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Zoogeographic Analysis of the Fish Fauna Associated with Soft Bottoms during El Niño - La Niña (98-99) In San Ignacio Lagoon, Baja California Sur, Mexico

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Abstract

The San Ignacio Lagoon is part of the Vizcaino Biosphere Reserve, a location that has been declared a critical area for the conservation of marine mammals and fish that use it for breeding, feeding and refuge. The present paper has as its main focus to determine the impact of a large-scale oceanographic phenomenon (El Niño/La Niña) on the zoogeographic composition of the community of soft-bottom fish of the San Ignacio Lagoon.

During the warm El Niño period of spring and fall 1998, the average water temperatures in San Ignacio Lagoon were between 20.9 and 21.1°C (± 0.2°C), while during the summer of 1998 average temperatures were higher (24.3°C), and during the cold La Niña period of the 1999 winter a 13.4°C average temperature was recorded. Eight species were present during all seasons: *Eucinostomus dowii, Hippocampus ingens, Hypsopsetta guttulata, Paralabrax maculatofasciatus, Paralichthys californicus, Sphoeroides annulatus, Sphoeroides lispus and Urobatis halleri*. The species with the highest abundance during El Niño were: *Paralabrax maculatofasciatus, Eucinostomus dowii*; whereas during La Niña the most abundant species were: *Sphoeroides lispus, Paralabrax auroguttatus and Sphoeroides annulatus*. The recorded fishes had zoogeographic affinity for the following provinces: Panamic (36%), Californian (32%), Eastern Pacific (18%) and Mexican (11%). Eleven fish species of tropical affinity that were recorded during El Niño event of 1997-1998.

Keywords: San Ignacio Lagoon; El Niño-La Niña events; Fish fauna; Soft bottoms

Introduction

The San Ignacio Lagoon is the second largest lagoon on the Pacific coast of Baja California Sur, Mexico (BCS). It is classified zoogeographically as belonging to the Californian Province [1] and is situated within a temperate region. However, during events like El Niño, when there is an influence of tropical waters from the eastern Pacific, and during La Niña, when temperatures are cooler than normal, the presence of species with tropical affinities, or the absence of species adapted to different temperatures, are common.

These events occur over irregular intervals of time spanning 2-7 years [2], although the average is about once every 3-4 years [3,4]. The main effects of the El Niño (EN) – La Niña (LN) episodes in the Pacific Ocean are changes in seawater temperatures, seawater levels, current patterns and atmospheric pressures, and interannual variability of the coupled ocean-atmosphere system. Warm surface waters during El Niño years promote an increase in latent heat in the lower atmosphere, and provide good conditions for the development of stronger hurricanes. During La Niña the atmosphere-ocean system conditions are different, and the formation of tropical hurricanes is avoided, thanks to low sea surface temperatures [5].

The effects of changing weather on marine ecosystems are only partially known, but there is evidence of effects on fish populations and fisheries [6-10]. La Niña is known as the anti-Niño, and is characterized by water-cooling. Its impacts on global climate are opposite to those of El Niño [11]. La Niña occurs after some, but not all El Niño episodes, and typically El Niño occurs more frequently than La Niña [12]. The influence of abnormally cool water on fish populations, as well as the effects of El Niño, is still not well understood. The present study was carried out in order to determine changes in the soft-bottom fish populations during these oceanographic events in San Ignacio Lagoon. This paper is the first of its kind in this important coastal lagoon; one of the effects of these phenomena was on the presence/absence of species detected during each event, although eight species were recorded throughout the study.

Material and Methods

San Ignacio Lagoon is located on the west coast of the Baja California peninsula between 26°43' and 26°58' N, and 113°08' and 113°16' W (Figure 1). It is a shallow lagoon; depths range from 2 to 4 meters, and can be up to 20 meters in the channels that connect the lagoon with the Pacific Ocean [13]. Inside the lagoon there is a system of channels separated by extensive sand bars that are exposed during low tide [13,14]. The coasts are composed of sandy beaches, muddy plains, mangrove forests, wetlands and a few rocky areas. The northern part of the lagoon comprises the main body of water, and a second body of water extends towards the east, and includes most of the mangrove area [15].

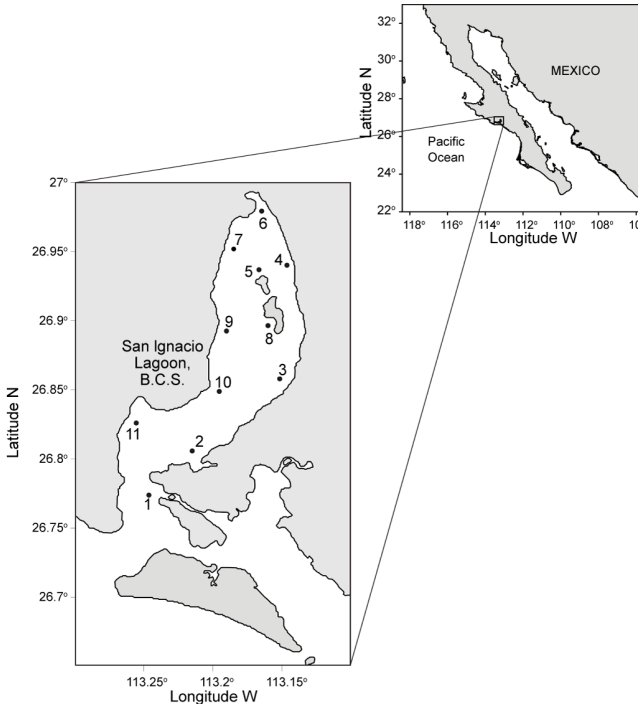

Figure 1: Sampling locations in San Ignacio Lagoon, Baja California Sur, México.Canal del Cardon (1), La Freidera (2), La Base (3), El Anegado (4), Norte Isla Garza (5), El Remate (6), Cantil Cristal (7), La Choya (8), Los Cerritos (9), Las Islitas (10), El Mapache (11).

Four sampling trips were carried out in spring, summer, and fall 1998, and winter 1999. A total of 44 trawls were made at 11 sites during the study period. A 9 m long otter trawl with a 45 m opening, 1.5 inch mesh size, and 95x50 cm metallic doors was used to catch fish. Trawls lasted thirty minutes at each site, and were done at 3.5 km/hour, using a 22 foot boat with 75 HP engine.

To determine temperature (± 0.1ºC) and dissolved oxygen concentration (± 0.1 mg/L), these variables were measured using an YSI model 63; salinity was measured using a refractometer Atago ATC-S / Mill-E, on a scale of 0 to 100 % (± 1%). These parameters were measured at each station at the end of the tow.

Fish were weighed, measured (total length and standard length), fixed in formalin, and transported to Laboratorio de Ictiología of UABCS in La Paz, Baja California Sur, Mexico, where they were preserved in isopropyl alcohol. Fish were identified using taxonomic keys and specialized bibliography for each taxonomic group [1,16-20].

An analysis of presence/absence was conducted based on the frequency of occurrence of fish species in at least four of the eleven areas.

An analysis of the spatio-temporal distribution was conducted to determine the distribution of the fish species recorded in San Ignacio Lagoon.

The zoogeographic affinity of fish was analyzed according to the basic scheme by [21], with modifications by [22-24], considering the following provinces and affinity:

1. San Diego Province: from Point Conception, California to Magdalena bay off the western coast of Baja California Sur. Corresponding affinity warm-temperate
2. Cortez Province: endemic fishes from the Gulf of California, taking as the southern limit Cabo San Lucas on the western coast and Mazatlan on the eastern coast of the Gulf. Corresponding affinity warm-temperate and subtropical.
3. Mexican Province: fishes found from Magdalena bay or Cabo San Lucas to the Gulf of Tehuantepec, Oaxaca. Corresponding affinity subtropical.
4. Panamic Province: fishes found in the subtropical-tropical zone, between 23° N and 5° S (Peru). Corresponding affinity tropical.
5. Eastern Pacific: fishes with a wide distribution in the Tropical Eastern Pacific from California to Peru.
6. Circumtropical: fishes with a wide distribution in tropical areas.
7. Indo-Pacific: fishes with a transpacific distribution, originating in the Indo-Pacific Ocean.

To determine fish diversity for every season, El Niño and La Niña, we use the Shannon & Weaver Index, using the ecological software PRIMER-E 6 & PERMANOVA+ version 1.0.2.

Analysis of Variance (ANOVA) was performed to determine statistical differences between seasons, using the software STATISTICA v.8.

Results

Temperature: During the sampling period, a seasonal variation in bottom temperatures was observed, with spring average temperatures of 21.1°C, and summer average temperatures of 24.3°C; in fall the 20.9°C temperature was probably influenced by La Niña; in winter the average temperature was 13.4°C. The average temperature recorded during the El Niño event corresponding to spring, summer and fall of 1998 was 22.1°C, and for the winter of 1999, corresponding to the La Niña event, the average temperature recorded was 13.4°C, with a calculated variation of 8.7°C. The anomaly found for both events was of 2 to 3°C (Jorge Urbán-Ramírez Dr. UABCS, pers. com.). In general, the temperature presented a well-defined seasonal pattern; it was clear that spring and fall are transition periods between summer and winter (Figure 2).

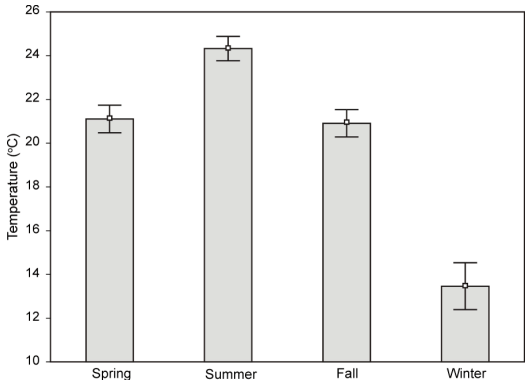

Figure 2: Seasonal bottom temperature in San Ignacio Lagoon during El Niño1998 and La Niña 1999. (ANOVA: F (3, 40)=413.8, p=<0.05), whit ±0.95 Conf. Interval.

Salinity: San Ignacio Lagoon is considered a hypersaline lagoon, which implies that higher salinity waters are dense and sink close to the ocean floor, while water that is relatively less dense is transported into the lagoon near the surface [25]. The salinities recorded in spring, summer, fall and winter at the mouth of the lagoon (site 1 and Figure 1) were 36, 37.5, 36 and 36 respectively, while in the inner area (site 6 and Figure 1) the salinities were 39, 42, 40, and 39 respectively (Figure 3).

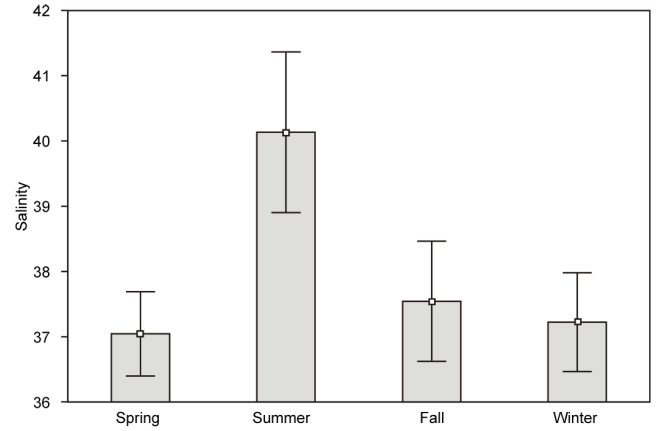

Figure 3: Salinity in San Ignacio Lagoon during El Niño 1998 and La Niña 1999. (ANOVA: F (3, 40)=12.4,p=<0.05), whit ±0.95 Conf. Interval.

Dissolved oxygen: concentration of dissolved oxygen (DO) in the lagoon was significantly different during an annual cycle (F (3,40)=153.89, p=<0.05); there were pronounced gradients, with the highest values occurring in spring and fall (4.13 mL * L.), and the lowest values occurring in summer and winter (2.9 mL * L and 2.6 mL * L respectively). The average DO value over the whole study period was 3.33 mL* L (Figure 4).

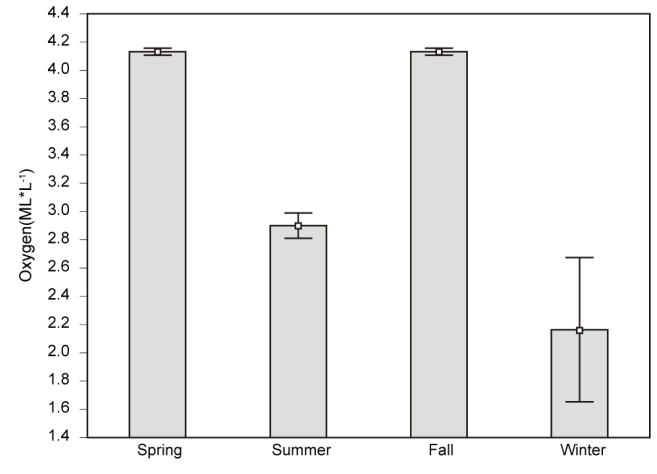

Figure 4: Dissolved Oxygen in San Ignacio Lagoon during El Niño 1998 and La Niña 1999. (ANOVA: F (3, 40)=153.8, p=<0.05),whit ± 0.95 Conf. Interval.

General composition of the fish community: 11 trawls were conducted during each season, totaling 44 trawls with a total drag area of 346,500 m2. A total of 1361 organisms were collected, with a biomass of 67,118 grams. The fish fauna of the lagoon was composed of 44 species, 35 genera and 21 families. The families that contributed the most species were: Serranidae, Haemulidae, and Sciaenidae with 4 species each; followed by Engraulidae, Bothidae, Gerreidae, and Tetraodontidae with 3 species each. The remaining families were represented by 1 or 2 species. Table 1 shows the species abundance during El Niño and La Niña.

Seasonal distribution: A presence/absence analysis revealed that eight species were present in the lagoon during all seasons: *Eucinostomus dowii, Hippocampus ingens, Hypsopsetta guttulata, Paralabrax maculatofasciatus, Paralichthys californicus, Sphoeroides annulatus, Sphoeroides lispus* and *Urobatis halleri* (Table 1). Eleven species were present during three seasons, six were recorded during two seasons, and the rest occurred in only one of the four seasons (Table 1). Of the 44 species, 27% were recorded in spring, 26% in summer, 24% in fall, and 21% in winter.

Species	EN	LN	ZOO.	Season
Achirus mazatlanus	10	8	EP	SP/F/W
Anchoa compressa	19	0	DP	SP
Anchoa ischana	6	0	PP	S
Atherinops affinis	8	0	DP	S
Bairdiella icistia	67	0	MP	SP/S/F
Calamus brachysomus	5	1	PP	S/F/W
Cetengraulis mysticetus	11	0	PP	SP/F
Cyclopsetta panamensis	0	34	PP	W
Chaetodipterus zonatus	7	0	PP	S/F
Etropus crossotus	8	0	EP	SP/S/F
Eucinostomus dowii	58	13	PP	ALL
Eucinostomus entomelas	0	11	PP	W
Eucinostomus gracilis	22	1	PP	SP/S/W
Exerpes asper	61	2	AP	SP/F/W
Halichoeres semicinctus	1	0	DP	F
Heterodontus francisci	2	1	DP	SP/S/W
Hippocampus ingens	8	2	EP	ALL
Hoplopagrus guntheri	1	0	PP	F
Hypsoblennius gentilis	46	0	DP	S/F
Hypsopsetta guttulata	26	4	DP	ALL
Menticirrhus undulatus	1	0	PP	SP
Microlepidotus inornatus	4	0	MP	S
Mycteroperca xenarcha	3	0	EP	F
Opisthonema libertate	0	1	PP	W

Orthopristis reddingi	62	0	MP	SP/S/F
Paraclinus integripinnis	1	0	DP	SP
Paralabrax auroguttatus	176	43	DP	SP/F/W
Paralabrax maculatofasciatus	126	8	DP	ALL
Paralabrax nebulifer	110	0	DP	SP/S
Paralichthys californicus	13	8	DP	ALL
Pleuronichthys verticalis	0	1	DP	W
Pomadasys panamensis	0	11	PP	W
Pseudupeneus grandisquamis	15	0	PP	SP/S
Quietula y-cauda	4	1	DP	SP/F/W
Scorpaena mystes	2	0	PP	SP/F
Sphoeroides annulatus	45	30	EP	ALL
Sphoeroides lispus	95	81	MP	ALL
Sphoeroides lobatus	2	0	EP	S
Syngnathus auliscus	2	0	EP	SP/F
Umbrina roncador	18	0	DP	S
Umbrina xanti	7	0	PP	S
Urolophus halleri	20	5	EP	ALL
Urolophus maculatus	12	5	MP	SP/S/W
Xenistius californiensis	6	0	PP	SP/S
Total species by season	39	21		27/26/24/21

Table 1: Abundance of fish species in San Ignacio lagoon during El Niño (EN) 1998 and La Niña (LN) 1999; Biogeographic affinity of fish fauna in San Ignacio Lagoon: PP=Panamic Province, EP=Eastern Pacific, MP=Mexican Province, DP=San Diego Province, AP=Amphipeninsular; Season: Spring (SP,) Summer(S), Fall (F) and Winter (W).

Spatial distribution: seven species were recorded at four to eleven sites within the lagoon (Table 2).

Species	**S 1**	**S 2**	**S 3**	**S 4**	**S 5**	**S 6**	**S 7**	**S 8**	**S 9**	**S10**	**S 11**
Eucinostomus dowii			P	P	P	P	P	P	P	P	P
Hippocampus ingens		P	P						P	P	
Hypsopsetta guttulata	P		P	P	P	P				P	P
Paralabrax maculatofasciatus			P	P	P	P	P	P	P	P	P
Paralichthys californicus	P		P	P	P		P	P		P	P
Sphoeroides annulatus	P	P	P	P	P	P	P	P	P	P	P
Sphoeroides lispus		P	P	P	P	P	P	P	P	P	P
Urobatis halleri			P	P	P	P	P	P	P	P	
Total species by site	3	3	8	7	7	6	6	6	6	8	6

Table 2: Principal fish species recorded by frequency of occurrence in at least four of the eleven sampling sites (S) in San Ignacio lagoon during 1998-1999. P=Presence.

Biogeographic affinity: The zoogeographic analysis yielded 16 species (36%) belonging to the Panamic Province, 14 species (32%) belonging to the San Diego Province, 8 species (18%) belonging to the Eastern Pacific, 5 species (11%) belonging to the Mexican Province, and one species (2%) listed as amphipeninsular since it is found on both sides of the Baja California Peninsula (Table 1).

Shannon & Weaver Index during spring scored the highest value (3.18 bits/ind), followed by fall (3.05 bits/ind), summer (2.96 bits/ind) and winter (2.83 bits/ind). Regarding the ENSO events, El Niño scored the highest value (4.21 bits/ind.) and La Niña scored a lower value (3.29 bits/ind.) (Figure 5).

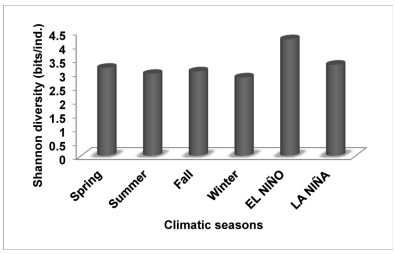

Figure 5: Shannon-Weaver diversity index (H') for spring, summer, fall and winter, and El Niño and La Niña events in San Ignacio Lagoon, BCS.

Discussion

Due to low precipitation, San Ignacio Lagoon is considered an anti-estuarine coastal lagoon, with mostly shallow depths between 2 and 4 meters, and up to 20 meters in the channel areas [13]. A high tide of up to 2 meters and a time lag of 45 minutes between the mouth and the innermost portion of the lagoon result in the tide currents affecting the physical parameters. It is also important to consider that it takes a long time to exchange the lagoon water; this process can last from 3 to 5 months (Leonardo Álvarez-Santamaría MS. UABCS, pers. com.). During the study, the presence of two events, El Niño from 1997-1998 and La Niña in 1999, had an effect on the composition and abundance of the fish fauna in San Ignacio Lagoon, as well as on the environmental parameters (temperature, salinity and dissolved oxygen).

The bottom temperature presented a well-defined seasonal gradient, with the maximum temperature recorded during summer (25°C), and the minimum recorded in winter (11.2°C). The intermediate climate seasons of spring and fall had very similar temperatures (average 21°C). These results coincide with the patterns recorded by [26,27] for Bahia Magdalena. These authors also mentioned that bathymetry, tidal currents, warming and irregular evaporation of the water are the main factors that affect this lagoon system south of San Ignacio Lagoon [28]. Working in Ojo de Liebre Lagoon, B.C.S., north of San Ignacio Lagoon, determined that extremes in surface temperature during the year ranged from 13.5 to 26°C. Comparing these results with those from San Ignacio Lagoon, we observed temperatures during spring and fall that were very similar, with fluctuations of 1.9°C between localities, while in summer and winter the average fluctuations were of 13.8°C. The highest temperature was recorded in summer; temperatures increased from spring to summer and decreased through winter, so it can be inferred that spring and fall are transitional seasons between summer and winter. It is interesting to note that transitional seasons are still detectable under extreme EN/LN episodes such as those of 1997/1998 and 1999, a fact also reported by [27] for Bahia Magdalena. The temperature pattern detected in San Ignacio Lagoon has been reported for other coastal lagoons to the south and north of San Ignacio Lagoon; this coincides with data reported by [27] for Bahía Magdalena and by [29] for Ojo de Liebre Lagoon. These coincidences between Ojo de Liebre Lagoon (north of San Ignacio) and Magdalena Bay (south of San Ignacio) may be due to these lagoons having similar solar heating and biotic elements, irregular topographic characteristics, permanent muddy bottoms, high turbidity, low depths, variable temperature and salinity, and minimal rainfall.

A gradient in the spatial and seasonal distribution of salinity was observed. Sites close to the mouth of the lagoon are influenced by the ocean (lower salinity), while localities in the interior of the lagoon have higher salinity. The seasonal salinity pattern observed in San Ignacio Lagoon was similar to the spatial salinity distribution, with places near the mouth of the lagoon showing the influence of the ocean, while locations inside the lagoon showed increased salinity. Likewise, water transparency increased in the same direction, since the inner part of the lagoon is shallower and muddier. A well-defined pattern could be observed, with maximum salinity in summer and minimum salinity in winter. The salinity values obtained support the observations by [25] who classify this type of lagoon as hypersaline, implying that waters with higher salinity are denser and so are transported near the bottom of the ocean, and waters with lower salinity are transported near the surface into the lagoon.

Based on the pattern of these parameters, spring and fall can be considered transitional seasons between summer and winter. [30] Reported that in Bahía Concepción (Gulf of California) there was a close relationship among water temperature, abundance and biomass of species; this concurs with results from other parts of the world [31,32]. These findings are consistent with those of the present work, since the structure of the fish community in San Ignacio Lagoon was influenced by the variation of the temperature during the events of EL/LN.

The spatial distribution analysis by season of the 44 collected species showed that the eight resident species presented a spatial distribution, or frequency of occurrence, that fluctuated between 4 and 11 sites. The analyses of distribution in space and time allowed us to infer that the recorded species are distributed in all of San Ignacio Lagoon at different times. [33] Considers that the sediment characteristics and the heterogeneity of the substrate are factors that affect fish distribution. A study made by [34] in the Humber estuary in the United Kingdom concluded that species composition was influenced by a variety of factors, both spatial and seasonal, since the magnitude of these variations was the result of differences in species composition among localities, and was also indirectly due to changes in temperature, salinity, dissolved oxygen, transparency, etc. Most of the organisms collected in San Ignacio Lagoon were small (20-150 mm), which suggests that this is an important area used mostly for breeding and feeding, with grazing areas, small algae and mangroves. In this study we observed that as the temperature increased toward the maximum value of 25°C, more species with tropical affinity were present (*Bairdiella icistia, Microlepidotus inornatus, Orthopristis reddingi, Sphoeroides lispus, Urobatis maculatus* and *Exerpes asper*), possibly influenced by the El Niño event, while when the temperature decreased in the cooler season (11°C), more species with temperate affinity were present (*Anchoa compressa, Atherinops affinis, Halichoeres semicinctus, Pleuronichthys verticalis, Paralabrax auroguttatus, Paralichthys californicus, Hypsoblennius gentilis* and *Hypsopsetta guttulata*), possibly influenced by La Niña, making the changes in community structure during these oceanographic events clear. In the estuary El Coyote (adjacent to our study area), [35] recorded 43 species when there was no effect of EN/LN, using gillnets (chinchorro), seine nets (charalero), and trawling as capture methods. The spring, summer, and fall seasons of 1998 were probably influenced by El Niño event, as can be seen by the presence of more species of tropical origin (Table 1).

Due to its geographic location, San Ignacio Lagoon is classified as a temperate lagoon, according to [36] who found that, for the western coast of the Baja California peninsula, 44.7% of species were of temperate affinity, 22% were of tropical affinity, and 33% were endemic to the San Diego Province. According to the zoogeographic affinity of species recorded in the present study, we found that 36% belonged to the Panamic Province (tropical affinity), 32% to the San Diego Province (the province where San Ignacio Lagoon is located zoogeographically), 18% to the Eastern Pacific, and 11% to the Mexican Province. It should be noted that the species *Exerpes asper* is an amphipeninsular species, being distributed on both sides of the Baja California peninsula, so that it cannot be assigned to any of the provinces considered.

The difference between the results of the present study and those reported by [36] might be due to an El Niño effect during spring, summer, and fall of 1998. In Ojo de Liebre Lagoon (north of San Ignacio Lagoon), [29], found that the percentage of fish with

temperate affinity was similar to that reported by [36]. [27] Found that fish species close to the mouth of Bahía Magdalena/Almejas (south of San Ignacio Lagoon) had temperate affinity, while species located in the innermost areas of the lagoon complex had tropical affinity. The percentages of species by province found in the lagoon complex of Bahía Magdalena were 49% Panamic, 25% Californian, 12% Eastern Pacific, 8% Mexican, with the remaining species being circumpacific and circumtropical. [11] Studied the changes in the structure of coastal fish communities during the El Niño-La Niña events in Bahía Navidad, Jalisco, and found that 68% of the species collected had affinity with the Panamic Province, 21% with the Eastern Pacific, 8% were circumtropical and 1.6% had Indo-Pacific affinity. In another study made in five coastal lagoons in Baja California Sur, [37] found that on the western coast of Baja California Sur the species of Panamic affinity were more abundant as the latitude decreased, while species of Californian Province affinity were less abundant.

Considering the above, we conclude that the seasons of spring, summer and fall of 1998 were influenced by the El Niño event, due to the increased presence of species of tropical origin which were *Bairdiella icistia, Cetengraulis mysticetus, Exerpes asper, Sphoeroides lobatus, Urobatis maculatus, Pomadasys panamensis* and *Umbrina xanti*. Moreover, there were 14 temperate species. Based on the 44 species recorded, the percentage for each province during all seasons was: 36% Panamic Province, 32% San Diego Province, 18% Eastern Pacific and 11% Mexican Province.

Regarding the Shannon & Weaver Index, the transitional seasons (spring and fall) had the highest values. According to several studies [4,6,7,9-11,15], El Niño influence an expansion of the distribution of several fish species, mainly in temperate areas, such as Laguna San Ignacio. This study agrees with these studies and therefore, the value of diversity of this study during El Niño was higher than the one obtained for La Niña event.

Conclusion

A direct effect of the large scale oceanographic phenomena of El Niño and La Niña could be detected by the presence or absence of certain species associated with soft bottoms in San Ignacio Lagoon, BCS, Mexico. Of the 44 species considered, only five were not present during the El Niño event (EN) and 23 were absent during La Niña event (LN); direct effects on the structure of the fish community in San Ignacio lagoon during EN were an increase in species with higher tropical affinity, and a decrease in species with subtropical affinity. LN had the opposite effect. High diversity also calculated during the El Niño event corroborates the above.

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