on the levels used, so that, the more species belonging to a different genera and families in a place, the larger the value of Δ^+ and therefore, shall be more diverse.

Variation in average taxonomic distinctness index (Δ^+) is the variation in taxonomic distinctness and reflects the degree to which certain taxonomic groups are over- or under- represented in a sample. This index can help distinguish between to taxonomic trees that may have the same number of species, and even an identical value of Δ^+, but to have a unequal structure tree in taxonomic units, it is necessary the presence of some genera with many species, so that Δ^+ tends to increase, but this would be offset by the presence of the families represented by only one (or very few) species. Therefore, Δ^+ measures inequality in the phylogenetic tree and is contrary to the concept of taxonomic diversity. So high taxonomic diversity would be expected for a community with uniform distribution of species along the taxonomic levels and units, situation that would lead to a low value of Δ^+ [23].

To determine taxonomic distinctness, six hierarchical levels were used (Phylum, Class, Order, Family, Genus and Species); the data used were the species richness and total abundance, which were then standardized by the square root [24]. Once the indices were calculated, an ANOVA was performed to establish whether there were significant differences between locations and between seasons. Where significant differences were obtained, a multiple comparison analysis was performed, using Fishers Least Significant Difference (LSD).

An analysis of average taxonomic distinctness and variation in average taxonomic distinctness was performed using taxonomic distinctness tunnels, those were made with 1000 random subsamples and the number of species (44) found during the study, thus calculating the distribution of taxonomic distinctiveness of the list. The results are presented delimited within the 95% probability between (major and minor) expected limits, connecting these points in a tunnel of expected ranges, according to the methodology of Clarke and Warwick [20].

In order to establish the relationship between seasons and the components, which include the dominant species, physic-chemical variables (salinity, bottom temperature and dissolved oxygen) and ecological indices (Delta+, Delta*, number of total species, total abundance and Fisher´s alpha), an analysis of correlations of components and variables was performed.

For the mathematical calculation of them, the ecological software PRIMER-E 6 & PERMANOVA+ version 1.0.2 was used [22]. To carry out the analysis of variance the software STATISTICA v. 8 was used. To prepare the maps ArcGIS software was used.

Results

A total of 44 sets were collected during the period of 98-99 (the four seasons were included) with a total of 1361 organisms collected. The composition of fauna of fish associated to soft bottoms in SIL was of 44 species, integrated into 2 classes, 7 orders, 21 families and 35 genera. The overall temperature presented a well-defined seasonal pattern, recording a high of 25°C during summer and a minimum of 11.2°C during winter. Salinity values recorded a maximum of 42‰ during summer and a minimum of 36‰ during winter, behaviour that confirms its classification as a hyper saline and anti-estuarine lagoon [2]. Dissolved oxygen showed pronounced gradients reaching the highest value of 4.12 ml/l in spring and fall, and a minimum value of 1.4 ml/l in winter (Table 1).

	S ‰	T C	ml/l	ᾱ	β	γ	α-Fisher	Delta*	Delta+	Lambda+
Canal Del Cardón	36.38	19.75	3.31	1	3%	4	0.8343	66.67	66.67	0
La Freidera	36.63	19.60	3.26	3.5	4.50%	8	1.714	53.22	59.52	147.39
La Base	37.25	19.43	3.26	6	11%	17	5.881	62.07	64.58	189.7
El Anegado	38.25	19.78	3.48	7.5	11.25%	19	6.951	61.83	65.01	184.06
Norte Isla Garza	39.13	19.63	3.50	6.25	10.75%	17	5.881	63.53	66.3	251.09
El Remate	40.00	20.10	3.16	8.75	12.75%	21	8.107	61.23	63.57	192.8
Cantil Cristal	39.38	20.33	3.52	7.75	16.25%	24	10.01	58.36	64.98	186.35
La Choya	38.63	20.25	3.22	4.75	7.25%	12	3.561	59.52	65.4	314.06
Los Cerritos	38.13	20.53	3.48	3.5	7.25%	11	3.154	63.89	63.64	202.94
Las Islitas	37.75	20.25	3.24	7.25	14.75%	22	8.719	62.19	64.29	231.22
El Mapache	36.38	19.85	3.25	7.75	14.25%	22	8.719	49.45	62.63	137.6
Spring 98	37.05	21.11	4.13	5.73	21.27%	27	12.15	60.57	65.05	176.25
Summer 98	40.14	24.33	2.90	6.82	20.18%	27	12.15	64.06	64.62	191.3
Autumn 98	37.55	20.91	4.13	5.55	17.45%	23	9.354	51.28	63.37	114.32
Winter 99	37.23	13.46	2.16	5.27	14.73%	20	7.518	60.38	64.91	222.07

Table 1: Diversity values between locations and between seasons throughout the campaign, Average Salinity (S‰), Average Temperature (T°C), Average Dissolved Oxygen (ml/l).

Fisher´s alpha

Fisher´s alpha was calculated for each location. The lowest value was recorded in Canal del Cardón with a value of 0.18 units and the highest value was obtained in the location called El Mapache with a value of 2.44 units. Considering that between the lowest and highest values observed, there is an important range, variances are high, showing no significant difference between locations ($F_{(10,33)}$=1.3768, p=0.2337). For each season, the values obtained of Fisher´s alpha ranging 1.38 units during winter to 1.83 in summer. However, no significant difference was observed between seasons ($F_{(3,40)=}$0.2855, p=0.8711).

Taxonomic distinctness (Δ^*)

The values of taxonomic distinctness obtained in the analysis between locations, ranging from 19.17 units in Canal del Cardón to 62.89 in La Base, values tend to have a separates range en them, but in some cases variances are wide, that´s why the ANOVA does not detect significant differences between locations ($F_{(10,33)}$=1.8524, p=0.0895). In the analysis between seasons, the minimum value was obtained in winter with a Δ^* of 46.23 units, in spring was recorded the highest value with a Δ^* of 55.44 units. However, according to the ANOVA, there are no significant differences between seasons ($F_{(3,40)}$=0.3959, p=0.7566).

Average taxonomic distinctness (Δ^+)

Regarding the average taxonomic distinctness (Δ+) between locations, statistically significant differences were observed ($F_{(10,33)}$=2.2513, p=0.0390). The analysis of Fisher´s LSD shows that Canal del Cardón is different to all locations except to the location called Los Cerritos (p= 0.0385). Los Cerritos showed difference with La Base, Norte Isla Garza, El Remate, La Choya and Las Islitas. These two locations obtained the lowest values of average taxonomic distinctness (16.67 and 29.75 units, respectively). The values obtained between seasons range from 49.65 units in winter, to 57.32 during spring. However the ANOVA reveals no significant difference between seasons ($F_{(3, 40)}$=0.207, p=0.8909).

To observe a general overview during all climatic seasons in the sample, the sum of the abundance in these locations was performed. The record with the greatest weight of the philogenetic distance in the tree was found in Canal del Cardón with a Δ^+ of 66.67 units followed by Norte Isla Garza with a Δ^+ of 66.30 units; and the minimum values with less distance on the average philogenetic tree were observed in the locations of El Mapache and La Freidera with Δ^+ 62.63 and 59.52 units respectively (Table 1 and Figure 2).

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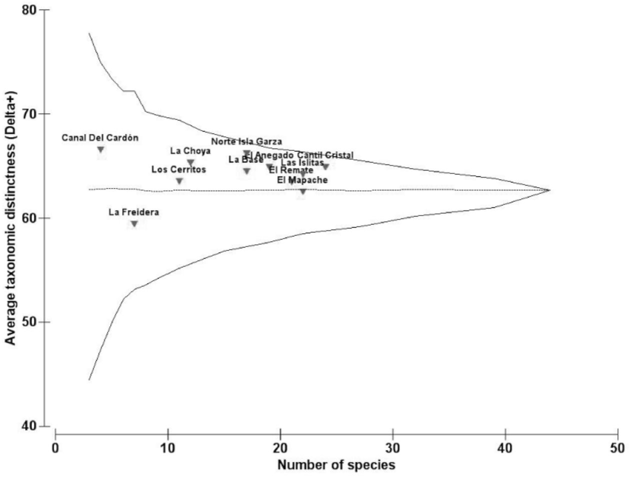

Figure 2: Average taxonomic distinctness tunnel of locations throughout the whole campaign, with a confidence interval of 95% (solid lines) and the average (dotted line) in the middle.

The sum of the abundances was conducted within the seasons. The record with the greatest weight of the philogenetic distance in the tree was found in spring with a Δ^+ 65.05 units, followed by winter with a Δ^+ of 64.91 units; and the minimum values with less distance on the average philogenetic tree were observed in the seasons of summer and autumn with a Δ^+ of 64 and 63 units, respectively (Table 1 and Figure 3).

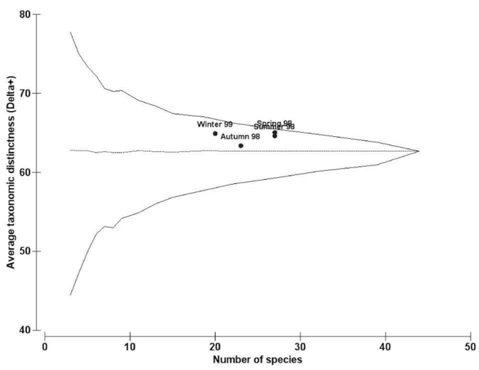

Figure 3: Average taxonomic distinctness tunnel of seasons throughout the whole campaign, with a confidence interval of 95% (solid lines) and the average (dotted line) in the middle.

To analyze the variation in average taxonomic distinctness, the locations with the highest values were La Choya with a Λ+ of 314.06 units, followed by Noerte Isla Garza with a Λ+ of 251.09 units; the values with less distance was recorded in El Mapache with a Λ+ of 137.60 units, followed by Canal del Cardón with a Λ+ of 0.00 units (Table 1 and Figure 4).

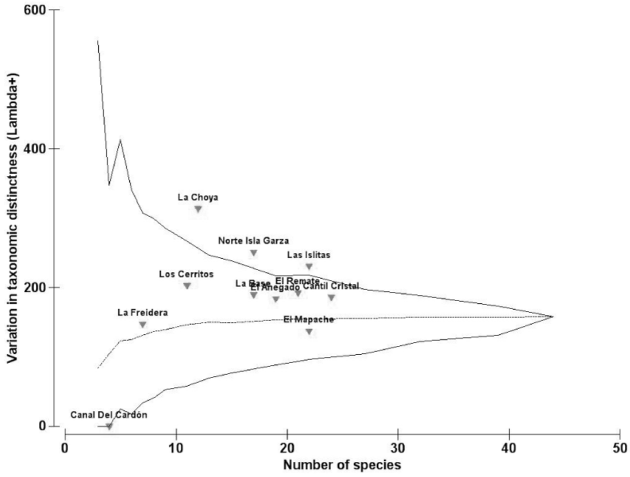

Figure 4: Variation in average taxonomic distinctness tunnel of locations throughout the whole campaign, with a confidence interval of 95% (solid lines) and the average (dotted line) in the middle.

Using the same criteria as above, the sum of the abundance was performed within seasons. The seasons with the highest values were winter with a Λ^+ of 222.07 units, followed by summer with a Λ^+ of 191.30 units; the values with less distance was recorded in spring and autumn with a Λ^+ of 176.25 and 114.32 units, respectively (Table 1 and Figure 5).

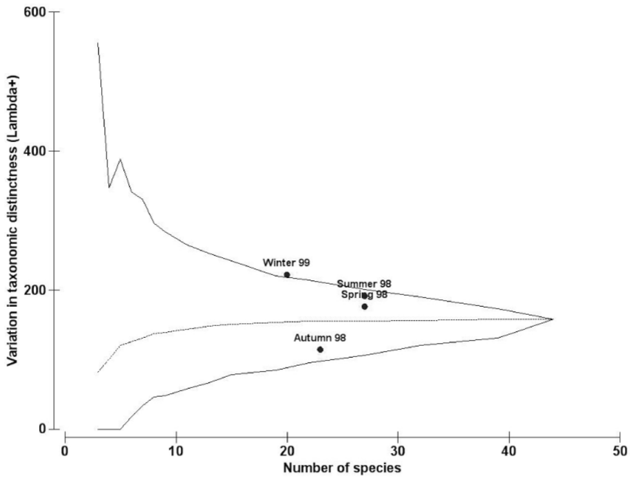

Figure 5: Variation in average taxonomic distinctness tunnel of locations in different seasons throughout the whole campaign, with a confidence interval of 95% (solid lines) and the average (dotted line) in the middle.

The analysis of Correlation between Components and Variables show us that depending on the water temperature, we can observe two periods, a warm period including summer and autumn, and a cold one including spring and winter. On the left side of the graph (warm period) we observe that most of the dominant species are grouped (Paralabrax nebulifer, Bairdiella incistia, Eucinostomus dowii,

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Orthopristis reddingi Paralabrax auroguttatus, Paralabrax maculatofasciatus, Exerpes asper y Spheroides annulatus) also Fisher´s alpha, total abundance and dissolved oxygen. On the right side of the graph we can see that the only dominant specie present is Spheroides Lispus, the only one related to the cold period, also the two indices of taxonomic distinctness (Δ^* and Δ^+), the number of total species and salinity (Figure 6).

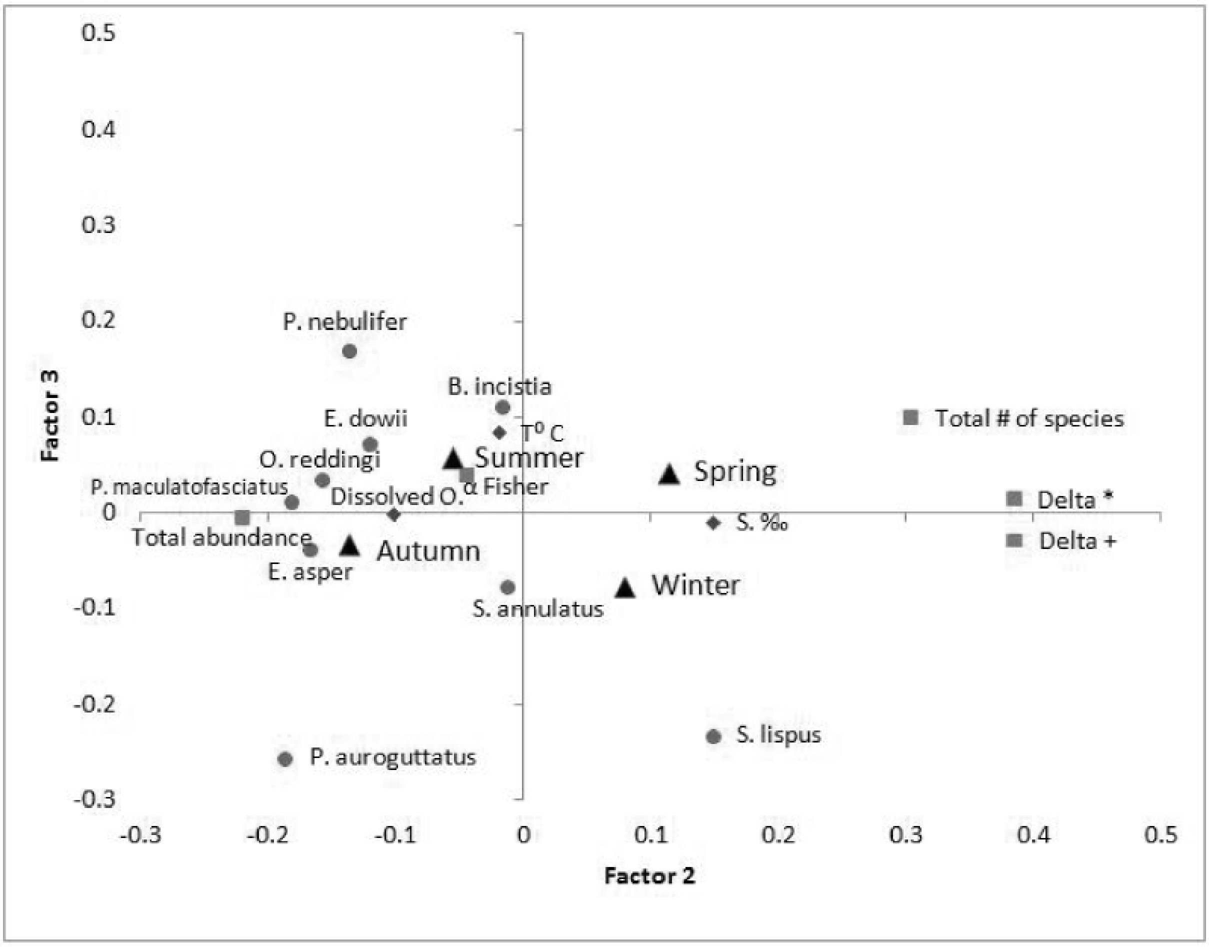

Figure 6: Analysis on Correlations between Components and Variables: Seasons (Triangle), dominant species (circles), Physical-chemical variables (diamonds) and ecological indices (squares).

Discussion

San Ignacio Lagoon is characterized by being a coastal lagoon with anti-estuarine characteristics, with limited rainfall and mostly shallow [18]. The physicochemical variables are influenced by the tides, and the tides cycle is mixed, with a high tide up to 2 meters, with a gap between the mouth of the lagoon and the end of it, of 45 minutes [2].

Several studies in other parts of the world shows that there are differences in structure of fish communities, mainly in composition and relative abundance, influenced by fluctuations in environmental factors such as salinity, temperature and dissolved oxygen variations [25-28]. In this connection, previous studies in SIL recorded the presence of species with tropical affinities as Bairdiella icistia, Centengraulis mysticetus, Exerpes asper, Sphoeroides lispus, Urophalos maculatus, Cyclopsetta panamensis, Umbrina xanti, Microlepidotus inornatus [2], according to several authors [7,9,29,30] the presence of these species has been recorded in years with neutral conditions, however Barjau-González [2] mentions that the abundance of these species could be influenced by El Niño event. The sea water temperature plays an important role in the distribution of many species of marine fish. Studies performed by Hubbs [31], Moore [32] and Barjau-González [33] observed changes in fish distribution by variations in temperature.

Analysis of taxonomic diversity allows us to visualize the state in which a site is, through variability in the diversity of species present in it. The Fisher´s alpha assesses diversity effectively based on the number of individuals and the number of species [34,35]. Fisher´s alpha is known for its stability for measuring diversity, both locally and regionally. Although it is one of the least used indexes, it is one of those with greater biological foundation [36-38]. Fisher´s alpha diversity showed no significant differences between locations. This result could be influenced by the extent of the variance, due to sample size, given that expected to find differences associated with the variety of substrates and depths along the lagoon [2,39], factors that are considered of great importance because it directly affects diversity in marine environments [40,41], because habitat complexity influence the arrangement of areas used for refuge and feeding. Fisher´s alpha diversity did not show significant differences between seasons too. However, we expected to find them, because salinity and temperature showed a marked seasonal variation and several authors suggest that these two variables affect directly to the diversity in fish populations [25-27,42].

Regarding the taxonomic distinctness (Δ^*), no difference was observed, although it was expected, because there is a variety of factors such as depth and substrate type [2,39], which change at different locations within the lagoon, affecting directly to diversity of each site [40,41]. The analysis between seasons didn't show significant differences, although it was expected, because the records of temperature and salinity varied between seasons. Several authors agree that these factors have a direct relationship with diversity in marine environments [25-27,42].

To counter criticism for using data of total abundance and species richness, Clarke and Warwick [22] proposed the average taxonomic distinctness index that uses only presence/absence data. When using this index we observed significant differences between locations. The location of Canal del Cardón had the lowest value, which may be due to the topographical features and location, as it is found in the mouth of the lagoon, area with greater depth [39] where the currents are stronger and substrate is sandy [2], which creates an area of low complexity. Los Cerritos also had low diversity values, due to the shallow depth [39] and the silky substrate observed [2]. It was observed that the average taxonomic distinctness index was more sensible than others, enough to detect the difference between locations. Seasonal analysis showed no significant difference, although the values of salinity and temperature recorded were different between each. According to several authors, these factors are crucial to the diversity in marine environments [25-27,42].

In order to observe the overall state of SIL throughout the season, the average taxonomic distinctness index was used, being observed that all localities are located in the expected range. This index helps us to infer that SIL is seasonally stable from the philogenetic point of view, since their values are also within the expected range, which indicates that, between seasons, there is no instability. Our results are similar to those reported by Saldivar-Lucio [43] who conducted a study on the long-term changes of reef fish fauna in Cabo Pulmo, located at the southern end of the Baja California Peninsula. Employing the taxonomic distinctness index, he obtained slightly higher values (Between 72.07 and 72.59 units). Studies by Fernandez-Rivera Melo [44] in Cabo Pulmo and Barjau- González [45] on Isla San José and La Paz Bay showed values very similar of Δ+, to those obtained in the present study, inferring that these ecosystems are still in good condition and anthropic impact has not affected the phylogenetic relationships, so it show that from the biological and ecological point of view, remains as a healthy ecosystem [45].

The average taxonomic distinctness shows that it is effective in situations where there are a limited number of higher taxa, so the absence of some of the levels with a great number of species tends to result in the reduction of Δ^+. This unbalances the presence of families with one ore few species. This difference in the structure will be reflected by changes in the average taxonomic distinctness (Λ^+) [22].

In order to observe the condition of the area of interest, the sum of the abundance of location throughout the whole campaign was made, again just considering absence/presence data. We observe that for Λ^+ index, the locations of La Choya, Norte Isla Garza and Las Islitas were located outside the expected range. Clarke and Warwick [22] argue that this type of behavior is typical of fauna of insular environment. Results between seasons show that all of indices values fall within the expected range, showing that, seasonally, there are no data showing evidence of anthropogenic impact in the area.

To summarize, we can say that the low values in Δ^+ are related to lower taxonomic levels, many species belonging to the same genus or family. While high values in Λ+ are related to an over- or under-representation of some taxa [23].

Fish communities with a redundant level of species where, few of them complement the primary functional roles, are less able to survive changes in a community [46]. Through these diversity indexes and distinctness, we can provide valuable information to understand what assemblies may be resistant to change and which aren't [47]. So it should be considered important for studies, management and conservation of the area of interest in the future.

The analysis of Correlations between Components and Variables is used to describe the relationship between seasons and components, which include the dominant species, physic-chemical variables (salinity, bottom temperature and dissolved oxygen) and ecological indices (Delta+, Delta*, number of total species, total abundance and Fisher´s alpha). We observed that the temperature is one of the main variables related to dominant species. This agrees with observations made by Rodriguéz-Romero et al. [48] whom report a relationship between water temperature and abundance of species in Bahía Concepción (B.C.S., México). The higher temperature was observed during summer and the dominant species are inclined towards that season. It also shows that the highest number of species leans to spring, finding that consists with the values observed in the analysis of average taxonomic distinctness and taxonomic distinctness on this study. Seasonal changes in composition of fish communities are relatively common, and the characterization of defined fish assemblages in tropical and sub tropical estuaries, rainfall seems to be an important feature to establish these changes [49,50]. In an antiestuarine lagoon, such as SIL, where the fresh water contribution is really poor or null, salinity and temperature seem to play the most important role in the composition of fish assemblages [25-27,42].

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