

Seasonal abundance of fish larvae in a subtropical lagoon in the west coast of the Baja California Peninsula

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Abstract

High diversity of fish along the west coast of the Baja California Peninsula is a consequence of strong climatic contrasts between the cool California Current and the warm subtropical California Countercurrent. This favors the distribution of biotas of temperate and tropical affinities belonging to the San Diegan and Panamic Provinces. This work analyzes the specific composition and abundance of fish larvae to characterize their assemblage and seasonal changes in Bahía Magdalena, Baja California Sur, during the first 10 months of the 1997–1998 El Niño event. For 46,229 fish larvae, 105 taxa were grouped into 84 genera of 45 families. During the study period, more than a twofold increase in the number of species with respect to other studies represents the largest collection to date. Species composition suggests that at least 40% of the 260 taxa reported as adults had reproductive activity. Two temporally distinct larval fish assemblages were characterized by dominant species with massive spawning, such as Pacific sardine in winter, and mojarras and thread herring in summer. The SST annual cycle, as an indicator of environmental variability, is consistent with the taxonomic change between cool and warm periods.

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1. Introduction

The biological and economic importance of Bahía Magdalena is evident in its faunal complexity and the abundance of its commercial resources, especially small pelagic fishes (Mathews-Christophersen, 1975; Félix-Uraga et al., 1996). The principal species in the commercial fishery is the Pacific sardine, *Sardinops caeruleus*, but the fleet also harvests thread herring, *Opisthonema libertate*, and chub mackerel, *Scomber japonicus*. The high diversity of the west coast of the Baja California region is reflected in approximately 400 species of fish (Fisher et al., 1995; Moser, 1996) belonging to the San Diegan and Panamic Provinces (Allen and Smith, 1988),

from which approximately 260 taxa (65%) are recorded in Bahía Magdalena (De la Cruz-Agüero et al., 1994; Galván-Magaña et al., 2000). Little is known about specific differences in behavior and reproductive strategies of resident species or species of marine origins, including those highly migratory species that enter the bay for reproductive purposes. In this respect, it is known that coastal lagoons serve as a complimentary ecosystem in the life cycle of some species because they are used as refuges for reproducing adults. In addition, availability of food in coastal lagoons favors the development of larvae and the growth of juvenile fish (Yáñez-Arancibia et al., 1985; Warlen et al., 2002).

In Bahía Magdalena, ichthyoplankton studies have been used to reveal general tendencies and timing in the use of lagoonal spawning areas of small pelagic fish (Aceves-Medina et al., 1992; Funes-Rodríguez et al., 2001). Information related to the remainder of the species,

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the majority of which are of tropical origins, is little known or unknown (Funes-Rodríguez et al., 1998). Records indicate the persistence of gradients in the distribution of fish larvae related to the preferences of adult habitats. This is a consequence of resident species generally preferring interior waters, while the larvae belonging to taxa of marine origin are numerous in the access areas open to the ocean and navigation channels that extend to the northwest (Castro-Barrera, 1975; Aceves-Medina et al., 1992; Funes-Rodríguez et al., 1998, 2001).

Estuaries and coastal lagoons are highly productive ecosystems. However, these environments may undergo extreme fluctuations, leading to high variability in the number and abundance of fish (McHugh, 1985; Harris et al., 2001; Kimmerer et al., 2001). Changes in the composition of fish species are of biogeographical interest, especially in the lagoonal system of Bahía Magdalena because it is located in a transition zone (Hubbs, 1960; Castro-Aguirre and Torres-Orozco, 1993). Hydrographic transitions confer an extraordinary complexity of fauna that favors the presence of biotas belonging to the Mexican, Panamic, and Californian provinces (Briggs, 1974). In general, the structure and density of different groups of plankton, such as copepods (Palomares-García and Gómez-Gutierrez, 1996; Gómez-Gutierrez et al., 1999), fish larvae (Funes-Rodríguez et al., 1998), and phytoplankton (Gárate-Lizárraga and Siqueiros-Beltrones, 1998), are controlled by seasonal environmental dynamics. Also, an unusual increase of tropical copepod species and a drastic reduction in phytoplankton and small pelagic fish larvae were caused by changes associated with El Niño events, such as those occurred in 1982–1983 and 1997–1998 (Palomares-García et al., 2003). This is known as ‘tropicalization’ of the system, reflected in an increase in species of tropical origin (Palomares-García and Gómez-Gutierrez, 1996; Gárate-Lizárraga and Siqueiros-Beltrones, 1998) and a decrease in the magnitude of the spawning of fish of temperate affinity (Funes-Rodríguez et al., 2001).

Most studies of larval fish in Bahía Magdalena centered on a few species (Funes-Rodríguez et al., 2001; Palomares-García et al., 2003) or sampled the lagoon over short time spans to define spatial or seasonal patterns (Castro-Barrera, 1975; Aceves-Medina et al., 1992; Funes-Rodríguez et al., 1998). This investigation analyzes specific composition and abundance of fish larvae with the objective of characterizing their structure and seasonal changes during the first 10 months of the 1997–1998 El Niño event in Bahía Magdalena on the west coast of Baja California Sur.

2. Materials and methods

The lagoon system of Bahía Magdalena–Bahía Almejas is the largest along the Pacific Coast

(1067 km²) of Baja California Sur, México (24°15′–25°20′N, 112°30′–112°12′W) (Fig. 1). In Bahía Magdalena proper (650 km²), the maximum depth is located in the inlet connecting with the ocean (40 m depth). The central part varies between 15 and 20 m. The northern zone is characterized by shallow channels, averaging 3.5 m, surrounded by extensive mangroves. The greater part of the lagoon has sandy bottoms and rocky reefs in front of Isla Magdalena and Isla Santa Margarita. The monthly average sea surface temperature (SST) and plankton biomass are comparatively lower during winter and early spring, followed by a rapid increase in late spring, with a maximum in summer (Funes-Rodríguez et al., 1998, 2001). During El Niño 1997, the SST anomaly was positive during the second half of the year, with a maximum in August (+4 °C) (Gómez-Gutierrez et al., 1999).

Ichthyoplankton samples were obtained monthly from January to December 1997. The sample station plan consisted of 14 stations in Bahía Magdalena. Additionally, 10 samples were taken from January to March in Bahía Almejas (Fig. 1), for a total of 154 samples. No sampling occurred in April because of logistical problems, and sampling in September was not completed because of Hurricane Nora. Plankton samples were collected with a standard conical net with 0.6 m mouth diameter (2.40 m long) and 0.333 μm mesh netting fitted with a digital flowmeter and towed at the surface following a semicircular course at a speed of approximately 1 m s⁻¹ for 5 min. Because of equipment limitations, only the SST was measured with a bucket thermometer at each sampling station. However, high velocities measured and modeled (± 1.0 m s⁻¹) during the ebb tide in Bahía Magdalena (Obeso-Nieblas et al., 1999) suggest a well-mixed water column.

Samples were preserved in 4% formalin and neutralized with a saturated sodium borate solution for final preservation. Plankton biomass was measured using the displaced volume technique (Beers, 1976). Larvae were removed from the plankton samples and identified to the lowest taxonomic level possible, using the works of Moser et al. (1984) and Moser (1996). Systematic arrangement of species was done according to Moser (1996), and modifications proposed by Nelson (1994), Fisher et al. (1995), and Eschmeyer (1998).

The Shannon–Wiener diversity index (H') was used as a measure of heterogeneity in the lagoonal larval community. This index expresses the number of species and uniformity in abundance of individuals of different species (Pielou, 1966; Peet, 1974). A large number of species increases diversity, but the same is true when abundance among them is uniform. This measure was applied to the relative abundance of species during each month's sampling; abundances were log₂-transformed prior to analysis. Analysis of dominance (J') was obtained by calculating maximum diversity of Shannon–Wiener

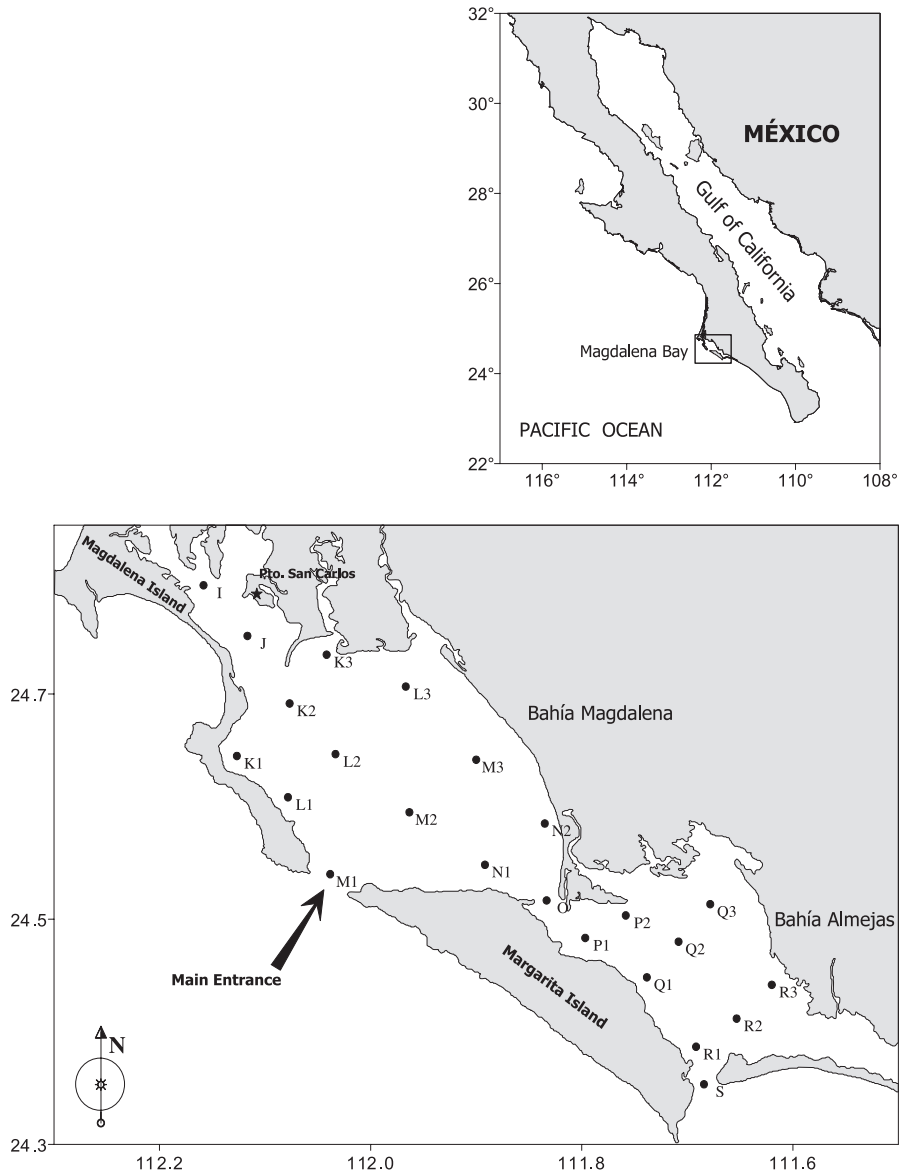


Fig. 1. Study area and sampling stations in Bahía Magdalena and Bahía Almejas, Baja California Sur, México.

(H_{\max}'). This index makes it possible to determine if, within a group of species, there exists a greater number of individuals in a reduced number of species, where H' is the Shannon–Wiener index and H_{\max}' is the maximum diversity for a collection of individuals. The biological value index (BVI) (Sanders, 1960) was used for ordering importance of species based on the time–space constant of abundance. Selection of the maximum number of species included in the analysis was equal to 95% of relative accumulated abundance. Order of importance of species highlights time–space constant and avoids ordering of less representative dominant species (Loya-Salinas and Escofet, 1990). Principal component analysis (PCA) was applied to the matrix of larval abundance by month of the 43 most important species that resulted from BVI (Table 2). PCA was used as a diagnostic tool to represent a large set of characteristics through a reduced number

of hypothetical variables to facilitate interpretation and relationships depending on the characteristics used. Using PCA on 10 monthly larval abundances records and 43 species as descriptors, recurrent groups were obtained from extreme values of species loading on axes 1 and 2. Temporal changes in species composition and abundance of groups were analyzed to explain observed abundance patterns. Software used to obtain diversity measures (H') was the Biodiversity Professional (McAleece et al., 1997), and PCA was performed in STATISTICA 6.1 (StatSoft Inc., 2003).

3. Results

In 154 samples of lagoon plankton collected in Bahía Magdalena during 1997, 46,229 larvae were extracted,

yielding 105 taxa grouped into 45 families and 84 genera (Table 1). Taxa that were impossible to identify at the species level were assigned to the genus level, or if necessary, the family level with the designation of “type” (20 taxa), according to specific patterns of pigmentation and morphometric characteristics (for example, *Opisthonema* spp., *Anchoa* spp., Syngnathidae, Pomacentridae).

SST was comparatively lower from January to May (19–20 °C), followed by an increase in June with maximum temperatures in August (>27 °C) (Fig. 2a). Plankton biomass showed the same tendency, with minimum values from January to May (159–220 ml/1000 m³) and maximum values during the summer

(553–1608 ml/1000 m³) (Fig. 2b). Species and abundance were positively correlated with temperature ($r = 0.64$; $P < 0.05$) and plankton biomass ($r = 0.73$; $P < 0.05$) (Figs. 2a–c).

Heterogeneity of the community (H') identified low values of diversity during the cool period (1–2.5 bits ind.⁻¹), followed by high values during the warm period from June to December (2.6–3.5 bits ind.⁻¹) (Fig. 2d). In general, dominance (J') was inversely proportional to diversity. High values for dominance were recorded from January to August (0.4–0.7 bits ind.⁻¹), while for the rest of the year dominance decreased considerably (0.03–0.32 bits ind.⁻¹). From 105 identified taxa only 43 had high values determined by the BVI (Table 2).

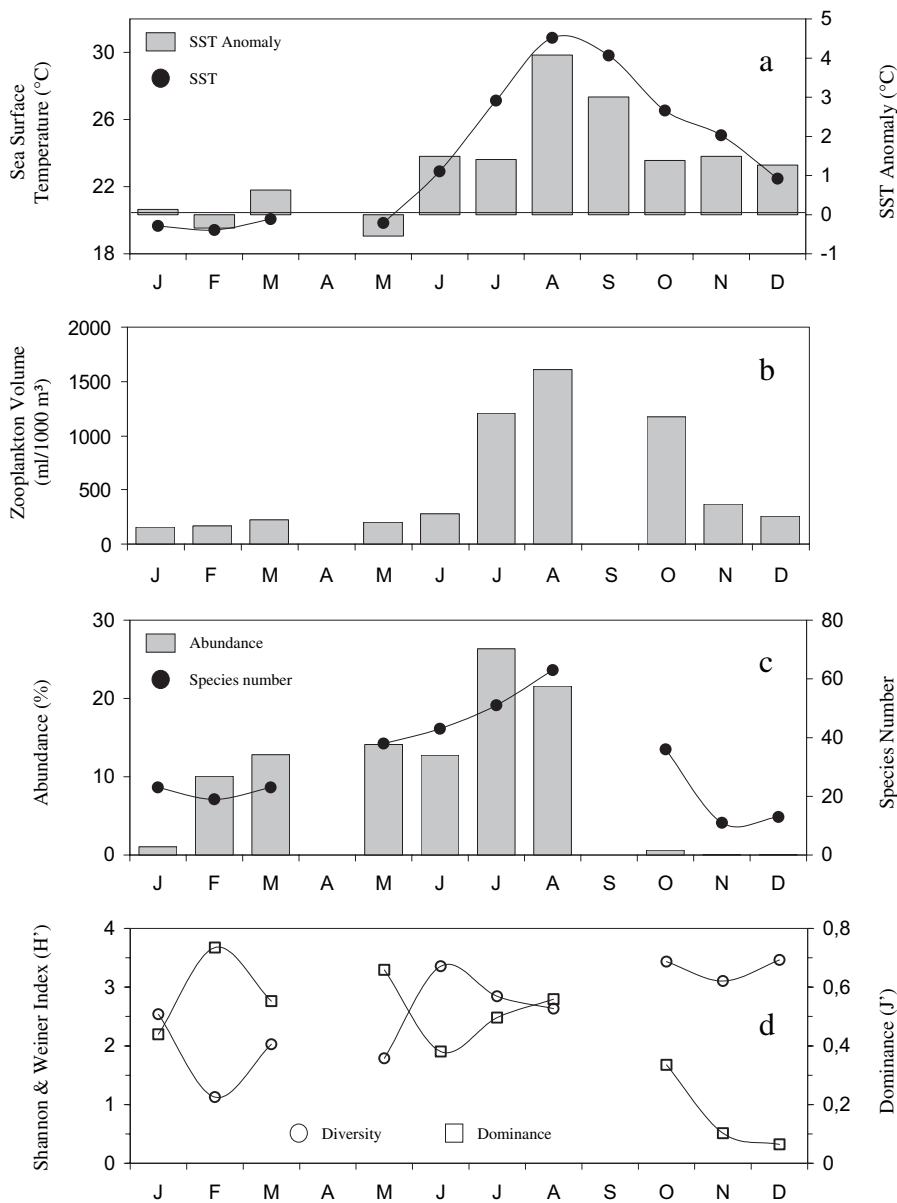


Fig. 2. Bahía Magdalena, Baja California Sur, México in 1997. (a) Mean sea surface temperature during 1997, and anomaly for the 1982–1998 period. (b) Mean zooplankton biomass. (c) Relative abundance and number of species. (d) Diversity and dominance.

Table 1

Proportion of catch ($P\%$), and frequency of occurrence ($F\%$) of fish larvae in Bahía Magdalena, Baja California Sur, México during 1997

Species	$P\%$	$F\%$
Class Actinopterygii		
Order Anguilliformes		
Family Ophichthidae		
Ophichthidae type 1	0.013	1.300
Ophichthidae type 2	0.003	0.650
Family Congridae		
Congridae type 1	0.005	1.300
Order Clupeiformes		
Family Clupeidae		
<i>Etrumeus teres</i> (De Kay, 1642)	0.038	3.900
<i>Harengula thrissina</i> (Jordan & Gilbert, 1882)	0.008	0.650
<i>Opisthonema</i> spp. (Gill, 1861)	1.894	14.29
<i>Sardinops caeruleus</i> (Mitchill, 1815)	1.817	24.67
Family Engraulidae		
<i>Anchoa</i> spp. (Jordan & Evermann, 1927)	12.22	39.61
<i>Cetengraulis mysticetus</i> (Günther, 1867)	0.033	3.250
Order Stomiiformes		
Family Phosichthyidae		
<i>Vinciguerria lucetia</i> (Garman, 1899)	0.005	1.229
Order Aulopiformes		
Family Synodontidae		
<i>Synodus</i> spp. (Bloch & Schneider, 1801)	0.003	0.649
Order Myctophiformes		
Family Myctophidae		
<i>Ceratoscopus townsendi</i> (Eigenmann & Eigenmann, 1889)	0.003	0.649
Order Ophidiiformes		
Family Ophidiidae		
<i>Lepophidium negropinna</i> (Hildebrand & Barton, 1949)	0.003	0.649
<i>Ophidion scrippsae</i> (Hubbs, 1916)	0.003	0.649
Order Atheriniformes		
Family Atherinidae		
<i>Atherinella eriarcha</i> (Jordan & Gilbert, 1882)	0.010	0.649
<i>Atherinella nepenthe</i> (Myers & Wade, 1942)	0.003	0.649
Atherinidae type 1	0.003	0.649
<i>Atherinops affinis</i> (Ayres, 1860)	0.013	2.597
<i>Atherinopsis californiensis</i> (Girard, 1854)	0.003	0.649
Order Beloniformes		
Family Belonidae		
<i>Strongylura exilis</i> (Girard, 1854)	0.005	1.299
Family Hemiramphidae		
<i>Hemirhamphus rosae</i> (Jordan & Gilbert, 1880)	0.158	3.896
<i>Hemirhamphus saltator</i> (Gilbert & Starks, 1904)	0.015	1.948

Table 1 (continued)

Species	$P\%$	$F\%$
Family Exocoetidae		
<i>Fodiatur acutus</i> (Valenciennes, 1847)	0.015	3.247
<i>Hyrundichthys</i> spp. (Breder, 1928)	0.003	0.649
<i>Oxyporhamphus micropterus</i> (Valenciennes, 1847)	0.018	3.247
<i>Prognichthys tringa</i> (Breder, 1928)	0.003	0.649
Order Stephanoberyciformes		
Family Melamphidae		
<i>Melamphaes</i> spp. (Günther, 1864)	0.005	1.299
Order Beryciformes		
Family Holocentridae		
<i>Myripristis</i> spp. (Cuvier, 1829)	0.003	0.649
Order Syngnathiformes		
Family Syngnathidae		
<i>Cosmocampus arctus</i> (Jenkins & Evermann, 1889)	0.008	1.948
<i>Hippocampus ingens</i> (Girard, 1858)	0.015	3.896
Syngnathidae	0.023	3.896
<i>Syngnathus auliscus</i> (Swain, 1882)	0.008	1.299
<i>Syngnathus leptorhynchus</i> (Girard, 1854)	0.008	1.948
Order Scorpaeniformes		
Suborder Platycephaloidei		
Family Triglidae		
<i>Prionotus ruscaius</i> (Gilbert & Starks, 1904)	0.003	0.649
Order Perciformes		
Suborder Percoidei		
Family Serranidae		
Anthiinae	0.005	1.299
<i>Diplectrum</i> type 1	0.005	0.649
<i>Diplectrum</i> type 2	0.003	0.649
Epinephelinae	0.003	0.649
<i>Paralabrax auroguttatus</i> (Walford, 1936)	0.010	1.948
<i>Paralabrax maculatofasciatus</i> (Steindachner, 1868)	0.342	14.94
<i>Paralabrax nebulifer</i> (Girard, 1854)	1.927	23.38
<i>Serranus</i> spp. (Cuvier, 1816)	0.005	0.649
Family Apogonidae		
<i>Apogon atricaudus</i> (Jordan & McGregor, 1898)	0.003	0.649
<i>Apogon retrosella</i> (Gill, 1863)	0.023	1.299
Family Carangidae		
Carangidae	0.041	1.948
<i>Caranx</i> type 1	0.010	1.299
<i>Chloroscombrus orqueta</i> (Jordan & Gilbert, 1883)	0.010	2.597
<i>Decapterus</i> type 1	0.033	1.299
<i>Gnathanodon speciosus</i> (Forsskål, 1775)	0.008	0.649
<i>Oligoplites saurus</i> (Bloch & Schneider, 1801)	0.184	9.091
<i>Oligoplites</i> type 1	0.013	1.948
<i>Selene peruviana</i> (Guichenot, 1865)	0.003	0.649

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Table 1 (continued)

Species	P%	F%
<i>Seriola</i> type 1	0.026	3.247
Family Lutjanidae		
<i>Lutjanus argentiventris</i> (Peters, 1869)	0.003	0.649
Family Gerreidae		
<i>Diapterus peruvianus</i> (Cuvier, 1830)	1.118	10.39
<i>Eucinostomus currani</i> (Zahuaranec, 1980)	0.072	3.247
<i>Eucinostomus dowii</i> (Gill, 1863)	3.494	18.18
<i>Eucinostomus gracilis</i> (Gill, 1862)	14.31	23.38
Gerreidae	5.179	3.247
Gerreidae type 1	0.082	3.247
Family Haemulidae		
Haemulidae	4.357	27.29
Haemulidae type 1	0.248	8.442
<i>Pomadasys</i> type 1	0.148	5.844
Family Sparidae		
<i>Calamus brachysomus</i> (Lockington, 1880)	0.125	12.34
Family Scianidae		
<i>Bardiella icistia</i> (Jordan & Gilbert, 1882)	0.003	0.649
<i>Cynosion</i> type 1	0.031	3.247
<i>Larimus</i> type 1	0.049	1.299
<i>Menticirrhus undulatus</i> (Girard, 1854)	0.015	1.299
<i>Menticirrhus</i> type 1	0.018	1.299
<i>Micropogonias ectenes</i> (Jordan & Gilbert, 1882)	0.059	3.900
Scianidae	0.005	0.649
Family Polynemidae		
<i>Polydactilus approximans</i> (Lay & Bennett, 1839)	0.003	0.649
Family Mullidae		
Mullidae type 1	0.314	12.99
Family Kyphosidae		
<i>Kyphosus analogus</i> (Gill, 1863)	0.255	9.740
Suborder Mugiloidei		
Family Mugilidae		
<i>Mugil</i> spp. (Linnaeus, 1758)	0.013	1.948
Suborder Labriodei		
Family Pomacentridae		
<i>Abudefduf troschelli</i> (Gill, 1862)	0.115	6.494
<i>Chromis</i> type 1	0.003	0.649
<i>Hypsypops rubicundus</i> (Girard, 1854)	0.026	2.597
Pomacentridae	0.003	0.649
<i>Stegastes rectifraenum</i> (Gill, 1862)	0.015	1.299
Family Labridae		
<i>Bodianus diplotaenia</i> (Gill, 1862)	0.015	0.649
Suborder Blennioidei		
Family Tripterygiidae		
<i>Axoclinus carminalis</i> (Jordan & Gilbert, 1882)	0.028	4.545
Family Labrisomidae		
<i>Exerpes asper</i> (Jenkins & Evermann, 1889)	0.610	14.94

Table 1 (continued)

Species	P%	F%
<i>Labrisomus multiporosus</i> (Hubbs, 1953)	0.082	9.091
<i>Labrisomus xanti</i> (Gill, 1860)	0.054	3.247
<i>Malacoctenus hubbsi</i> (Springer, 1959)	0.094	0.649
<i>Paraclinus integripinnis</i> (Smith, 1880)	0.383	3.896
Family Chaenopsidae		
<i>Chaenopsis alepidota</i> (Gilbert, 1890)	1.825	37.66
<i>Coralliozetus</i> spp. (Evermann & Marsh, 1899)	0.023	1.299
<i>Stathmonotus sinuscalifornici</i> (Chabanaud, 1942)	0.015	3.247
Family Dactyloscopidae		
Dactyloscopidae	0.049	5.195
Family Blenniidae		
Blenniidae	0.013	2.597
<i>Hypsoblennius gentilis</i> (Girard, 1854)	0.120	9.091
<i>Hypsoblennius gilberti</i> (Jordan, 1882)	0.003	0.649
<i>Hypsoblennius jenkinsi</i> (Jordan & Evermann, 1896)	0.406	13.64
<i>Ophioblennius steindachneri</i> (Jordan & Evermann, 1898)	0.003	0.649
Suborder Gobioidi		
Family Gobiidae		
<i>Gillichthys mirabilis</i> (Cooper, 1864)	0.054	7.143
Gobiidae	0.003	0.649
<i>Ilypnus gilberti</i> (Eigenmann & Eigenmann, 1889)	32.60	62.99
<i>Lythrypnus dalli</i> (Gilbert, 1890)	0.003	0.649
<i>Lythrypnus zebra</i> (Gilbert, 1890)	0.003	0.649
<i>Quietula y-cauda</i> (Jenkins & Evermann, 1889)	13.00	44.16
Suborder Acanthuroidei		
Family Ehippidae		
<i>Chaetodipterus zonatus</i> (Girard, 1858)	0.013	1.948
Suborder Sphyraenoidei		
Family Sphyraenidae		
<i>Sphyraena ensis</i> (Jordan & Gilbert, 1882)	0.023	1.948
Suborder Scombroidei		
Family Scombridae		
<i>Auxis</i> spp. (Cuvier, 1829)	0.005	0.649
<i>Scomber japonicus</i> (Houttuyn, 1782)	0.518	18.83
Order Pleuronectiformes		
Family Paralichthyidae		
<i>Etropus crossotus</i> (Jordan & Gilbert, 1882)	0.222	15.58
<i>Paralichthys californicus</i> (Ayres, 1859)	0.043	7.143
<i>Paralichthys</i> type 1	0.005	1.299
<i>Xystreus liolepis</i> (Jordan & Gilbert, 1880)	0.008	1.948

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Table 1 (continued)

Species	P%	F%
Family Achiridae		
<i>Achirus mazatlanus</i> (Steindachner, 1869)	0.212	9.740
Family Cynoglossidae		
<i>Symphurus</i> spp. (Rafinesque, 1810)	0.005	1.299
Order Tetraodontiformes		
Family Balistidae		
<i>Balistes polylepis</i> (Steindachner, 1876)	0.010	1.299
Family Tetraodontidae		
<i>Sphoeroides lobatus</i> (Steindachner, 1870)	0.038	1.299
<i>Sphoeroides</i> type 1	0.327	7.792

PCA shows that the first two components explain 49% of the variance and distinguished, in general, four groups of species (Fig. 3). These recurrent groups were established with loading values above 0.4 as a critical level (absolute value) from axes 1 and 2 (Table 3). The first axis separated two species groups. Species in Group I (six taxa) were more abundant in winter (Fig. 4), dominated numerically by the larvae of *Scomber japonicus* (Table 2). Species in Group II (14 taxa) were abundant in summer (Fig. 4), principally during July and August, dominated by three species of Gerreidae, *Anchoa* spp., and Haemulidae (Table 2).

On the second axis (Fig. 3), Group III (16 taxa) species were abundant in spring and the beginning of summer, principally from May to July (Fig. 4). However, *Ilypnus gilberti* and *Quietula y-cauda* were also abundant in winter, dominated numerically by larvae of *I. gilberti* and *Q. y-cauda* (Table 2). Group IV (seven

taxa) species, even though scarce, showed high relative abundance in October (Fig. 4), dominated by *Apogon retroseilla* larvae (Table 2).

Abundance curves of Groups I and II show a strong relationship with SST. Species of Group II increased in abundance with temperature (26 °C) and the opposite occurred for Group I species (Fig. 4). The largest number of shared species with significant values on axes 1 and 2 was between Groups II and III (*Opisthonema* spp., *Etropus crossotus*, and *Anchoa* spp.) because the relative abundance of larvae of these species was greater at the end of spring (June).

4. Discussion

This was the first and most complete collection of ichthyoplankton from Bahía Magdalena and can be considered representative of the general composition of fish larvae inhabiting the Bahía Magdalena region. Analysis of the taxonomic composition of fish larvae permitted the integration of a checklist of 105 species in 45 families of fish. This represents more than a twofold increase over the number of species previously recorded.

Larval species composition suggests that at least 40% of the 260 taxa recorded as adults have reproductive activity in the bay. Nevertheless, this result could be biased by the limitations in identifying species in their larval stage, and by the selectivity of the sampling method. In summary, there are 42 families of fish for which there is evidence of reproduction. Additionally, the fish larvae of mesopelagic species, although scarce, show evidence of movement by advective processes and

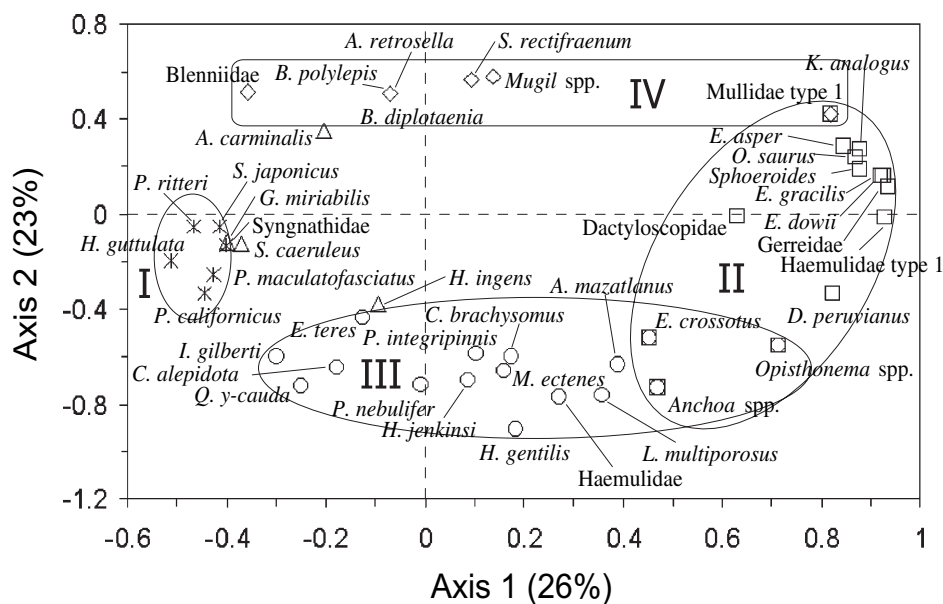


Fig. 3. Principal component analysis of species in the first two axes using the matrix of temporal relative abundances. Variance explained by the first axis, 26%, and by the second axis, 23%.

Table 2

Ranked species in order of spatio-temporal constancy of their abundances expressed throughout the biological index value (BIV), ranked abundance (RA), and ranked frequency of occurrence (RF), in Bahía Magdalena, México during 1997

Taxa	Jan	Feb	March	May	June	July	Aug	Oct	Nov	Dec	BIV	RA	RF
<i>Ilypnus gilberti</i>	0.533	7.538	6.861	8.997	1.847	7.361	0.049	0.013	0.010	0.023	1	1	1
<i>Quietula y-cauda</i>	0.198	2.433	3.060	2.904	1.415	3.221		0.003	0.013	0.010	2	3	2
<i>Eucinostomus gracilis</i>				0.003	0.211	2.956	10.86	0.271	0.026	0.013	3	2	7
<i>Anchoa</i> spp.	0.008		0.349	1.317	2.901	6.601	1.262	0.008			4	4	3
<i>Chaenopsis alepidota</i>	0.031	0.081	0.757	0.112	0.513	0.341	0.013	0.005	0.003	0.005	5	10	4
<i>Paralabrax nebulifer</i>	0.005	0.034	0.008	0.700	1.056	0.127		0.010	0.016	0.008	6	8	8
Haemulidae				0.065	2.740	1.366	0.185	0.078	0.008		7	6	5
<i>Sardinops caeruleus</i>	0.078	0.081	1.520	0.029	0.146						8	11	6
<i>Scomber japonicus</i>	0.078	0.049	0.385		0.008					0.008	9	14	9
Mullidae					0.003		0.224	0.047	0.021	0.005	10	19	16
<i>Exerpes asper</i>	0.008		0.008	0.003	0.010	0.010	0.554	0.008	0.003	0.008	11	13	12
<i>Eucinostomus dowii</i>					0.130	0.580	2.649	0.044			12	7	10
Gerreidae						1.379	3.900				13	5	37
<i>Opisthonema</i> spp.					0.825	0.513	0.593				14	9	14
<i>Paralabrax maculatofasciatus</i>		0.026	0.161	0.148	0.010				0.003		15	17	13
<i>Axoclinus carminalis</i>	0.010								0.013	0.005	16	35	30
<i>Gillichthys mirabilis</i>	0.018	0.026	0.003	0.003	0.010					0.005	17	30	26
<i>Diapterus peruvianus</i>				0.016	0.104	0.593	0.427				18	12	18
<i>Hypsoblennius jenkinsi</i>	0.008	0.003		0.042	0.320	0.042					19	15	15
<i>Etropus crossotus</i>	0.052				0.039	0.104	0.021	0.005	0.005		20	22	11
<i>Hypsopsetta guttulata</i>		0.029	0.018	0.005	0.005						21	29	28
<i>Kyphosus analogus</i>				0.003		0.021	0.195	0.013			22	20	19
<i>Calamus brachysomus</i>		0.003	0.013	0.008	0.075	0.005	0.016	0.003		0.005	23	25	17
<i>Apogon retrosella</i>								0.023			24	37	40
Blenniidae			0.003					0.003	0.003	0.005	25	42	38
<i>Bodianus diplotaenia</i>								0.016			26	39	43
<i>Paralichthys californicus</i>	0.003	0.010	0.021		0.010						27	32	27
<i>Stegastes rectifraenum</i>							0.003	0.013			28	40	41
<i>Paraclinus integripinnis</i>					0.375		0.016				29	16	31
<i>Sphoeroides</i> type 1				0.013	0.023	0.023	0.273				30	18	25
<i>Hypsoblennius gentilis</i>	0.008	0.003	0.005	0.026	0.036	0.044					31	26	22
Dactyloscopidae	0.013					0.010	0.010				32	31	29
<i>Labrisomus multiporosus</i>				0.008	0.039	0.021	0.008	0.003	0.005		33	27	23
<i>Etrumeus teres</i>				0.029	0.010						34	33	33
<i>Achirus mazatlanus</i>				0.023	0.031	0.151	0.010				35	23	20
<i>Pleuronichthys ritteri</i>	0.003	0.018	0.005	0.003							36	34	34
<i>Mugil</i> spp.							0.003	0.010			37	41	39
<i>Balistes polylepis</i>								0.010			38	43	42
Syngnathidae	0.003	0.013		0.008							39	36	35
<i>Hippocampus ingens</i>		0.005		0.003		0.005			0.003		40	38	36
Haemulidae type 1				0.023		0.083	0.135	0.008			41	21	24
<i>Oligoplites saurus inornatus</i>				0.003	0.003	0.013	0.167				42	24	21
<i>Micropogonias ectenes</i>			0.003	0.023	0.005	0.029					43	28	32

the consequent species exchange through the access to the open ocean. Advective processes are probably associated with currents that flow in a southwest and northeast direction into the bay (Obeso-Nieblas et al., 1999).

In contrast, adults belonging to 31 fish families have been recorded (De la Cruz-Agüero et al., 1994; Galván-Magaña et al., 2000) for which larval stages have not been found in the bay. Pelagic organisms in this category belong to Lobotidae and Stromateidae, reef organisms include Fistularidae, Grammistidae, Malacanthidae, Chaetodontidae, Cirrhitidae, Scaridae, and Diodontidae, and demersal organisms of shallow water and the continental shelf include Elopidae, Albulidae, Muraenidae,

Chanidae, Ariidae, Merluccidae, Lophiidae, Antennariidae, Ogocephalidae, Batrachoidae, Gobiesocidae, Cyprinodontidae, Cottidae, Centropomidae, Percichthyidae, Priacanthidae, Nematistiidae, Opisthognathidae, Uranoscopidae, Callionymidae, Microdesmidae, and Bothidae.

The wide annual variations in environmental conditions of the lagoonal system have an important influence on the composition and structure of the plankton community observed in the contrasting values of temporal diversity (H') and dominance (J'). Interpretation of these results is that there are two periods in the system: one warm and with high diversity (summer–autumn) and one cool with low diversity

(winter–spring). A transition includes a situation of low species richness, low dominance, and low abundance during autumn and a situation of low species richness, few dominant species, and a growing abundance during spring.

This conclusion is confirmed by PCA, which distinguishes four groups, two on the first axis (Groups I and II) associated with a strong change in species composition between cool and warm periods; with the first axis explaining 26% of the variability of the system and the groups have no species in common. Two groups on axis 2, explaining 23% of the variability, can be defined as a cool-to-warm transition group (Group III), and a warm-to-cool transition group (Group IV). Transitional periods reflect changes in species composition and spawning succession between cool and warm periods.

Group III (cool-to-warm transition) is composed of species present for long periods, particularly gobies, known as residents that tolerate environmental stress, compared to species of Group IV (warm-to-cool transition) that show lower abundance and occur for a short period. This condition is related to changes in the environment, reflected in the rapid increase in SST during only 3 months (June–August). This implies environmental stress, compared to the gradual cooling that occurs for 5 months (September–January). On the other hand, during periods of relative stability, identified here as winter and summer, the dominant species are mainly the species with massive spawning, such as chub mackerel in winter and mojarras and thread herring in summer.

The associations reflect a seasonal variability in abundance of fish larvae in response to the variation that the environment imposes, establishing possible relationships between reproduction of species and oceanographic events. SST annual cycle, an indicator of environmental variability, is consistent with taxonomic succession between cool and warm periods, and also with the increase in diversity and abundance of subtropical–tropical taxa from late spring and summer and occurrence of some temperate species during winter to spring.

It is noteworthy that the biological diversity of the lagoon complex is related to the variety of habitats and its location in a transition zone. Important species in the community (BVI) are directly related to the geographical characteristics of the area and habitat preferences of adults (Miller and Lea, 1972; Eschmeyer et al., 1983; Fisher et al., 1995). For example, gobies and blennies inhabit shallow areas, sea grasses, soft bottoms, mud flats, and intertidal regions. Adults, even though small, probably have high ecological value within the food cycle because they are an abundant species. Similarly, mojarras and anchovy larvae are dominant. They are associated with shallow bays over soft and sandy bottoms. There are other reef fish, such as sea bass, grunts, and goatfish that inhabit coastal waters and

Table 3

Loading values of the first two axes in the PCA of species of fish larvae in Bahía Magdalena, Baja California Sur, México in 1997 (values above the 0.4 (absolute value) critical level are in bold)

Taxa	Axis 1	Axis 2
Gerreidae	0.934	0.116
Haemulidae type 1	0.928	−0.016
<i>Eucinostomus gracilis</i>	0.927	0.160
<i>Eucinostomus dowii</i>	0.920	0.164
<i>Sphoeroides</i> type 1	0.880	0.189
<i>Kyphosus analogus</i>	0.878	0.272
<i>Oligoplites saurus inornatus</i>	0.870	0.240
<i>Exerpes asper</i>	0.844	0.283
<i>Diapterus peruvianus</i>	0.824	−0.334
Mullidae type 1	0.821	0.420
<i>Opisthonema</i> spp.	0.715	− 0.558
Dactyloscopidae	0.632	−0.010
<i>Anchoa</i> spp.	0.470	− 0.728
<i>Etropus crossotus</i>	0.455	− 0.521
<i>Achirus mazatlanus</i>	0.389	− 0.631
<i>Labrisomus multiporosus</i>	0.357	− 0.763
Haemulidae	0.271	− 0.767
<i>Hypsoblennius gentilis</i>	0.186	− 0.905
<i>Calamus brachysomus</i>	0.175	− 0.602
<i>Micropogonias ectenes</i>	0.160	− 0.659
<i>Mugil</i> spp.	0.138	0.579
<i>Paraclinus integripinnis</i>	0.103	− 0.585
<i>Stegastes rectifraenum</i>	0.096	0.568
<i>Hypsoblennius jenkinsi</i>	0.088	− 0.697
<i>Paralabrax nebulifer</i>	−0.009	− 0.718
<i>Apogon retrosella</i>	−0.071	0.509
<i>Bodianus diplotaenia</i>	−0.071	0.509
<i>Balistes polylepis</i>	−0.071	0.509
<i>Hippocampus ingens</i>	−0.095	−0.381
<i>Etrumeus teres</i>	−0.125	− 0.437
<i>Chaenopsis alepidota</i>	−0.178	− 0.643
<i>Axoclinus carminalis</i>	−0.202	0.353
<i>Quietula y-cauda</i>	−0.251	− 0.725
<i>Ilypnus gilberti</i>	−0.299	− 0.599
Blenniidae	−0.359	0.511
<i>Sardinops caeruleus</i>	−0.369	−0.128
Syngnathidae	−0.400	−0.121
<i>Gillichthys mirabilis</i>	− 0.402	−0.130
<i>Scomber japonicus</i>	− 0.413	− 0.053
<i>Paralabrax maculatofasciatus</i>	− 0.427	−0.253
<i>Paralichthys californicus</i>	− 0.446	−0.332
<i>Pleuronichthys ritteri</i>	− 0.466	− 0.055
<i>Hypsopsetta guttulata</i>	− 0.514	−0.198
Total	11.523	9.962
Variance explained (proportions)	0.268	0.232

shallow bays with rocky, algae, sandy, or muddy bottoms. Meanwhile the presence of fish larvae of small pelagic species, whose maximum population occurs in the coastal zone (Moser et al., 1993), suggests that part of those populations enters the lagoon system as reproductive adults, based on high densities of eggs and larvae distributed on the west side of the lagoon, between the inlets and the estuarine or tidal zone (Funes-Rodríguez et al., 1998, 2001).

Temporal variations in taxonomic composition between cool and warm seasons in the lagoon system have

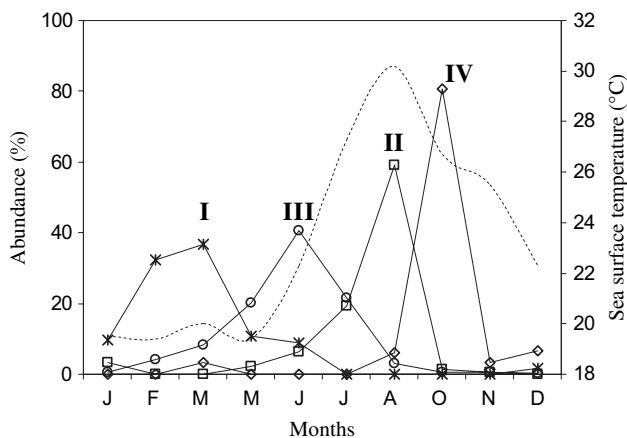


Fig. 4. Proportion of abundance of recurrent fish larvae groups obtained by principal component analysis and sea surface temperature in Bahía Magdalena, Baja California Sur, México in 1997.

been observed before with other phytoplankton and zooplankton groups (Palomares-García and Gómez-Gutiérrez, 1996; Gárate-Lizárraga and Siqueiros-Beltrones, 1998). Also, environmental dynamics caused by changes associated with El Niño warming modified spawning activity of small pelagic fishes (Funes-Rodríguez et al., 2001; Palomares-García et al., 2003), and modified the phytoplankton and zooplanktonic composition (Palomares-García and Gómez-Gutiérrez, 1996; Gárate-Lizárraga and Siqueiros-Beltrones, 1998; Gómez-Gutiérrez et al., 1999). Evidence of the El Niño event was not established because the sampling period was not long enough to separate El Niño and normal seasonal signals, and also because all taxa had been recorded as adults in this lagoon system. However, seasonal succession of dominant species in this and previous studies is maintained, which suggests high seasonal stability and adaptation of the species. The same has been observed in Bahía Magdalena for other groups of plankton, where seasonal patterns are maintained even during warming events (Palomares-García and Gómez-Gutiérrez, 1996; Gómez-Gutiérrez et al., 1999).

In conclusion, fish reproduction in Bahía Magdalena is associated with a wide seasonal thermal variation that makes possible seasonal succession of communities, but high diversity and abundance of spawning is related to the different strategies of reproduction and behavior of species according to habitat preferences of adults. These conditions make merging of resident species and off-shore species possible, and this increases diversity of the lagoon system.

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