Variation of the Fish Community Associated with Soft Bottoms in a Coastal Lagoon on the Pacific Side of B.C.S, México

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Abstract The San Ignacio lagoon is located inside the "Biosphere reserve El Vizcaíno". The study of fish within coastal lagoon systems allows a better understanding of how these organisms are responsible for performing various activities that are necessary for the stability of the ecosystem. There is very general and outdated research of the ichthyofauna in the San Ignacio lagoon. In the present study, the structure of the fish community associated with soft bottoms and the ecological role of the most dominant species was analyzed. Six bimonthly samplings were carried out in 11 localities from April 2013 to April 2014 resulting in 66 replicates, each time an experimental trawl net was used to capture the organisms and physicochemical parameters were recorded. 2,887 organisms belonging to 26 families, 38 genera and 46 species were captured. There were significant differences in seasonal richness but not spatial richness, and there were no significant differences in diversity or evenness. According to the BVI, 12 species were the most biologically important.

Keywords Structure; Residents; Diversity; Dominance; Relative abundance

Background
México has more than 100 coastal water systems (coastal lagoons and estuaries) of which 22 lagoon-estuarine systems exist in the Baja California Peninsula (Lankford, 1977). The San Ignacio lagoon is located on the North Pacific zone of the state of Baja California Sur within the "Biosphere reserve El Vizcaíno", an area aimed to provide protection to wild flora and fauna (Bocanegra-Castillo, 1998).

The stability of the basic structure of fish communities of the lagoon-estuarine systems is attributable to four main conditions: 1) The regular distribution of the species, associated to environmental gradients of temperature, salinity and other variables; 2) migratory movements in and out of the system, 3) dominance of few species within the system, and 4) a very stable food web (Moyle and Cech, 1982).

Barjau-González (2003) studied the ichthyofauna associated with soft bottoms in San Ignacio lagoon in which he recorded 44 species. Barjau-González et al. (2014a) did a zoogeographic analysis of the fishes associated with soft bottoms in San Ignacio lagoon during the El Niño – La Niña (98-99) events. In this analysis they describe that the species of fishes had zoogeographic affinities to the provinces: Panamanian (36%), California (32%), Eastern Pacific (18%) and Mexican (11%). Barjau-González et al. (2014b) studied the variation in taxonomic diversity of the fish assemblage associated with soft bottoms in San Ignacio lagoon from the spring of 1998 to the winter of 1999. In this study they found that the average taxonomic distinctness analysis does not reflect anthropologic impact which shows that she study area is in an adequate condition. Kosegarten-Villarreal et al. (2016) did a zoogeographic analysis of fishes associated with soft bottoms in San Ignacio Lagoon from April 2013 to April 2014 in which they found that the zoogeographic affinities correspond to 28% Californian Province, 4% Cortez Province, 7% Mexican Province, 41% Panamanian Province, 18% Eastern Pacific and 2% Circumtropical.

The aim of the present study was to describe the current structure of the fish community associated to soft bottoms; so that it serves as background to establish management and conservation plans of this lagoon.
1 Materials and Methods

The San Ignacio lagoon is located on the west coast of the Baja California peninsula, México, in the city of Mulegé, in the state of Baja California Sur. Geographically is located between parallels 26°43’ and 26°58’ N and between meridians 113°08’ and 113°16’ W. Sampling localities were specifically chosen to cover most of the lagoon, from entry to end (Figure 1; Table 1).

![Area of study and location of the sampling stations in Laguna San Ignacio Baja California Sur, Mexico](image)

**Figure 1** Area of study and location of the sampling stations in Laguna San Ignacio Baja California Sur, Mexico

Note: Canal del Cardón (1), La Freidera (2), La Base (3), El Anegado (4), Norte Isla Garza (5), El Remate (6), Cantil Cristal (7), La Choya (8), Los Cerritos (9), Las Islitas (10), El Mapache (11)

<table>
<thead>
<tr>
<th>Sites</th>
<th>North latitude</th>
<th>West length</th>
<th>Substrate</th>
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</thead>
<tbody>
<tr>
<td>1.- Canal el Cardon</td>
<td>26° 44’ 17.5”</td>
<td>113° 13’ 21.7”</td>
<td>Sandy</td>
</tr>
<tr>
<td>2.- La Freidera</td>
<td>26° 49’ 46.6”</td>
<td>113° 10’ 13.0”</td>
<td>Muddy</td>
</tr>
<tr>
<td>3.- La Base</td>
<td>26° 51’ 41.9”</td>
<td>113°08’ 36.5”</td>
<td>Conchal</td>
</tr>
<tr>
<td>4.- El Anegado</td>
<td>26° 55’ 10.2”</td>
<td>113°08’ 43.9”</td>
<td>Muddy</td>
</tr>
<tr>
<td>5.- Norte Isla Garza</td>
<td>26° 56’ 33.9”</td>
<td>113°09’ 41.3”</td>
<td>Muddy</td>
</tr>
<tr>
<td>6.- El Remate</td>
<td>26° 58’ 05.9”</td>
<td>113°09’ 35.9”</td>
<td>Muddy</td>
</tr>
<tr>
<td>7.- Cantil Cristal</td>
<td>26° 56’ 35.0”</td>
<td>113°11’ 21.7”</td>
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</tr>
<tr>
<td>8.- La Choya</td>
<td>26° 53’ 00.8”</td>
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<td>Conchal</td>
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<tr>
<td>9.- Los Cerritos</td>
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<tr>
<td>10.- Las Islitas</td>
<td>26° 50’ 52.8”</td>
<td>113°12’ 05.3”</td>
<td>Sandy</td>
</tr>
<tr>
<td>11.- El Mapache</td>
<td>26° 48’ 55.6”</td>
<td>113°15’ 43.9”</td>
<td>Clayey</td>
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</tbody>
</table>
The San Ignacio lagoon has a coastline with sandy beaches, muddy lowlands, mangroves, marshes and a few rocky areas. It is a shallow water body with average depths from 2 to 4 meters and a depth of 20 meters in the channel zone that communicates with the ocean (Swartz and Cummings, 1978). The substrate of this lagoon is variable (Barjau-González, 2003) (Table 1). Geographically it is in the Californian province (Robertson and Cramer, 2009).

Six bi-monthly samplings were carried out in 11 localities from April 2013 to April 2014. An experimental trawl net with a length of 9 m, a vertical opening of 4.5 m, a mesh size of 1.5 inches, and metal doors of 95x50 cm, was used to catch the fish. The trawl speed was 3.5 km/h, sweeps were carried out with a duration of 20 minutes at an average depth of 5 m at each locality. Sweeps in which no capture was recorded were considered as water sweeps.

A 22 feet boat with a 90 HP four stroke outboard motor was used as a trawler. Ecological indexes used in this study were relative abundance, Margalef’s species richness, Shannon-Weiner diversity (log 2), Fisher’s alpha diversity, Pielou’s evenness and Biological Value Index (BVI). Fish species were classified in four groups based on abundance and catch frequency: abundant, frequent, common and rare. At each locality, the physicochemical variables were recorded using YSI 2030 Pro multiparameter instrument to determine the salinity and bottom temperature. Species identifications were carried out using specialized literature (Miller and Lea, 1972; Fischer et al., 1995; Thomson et al., 2000). Ecological indexes were analyzed using the software Primer-E & Permanova 6 and statistical analysis were performed using Statistica v.7.

2 Results

2.1 Physicochemical variables

According to the analysis of environmental variables, there were significant differences in temperature between months (F (5, 60) = 107.31, P<0.05). The highest average temperature (25.2°C) was recorded in August and the lowest (16.3°C) in December. No significant differences were found between localities (F (10.55) = 0.3163, P>0.05) (Table 2; Table 3).

Table 2 Monthly average values of parameters and ecological indexes

<table>
<thead>
<tr>
<th></th>
<th>April</th>
<th>June</th>
<th>August</th>
<th>October</th>
<th>December</th>
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<tr>
<td>Temperature (°C)</td>
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<td>24.52</td>
<td>25.21</td>
<td>22.34</td>
<td>16.26</td>
<td>18.63</td>
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<tr>
<td>Salinity (‰)</td>
<td>37.05</td>
<td>38.02</td>
<td>36.87</td>
<td>35.37</td>
<td>32.61</td>
<td>31.15</td>
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<td>Species richness</td>
<td>0.75</td>
<td>1.1</td>
<td>1.88</td>
<td>1.2</td>
<td>0.28</td>
<td>0.78</td>
</tr>
<tr>
<td>α-Fisher’s diversity</td>
<td>2.3</td>
<td>4.87</td>
<td>10.19</td>
<td>7.88</td>
<td>1.08</td>
<td>2.48</td>
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<td>1.89</td>
<td>1.2</td>
<td>0.37</td>
<td>0.81</td>
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<td>0.52</td>
<td>0.67</td>
<td>0.62</td>
<td>0.3</td>
<td>0.35</td>
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</table>

Table 3 Average values of parameters and ecological indexes by sites

<table>
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<th>4</th>
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<th>9</th>
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<tr>
<td>Salinity (‰)</td>
<td>33</td>
<td>33.38</td>
<td>36.62</td>
<td>36.25</td>
<td>36.1</td>
<td>36.97</td>
<td>36.65</td>
<td>35.75</td>
<td>35.48</td>
<td>33.97</td>
<td>32.78</td>
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<tr>
<td>Species richness</td>
<td>0.77</td>
<td>0.82</td>
<td>0.8</td>
<td>1.03</td>
<td>1.27</td>
<td>2.27</td>
<td>1.28</td>
<td>0.1</td>
<td>0.97</td>
<td>0.48</td>
<td>1.19</td>
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<tr>
<td>α-Fisher’s diversity</td>
<td>1.97</td>
<td>2.77</td>
<td>2.16</td>
<td>3.92</td>
<td>12</td>
<td>13.5</td>
<td>3.19</td>
<td>0.36</td>
<td>3.7</td>
<td>4.09</td>
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<tr>
<td>Shannon-Wiener diversity</td>
<td>0.86</td>
<td>0.93</td>
<td>0.78</td>
<td>1.07</td>
<td>1.3</td>
<td>2.3</td>
<td>1.33</td>
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<td>0.98</td>
<td>0.5</td>
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<tr>
<td>Pielou’s evenness index</td>
<td>0.46</td>
<td>0.32</td>
<td>0.46</td>
<td>0.44</td>
<td>0.6</td>
<td>0.84</td>
<td>0.64</td>
<td>0.12</td>
<td>0.47</td>
<td>0.33</td>
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Note: Canal del Cardón (1), La Freidera (2), La Base (3), El Anegado (4), Norte Isla Garza (5), El Remate (6), Cantil Cristal (7), La Choya (8), Los Cerritos (9), Las Islitas (10), El Mapache (11)

There were significant differences in salinity between months (F (5.60) = 18.3754, P<0.05). The highest average salinity was recorded in June (38‰) and the lowest in April 2014 (31.1‰). There were no significant differences in salinity between localities (F (10.55) = 1.5622, P>0.05) (Table 2; Table 3).

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2.2 Ecological indexes

A total of 2,887 organisms from 46 species grouped into two classes, nine orders, 26 families and 38 genera were captured. The most representative families according to their relative abundance were: Ephippidae (76.5%), Serranidae (3.74%), and Clupeidae (2.15%).

According to total abundances per month, an abundance of 108 organisms was recorded in April 2013, followed by June 2013 with 80 organisms, August 2013 with 194 organisms, October 2013 with 93 organisms, December 2013 with 313 organisms and April 2014 with the highest abundance of 2,099 organisms.

According to abundances by localities, El Remate (6), located at the end of the lagoon, had the highest abundance with 2,294 organisms from which 1,964 were individuals of the species C. zonatus, followed by the northern locality of Isla Garza (5) with 96 organisms, El Cardón (1) with 81 organisms and La Base (3) with 75 organisms.

General relative abundance was calculated with seven species comprising 90.2% of the sampling total, these species are C. zonatus (76.5%), Leuresthes tenuis (3.6%), E. currani (2.8%), S. caeruleus (1.9%), P. maculatofasciatus (1.8%), S. lobatus (1.8%) and P. nebulifer (1.8%).

According to the species richness analysis, there were significant differences between months (F (5.60) = 2.7306, P <0.05). The highest average (1.87) was recorded in August, while the lowest average (0.28) was recorded in December. These differences comprised two homogeneous groups: the first group (June, August and October of 2013) had the highest value of species richness, and the second (April, June, October of 2013 and April 2014) had the lowest value. According to the analysis of species richness by localities, no significant differences were found (F (10, 55) = 1.6726, P>0.05). Richness values by localities ranged from 0.01 to 2.27 (Table 2; Table 3).

The highest values of Fisher’s alpha diversity were recorded in the warmer months (August and October) while the lowest diversity values were recorded in the temperate months (December and April). No significant differences were found between months (F (10, 55) = 1.8821, P>0.05). Diversity values for the northern localities, Isla Garza (5) and El Remate (6), were 12 and 13.5, respectively, being these the highest values, while the localities La Base (3) and La Choya (8) presented the lowest values of diversity 2.16 and 0.11 respectively. There were no significant between localities (F (10, 55) = 1.2688, P>0.05) (Table 2; Table 3).

According to the analysis of variance, no significant differences were observed for the Shannon-Wiener diversity index per month (F (5.60) = 2.3676, P>0.05). A similar pattern was observed for temperature, with the highest values of diversity in the warmer months and the lowest diversity in the temperate months. These values indicate a low to medium diversity (0.37 to 1.89 bits/ind.). The analysis of the Shannon-Wiener diversity index by localities showed no significant differences (F (10, 55) = 1.6452, P>0.05). The locality of La Choya (8) showed the lowest diversity value with an average of 0.2 bits/ind., while the locality El Remate (6) showed the highest value with an average of 2.3 (Table 2; Table 3).

According to the evenness index, there was a natural variation over time, with a minimum value of 0.3 in the month of December 2013, and a maximum value of 0.67 in the month of August of 2013. The analysis of variance did not show significant differences between months (F (5, 60) = 1.259, P>0.05) (Table 2). Evenness index by localities showed no significant differences (F (10, 55) = 1.0076, P>0.05). The highest values of evenness were found in the inland areas of the lagoon, the other localities had similar values except for La Choya, which had the lowest evenness value (0.1) (Table 2; Table 3).

The biological value index (BVI) is an indicator of the general dominance by species. It is recommended to use 95% of the relative abundance of individuals per sample to eliminate data lacking relevant information (Loya-Salinas and Escofet, 1990) In this analysis the most dominant species were: C. zonatus, P. maculatofasciatus, S. lobatus, P. nebulifer, S. annulatus, Pleuronichthys guttulatus, C. brachysomus, A. ischana, with the highest frequency and relative abundance, obtaining a maximum BVI of 59 and a minimum BVI of 1 (Figure 2).

The 46 species were classified in four groups based on their occurrence and relative abundance (Figure 3).
Abundant species: 14 species were grouped as abundant, since their relative abundance was greater than 1%. Within this group the species with greater abundance and frequency were *C. zonatus*, *L. tenuis*, *E. currani* and *S. caeruleus*.

Frequent species: Nine species were classified as frequent because their relative abundance ranged from 0.10% to 0.96%. The species with greater abundance and frequency within this group were *E. dowii*, *E. asper* and *B. polylepis*.

Common species: Eight species were included in this group since their relative abundance ranged from 0.09% to 0.02%. Within this group the species with greater abundance and frequency were *Haemulon flaviguttatum*, *Halichoeres semicinctus* and *Cynoscion xanthulus*.

Rare species: This group comprised 15 species with a relative abundance value less than 0.01%. Within this group the species with greater abundance and frequency were *Ancylopsetta dendritica*, *Atherinops affinis* and *Cynoscion phoxocephalus*.

3 Discussion

3.1 Physicochemical variables

According to physicochemical variables, studies in nearby lagoons such as Bahia Magdalena (south of San Ignacio) (Gutiérrez-Sánchez, 1997), Laguna Ojo de Liebre (north of San Ignacio) (Acevedo-Cervantes, 1997) and Barjau et al. (2015), found similar results to this study. Based on the temperatures recorded in our study, there are two climatic seasons, warm (June to October) and cold (December to April). Temperature records in San Ignacio show that minimums are in the mouth of the lagoon while maximums are in the end, and are similar to previous studies from this lagoon and adjacent lagoons. We infer a similar pattern because the deepest area of the lagoon is in the entrance while the shallow areas are in the end, suggesting warm-up of the water, coupled with a replacement of the water that takes around three to five months (Ocean. Leonardo Álvarez Santamaría, Personal Conv. UABCS) (Table 2; Table 3).
High values of salinity recorded in this study with a maximum of 38‰ in June 2013 and a minimum of 31.1‰ in April 2014, are similar to values recorded by Núñez-López (1996), with a minimum salinity of 32‰ in winter and a maximum of 37‰ in autumn during 1992-1993. On the other hand, Barjau-González (2003) recorded higher values, a maximum of 42‰ in summer of 1998, and a minimum of 36‰ in winter of 1999, with oceanographic events such as El Niño in 1998 and La Niña in 1999, which may have caused these differences.

3.2 Ecological indexes
The species registered in this study have been previously recorded in this lagoon (Barjau-González, 2003) and in lagoons near San Ignacio (Acevedo-Cervantes, 1997; Gutiérrez-Sánchez, 1997). From the 44-species recorded by Barjau-González (2003), 18 were also recorded in this study. Gutiérrez-Sánchez (1997) recorded 75 species of which 19 species were also recorded in this study. Acevedo-Cervantes (1997) recorded a total of 59 species, 15 species of these were also captured during our samplings. It is important to mention that these studies do not show the same list of species nor the same methodology, which highlights the selectivity of the fishing gear used, sampling effort, characteristics of the area, mobility of the species and habitat diversity (Gutiérrez-Sánchez, 1997; Barjau-González, 2003).

Main factors that affect abundance and distribution of the species are the physical, chemical and biological properties of their habitat, as well as the capacity of each species to tolerate these conditions (Lagler et al., 1984; Torres-Orozco and Castro-Aguirre, 1992; Barjau-González, 2003; Barjau et al., 2015).

In the present study we recorded a higher abundance than the one recorded by Barjau-González (2003) with an abundance of 1,361 organisms. A difference between this studies was the number of samplings, in this study six samplings were carried out, while in 2003 four were carried out.

Regarding seasonal abundance, the greater abundances were recorded in April, August and December, and the lower abundances were recorded in June and October. These results differ from those found by Barjau-González (2003), with higher abundances recorded during the fall season, and lower values recorded during spring. This is probably due to the events El Niño in 1998 and La Niña in 1999.

Regarding spatial abundance, all the localities presented a similar spatial variation, except for locality 6, in which only 2,294 organisms were captured, of which 1,964 were captured in a single sweep. One factor that could have caused this was that locality of El Remate is the furthest from the entrance of the lagoon, with muddy sediment because is a discharge area during rainy seasons, also is one of the shallowest localities and is influenced by low tides.

In contrast to this study, Barjau-González (2003) recorded that 20 species contributed with 90.36%, of which, seven species contributed with values greater than 4%, these species were: Paralabrax auroguttatus, Sphoeroides lispus, P. maculatofasciatus, P. nebulifer, S. annulatus, E. dowii and Bairdiella icistia. Studies in nearby lagoons, such as Ojo de Liebre lagoon (north of our study area), have recorded six species that contributed 80.8% using a fishing gear like the one used in this study: Sphoeroides sp., P. maculatofasciatus, Urobatis halleri, Urobatis maculatus, Hypsosetta guttulata and S. annulatus (Acevedo-Cervantes, 1997). In Magdalena-Almejas Bay (south of our study area), five species with abundances greater than 4% were recorded (Etropus crosstotus, P. maculatofasciatus, E. dowii, U. maculatus and Arius platypogon) (Gutiérrez-Sánchez, 1997). In the El Coyote estuary, an adjacent and northern area to San Ignacio lagoon, Ramírez-De Aguilar Azpiroz (2001), mentioned that the six most abundant species were: S. annulatus, S. lispus, U. maculatus, P. maculatofasciatus, E. dowii and B. icistia. When comparing these studies, there are similar species that exist within these lagoons, and some of these species were found in the lagoon throughout the whole year, which suggests they are adapted to this type of environment, therefore they are considered resident species with euryhaline and eurythermal adaptations. Physiological and biological processes such as reproduction, breeding, feeding and shelter are carried out in these lagoons by these species (Barjau-González, 2003; Barjau-González et al., 2015).
In this study, significant differences in the monthly values of specific richness were found, higher values were recorded in the warmer months (June-August-October) and lower values were recorded in the temperate months (December-April). This may be because in the warmer months there are more species with tropical affinity (Barjau-González, 2003; Kosegarten-Villarreal et al., 2016). These results were partially similar to what Gutiérrez-Sánchez (1997) recorded in Magdalena-Almejas Bay, higher values in the colder months and lower values in the warmer months. This may be due to ecosystem differences and that this area is in a subtropical zone, considered an ecotone between California (cold) and sub-equatorial (warm) currents.

The α-Fisher diversity analysis of this study revealed no seasonal or spatial differences. These results are similar to what was found by Barjau-González et al. (2014), who carried out the same analysis in this lagoon. In both studies, it was expected that diversity would be different, because variations of temperature and salinity throughout the year and difference of substrates and depths along the lagoon have been described as factors of great relevance in the role of the diversity of ecosystems (Allen and Horn, 1975; Amezcua-Linares, 1977; Quinn, 1980; Amezcua-Linares, 1996; Manjarrez-Acosta, 2001). The Shannon-Wiener diversity analysis, as with the α-Fisher diversity, revealed no significant differences between seasons and localities. Diversity values recorded in the present study had a temporal variation of 0.3 to 1.9 bits/ind. and a spatial variation of 0.1 to 2.3 bits/ind.

Based on results of the evenness analysis, there was not a seasonal and spatial distribution of evenness, probably because of the dominance of some species. Barjau-González (2003) also recorded no spatial or seasonal distribution of evenness in the San Ignacio lagoon.

BVI analysis showed 12 dominant species, of which the ones with the highest values were: C. zonatus, P. maculatofasciatus, S. lobatus, P. nebulifer, S. annulatus, P. guttulatus, C. brachysomus , A. ischana. Barjau-González (2003) and Barjau-González et al. (2015) recorded 14 species as the most dominant in the lagoon, and described the species with the highest values were S. lispus, P. auroguttatus, P. maculatofasciatus, P. nebulifer, B. icistia, E. asper and S. annulatus. Based on these species, P. maculatofasciatus, P. nebulifer and S. annulatus coincide with our study. Comparing these results with those found in nearby lagoons, Magdalena-Almejas Bay with 12 dominant species and most abundant were: A. platypogon, S. annulatus, Paralichthys californicus, Diplobatis ommata, Pleuronichthys ritteri, Urobatis halleri and Achirus maczlanus (Gutiérrez-Sánchez, 1997). On the other hand, in Laguna Ojo de Liebre, Acevedo-Cervantes (1997) recorded the most dominant species were: P. maculatofasciatus, U. halleri and U. maculatus. In these studies, the species that was always present is P. maculatofasciatus. The species previously mentioned present a spatio-temporal constancy within the lagoon systems, which directly influences their dominance (Loya-Salinas and Escotef, 1990).

These dominant species present certain biological strategies that allow them to dominate over others, such as their reproductive capacity, feeding habits (opportunist, generalists), tolerance to changes in environmental factors, etc., which allows them to carry out processes such as feeding, breeding, and the use of the area as protection (Acevedo-Cervantes, 1997). Most dominant species show similar feeding habits, suggesting a proximity to the benthos and that they belong to the first levels of the food web. These feeding habits have been noted as of high importance because fish have been recognized by difference authors as important regulators of the community structure of the benthos, which can be of economic importance for the area, like some of the crustaceans that inhabit the lagoon.

Classification of species by their relative abundance and their frequency of occurrence in the samplings, is useful to identify which species are present throughout the year. This analysis contrasted from previous studies such as those by Aburto-Ortizpeza (2000) and Barjau-González (2012), who mentioned that according to this classification, depending on time of sampling, a species can be abundant or may be rare.

Based on the previous, we conclude that pattern of physicochemical parameters showed a defined seasonal variation, similar to what was recorded by other authors. The lagoon presents a low to medium diversity (0.3 to 2.3 bits/ind). According to the BVI analysis, most dominant species were, C. zonatus, P. maculatofasciatus, S. lobatus, P. nebulifer, S. annulatus, Pleuronichthys guttulatus, C. brachysomus and A. ischana.
Authors' contributions
FMF wrote this manuscript and carried out the statistical analysis. EBG collected data, applied for funding, carried out samplings and identified organisms. AKRP and JMLV revised the manuscript. All authors revised this manuscript and declare no conflict of interests.

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